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Effects of Flooding Dates and Disposals of Rice Straw on Crayfish, Procambarus Clarkii (Girard), Culture in Rice Field.

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EFFECTS OF FLOODING DATES AND DISPOSALS OF RICE STRAW ON CRAYFISH, *Procambarus clarkii* (GIRARD), CULTURE IN RICE FIELD

A Dissertation

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure Page

Figure | Page

ABSTRACT

Studies were conducted to determine the effects of flooding dates and different disposals of rice straw on crayfish culture in rice field. Nutritional composition of decayed rice straw, periphyton growth, and water quality were also determined. Eighteen earthen ponds were randomly assigned to six treatments in a two by three factorial arrangement: early flooding (20/Sept/1978), late flooding (15/Oct/78), and aerobic (baled), anaerobic (disked), partially aerobic (standing) decomposition of rice straw with three replications each.

The average crayfish production in early-flooded ponds (1183 kg/ha) did not differ significantly from that in late-flooded ponds (1127 kg/ha). Significant differences ($P<0.05$) in average crayfish production were found between standing ponds (1506 kg/ha) and disked ponds (803 kg/ha), and between baled ponds (1157 kg/ha) and disked ponds. The average crayfish production in standing ponds was not significantly higher than in baled ponds.

von Bertalanffy's growth model revealed that all crayfish in early-flooded ponds attained an average maximum length (l_{∞}) and Brody's growth coefficient (k) of 92.2 mm and 0.55, respectively, whereas all crayfish in late-flooded ponds had an l_{∞} and k of 82.7 mm and 0.09. Crayfish in disked ponds showed the poorest growth of all treatments.

Late-flooded ponds had a higher population density than early-flooded ponds. The population density was highest in baled ponds

followed by standing and disked ponds. The harvestable crayfish size (total length > 75 mm) in decreasing order were: standing ponds (19.4 g), baled ponds (18.3 g), and disked ponds (17.0 g).

Rice straw decomposed fastest in baled ponds, followed by standing ponds and disked ponds with average weight loss of 77.1, 66.6 and 48.9%, respectively, after 5-months decomposition. The C:N ratio or rice straw at flooding was 57. It took 4 months for the C:N ratio to drop below 17 for rice straw in baled and standing ponds. The average C:N ratio of rice straw in disked ponds was 23 after 5 months decomposition.

The average dawn dissolved oxygen (DO) was consistently higher in early-flooded ponds than in late-flooded ponds with a difference of 1.3 mg/l. For the first 5-weeks after flooding, average dawn DO was highest in baled ponds (1.5 mg/l). After that, disked ponds had the highest dawn DO.

Eighteen weeks after flooding, early-flooded ponds had higher periphyton biomass (337 g/m^2) than late-flooded ponds (216 g/m^2). The periphyton biomass was highest in standing ponds (358 g/m^2), followed by baled ponds (333 g/m^2) and disked ponds (307 g/m^2).

INTRODUCTION

The managed pond area of crayfish has expanded from less than 5,000 ha in 1969 (Perry and LaCaze 1969) to 22,389 ha in 1980 (Craft 1980) with a potential expansion to over 80,000 ha (Franz 1974). The area increase is due to a growing market demand for crayfish.

Rice fields offer the most readily adaptable land for crayfish culture since levees, pumps, and irrigation ditches are already in place. The annual area planted in rice during the last 10 years has been stable at around 285,000 ha (Hill and Faulkner 1970). Hendrick (1965) stated that in a well-managed rice-crayfish rotation the cash return from the secondary crop, crayfish, often exceeded that from the primary crop, rice. Because of the increasing demand for crayfish and the sometimes low profit margin from rice monoculture (Avault 1977), double cropping of rice and crayfish has greatly interested rice farmers.

When rice farmers begin crayfish farming, they face two major problems: oxygen depletion and food deficiency (Avault et al. 1975). If fall flooding is too early, warm water conditions may result in rapid decomposition of rice straw and concomitant low levels of dissolved oxygen (DO). This stress may result in the mortality of young crayfish recently flushed out of burrows. Melancon and Avault (1978) reported that small crayfish, 9-12 mm in length were not very tolerant to abrupt changes in dissolved oxygen, and the LC_{50}^{96} [1] value

[1] Lethal concentration at which 50% of the organisms died within 96 hours.

for low DO was estimated at 0.75 to 1.10 ppm. Chien (1978) observed that the morning after warm cloudy days crayfish often climbed sluggishly onto the bank or rice straw at the water surface, because of low levels of DO.

When ponds are flooded in late October, cool water temperatures increase oxygen solubility and reduce the biochemical demand, thus minimizing DO depletion. However, reduced water temperatures may result in temporary food deficiency and slow crayfish growth. Russel-Hunter (1971) stated that detritus must attain a C:N ratio of 17 or lower before it is suitable for animal nutrition; a higher ratio would result in protein deficiency. Goyert et al (1975) showed in laboratory studies that at 21 C, under aerobic decomposition, it took eight weeks for the C:N ratio of rice straw to drop to below 17. In a field study (Chien and Avault 1980), where rice straw decomposed at an average water tempearture of 10 C, under partially aerobic conditions, 16 weeks were required to attain a C:N ratio below 17. Thus more time is needed to decompose rice straw under low water temperatures at late flooding than early flooding. Decaying rice straw and associated microorganisms are the main source of food for crayfish in rice ponds. Without adequate decomposition, slow growth due to poor quality food can result. Avault et al (1975), in field observations, found that if the crayfish population was large and/or the food supply was low, crayfish would eat virtually all vegetation in the pond. Crayfish raised under such conditions are small in size and or poor quality.

Acharya (1935a,b) demonstrated that the decomposition of rice

straw was most rapid in aerobic environments, slower under waterlogged conditions, and slowest under complete anaerobiosis. Nitrogen immobilization during anaerobic decomposition is low. On the contrary, aerobic metabolism results in vigorous decomposition of organic matter, coupled with a higher incorporation of nitrogen (Tusneem and Patrick 1971). Therefore, the C:N ratios of rice straw after decomposition can be expected to be the lowest in aerobic environments, highest under complete anaerobiosis, and intermediate in waterlogged conditions. However, aerobic decomposition consumes the largest amount of oxygen. Avault et al (1975) suggested that terrestrial vegetation be mowed and, if possible, disked under to minimize DO depletion. At this time, virtually no information is available on the effects of different disposals of rice straw under aerobic, anaerobic, and partially aerobic decomposition on crayfish culture.

This study was conducted to determine (1) how disposals of rice straw (aerobic, anaerobic, partially aerobic decomposition) and flooding dates (two temperature regimes) affect crayfish production, overall water quality, and the C:N ratio of rice straw; and (2) the best combinations of flooding dates and rice straw disposals to minimize oxygen depletion problems and yet maximize food supply.

LITERATURE REVIEW

Polyculture and Multiple-cropping

Polyculture and multiple-cropping are two aquaculture systems that make the best use of the natural environment. Polyculture is the rearing of two or more non-competitive species in combination to obtain greater fish production with little added facilities or increased energy requirements (Stickney 1978). Yashouv (1968) concluded that a mixed stock of selected fish species, with complementary feeding habits and different ecological niches in the pond, is the most efficient way for increasing fish production.

Multiple-cropping is the rotation of several crops on the same lands during different times of the year to maximize production by taking advantage of different thermal, hydrological, and environmental requirements of each crop. One condition for multiple-cropping is that there must be no adverse residual effects left from one crop to the other. Brown (1976) stated that the net profit of double-cropping channel catfish (*Ictalurus punctatus*) and trout (*Salmo gairdneri*) in a cage system can be increased as much as 320% as compared to channel catfish monoculture. Catfish are grown during warm months and trout during cooler months.

Polyculture with Crustaceans

Although the polyculture of fishes and crustaceans in brackish water is a century-old technique in southeast Asia (Bardach et al.

1972, Chen 1976), it has been only scantily investigated in the United States (Lunz 1951). Crab (Scylla serrata), shrimps (Penaeus monodon, Metapenaeus monoceros), milkfish (Chanos chanos) and/or agar seaweed Gracilaria sp. have been all cultivated together in Taiwan, with an annual yield of 750 to 1500 kg/ha for shrimp, 3000 kg/ha for milkfish, and 200 crabs/ha (Bardach et al. 1972). In Indonesia and the Philippines, shrimps (P. indicus, P. semisulcatus, Metapenaeus ensis, and M. brevicornis) are allowed to invade milkfish ponds. Shrimp yields varied from 25 to 400 kg/ha/year (Bardach et al. 1972). Tatum and Trimble (1978) polycultured pompano (Trachinotus carolinus) with penaeid shrimp (P. aztecus, P. duorarum, and P. setiferus) in Alabama. They found that high levels of DO were maintained in ponds containing both pompano and the detrivorous penaeids, but not in pompano monoculture ponds. Both the total yield and pompano yield were higher in pompano-shrimp polyculture than in pompano monoculture. Rearing the spot prawn (Pandalus platyceros) and salmon (Salvelines namaycush) in the same net pen has proved encouraging (Rensel and Prentice 1979). After 6.5 months of culture, the growth of prawns in polyculture exceeded that of those in monoculture. There was no evidence of adverse salmon/prawn interaction. A limiting factor to stocking juvenile prawns in commercial salmon net pens is the requirement that prawns must be large enough to prevent escape from the net.

Rundquist et al. (1977) invented a system of watercress-crayfish polyculture. Watercress stripped nitrates, ammonia, and phosphorus off the nutrient-rich effluent from a connecting trout hatchery and in turn provided a food source for crayfish. The polyculture of finfish and freshwater crustaceans started only a few years ago.

Merkowsky and Avault (1977) raised crayfish (*Procambarus clarkii*) with hybrid grass carp (male white amur, *Ctenopharyngodon idella* X female Israeli mirror carp, *Cyprinus carpio*) in weed infested pools. They found that crayfish appeared to be unaffected by hybrid grass carp since growth and survival of crayfish were the same in pools with or without carp. However, Forester and Avault (1978) found that grass carp (*C. idella*) significantly reduced the average yield (number and total weight) of harvestable crayfish, because they competed for available food resources and, when plant matter was scarce, grass carp switched food habits and preyed on young crayfish. The distinction between the feeding habits of polycultured species is not definite. Fish are able to adjust to different foods, so when their preferred food diminishes they search for food from other sources (Reich 1975). However, food competition or predation in a polyculture system can be prevented by an artificial blockade. A successful finfish/crayfish polyculture was accomplished by Tuten and Avault (Green et al. 1978). They stocked channel catfish (*Ictalurus punctatus*) in floating cages, and let crayfish, paddlefish (*Polydon spathula*) and bigmouth buffalo (*Ictiobus cyprinellus*) loose in the same pond. The catfish were released from the cages after the crayfish (*P. clarkii*) harvest ended in May. The crayfish benefitted from excess supplemental feed not used by the caged fish and from catfish feces, which enriched the waters, and crayfish production averaged 1345 kg/ha. Crayfish not only efficiently used excess catfish feed, which otherwise would normally have decayed and deteriorated water quality, but also provided a food supply for the catfish when the latter were released. Catfish production averaged 3191 kg/ha;

bigmouth buffalo averaged 302 kg/ha; and paddlefish avearged 109 kg/ha.

Green (1978) combined caged channel catfish, bigmouth X black hybrid buffalo (I. cyprinellus X I. niger), golden shiner (Notemigonus crysoleucas) and crayfish. The channel catfish were caged throughout the study to avoid predation on crayfish. However, crayfish production avearged only 143 kg/ha. The reduced production of crayfish was attributed to deviations from established management practices; rapid dewatering during summer; late flooding until January; and food deficiency due to poor growth of rice and rye grass in winter.

Multiple Cropping with Crustaceans

Fish culture in rice fields provides a means for production of both grain and animal protein on the same land (Schuster 1955). It is an almost ideal method of land use. Vibert and Lagler (1961) stated that if all the rice fields also grew fish, the yield would represent 15 to 20% of the total quantity of fish consumed each year in the world. Coche (1967) gave an excellent review of fish culture in rice fields. In relation to the rice crop, he classified fish culture as follows: (1) as a single annual crop after the single annual crop of rice, (2) as an intermediate crop between the rice harvest and the next planting, with rice crops of more than annual frequency, and (3) concurrent with the growing of rice (rizipisciculture). Although there is considerable literature on finfish culture in rice fields, until the past two or three decades, few studies have been done on rotation of crustaceans and rice. Gopinath

(1955) described a prawn-rice rotation in India. There were 4,000 to 5,000 ha of rice fields in the north-western coastal area utilized for prawn culture. Rice was planted from June to October, which coincided with the freshwater monsoon season. After the monsoon, the water level in the surrounding backwater gradually dropped, and the water became more and more brackish as the result of tidal influence. For the rest of the year prawn operations were carried on. The cultured prawns were Metapenaeus dobsoni, M. nomoceros, and P. indicus. Since the bottom was rich in organic matter caused by decaying rice straw and other plant residues, prawn yields ranged from 164 to 492 kg/ha without supplementary feeding. Johnson (1956) described a freshwater prawn, Macrobrachium lanchesteri, which has potential value in rice-prawn double cropping in India. This prawn has several favorable features, such as the ability to reproduce in standing freshwater, a pronounced eurytopicity, and vegetarian and detrivorous food habits.

Crayfish culture, as practiced in Louisiana, represents the only commercially viable, large-scale crustacean culture in the continental United States (Huner et al. 1979). There were 22,398 ha in 1980 devoted to crayfish culture (Craft 1980). In 1974, 22% (4,500 ha) of the crayfish ponds were rice-field ponds (Gary 1974). In 1960, crayfish farming after rice production was still on a trial and error basis without scientific guidance and without detailed knowledge of the crayfish life cycle and behavior (Viosca 1961; Sonnier 1960). However, the advantages of rice-crayfish culture were perceived by rice farmers since investment in crayfish farming after

rice was small and the potential profit large. Viosca (1953, 1961) first described the rearing of crayfish in rice fields. He found both red swamp crayfish (P. clarkii) and white river crayfish (P. acutus acutus) suitable for rearing in rice fields. Hill and Cancienne (1963) and Thomas (1963) suggested management techniques for producing crayfish in rice fields, and their procedures were later tested by Chien and Avault (1980).

The general procedure for cultivating crayfish in rice ponds is to stock mature crayfish in late spring or early summer when few wild crayfish are in the field. Rice fields are drained in late summer and allowed to dry for about two weeks to support rice harvesting equipment. Meanwhile, the crayfish have completed burrowing. Rice is usually harvested from mid-August to mid-September. After this the field is reflooded and young crayfish are flushed out of burrows to feed on decomposing rice straw and associated microorganisms. The crayfish harvest usually begins in January and continues into May.

Crayfish production of over 1000 kg/ha has been achieved on several occasions in rice ponds (Thomas 1963; Hendrick 1965; Chien and Avault 1980; Miltner 1980). There is a complementary effect of growing crayfish in rice ponds. Chien and Avault (1980) found that crayfish grown in rice fields did not adversely affect rice production and that crayfish attained a larger size and provided higher total production when compared to crayfish in ponds containing volunteer aquatic plants. Miltner (1980) concluded that, compared with millet, which yielded an average of 790 kg/ha of harvestable crayfish, rice

was a superior forage, yielding 1071 kg/ha. In addition, rice fields are more productive following crayfish crops (Vizena 1977; Chien and Avault 1980). With all these favorable factors in rice-crayfish double cropping, and with an expanding market creating a demand for increased crayfish production, more rice farmers are likely to double crop rice and crayfish.

However, before crayfish are introduced and farmed in other regions, the life history of crayfish and their behavior responding to local climatic, hydrological, and ecological conditions must be studied. Lowery and Mendes (1977) found that P. clarkii in Kenya breeds throughout the year but with a distinct peak when the water level erratically increases. With the similar environmental conditions in Louisiana, the double cropping of rice and crayfish has expanded to the Delta of Mississippi (Rutz 1980). Although cultivating rice and crayfish has been a common practice in Louisiana for years, it has not yet succeeded in California. In California, Orconectes virillis and P. clarkii were both reported as rice field pests (Riegel 1959), chiefly because they often burrow into levees, allowing water to escape and thus interfering with proper irrigation procedures. Chang and Lange (1967) even evaluated several pesticides for control of crayfish in California rice fields. Penn (1954) stated that crayfish troubled rice farmers in Japan because of their burrowing activities and because they fed on the young rice shoots. The crayfish has been a major pest in the suburbs of Osaka since 1948, with the crayfish population estimated at 1,200 kg/ha. Chien (1978) postulated that, in Penn's study, the rice harmed by crayfish might

be the second (fall) rice crop, since young-of-the-year crayfish were flushed out of burrows at that time.

Two major problems in rice-crayfish culture are: (1) rice pesticides may kill crayfish; and (2) either rice or the crayfish crop must be sacrificed to a degree to mesh the tight rotation schedule. Cheah et al. (1979) concluded that insecticides are the most toxic pesticides to juvenile crayfish, while fungicides (seed-protectants) are least toxic. The herbicides are of intermediate toxicity in relation to insecticides and fungicides. The addition of compounds such as furadan (for control of the rice water weevil, Lissorhoptrus oryzophilus, Kuschel) can result in the complete mortality of crayfish if applied to ponds after flooding. Vizena (1977) reported that rice-crayfish farmers must be willing to sacrifice some rice production to grow crayfish, since pesticides cannot be used on lands where crayfish are grown, and rice yields are often lower due to insect damage.

Draining fields in late March to replant rice cuts the crayfish harvest season off during the maximum production month, as crayfish harvest usually continues into May. After crayfish farming, soybeans may be a more suitable crop than rice, since soybeans can be planted over a relatively long period of time (Williams and Marshall 1976). For best results, soybeans can be planted from May 10 to June 15 in Louisiana (USDA 1961). The rotation of soybeans with crayfish has been proposed by Avault and Chien (1979).

MATERIALS AND METHODS

This study was conducted at the Ben Hur Farm, LSU, Baton Rouge, LA., during 1978 and 1979.

General Field Preparation

On 14 March 1978, soil samples were obtained from each of 18 ponds and analyzed for phosphorus, potassium, calcium, magnesium, organic matter, and pH by the Soil Testing Laboratory, LSU, according to methods and procedures outlined by Brupbacker et al. (1968). The results were used as references for the fertilizer required. Beginning 10 April 1978, 18 0.05 ha earthen ponds, with average depths of 0.8 m, were thoroughly disked, fertilized at a rate of 227 kg/ha of 8-24-24, and then flooded with about 2.5 cm of water. After flooding, fungicide-treated (Difolatan) LaBelle rice seed (*Oryza sativa*) was broadcasted in all ponds at a rate of 153 kg per ha. Cheah (1978) noted that fungicides (seed-protectants) are relatively non-toxic to juvenile crayfish compared with insecticides and herbicides. After rice was planted, ponds were slowly dewatered. When barnyard grass (*Echinocloa* sp.) and other annual weeds grew 5 to 6 cm high, the herbicide propanil was used at a rate of 2.3 kg/ha (Smith and Seaman 1973). Four days after sparying, ponds were reflooded with 5 cm of water. Chien and Avault (1980) found that when propanil was used at a rate of 2.3 kg/ha, there were no significant adverse effects on crayfish production. However, to avoid direct chemical damage that propanil might cause to crayfish, ponds were not

stocked with crayfish until 27 May 1978, two weeks after propanil had been applied. The stocking rate was 48 pairs per pond (about 51 kg/ha). The water level was gradually increased as rice grew and was ultimately maintained at 8 cm.

When rice was in the joint stage, i.e. at the first internode elongation, 170 kg/ha of nitrogen fertilizer (urea) was applied to each pond. In late August, ponds were completely drained and allowed to dry out to facilitate harvesting. However, because of unfavorable weather conditions and lack of adequate harvest equipment, the rice was not harvested but, instead, was cut at a height of 30 cm on 1 September 1978. The grain fell on the ground at cutting and was left.

Experimental Design

Ponds were randomly assigned to six treatments in a 2 X 3 factorial arrangement with two flooding dates and three types of rice straw disposals; each treatment had three replicates. The treatments were as follows:

		Two Flooding Dates	
		Early Flooding (9/20/78)	Late Flooding (10/15/78)
Three Rice Straw Disposals	Baled (Aerobic Decomposition)	3	3
	Standing (Partially Aerobic Decomposition)	3	3
	Disked (Anaerobic Decomposition)	3	3

All ponds were flooded 20 September or 15 October 1979 for early- and

late-flooded ponds, respectively. The rice straw was disposed of in the following manner: (1) Baled- the cut part of the rice straw was collected from the ponds and piled into heaps on the banks, covered with pieces of black vinyl, and kept moist by watering whenever necessary. The rice straw was put back into the ponds after the end of February 1979 monthly. The uncut part of the rice straw was left standing, (2) Standing- all the rice straw was left as it was after cutting, (3) Disked- all rice straw was incorporated into the soil about 5-7.5 cm deep by disking.

Environmental Parameters

Water Quality

From 27 September 1978 through 15 April 1979, dissolved oxygen (DO) and water temperature were recorded weekly in each pond at a depth of 15 cm at dusk, dawn, and the next dusk with a polarographic DO meter (Yellow Spring, Model 54A). The purpose of this investigation was to compare diurnal DO, net daytime photosynthesis, night respiration, and average temperature among treatments. Diurnal DO is defined as the average of DO at dawn and dusk. Net daytime photosynthesis (NDP) is defined as the gain of oxygen during the daytime or DO at dusk minus DO at dawn the same day. Nighttime respiration (NR) is defined as the loss of oxygen during the night or DO at dusk minus DO at next dawn (Hall and Moll 1975).

Water samples were also taken from each pond monthly. Water samples from three replicate ponds of each treatment were mixed and analyzed for NH_4^+-N, NO_2^-+NO_3^--N, total N, PO_4-P, and total P using

procedures of Strickland and Parsons (1965) as modified by Ho and Schneider (1974).

Periphyton

Periphyton (aufwuch) has been suggested as a main food source for crayfish (Goyert et al. 1975; Chien 1978). A periphyton sampler was developed and used to measure the quantity of periphyton in each pond over time.

The sampler consisted of a horizontal cylinder attached to a vertical cylinder by a galvanized support wire (Fig. 1). Each cylinder was assembled by wrapping a strip of transparent plastic (XEROX 3R163, 7 X 11.5 cm in area and 0.1 mm in thickness) around a No. 14 cork. The total exposed surface area of the transparency for external and two thirds internal surface was 128.8 cm^2 (7 X 11.5 X 1.6). When the transparent plastic was folded into a cylinder, a gap of 2 mm was left to allow for the release of gas bubbles formed by the respiration of organisms inside the cylinder. The support wire was attached by cables to a buoy and an anchor. The periphyton sampler has several advantages: (1) The transparent plastic is not as fragile as glass slides. (2) It provides a larger attachment area than glass slides. (3) The double-cylinder is exposed to periphyton in every direction.

One month after ponds were flooded, three periphyton samplers were placed in each pond at a depth of 10 cm. Every one and one-half months, one sampler was removed from each pond. The transparency was taken apart and dried at 105 C for 5 hours (Sladeckova 1962). The biomass of periphyton was obtained by subtracting the weight of the

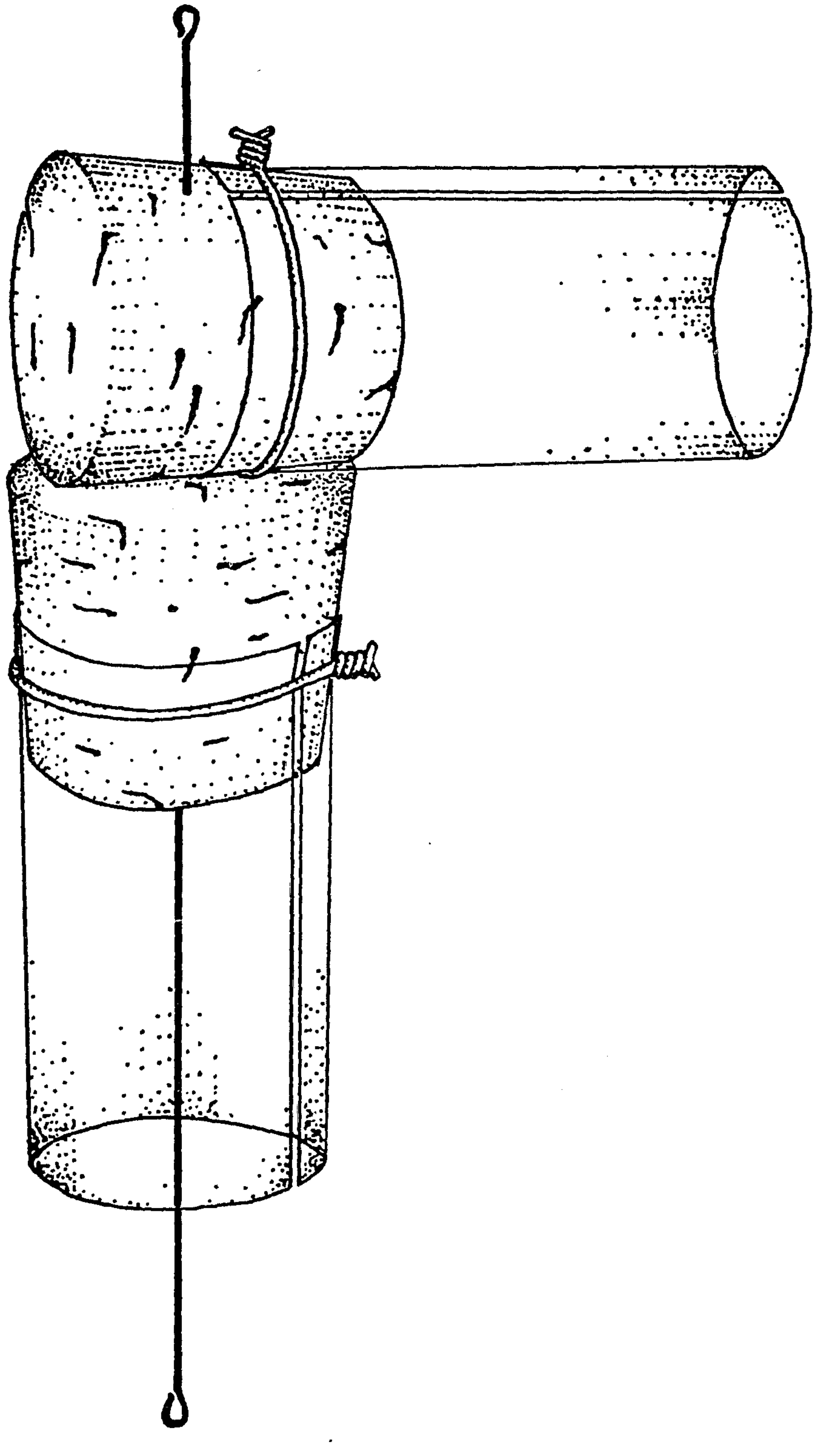

Fig. 1. Assembled view of the 3-dimensional periphyton sampler.

original unattached transparency from the weight of the periphyton-attached transparency. The biomass of periphyton was compared among treatments over time.

Rice Straw Decomposition and C:N Ratio Dynamics

The decrease in weight of organic matter is a measure of the decomposition rate (Alexander 1977). The litterbag technique (Odum and de la Cruz 1967) was used in this study. Five bags, each with 20 g of rice straw, were placed into each pond two weeks after the ponds were flooded. Bags were made of 20 X 20 cm aluminum screen with a mesh size of 1.6 mm. The rice straw in bags was disposed of in such ways that it decomposed aerobically, partially aerobically, and anaerobically in baled, standing, and disked rice straw treatments, respectively.

In the baled rice straw treatment, bags were placed inside a wooden box of 0.7 X 0.7 X 0.5 m, and sandwiched between two pieces of black vinyl to reduce evaporation. The box was 10 cm above the water. The top of the box was open and the bottom consisted of a screen made of 6.4 mm wire mesh galvanized hardware cloth, which allowed the rice straw to absorb moisture from pond water evaporation. Moreover, the rice straw was kept moist by watering whenever necessary. In the standing-rice straw treatment, bags were tied onto stakes and suspended in water at a depth of 10 cm. This method simulated rice straw submerged in the water column. In the disked rice straw treatment, bags were buried 5-7.5 cm deep.

One bag of rice straw was removed from each pond monthly. Each rice straw sample was rinsed to wash away extraneous materials,

oven-dried for 24 hours at 105 C, and weighed. The C:N ratio of rice straw was then analyzed in the LSU Geochemistry Laboratory of the Coastal Studies Institute for total organic nitrogen by EPA method 350.2 (EPA 1979). Total carbon was analyzed by EPA method 415.1 in which the LECO carbon analysis system was used (EPA 1979).

Population Dynamics

Initial Survival and Growth Rate of Crayfish

Crayfish were confined in cages in order to observe initial growth and survival. For both flooding dates, one week after ponds were flooded, crayfish were collected. The average lengths (tip of the rostrum to the tip of the telson) of crayfish used in early- and late-flooded ponds were 14.5 ± 2.0 and 14.6 ± 1.8 mm, respectively. Crayfish were stocked in aluminum screen cages (10 X 10 X 20 cm) at 10 per cage. Two cages were placed in each pond in late afternoon when DO was highest. The top 5 cm of each cage was above the water surface in order to give crayfish access to the air-water interface in the event of DO depletion. Twice weekly, water temperature and DO were measured at a depth of 10 cm at dusk and dawn. Crayfish were fed a pelleted ration every other afternoon at a rate of 0.5 g per crayfish to avoid cannibalism due to food deficiency. Total lengths of crayfish were measured and survivals were determined at the second and fourth week after stocking in the cages.

Growth and Population Density

First wave young-of-the-year crayfish were sampled biweekly from

2 December 1978 to 7 April 1979 to determine overall growth and population density. Cylindrical, upright traps, made from 6 mm hardware cloth with two funnel-shaped entrances at the bottom, were used for sampling. Two sampling traps baited with gizzard shad (Dorosoma cepediaum) or catfish heads were set in each pond for 18 to 24 hours. The crayfish were counted, and total length and sex were obtained for each crayfish sampled. After this, crayfish smaller than 75 mm were returned to their respective ponds. Crayfish larger than 75 mm were not returned. Their weights and counts were used in yield data.

The average length of sampled crayfish from each pond was used to fit the von Bertalanffy growth model (von Bertalanffy, 1938):

$$lt = l_{\infty} \cdot (1 - e^{-k(t-to)})$$

where

lt = length at age t in mm,

l_{∞} = average maximum total length,

e = 2.71818...,

k = Brody's growth coefficient (Brody, 1927, 1945),

t = age, in weeks,

to = theoretical adjustment parameter, which express the age when the length would have been zero.

The growth equations were estimated by least squares procedures of a non-linear model $lt = l_{\infty} + B \cdot e^{-k \cdot t}$. B was transformed to $-l_{\infty} \cdot e^{k \cdot to}$ to get $lt = l_{\infty} \cdot (1 - e^{-k \cdot (t-to)})$. For the procedure, refer to Barr et al. (1979).

Relative changes in Catch Per Unit Effort (CPUE) from sampling

and from harvesting for yield data were used as an index of crayfish abundance. This method was based on the assumption that the traps in each pond were equally accessible to the crayfish. Since the traps were made uniformly, this assumption was reasonable. LaCaze (1976) stated that crayfish are inactive below 10 C. Since the trapping success was affected by water temperature, comparison of abundance through time was not attempted.

Yield

To harvest crayfish, two traps were used per pond. The only difference between the sampling traps and the harvesting traps was that the latter were constructed of 1.9 cm mesh poultry netting to harvest crayfish greater than 75 mm (commercial harvestable size). Crayfish were harvested on every weekend from December 2 1978 to 7 April 1979 at a rate of one trapping per week. From 7 April 1979 until 29 May 1979 crayfish were harvested every day or two. Crayfish in each pond were harvested for a total of 144 trappings.

RESULTS

Environmental Parameters

Water Quality

When baled, standing, and disked pond treatments were combined, the average diurnal DOs throughout the study were consistently higher in early-flooded ponds than in late-flooded ponds with a difference of 1.4 mg/l (Fig. 2). The average diurnal DO concentrations during the first five weeks after flooding were 4.4 and 3.6 mg/l in early- and late-flooded ponds, respectively. The average dawn DOs throughout the study were consistently higher in early-flooded ponds (5.4 mg/l) than in late-flooded ponds (4.1 mg/l) (Fig. 2). The first five weeks after flooding, the average dawn DOs were 1.3 and 1.1 mg/l in early- and late-flooded ponds (Table A-1).

When early- and late-flooded ponds treatments were combined, there were no significant differences in the overall average diurnal DOs among baled, standing, and disked ponds. However, the average diurnal DOs during the first five weeks after flooding were highest in baled ponds (4.9 mg/l) followed by standing ponds (3.8 mg/l) and disked ponds (3.4 mg/l). The overall average dawn DOs throughout the study were highest in disked ponds (5.3 mg/l) followed by baled ponds (4.7 mg/l) and standing ponds (4.3 mg/l). During the first five weeks after flooding, dawn DOs were 1.5, 1.2, and 1.0 mg/l for baled, standing, and disked ponds, respectively. After five weeks, the disked ponds had the highest dawn DOs (Fig. 3). From the fifth week

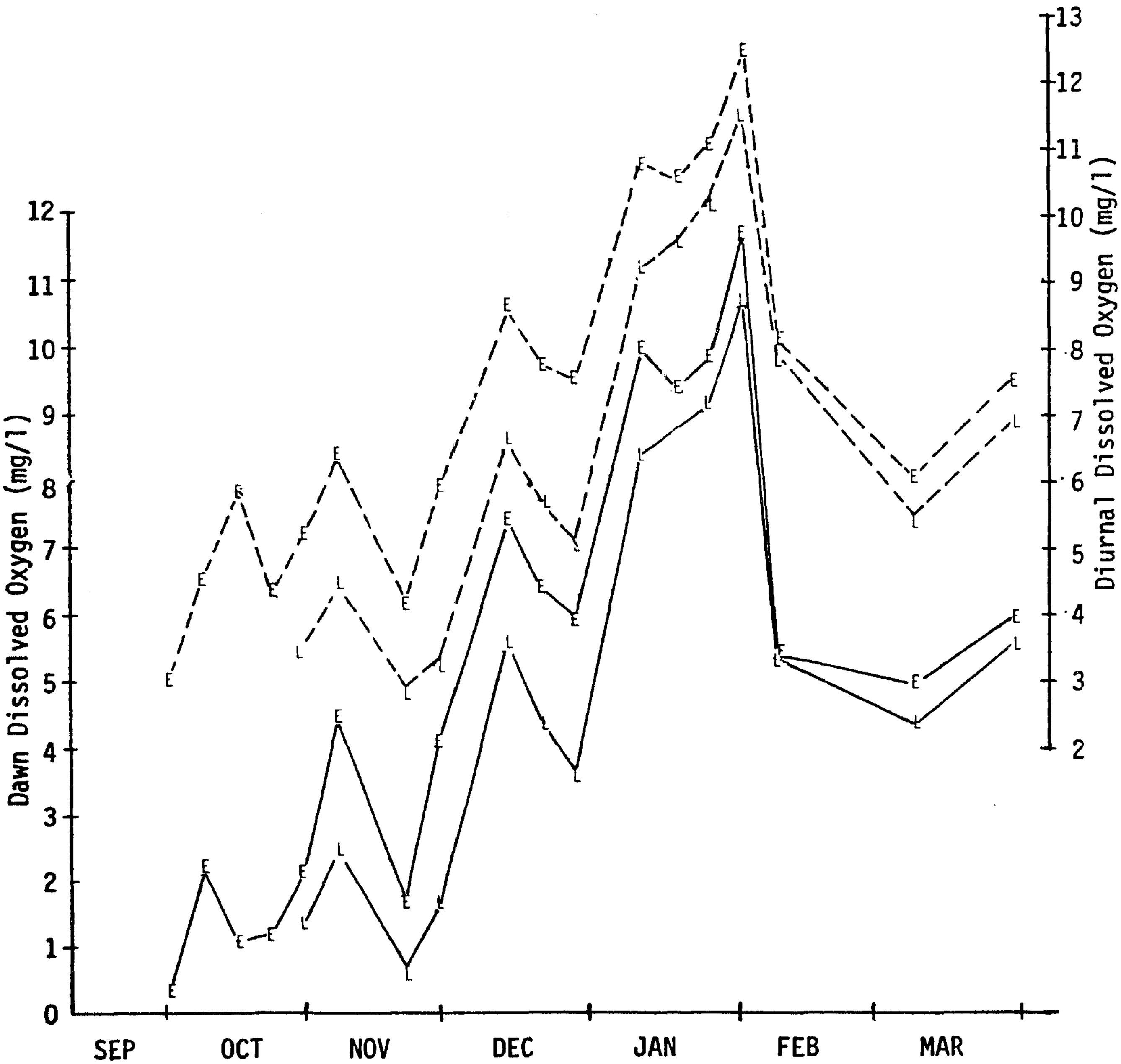

Fig. 2. The average dawn dissolved oxygen (——) and diurnal dissolved oxygen (– –) in early-flooded ponds (9/20/78) (E) and in late-flooded ponds (10/15/78) (L) from 27 September 1978 to 15 April 1979, Ben Hur Farm, LSU.

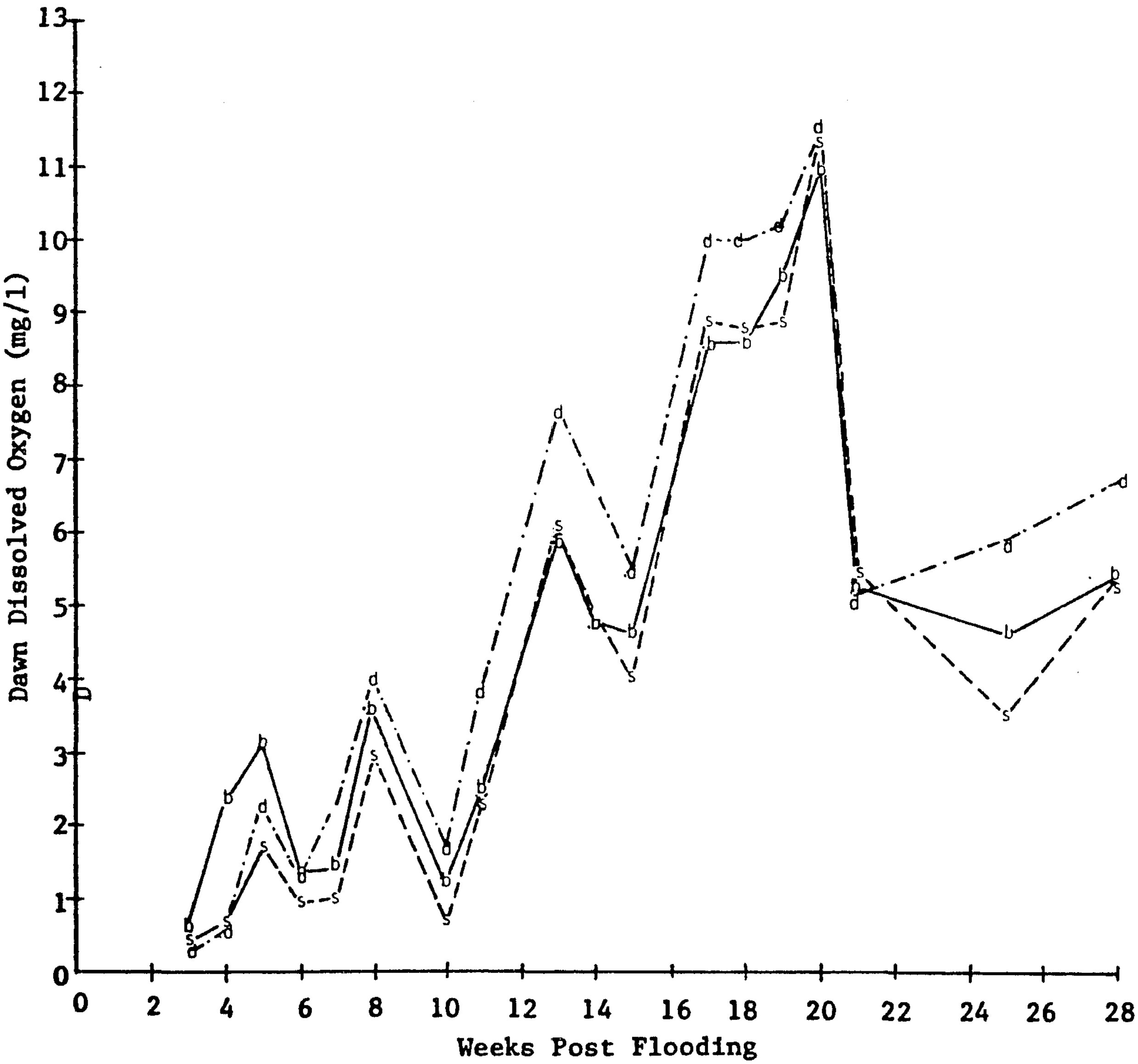

Fig. 3. The average dawn dissolved oxygen in baled ponds (b—), standing ponds (s--), and disked ponds (d-·-) from 27 September 1978 to 15 April 1979, Ben Hur Farm, LSU.

to eleventh week after flooding, the standing ponds had the lowest dawn DO. After that, no significant difference in dawn DOs were observed between standing ponds and baled ponds. The sudden drop of dawn DO in mid February (Fig. 2 and 3) was due to the rising temperature from mid 40 to mid 50.

Among early-flooded ponds during the first 10 weeks post flooding (Table A-2), standing ponds had average dawn DO of 1.2 mg/l, lower than baled (2.3 mg/l) and disked (2.6 mg/l) treatments. There were two, six, and three critical[1] average dawn DOs of less than 1.0 mg/l in baled, standing, and disked ponds, respectively. During this same period, the average dawn DO among late-flooded ponds was highest in standing ponds (2.8 mg/l), followed by disked ponds (2.5 mg/l) and baled ponds (2.0 mg/l). There were two, one, and three critical dawn DOs in baled, standing, and disked ponds, respectively. No critical dawn DOs occurred in any treatment after the tenth week post flooding, as cooling temperatures not only increased the solubility of oxygen but also lowered the biochemical oxygen demand.

The overall average water temperature was only 0.3 C higher in late-flooded ponds than in early-flooded ponds. Temperatures for the first 10 weeks averaged 19.7, 19.1, and 18.7 C in disked, baled, and standing ponds, respectively (Table A-2). There were no significant temperature differences among ponds that received different rice straw disposals thereafter.

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[1] DO concentration of less than 1.0 mg/l is considered critical, since the LC_{50}^{96} value for 9-12 mm crayfish was estimated to be between 0.8 mg/l and 1.1 mg/l oxygen (Melancan and Avault 1978).

There was no significant difference ($P<0.05$) in net daytime photosynthesis between early-flooded ponds (3.8 mg/l) and late-flooded ponds (3.5 mg/l). Overall average NDPs were 4.2, 4.2, and 3.3 mg/l for baled, standing, and disked ponds, respectively. Before 22 November 1978, NDP was highest in baled ponds, but standing ponds had the highest thereafter (Fig. 4). The disked ponds generally had the lowest NDP (12 times out of 18 measurings). Nighttime respiration generally paralleled NDP.

Very low levels of nitrogen and phosphate were found in all water samples from October 1978 to March 1979 (Table A-3(a),(b)). Overall average concentrations were 0.9 mg/l and 0.1 mg/l for total-N and total-P, respectively. There was no trend in increase or decrease of nutrients through time, and little differences in nitrogen and phosphate were found between flooding dates or among disposals of rice straw.

Before mid February 1979, the water was brownish and turbid in disked ponds and clear in both baled and standing ponds. All ponds gradually turned yellowish-green and turbid, as the weather became warmer.

Periphyton

Periphyton biomass increased significantly through time (Table 1 and B-1). When baled, standing, and disked pond treatments were combined, average periphyton biomass over 18 weeks was significantly ($P<0.05$) higher in early-flooded ponds (337 g/m^2) than in late-flooded ponds (216 g/m^2) (Table 1). The periphyton biomass was also significantly higher in early-flooded ponds than in late-flooded

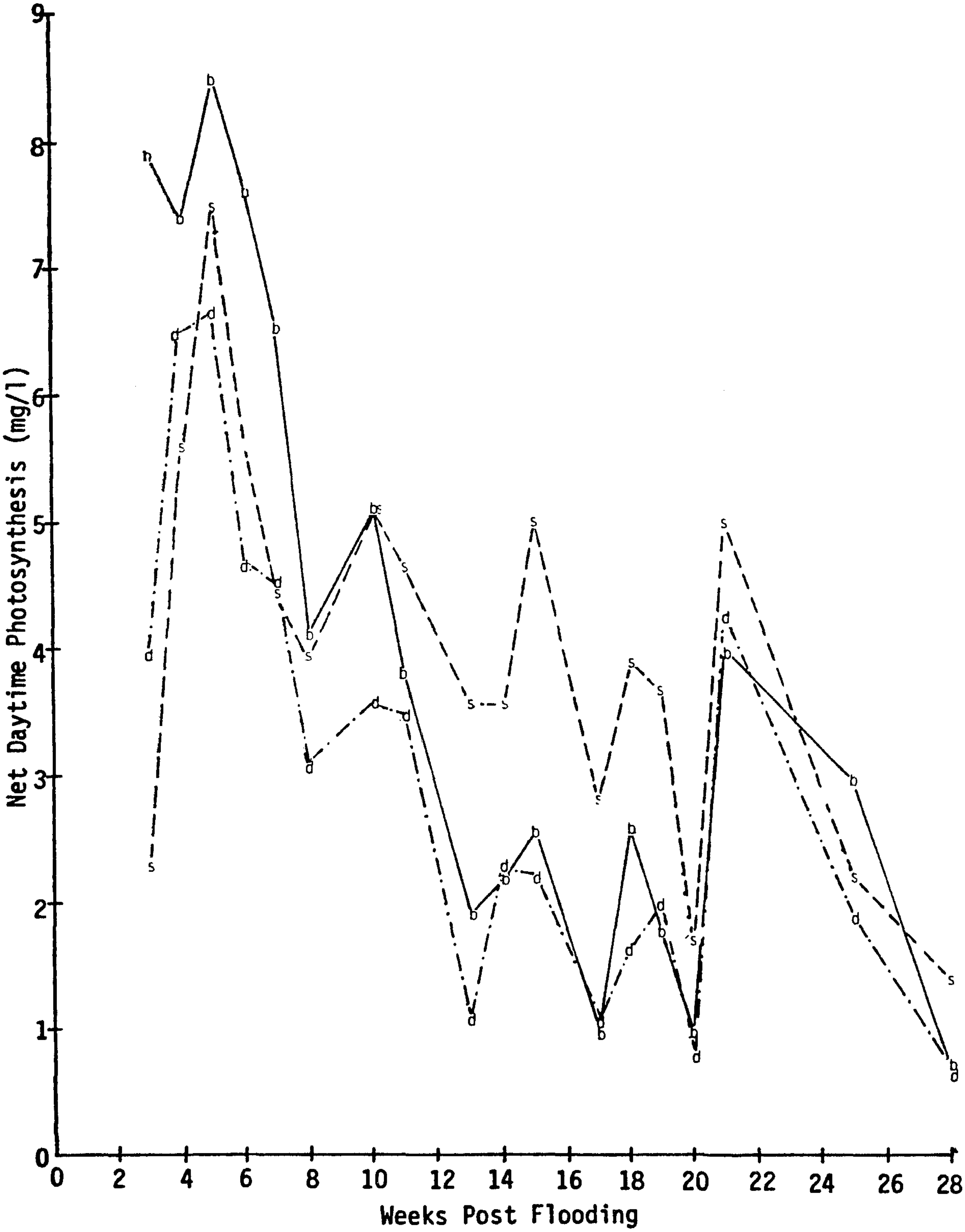


Fig. 4. Net daytime photosynthesis in baled ponds (b—), standing ponds (s--), and disked ponds (d-·-), from 27 September 1978 to 15 April 1979, Ben Hur Farm, LSU.

Table 1. Dry weight (g/m^2) of periphyton grown on the samplers in ponds receiving six treatments of two flooding dates X three disposals of rice straw for three durations of exposure, Ben Hur Farm, LSU.

Duration of Exposure	Date of Flooding	Disposals of Rice Straw: Baled [3]	Standing [4]	Disked [5]	Average
6 weeks	Early [1]	159.4	364.4	265.4	263.1
	Late [2]	180.1	273.7	130.4	194.7
Average		169.8	319.1	197.9	228.9
12 weeks	Early	325.9	454.2	258.4	346.2
	Late	166.0	281.6	116.4	188.0
Average		246.0	367.9	187.4	267.1
18 weeks	Early	407.8	361.9	431.9	400.5
	Late	257.1	353.2	182.6	264.3
Average		332.5	357.6	307.3	332.5
Average	Early	297.7	393.5	318.6	336.6
	Late	201.1	302.8	143.1	215.7
Average		249.4	348.2	230.9	

[1] Ponds were flooded 20 September 1978.

[2] Ponds were flooded 15 October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

ponds at all three samplings. At 18 weeks, periphyton biomass were 401 and 264 g/m^2 for early- and late-flooded ponds, respectively. When early- and late-flooded ponds were combined, average periphyton biomass over 18 weeks were 348, 249, and 231 g/m^2 for standing, baled, and disked ponds, respectively. At six weeks and 12 weeks, periphyton biomass was significantly ($P<0.05$) higher in standing ponds than in both baled ponds and disked ponds. At 18 weeks, periphyton biomass was significantly higher in standing ponds (358 g/m^2) than in disked ponds (307 g/m^2). However, the difference of periphyton biomass between standing ponds and baled ponds (333 g/m^2) was not significant.

A comparison was made between periphyton biomass and NDP to determine if a correlation existed. At six weeks, no significant correlation was found, but at 12 and 18 weeks, the periphyton biomass (G) was higherly correlated ($P<0.001$) with the average NDP (P) after flooding (Fig. 5). The higher the periphyton biomass, the higher the NDP, and vise versa. The linear regression equations were $P=2.14+0.51G$ and $P=2.15+0.84G$, at 12 and 18 weeks, respectively.

Regardless of treatments, a t-test was conducted on the amount of periphyton growth on horizontal cylinders versus that on vertical cylinders. The dry weight of periphyton on horizontal cylinders (159 g/m^2) was significantly higher than that on vertical cylinders (128 g/m^2).

Rice Straw Decomposition and C:N Ratio Dynamics

The weight loss (W) of rice straw during decomposition was highly correlated with time (T). The linear regression equations were $W=36.39+5.65T$ and $W=12.45+9.67T$ for rice straw in early-flooded

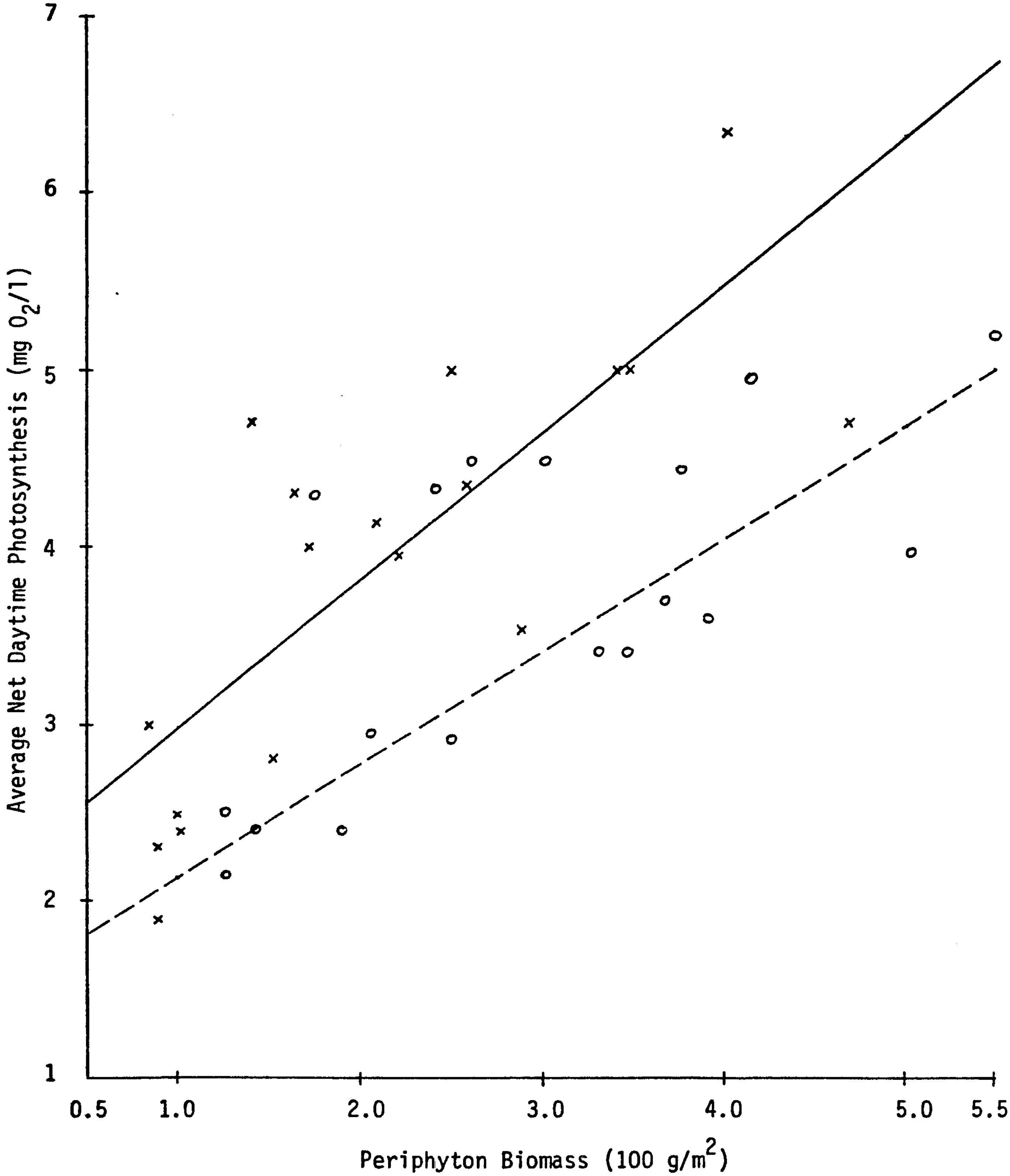


Fig. 5. Linear regression between average net daytime photosynthesis (P) and periphyton biomass (G) at 12 weeks period (× ——, P=2.15+0.84G, R^2=0.65**) and at 18 weeks (o ——, P=2.14+0.51G, R^2=0.47**), Ben Hur Farm, LSU.

and late-flooded ponds, respectively (Fig. 6).

There were marked differences in decomposition of rice straw among treatments (Fig. 7, Table A-4, Table B-2). The first month after flooding, the weight loss of rice straw in early-flooded ponds (43%) was 19% higher than that in late-flooded ponds (24%). By the end of the fifth month, however, the average weight losses were almost equal at 67% and 61% for early- and late-flooded ponds, respectively.

The first month after flooding, decomposition of rice straw in disked ponds (29%), as compared to that in baled (37%) and standing ponds (34%), was the slowest. Five months later, baled rice straw had the most rapid decomposition with an average weight loss of 77% as compared with 67% in standing ponds and 49% in disked ponds (Fig. 7, Table A-4).

The C:N ratios for decomposing rice straw over a five month period from different treatments are shown in Table 2. At flooding, the C:N ratio of rice straw was 57. There was a general trend in C:N ratios to decrease through time in each treatment (Table 2). The overall average C:N ratio dropped sharply to 44 during the first month but the drop slowed down after the fourth month. There was no significant difference in the rate of C:N ratio decline between early-flooded and late-flooded ponds over five months. The C:N ratio of rice straw dropped to less than 17 after mid February in early-flooded ponds, and after late March in late-flooded ponds.

The rate of C:N ratio decline over five months was fastest in baled ponds (aerobic decomposition) followed by standing ponds (partially aerobic decomposition), and disked ponds (anaerobic

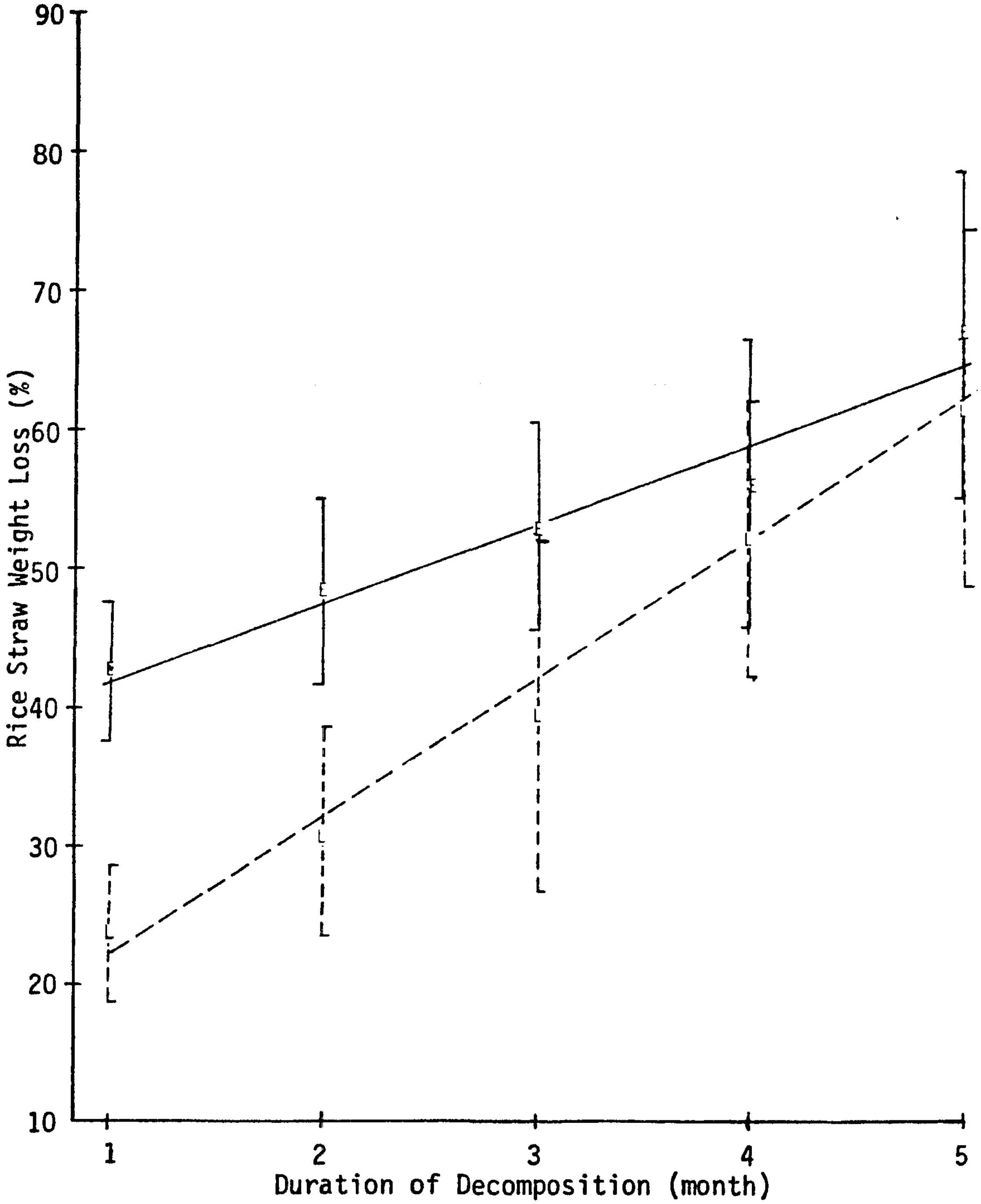


Fig. 6. Linear regression between weight loss of rice straw and time of decomposition for early-flooded ponds (E ——) and for late-flooded ponds (L – – –), Ben Hur Farm, LSU. Vertical bar= $\pm$ 1 S.D.

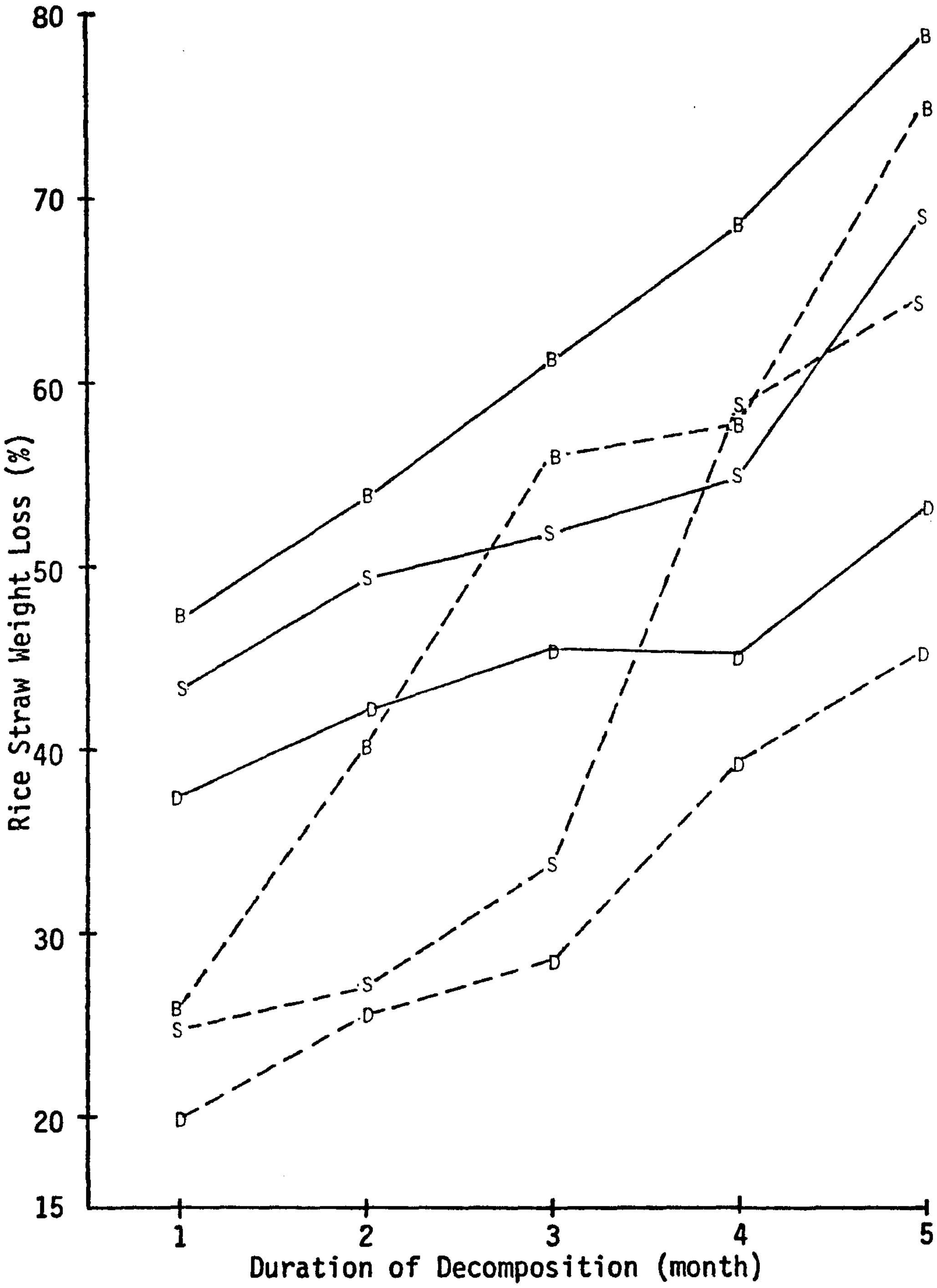


Fig. 7. The weight loss of rice straw decomposed under treatments of 2 flooding dates: early-flooding (——) and late-flooding (— —), and 3 disposals of rice straw: baled (B), standing (S), and disked (D), during a 5-month period, Ben Hur Farm, LSU.

Table 2. Changes in C:N ratio of rice straw under six treatments with two flooding dates (early (E)- and late (L)-flooding) X three disposals of rice straw (baled, standing, and disked) through five periods of decomposition, Ben Hur Farm, LSU.

Months Post Flooding	Flooding Date	Sampling Date	Rice Straw Disposals Baled[3]	Standing[4]	Disked[5]	Average
1	E[1]	10/18/78	36.60	41.74	46.45	41.60
	L[2]	11/22/78	41.78	46.40	48.84	45.67
	Average		39.19	44.07	47.65	43.64
2	E	11/22/78	27.49	28.50	39.60	31.86
	L	12/18/78	32.69	36.09	47.71	38.83
	Average		30.09	32.30	43.66	35.35
3	E	12/18/78	23.79	23.93	31.20	26.31
	L	1/19/79	24.35	25.21	38.69	29.42
	Average		24.07	24.57	34.95	27.87
4	E	1/19/79	15.90	16.17	27.49	19.85
	L	2/19/79	17.39	19.25	22.98	19.87
	Average		16.65	17.71	25.24	19.86
5	E	2/19/79	12.66	13.49	23.37	16.51
	L	3/18/79	13.74	15.30	22.40	17.15
	Average		13.20	14.40	22.89	16.83

* The initial C:N ratio of rice straw before decomposition was 57:1.

[1] Ponds were flooded 20 September 1978.

[2] Ponds were flooded 15 October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

decomposition). The C:N ratio decline of rice straw in standing ponds was closer to that in baled ponds than that in disked ponds, dropping to 17 after four months' decomposition in baled and standing ponds and 17 after five months' decomposition in disked ponds.

Population Dynamics

Initial Survival and Growth Rate of Crayfish

Regardless of treatment, no significant correlation was found between survival and average diurnal DO, minimum dawn DO, or average dawn DO during the four week period. Survival was inversely related to average water temperature (Fig. A-1). In other words, high water temperatures resulted in low survival and vice versa.

Survival rate of the juvenile crayfish was significantly higher in late-flooded ponds (84%) than in early-flooded ponds (70%) at the end of the four week period (Table A-5). Survival rates during the first two weeks were 95 and 86% in late-flooded and early-flooded ponds, respectively, and 88 and 81% the last two weeks[1]. No significant differences in survival rates were found among baled (74%), standing (80%), and disked (76%) rice forage treatments at the end of the four week period.

Crayfish growth rate was inversely correlated with survival (Fig. A-2), i.e., high survival resulted in low growth and vice versa. Increasing DO concentrations and water temperatures resulted

[1] The last two weeks survival rate = (the number of crayfish that survived at the end of the fourth week/the number of crayfish that survived at the end of the second week)*100%.

in faster growth during the four week period (Fig. A-3 and A-4).

No significant differences in growth rates were found between early-flooded ponds (9.3 mm/4 weeks) and late-flooded ponds (8.7 mm/4 weeks) at the end of the four week period. However, during the first two weeks, growth rate was significantly higher in early-flooded ponds (5.8 mm/2 weeks) than in late-flooded ponds (4.3 mm/2 weeks) (Table A-5). This resulted from 4.4 C higher water temperature and/or 9% lower survival in early-flooded ponds than in late-flooded ponds. During the last two weeks, growth rate was unexpectedly higher in late-flooded ponds (4.5 mm/2 weeks) than in early-flooded ponds (3.6 mm/2 weeks). The growth rates at the end of four week period were 4.0, 8.6, and 9.5 mm/4 weeks for baled, standing, and disked ponds, respectively. Although there were no significant differences in crayfish growth among treatments of rice straw disposals, there was significant ($P<0.05$) interaction between flooding dates and rice straw disposals. The highest average growth rate (10.2 mm/4 weeks), observed in early-flooded ponds in which rice straw was disked, was attributed to higher water temperatures and a lower survival rate.

Growth

von Bertalanffy's growth curve (1938) was used to describe crayfish growth because it fit data well (Romaire 1976; Chien 1978). Faben (1965) illustrated that the difference between the asymptotic size (l_{∞}) and the actual size of an organism decreases exponentially at a rate, k. The larger k is, the more rapid is the decrease. Or, for any given initial organism size (at the time decreasing exponential growth starts), a larger k means a smaller l_{∞} and thus slower

growth from that time onward.

Both the growth rate and asymptotic length of crayfish were higher in early-flooded ponds (k=0.0550 l_{∞}=92.2 mm) than in late-flooded ponds (k=0.0896, l_{∞}=82.7 mm) (Fig. 8). When early- and late-flooded ponds were combined, the growth rate was highest in baled ponds, followed by standing ponds and disked ponds (Fig. 9). Crayfish from the late-flooded baled ponds had the highest growth rate (k=0.0171) and l_{∞} (131.5 mm) among the six treatments (Table A-6). Crayfish from late-flooded-disked ponds had the lowest growth rate (k=0.2387) and l_{∞} (72.5 mm) (Table A-6).

Population Density (CPUE) and Size of Crayfish

The catch per unit of effort (CPUE) is an index of abundance (Ricker 1975). Ricker (1940) stated that when a single homogeneous population is being fished, and when effort is proportional to the rate of fishing, CPUE is proportional to the mean stock present during the time of fishing. Vulnerability of crayfish to traps varies with water temperature (LaCaze 1976), thus only the CPUE's obtained at the same trapping time were used to compare the abundance among treatments.

The average CPUE (4 trap-days[1]) in number was consistently higher in late-flooded ponds than in early-flooded ponds with an average difference of 42 crayfish/4 trap-day (Fig. 10). The average individual weight, in accordance with length but in contrast to CPUE in number, was higher in early-flooded ponds than in late-flooded ponds (Fig. 10). Apparently, there existed a reverse relationship

[1] Two 6 mm mesh size traps and two 19 mm mesh size traps per pond per day.

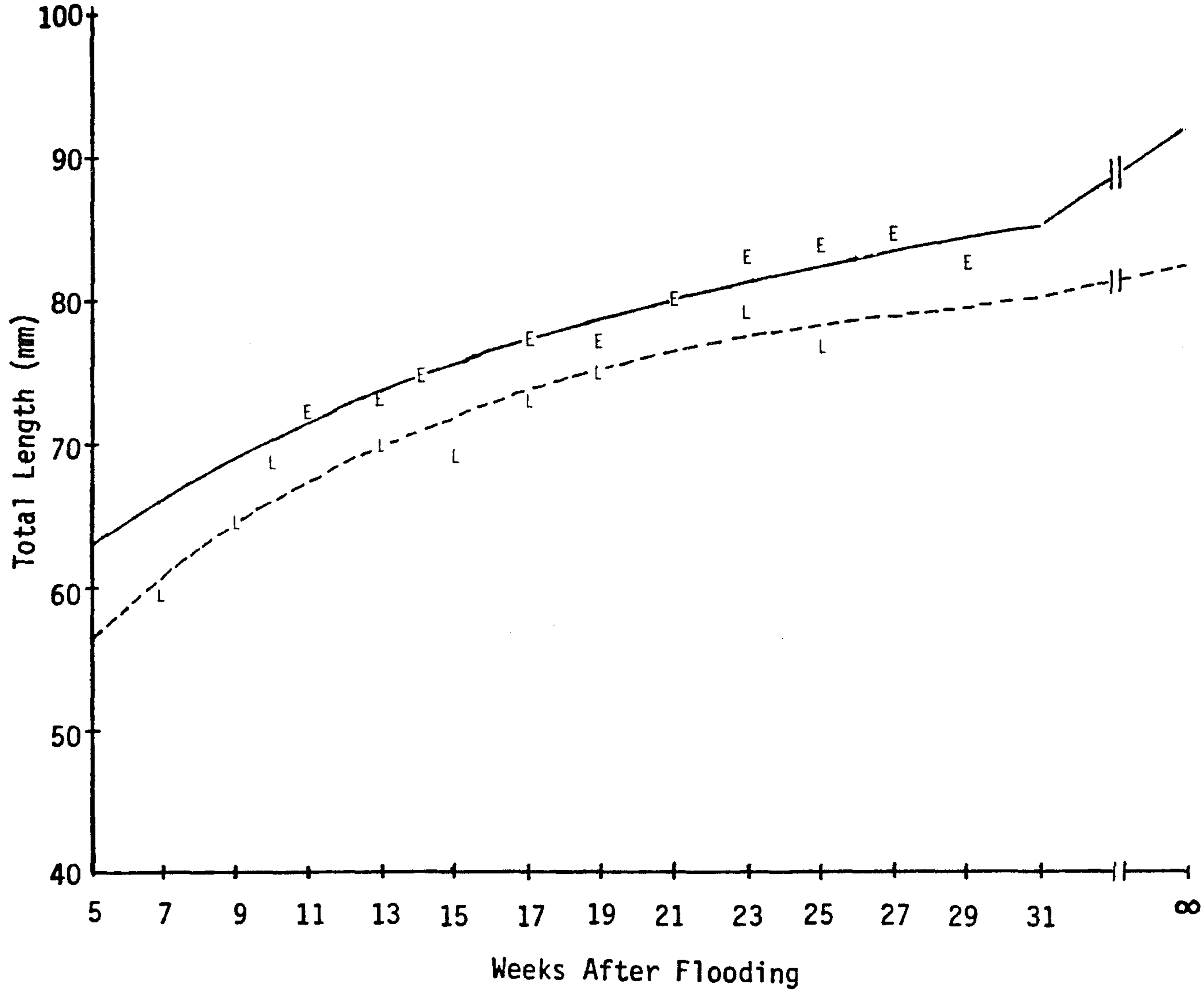


Fig. 8. von Bertalanffy's growth curves, in length (mm), of crayfish from early-flooded ponds (E ——, $L_t = 92.223\left[1-e^{-0.055(t+16.157)}\right]$) and late-flooded ponds (L - - -, $L_t = 82.721\left\{1-e^{-0.090(t+7.766)}\right\}$), Ben Hur Farm, LSU.

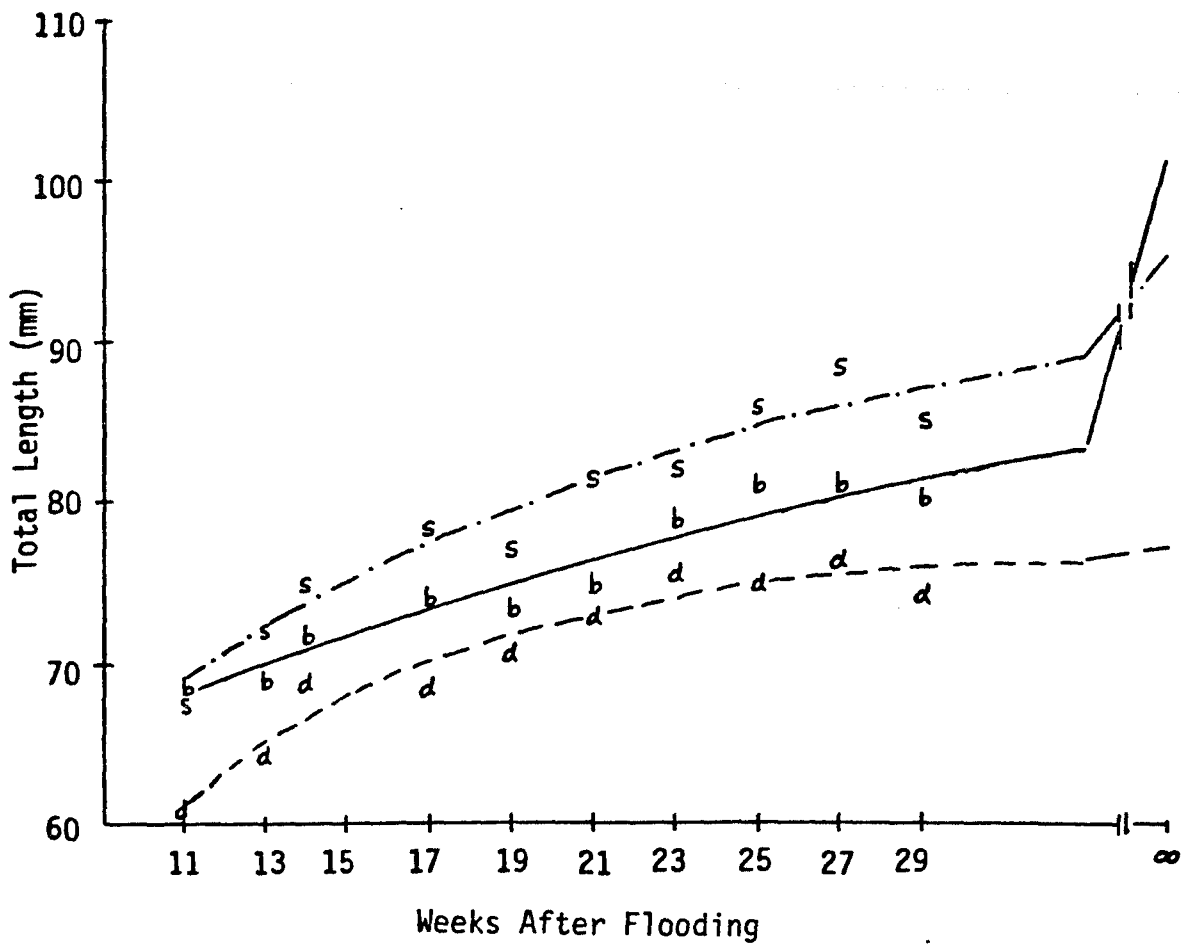


Fig. 9. von Bertalanffy's growth curves, in length (mm), of crayfish from baled ponds (b ——, $Lt=101.5(1-e^{-0.0286(t+27.7)})$), standing ponds (S — —, $Lt=95.4(1-e^{-0.0641(t+9.1)})$), and disked ponds (d —·—, $Lt=77.4(1-e^{-0.1337(t+0.8)})$) when early- and late-flooded ponds were combined, Ben Hur Farm, LSU.

Fig. 10. The catch per unit of effort (two traps/ pond) and the size, in weight (g), of crayfish from early-flooded ponds (E——) and late-flooded ponds (L— —), during 11th to 29th week post flooding, Ben Hur Farm, LSU.

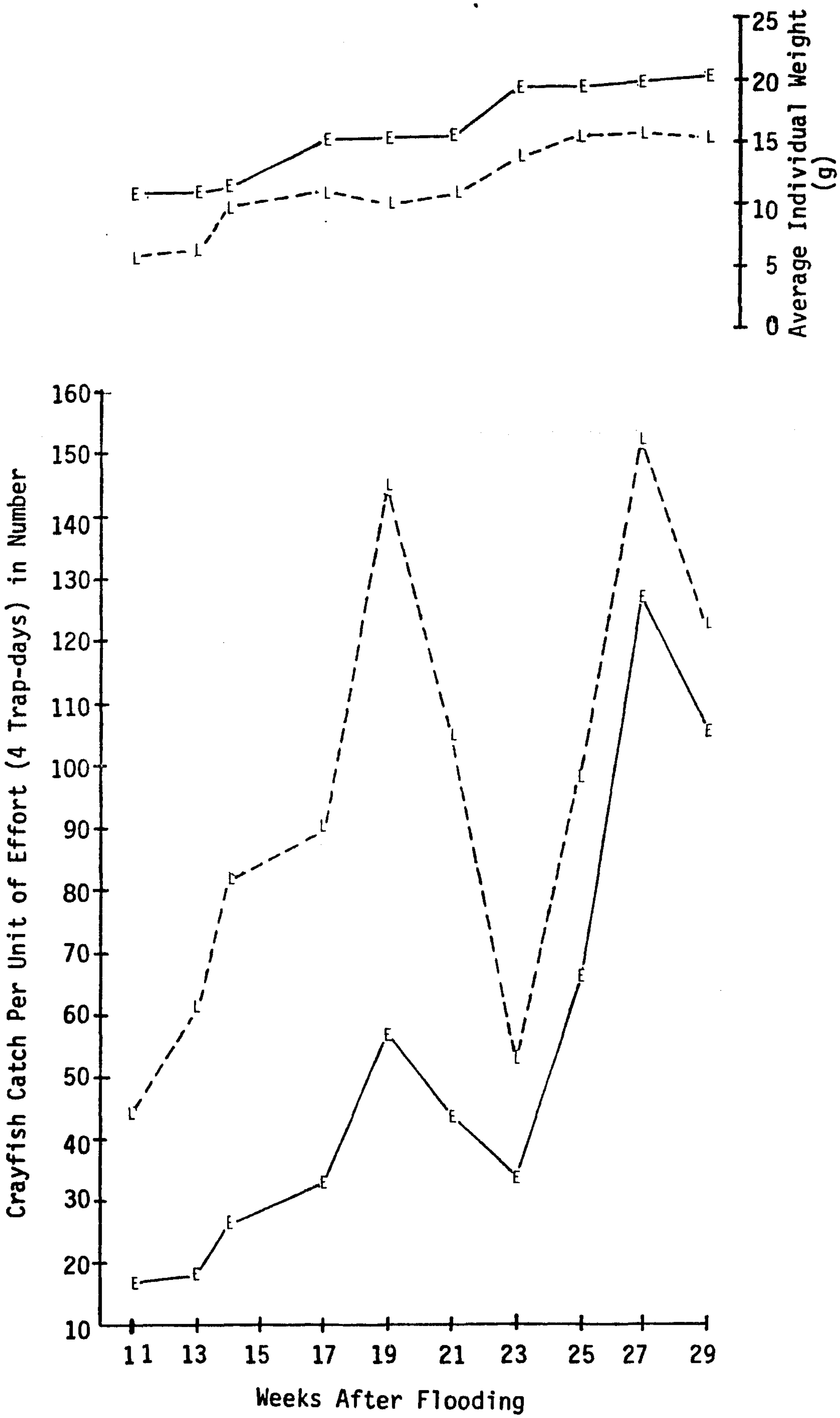

25
20
15
10
5
0
Average Individual Weight
(g)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Crayfish Catch Per Unit of Effort (4 Trap-days) in Number
11 13 15 17 19 21 23 25 27 29
Weeks After Flooding

Fig. 10.

Fig. 11. The catch per unit of effort (two traps/pond) and the size, in weight (g), of crayfish from baled ponds (b——), standing ponds (s— —), and disked ponds (d— · —), (early-flooded ponds and late-flooded ponds combined), during 2 December 1978 to 7 April 1979, Ben Hur Farm, LSU.

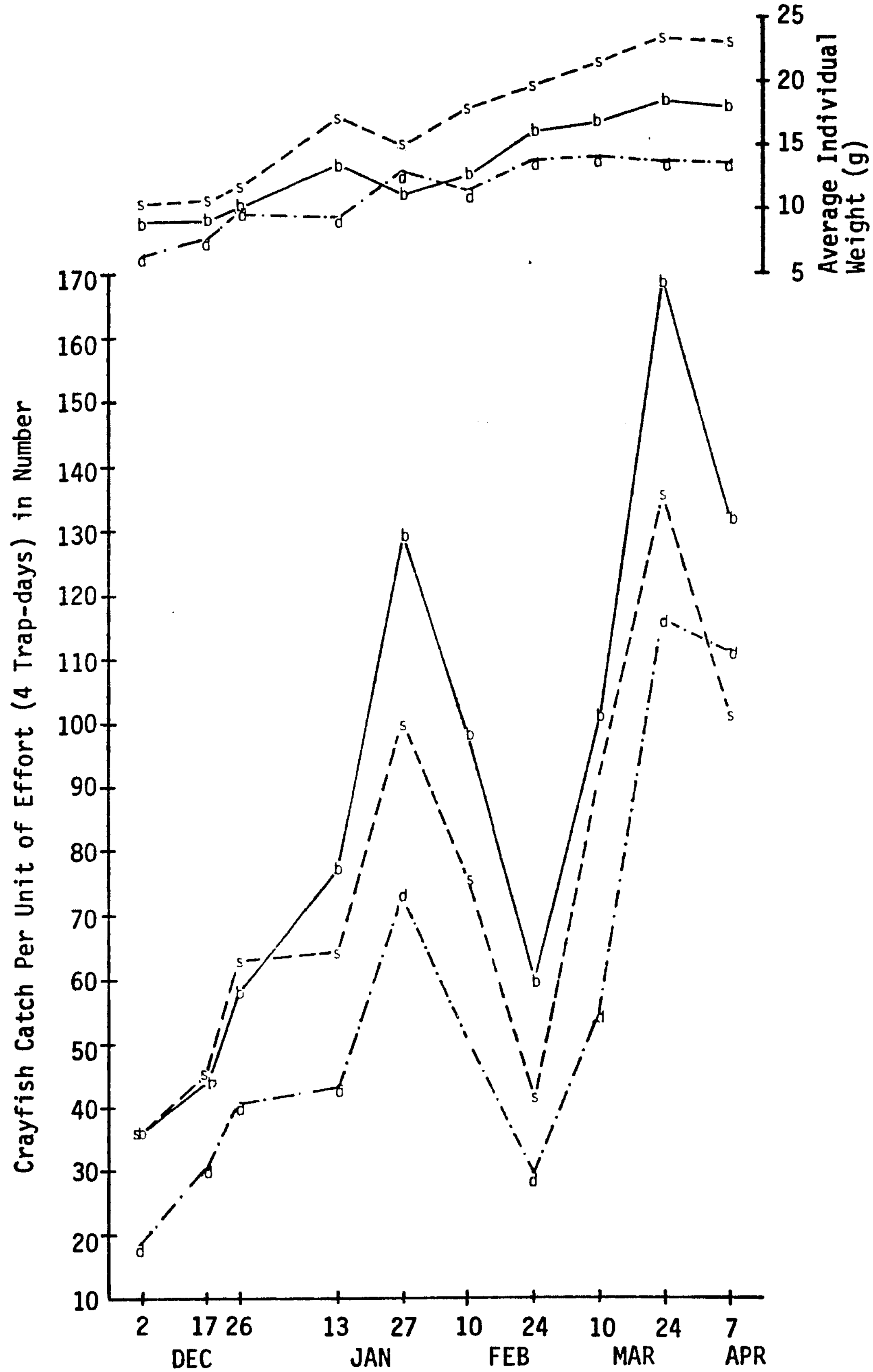

Average Individual Weight (g)
5
10
15
20
25
Crayfish Catch Per Unit of Effort (4 Trap-days) in Number
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
2
17
26
13
27
10
24
10
24
7
DEC
JAN
FEB
MAR
APR

Fig. 11.

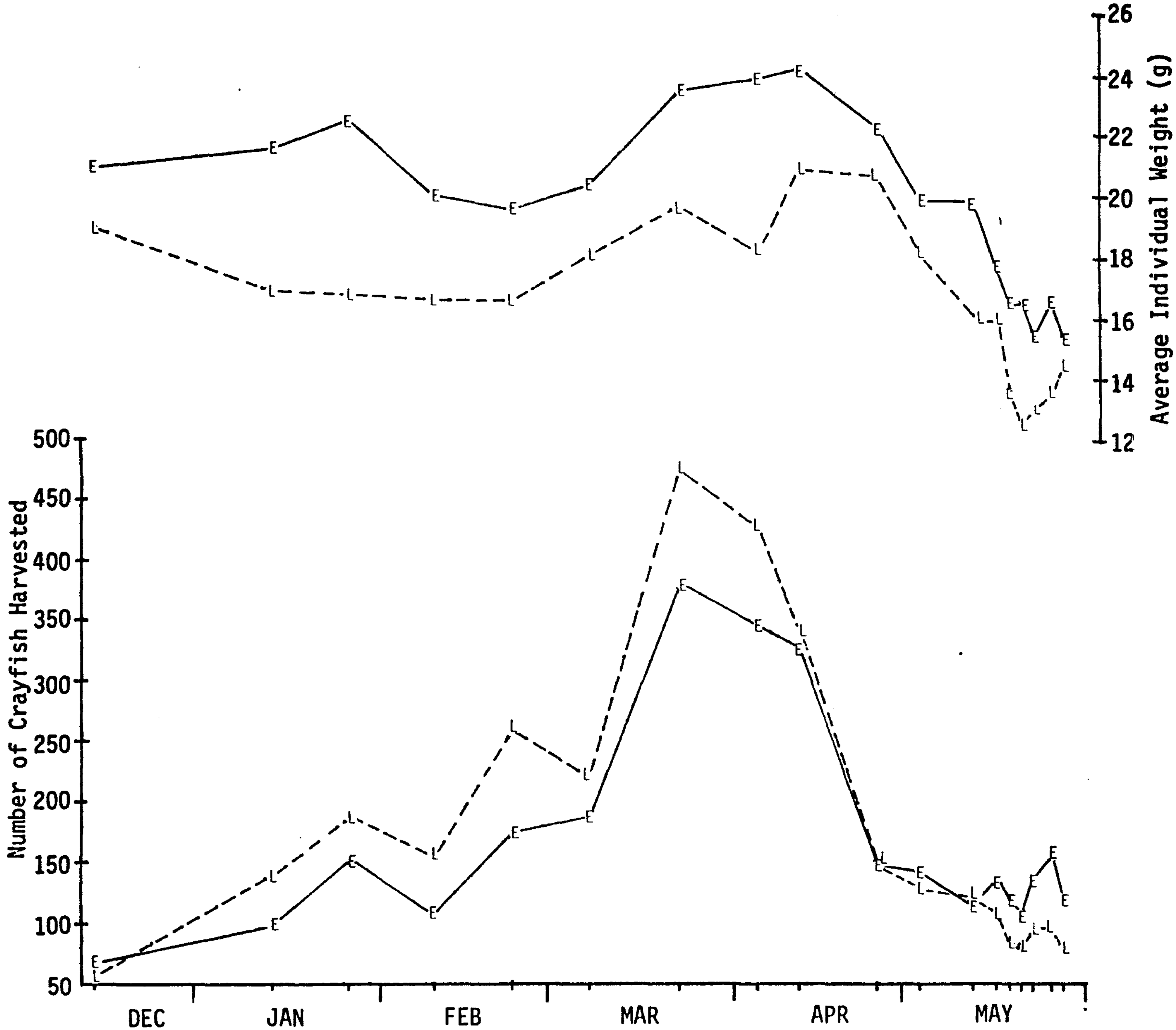
between population density and size of crayfish.

When early- and late-flooded ponds were combined, the lowest average CPUE was found in disked ponds (Fig. 11); crayfish from these ponds also had the lowest individual weight. The average individual weight of crayfish was higher in standing ponds than in either baled or disked ponds at all times, and these differences increased through time (Fig. 11). Except for the third sampling in early-flooded ponds (Fig. A-5) and the first three samplings in late-flooded ponds (Fig. A-6), the average CPUE in number was highest in baled ponds.

The CPUE of harvestable crayfish generally increased from the onset of the trapping effort for all treatments. Peak CPUE levels occurred during the end of March to mid April for all treatments, and declined rapidly after mid April. Trapping effort was terminated after the CPUE dropped below 1.0 kg/8 trap-days for most of the ponds. The CPUE-time curve was left-skewed, with slow CPUE increase before the peak, and a sharp decline after the peak. The average individual weight of harvestable crayfish declined sharply after the CPUE reached the peak (Fig. 12).

There were more harvestable-size crayfish in late-flooded ponds than in early-flooded ponds before 26 April 1979, but with slightly more crayfish in early-flooded ponds thereafter (Fig. 12). The overall CPUE's were 169 and 178 crayfish/8 trap-day for early- and late-flooded ponds, respectively (Table A-7) (Fig. 12). The overall average individual weight of crayfish in early-flooded ponds (19.8 g) was significantly ($P<0.05$) higher than in late-flooded ponds (16.7 g)

Fig. 12. The catch per unit of effort (8 traps/pond) and the size, in weight (g) of harvestable crayfish from early-flooded ponds (E——) and late-flooded ponds (L— —), during 2 December 1978 to 29 May 1979, Ben Hur Farm, LSU.



Average Individual Weight (g)
26
24
22
20
18
16
14
12
Number of Crayfish Harvested
500
450
400
350
300
250
200
150
100
50
DEC
JAN
FEB
MAR
APR
MAY

Fig. 12.

Fig. 13. The catch per unit of effort (8 traps/pond) and the size, in weight (g) of harvestable crayfish from baled ponds (b———), standing ponds (s— —), and disked ponds (d— · —), which were early-flooded on 20 September 1978, during 2 December 1978 to 29 May 1979, Ben Hur Farm, LSU.

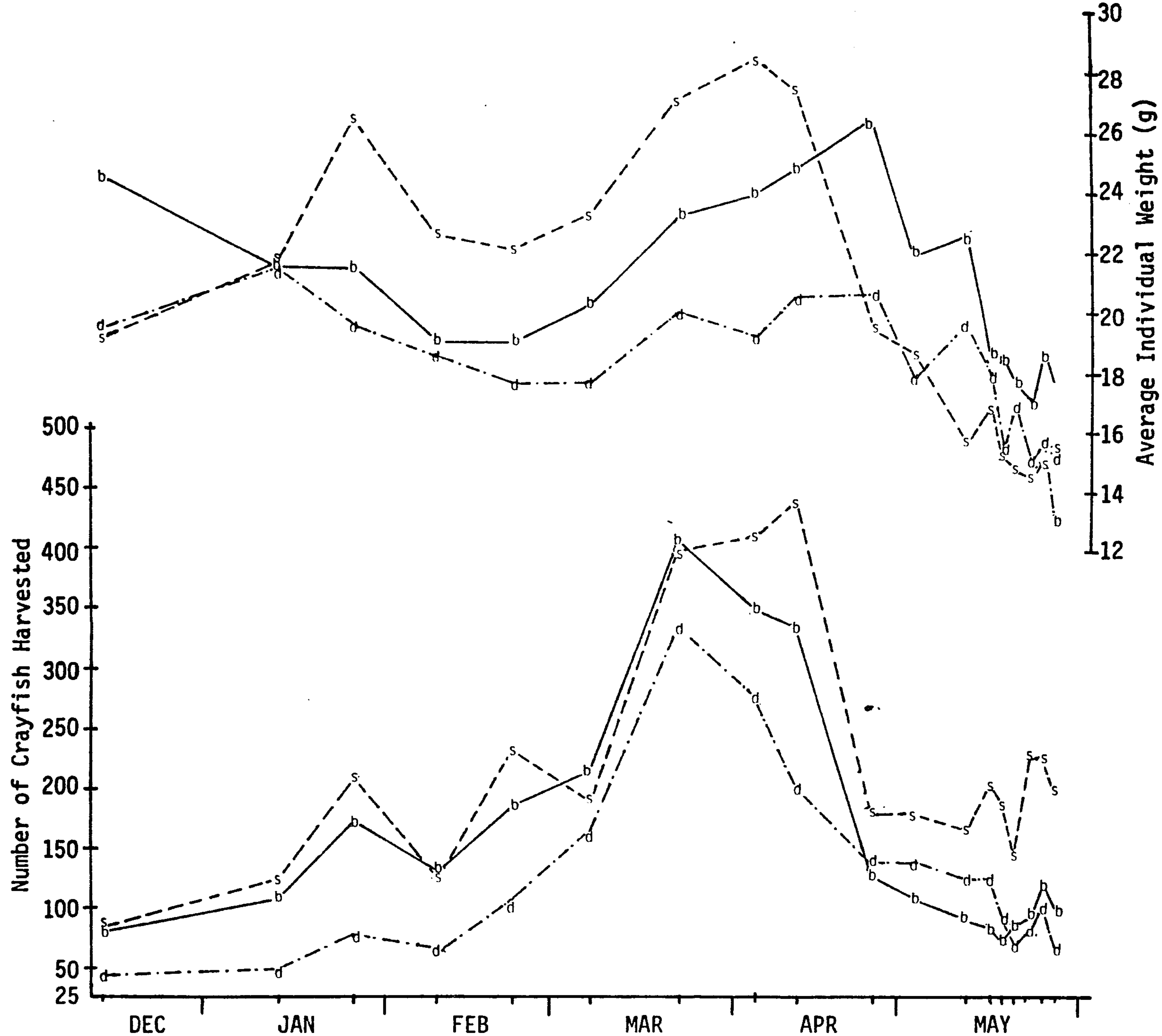

Number of Crayfish Harvested
500
450
400
350
300
250
200
150
100
50
25
Average Individual Weight (g)
30
28
26
24
22
20
18
16
14
12
DEC
JAN
FEB
MAR
APR
MAY

Fig. 13.

Fig. 14. The catch per unit of effort (8 traps/pond) and the size, in weight (g) of harvestable crayfish from baled ponds (b——), standing ponds (s— —), and disked ponds (d— · —), which were late-flooded on 15 October 1978, during 2 December 1978 to 29 May 1979, Ben Hur Farm, LSU.

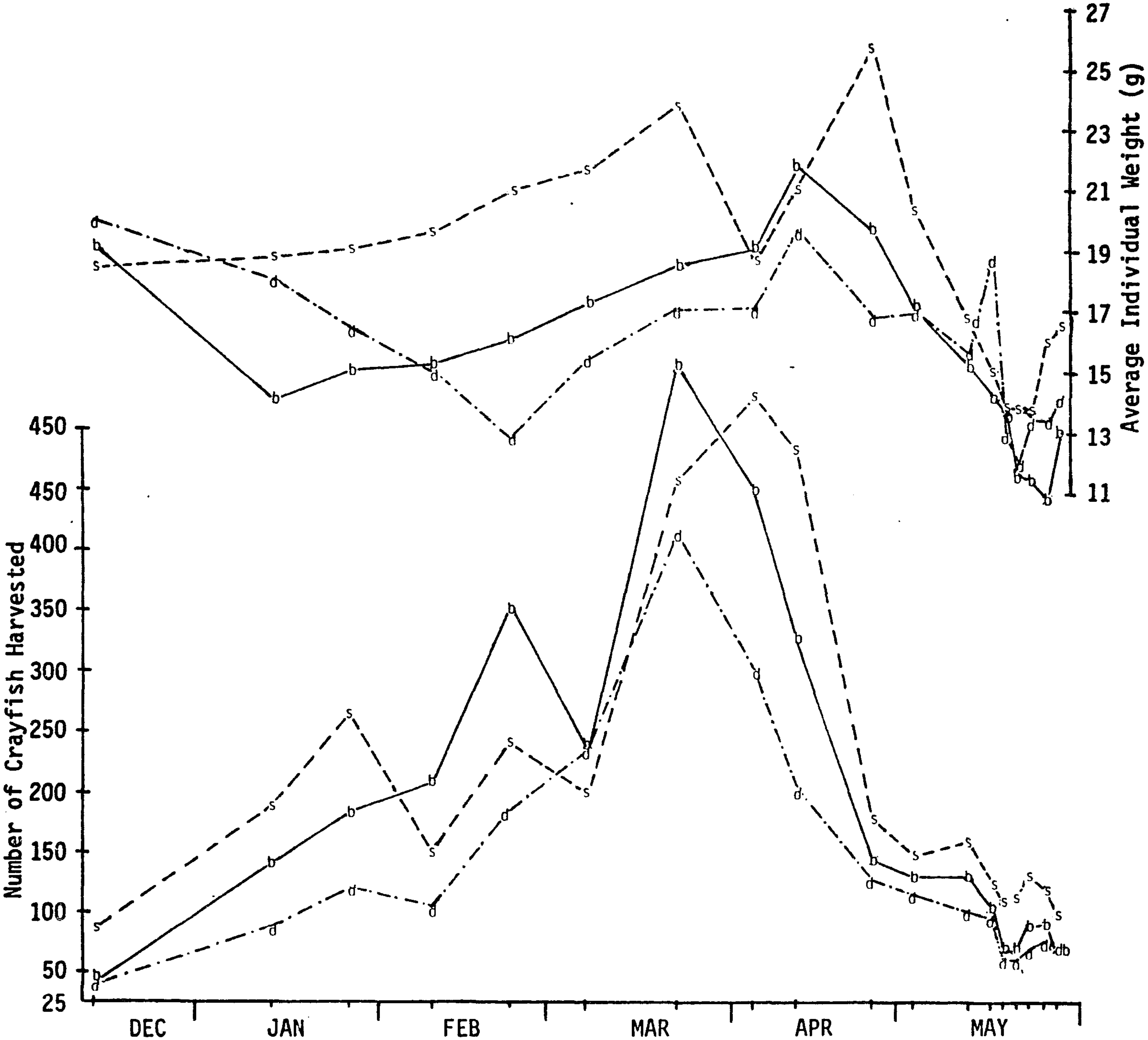

Average Individual Weight (g)
11
13
15
17
19
21
23
25
27
Number of Crayfish Harvested
25
50
100
150
200
250
300
350
400
450
450
DEC
JAN
FEB
MAR
APR
MAY

Fig. 14.

(Table A-7). The density-dependent growth was again in evidence.

In general, the average number and individual weight of harvestable crayfish was significantly greater in standing ponds and baled ponds than in disked ponds (Table A-7, B-3, B-4). Among early-flooded ponds, the disked ponds had fewer and smaller crayfish than did baled and standing ponds before 26 April 1979. In general, standing ponds had a higher CPUE and larger size of harvestable crayfish before 11 April 1979, but baled ponds had the largest crayfish thereafter (Fig. 13). Among late-flooded ponds, except on a few occasions, disked ponds had the lowest CPUE, and the crayfish showed the lowest individual weights after 22 February 1979. Baled ponds had the highest CPUE in number and the crayfish had average individual weights most of the time (Fig. 14).

Yield

The yield in weight of harvestable crayfish (>75 mm) from each pond is summarized in Table 3. The analysis of variance for yield differences in treatments is shown in Table B-6.

Crayfish yield ranged from 28.2 kg/pond (559/ha) to 91.3 kg/pond (1807 kg/ha). The average yield in early-flooded ponds (1183 kg/ha) was not significantly ($P>0.05$) higher than that of late-flooded ponds (1127 kg/ha). The average yield of standing ponds (1506 kg/ha) and baled ponds (1157 kg/ha) was significantly ($P<0.05$) higher than that of disked ponds (803 kg/ha), but the difference in average yield between standing ponds and baled ponds was not significant. The highest average yield of 1554 kg/ha was observed in early-flooded ponds with standing rice straw. The two lowest average crayfish

Table 3. Production (kg/ha) of harvestable crayfish (>75 mm) from 2 December 1978 to 29 May 1979 from six treatments of two flooding dates X three disposals of rice straw, Ben Hur Farm, LSU.

Dates of Flooding		Disposals of Rice Straw: Baled[1]		Standing[2]		Disked[3]	Average[4]
	Pond no.		Pond no.		Pond no.		
Early-	1	698	8	1143	2	684	
flooding	6	1628	16	1807	4	1025	
(20/9/78)	13	1194	18	1713	9	753	
Average		1173		1554		821	1183
Late-	7	1379	3	1483	10	559	
flooding	11	1076	5	1551	12	952	
(15/10/78)	15	967	17	1336	14	841	
Average		1141		1457		784	1127
Average[5]		1157		1506		803	

[1] Ponds where the rice straw was collected and piled into heaps on the bank.

[2] Ponds where the rice straw was left as was in the ponds.

[3] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

[4] Disposals of rice straw combined average.

[5] Flooding dates combined average.

yields were obtained from both disked ponds with 821 and 803 kg/ha in early- and late-flooded ponds, respectively.

Yield-Effort Curve

When cumulative yield was plotted against cumulative fishing effort, an S-shaped curve, referred to as yield-effort curve (Fig. 15), was obtained. The cumulative yield increased slowly as trapping began when few crayfish reached harvestable size. When the mode of the population reached harvestable size, the slope became steep. The curve leveled and tapered off at the end of the season, at which time harvestable crayfish were fewer in number and smaller in size.

An asymptotic regression equation $Y=A\cdot(1-e^{-K\cdot x})^{M}$ was used to represent this yield-effort curve. Y was the cumulative catch in weight and x was the cumulative fishing effort. Mathematically, the K specifies the curvature of the solution, the A the asymptotic value (Gallucci and Quinn 1979), and M and K the location of inflection point. The K and M are positively correlated. The A inversely correlated with both M and K. The curve with the higher value of M and k has a lower value of A. The model was chosen because if fit quite well on the observed data. Furthermore, it has biological significance. The biological considerations imply that A is the biological potential-yield, curvature K tells how rapidly A will be

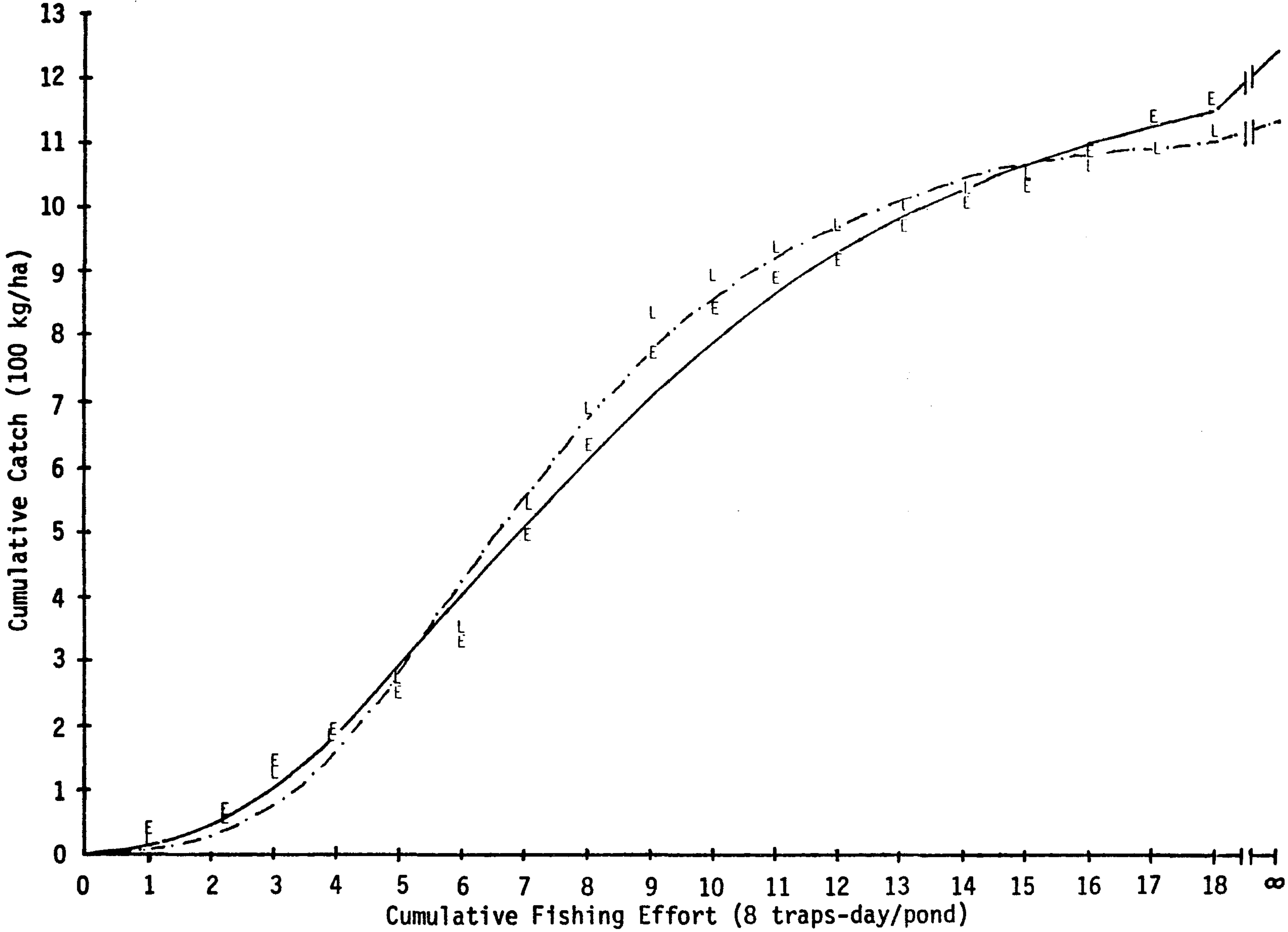


Fig. 15. The yield (Y)-effort (X) of crayfish from early-flooded (E ——, $Y=1251(1-e^{-0.2098X})^{3.4176}$) and late-flooded ponds (L - - -, $Y=1141(1-e^{-0.2964X})^{5.3508}$) during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

approached, and $\frac{\ln(M)}{K}$ [1] indicates when the peak catch starts.

Early-flooded ponds had a higher potential-yield (1251 kg/ha) than late-flooded ponds (1141 kg/ha) (Fig. 15 and Table A-7). The differences between potential-yield and actual yield were 68 and 14 kg/ha for early- and late-flooded ponds, respectively. The yield-effort curve showed that among early-flooded ponds, the standing ponds had the highest potential yield of 1672 kg/ha which was 118 kg/ha more than the actual yield (Fig. A-7). With the small value of curvature K, and large difference of potential and actual yields, crayfish in standing ponds would be worthy of further exploitation. Among late-flooded ponds, standing ponds again had the highest potential yield of 1527 kg/ha (Fig. A-8). The potential yields were 1141 and 784 kg/ha for baled ponds and disked ponds, respectively. The differences between potential yield and actual yield were 3 and 9 kg/ha for baled ponds and disked ponds, respectively. The small difference between potential yield and actual yield means that the biological maximum yield has been fully exploited. When early- and late-flooded ponds were combined, the differences between potential

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[1] The inflection point (Anton 1980) is obtained as follows: $Y = A\cdot(1-e^{-K\cdot x})^M$ the first partial derivative of Y with respective to x is $\frac{dY}{dx} = A\cdot M\cdot K(1-e^{-K\cdot x})^{M-2}\cdot e^{-K\cdot x}\,(M\cdot e^{-K\cdot x}-1)$ the second partial derivative of Y with respective to x is $\frac{d^2Y}{dx^2} = A\cdot M\cdot K^2\,(1-e^{-K\cdot x})^{M-2}e^{-K\cdot x}(M\cdot e^{-K\cdot x}-1)$ since none of A, M, and K equal to zero to satisfy $\frac{d^2Y}{dx^2} = 0$, and the solutions are $x=0$ or $x = \frac{\ln(M)}{K}$.

yield and actual yield were 63 kg/ha for standing ponds, 27 kg/ha for baled ponds, and 9 kg/ha for disked ponds.

The differences in inflection point values among disposals of rice straw in early-flooded ponds were more pronounced than those in late-flooded ponds (Table A-7). In other words, the peak catch started at different times for early-flooded ponds, but at similar times for late-flooded ponds. Among the six treatments, the peak catch came in the latest in early-flooded-disked ponds, at a total of 6.6 unit fishing effort (8 trap-day). When early- and late-flooded ponds were combined, disked ponds not only had the least potential yield, but also the latest peak catch. The high A value of the yield-effort curve in standing ponds was probably due to its low curvature value of 0.2255. The sustained high CPUE in standing ponds resulted in their high potential yield.

DISCUSSION

Water Quality

Dissolved Oxygen and Temperature

Rice straw in early-flooded ponds had been decaying for a longer period of time than that in late-flooded ponds when measured. Since less rice straw remained in early-flooded ponds, less O_2 was consumed, resulting in consistently higher dawn DO in early-flooded ponds.

From the second to the fifth week after flooding, the average diurnal DO was highest in ponds with baled rice straw, since less decomposition took place in water column than in standing and disked treatments. Lowest diurnal DO was found where rice straw was disked into the soil and decayed anaerobically. Disking soil increased soil-water contact area and water turbidity. The enlarged oxidizing surface area of the soil and the high concentration of suspended particulate matter and colloidal organic matter in water resulted in the greatest oxygen consumption.

The lower dawn DOs in standing ponds as compared with DO in baled and disked ponds from the fifth week to eleventh week after flooding, reflected the higher oxygen consumption during decay of vast amount of rice straw. It resulted mainly from higher decomposition rate of rice straw in standing ponds (partial aerobic decomposition) than in disked ponds (anaerobic decomposition); the former had higher oxygen demand. The suspended organic particles in disked ponds, which had been rapidly oxidized during the first 5 weeks (as shown by

low DO values), had a minor effect on oxygen consumption. Oxygen transport in flooded systems depends largely on surface water turbulence (Bouldin 1968). Since there was little rice straw remaining in the water column in disked ponds, the highest dawn DOs in disked ponds five weeks after flooding were partly due to better transport of DO at the air-water interface and better circulation in the pond. This factor was especially important in winter when it was windy.

During the five weeks after flooding, shading by rice straw in standing ponds contributed to the lowest average temperature (21.4 C). Highest average water temperature in disked ponds (22.6 C) was mainly due to greater absorption of solar radiation by suspended particles in turbid water (Boyd 1979).

Nutrients

It was expected that early-flooded ponds would have released higher amounts of nutrients than late-flooded ponds, due to rapid decaying of rice straw under warmer water in early-flooded ponds. Patrick et al. (1973) indicated that the release of phosphate occurs under conditions of low oxidation-reduction potential in combination with low pH. Fermentation products, acetic acid, butyric acids, and other organic acids under anaerobic decomposition of rice straw may result in low soil pH thus favoring phosphate release. Patrick and Khalid (1974) demonstrated that anaerobic soil released more phosphate to soil solution low in soluble phosphate than did aerobic soil. In addition to phosphate, higher amounts of nitrogen were also expected in disked ponds than in baled and standing ponds. Rice straw that

decomposed anaerobically releases four to six times more nitrogen rice straw that is decaying aerobically (Acharya 1935a and Sircar 1940). In an anaerobic environment, oxidized nitrogen was eventually reduced to nitrogenous gases (N_2, N_2O) and this resulted in significant nitrogen losses from flooded soils (Broadbent and Stojanovic 1952; Patrick 1960; Reddy et al. 1976) and from the water overlying reduced sediments (Engler and Patrick 1974). Large quantities of gas bubbling up in disked ponds were observed when the pond bottom was disturbed. It was hypothesized that fewer nutrients existed in baled ponds than in standing ponds, since the cut part of rice straw of baled ponds decayed on the bank.

An insignificant difference in nutrients among the treatments through time and a low level of nutrients in all treatments were found. That was attributed to the immediate assimilation of nutrients by autotrophs as soon as they were released from decaying rice straw. Cole (1975) stated that only traces of soluble orthophosphate can be found in water when photosynthesis is proceeding at a good rate, since soluble orthophosphate is immediately used by autotrophs. Rigler (1964) also provided evidence from his tracer study that phosphate was rapidly absorbed by the plankton. That the water in all ponds gradually turned yellowish-green was an indication of the building up of an autotroph community.

Periphyton

Differences in periphyton biomass among treatments were due mainly to differences in surface area for attachment and amounts of available nutrients. With the favorable conditions of warmer

temperatures and greater nutrient availability through faster decaying of rice straw, periphyton in early-flooded ponds established faster than that in late-flooded ponds. The highest amount of periphyton biomass occurred in standing ponds, followed by baled and disked ponds. The disposals of rice straw affected attachment areas for periphyton. The attachment area was highest in standing ponds, followed by baled ponds and disked ponds. Since rice straw on the bank decayed faster under aerobic environment, even when it was put back into the ponds, the total substrate (rice straw biomass) in baled ponds was still less than in standing ponds. As previously mentioned, the supply of nutrients were highest in standing ponds, followed by baled and disked ponds.

Net Daytime Photosynthesis and Periphyton

Net daytime photosynthesis (NDP) was measured by the difference between dusk and dawn DO. Standing ponds generally had the highest NDP, resulting from the highest dusk DO and lowest dawn DO. Goyert et al. (1975) postulated that the mineralization of organic materials served to stimulate periphyton growth. During decay, rice straw released large amounts of nutrients, which were utilized by phototrophs. Vast amounts of rice straw in standing ponds provided large attachment areas that favored periphyton growth. High populations of phototrophs resulted in high DOs at dusk in standing ponds. Conversely, aerobic decay of vast amounts of rice straw and the respiration of a high population of phototrophs led to the lowest dawn DO in standing ponds.

Disked ponds generally had the lowest NDP, resulting from lower dusk DO and higher dawn DO. The lower dusk DO was attributed to two actors. First, the lower phototroph population resulted in less photosynthetic activity and oxygen production. The released nitrogen from decaying rice straw probably was later denitrified as gaseous N_2 and/or N_2O, which could not be utilized by the autotrophs in the water column. This was manifested by the lowest average periphyton dry weight in disked ponds. Second, the turbidity reduced light penetration and decreased photosynthesis. The anaerobic decay of rice straw and the respiration of a low population of phototrophs consumed less oxygen and led to higher dawn DO in disked ponds.

The lack of relationship between periphyton growth and average NDP for the first six weeks of sampling was because the periphyton community was not well established, with concomitant low photosynthetic activity. Periphyton growth was highly correlated ($P<0.001$) with the average NDP for 12 and 18 weeks of samplings with the coefficient of determination (R^2) of 0.65 and 0.47. In other words, 65% and 47% of the variation of photosynthesis can be explained by the variation of periphyton abundance at the second and the third sampling, respectively.

Rice Straw Decomposition Rate and C:N Ratio Dynamics

The decomposition of organic matter depends mainly on temperature, oxygen supply, moisture, pH, inorganic nutrients, and initial C:N ratio of the decaying matter. The positive correlation between water temperature and microbial activity was the primary explanation

for the decomposition rate of rice straw through time. Acharya's (1935b) experiment showed that anaerobic decomposition, as judged by the loss of dry matter and total weight of products obtained, increases with temperatures from 20 to 30 C. The rapid initial decomposition of rice straw in all treatments during the first month after flooding was due to high temperatures coupled with the rapid leaching and oxidation of the water-soluble fraction of rice straw constituents. Rapid loss of soluble leachates such as soluble carbohydrates (sugar and starches) and dissoluble nitrogen probably accounted for the rapid weight loss of decaying rice straw. The higher average water temperature the first month after flooding in early-flooded ponds (24.5 C) than that in late-flooded ponds (20.5 C) explained the higher weight loss of rice straw in early-flooded ponds (43%) than in late-flooded ponds (24%).

Acharya (1935a,b) demonstrated that decomposition of rice straw was most rapid in aerobic environments, slower under waterlogged conditions, and least pronounced under complete anaerobiosis. In corroboration with Acharya's results, at the end of five months in this study, the litter bag weight losses of rice straw were 75, 64, and 45% for baled, standing, and disked ponds, respectively. Tenny and Waksman (1930) also found that anaerobic decomposition was slower than aerobic decomposition regardless of the type of plant material. They found that complex polysaccharides decomposed twice as fast under aerobic as under anaerobic conditions during the first four weeks. The differences between decomposition rates under aerobic and anaerobic conditions can be explained by the types of micro-organisms involved in the decaying processes and their respiration

energy efficiency. Microbial decomposition of organic matter in an aerobic environment is accomplished by a wide group of microorganisms (facultative microbes), whose respiration is associated with high energy release. Therefore, decomposition of substrate proceeds at a rapid rate. On the other hand, anaerobic decomposition is almost entirely dependent on the activities of anaerobic bacteria. Since anaerobic bacteria operate at a much lower energy level, they are much less efficient than aerobic flora. Consequently, the processes of decomposition are much slower in anaerobic conditions than in aerobic conditions. In disked ponds, the rice straw had close contact with soil; however, the inefficiency of more restricted anaerobic bacteria resulted in its slower decomposition.

Russell-Hunter (1971) stated that the C:N ratio is of considerable value in assessing the nutritional value of dietary substances. A C:N ratio of 17:1 or lower is required for adequate animal nutrition. A higher ratio could result in protein deficiency. Goyert et al. (1975) and Chien (1978) used changes in C:N ratios as an index of the nutritional value of plant material to crayfish. During the decomposition of plant material, carbonaceous substances furnish the energy for microbes, nitrogen is assimilated and metabolized as protein in the synthesis of cell substance, and the C:N ratio declines (Tusneem and Patrick 1971). A general trend of C:N ratio decrease through time was also observed in this experiment.

In general, as decomposition progresses, mineralization was always accompanied by immobilization; the two processes tended to counteract each other so far as production of inorganic N was concerned (Jansson 1963). The narrowing of the C:N ratio in the

decomposition of nitrogen-poor substrates is not linear; and the decaying exponential curve approaches a ratio of approximately 10:1. Wider ratios favor immobilization, and narrow ratios mineralization. The sharp decline of the C:N ratio of rice straw from 57 to 44 during the first month after flooding in all treatments was due to a high initial C:N ratio and a high temperature.

Since anaerobic bacteria operate at a low fermentation energy, the synthesis rate of new cell material is very low; for example, only 2 to 5% of the substrate carbon is assimilated by anaerobic bacteria, compared with about 30 to 40% that is assimilated by fungi in an aerobic system (Alexander 1977). Thus, the nitrogen immobilized during anaerobic decomposition should be low, and that released to the soil suspension should be high. In contrast, aerobic metabolism resulted in a vigorous decomposition of organic matter, coupled with a high immobilization of nitrogen. Degradation of organic matter under aerobic conditions was caused by heterotrophic bacteria, fungi, and actinomycetes. In an anaerobic condition, a less efficient and more restricted bacterial microflora takes over the activities of the efficient fungal microflora. Hence, both mineralization and immobilization rates are considerably retarded. The protein formed under aerobic conditions is mostly insoluble in water, due to the synthesis of insoluble microbial tissue, while that under anaerobic conditions remains in solution due to poor immobilization. It has been noted by Acharya (1935c) that the amount of protein in the insoluble residue is lowest in the anaerobic system and highest in the aerobic system.

The fastest C:N ratio decline of rice straw was in baled ponds,

followed by standing ponds and disked ponds. This was primarily the result of decaying in various oxygen budgets--aerobic, partially aerobic, and anaerobic conditions. The rice straw in standing ponds had a similar C:N ratio dynamic to that in baled ponds. One reason is that, except for the first month after flooding, diurnal DO in standing ponds generally exceeded 6 mg/l, nearing saturation especially in winter; thus, the rice straw mostly decomposed under an aerobic condition. Another reason is that in standing ponds the attached periphyton was not completely removed although the rice straw was rinsed at sampling. The periphyton probably boosted the C:N ratio of the rice straw.

Population Dynamics

Initial Survival and Growth Rate of Crayfish

The relationships between average daytime DO, minimum dawn DO, and average dawn DO versus survival rate in this study were insignificant because of several factors. First, transfer of juvenile crayfish to cages was carried out in the afternoon when DO was at its highest level, and the gradual decline in DO could have given the crayfish time to adjust. Secondly, conditions of low DO were not persistent. Jaspers and Avault (1969) noted that DO in waters of crayfish burrows ranged from 1.4 to 0.2 mg/l without notable mortality in young crayfish. They indicated that the water may have acted as a humidity source to keep gills wet. Melancon and Avault (1978) observed that crayfish of 9-12 mm in total length, when subjected to an abrupt DO change from 6.0 to 0.4 mg/l and 6.0 to 1.1

mg/l, had survival rates after 60 hours of 0 and 58%, respectively. Death may be due to the inability of crayfish to regulate oxygen consumption when suddenly placed under low oxygen conditions (Maloeuf 1937).

Survival rate was inversely related to average water temperature. Mason (1978) also found an adverse effect of high temperature on the survival of crayfish _Pacifastacus leniusculus_. Frequent molting at faster growth under high temperature could make crayfish more vulnerable to cannibalism. High temperature might also make the hard-shelled individuals more aggressive and cause them to prey on the soft-shelled ones.

High survival in late-flooded ponds was due mainly to a low water temperature than in early-flooded ponds. No significant differences in survival rate were found among baled, standing, and disked rice ponds during the four-week period. It appears that average diurnal DO maintained in the range of 2.3 to 6.6 mg/l had no detrimental effect on survival rate.

Crayfish growth rate was inversely correlated to survival rate. Goyert (1978) reported that crayfish raised at a low density (10 crayfish/m^2) grew 14.2 mm larger than crayfish grown at a high density (40 crayfish/m^2) over 10 weeks. Abrahamsson and Goldman (1970) observed that body length was inversely related to population density. The food supply was adequate, thus, the inverse relationship between growth and survival may have been due to a 'space factor' (Hile 1936), whereby crowding impedes growth independent of food abundance.

Crayfish generally cease feeding and growing if under persistent

low DO (LaCaze 1976). Growth rate during the four-week period was positively correlated with average daytime DO and average water temperature. Increasing DO concentration and water temperature resulted in faster growth.

Growth rate was significantly higher in early-flooded ponds than in late-flooded ponds during the first two-weeks. This was due to higher water temperatures and/or lower survival. Mason (1978) found that the combination of high temperature and short photoperiod gave the best growth of juvenile crayfish P. leniusculus, with temperature being the predominant influence. The highest average initial growth observed in early-flooded ponds in which rice straw was disked was attributed to the higher water temperature and lower survival rate. Like the effects of the photoperiod, the weaker photointensity caused by turbidity in ponds with disked rice straw may have resulted in a high growth rate of crayfish.

Growth, Population Density, and Yield

Crayfish yield was primarily the product of the average size and number of crayfish harvested. Variation of yield among treatments can be explained by the differences in growth and population sizes among treatments.

Population size of young crayfish at fall flooding was dependent then on the size and the reproductivity of the parent population. In an attempt to equalize the parent populations among ponds and to reduce the effect of the wild (native) parent population, crayfish were stocked in every pond at a rate of 48 pairs per pond (51 kg/ha). Virtually all ponds received the same preparation, that is, disking,

rice planting, fertilizing, draining and drying. It was reasonable to assume that an equal number of progeny existed in every pond before treatments were applied; the variation in populations among ponds at sampling was attributed to the various treatment effects. Growth, survival and yield of crayfish were affected by a number of factors: temperature, oxygen concentration, food abundance, population density, and configuration of substrate. Many factors were interrelated.

The factors that affected population dynamics between early- and late-flooded ponds are as follows:

(1) Temperature: Higher water temperatures were generally favorable to growth but not survival. The average water temperature in early-flooded ponds (23.4 C) was 2.9 C higher than in late-flooded ponds (20.5 C) five weeks after flooding. Westman (1973) found that temperatures between 18 and 21 C were good for the growth of crayfish (P. leniusculus) but poor for survival, while temperatures near 10 C resulted in reduced growth but higher survival. He concluded that temperature rather than an internal rhythm was the controlling factor for growth. Hoffman et al. (1975) found that as temperature increased from 5 to 10 C, the aggressive behavior of the lobster (Homarus americanus) also increased. Miltner (1980) stated that the relatively rapid growth of crayfish at fall flooding was primarily due to the warm water temperatures and the high molting frequency associated with newly hatched crayfish. Mason (1978) found an adverse effect of temperature on the survival of the crayfish P. leniusculus. More frequent molting at faster growth under high

temperature could have made crayfish more vulnerable to cannibalism. High temperature may also make the hard-shelled individuals more aggressive so that they prey on the soft-shelled ones. Goyert (1978) in his density-temperature experiment, found that the highest temperature treatment (30 C) resulted in the lowest survival (62%), as compared to 24 C (76%) and 27 C (78%), for a period of 42 days. The overall smaller population size of crayfish in early-flooded ponds than in late-flooded ponds may have been due to the poorer survival rate under warmer temperature.

(2) Oxygen content: Although the average diurnal DO in early-flooded ponds (4.4 mg/l) did not significantly ($P>0.05$) differ from that in late-flooded ponds (3.6 mg/l), there were 11 and 6 critical dawn DOs of less than 1.00 mg/l in early- and late-flooded ponds, respectively, during the first 10 weeks' samplings. Under more frequent DO depletion stresses, low survival in early-flooded ponds may have resulted. The combination of low DO and warm temperature may even be more detrimental to crayfish survival; it may further stimulate cannibalistic behavior. Further research is needed in this area to determine the optimal temperature for crayfish for both better growth and survival.

(3) Food abundance: Differences in crayfish growth between early- and late-flooded ponds during the early stage after flooding were not believed to be related to the abundance of rice straw substrate, since crayfish biomass was low and the rice straw was not nutritious enough (C:N<17). Chien (1978) stated that the periphyton on rice straw served as the main food for crayfish before the rice straw decayed sufficiently to become nutritious. As previously

mentioned, the periphyton community in early-flooded ponds was better established than that in late-flooded ponds. The availability of more food in early-flooded ponds at the early stage after flooding allowed faster growth. Since there was no significant difference in the C:N ratio decline between early-flooded and late-flooded ponds, the similar nutrition values of decaying rice straw have no apparent effects on observed differences in growth.

(4) Population density: High population density in itself adversely affects survival and growth. Westman (1973) noted that mortalities increased with increasing densities (150 to $250/m^2$) for young-of-the-year crayfish. He also noted that the single greatest cause of mortality among crayfish reared at high densities is cannibalism. Dye and Jones (1975) found that survival was markedly better for young crayfish raised at densities of $11/m^2$ compared with crayfish raised at densities of $43/m^2$ and $172/m^2$. The inverse relationship between stocking density and survival in these studies with crayfish are in agreement with the result of Willis et al. (1976) in their study with the freshwater prawn.

With a higher population density, each crayfish obtained a smaller share of available food and grew slowly. Burrows and Combs (1968) noted that high population densities could result in reduced growth due to stress and poor food utilization. Crayfish generally avoid one another in their foraging, but when they do meet it is a tension contact (Bovjerg 1956). With higher population densities, the number of these aggressive encounters increases, and more energy is diverted away from growth. Goyert (1978) also suggests that growth inhibitions of crayfish at high stocking densities are due to

both social interactions and territorial restrictions. McLeese (1972) found that growth per molt was greatest at low stocking densities for the lobster (H. americanus) reared in intensive systems. Huner et al. (1975) also noted better growth and survival among crayfish raised at low density. The average individual weight and length of crayfish in early-flooded ponds are higher than those in late-flooded ponds because of the lower population density (CPUE) in early-flooded ponds. With higher population densities and lower individual weight, yield in late-flooded ponds did not significantly differ with that in early-flooded ponds, which had lower population density but higher individual weight. Near the end of the season (intensive harvesting) crayfish in early-flooded ponds not only had a higher population density, but also higher average individual weight than in late-flooded ponds, which resulted in higher biological-potential yield in early-flooded ponds.

Factors that affected population dynamics among baled, standing, and disked ponds are describec as follows:

(1) Temperature: During the first 10 weeks after flooding, the water temperature was highest in disked ponds, followed by baled ponds and standing ponds. However, water temperature did not appreciably differ among these treatments throughout the study. Therefore, it had no apparent effects on observed differences in growth and survival among the treatments.

(2) Oxygen content: During the second to the fifth week after flooding, baled ponds had the highest average diurnal and dawn DOs, and the highest survival of crayfish. During the same period, disked ponds had the lowest average diurnal DO and the highest number of

critical dawn DOs. During oxygen depletion, crayfish may climb along the substrate to the air-water interface and obtain the oxygen directly from the air through gill respiration. When the rice straw was disked under, the bank of the pond was the only surface on which the crayfish could climb out, and failure to reach the air-water interface resulted in mortality. Although DO levels in standing ponds were not significantly higher than those in disked ponds, crayfish had access to rice straw to reach the air-water interface when DO was low.

(3) Substrate configuration, population density: Lower survival of crayfish in disked ponds may also be attributed to less substrate or poor configuration of the substrate. Abrahamsson and Goldman (1970) observed that crayfish suffered less predation and exhibited higher densities in areas with a rocky substrate that provided good cover, the crayfish were subjected to predators such as birds and bullfrogs when they climbed on the bank of the pond during DO depletion. Willis et al. (1976) concluded that habitat complexity is a requirement for Macrobranchium sp. high density grow-out system. According to Sandifer and Smith (1976), the most promising approach to the mass rearing of prawns is providing a large surface area of shelters in the tank. Since crayfish are anti-social, aggressive, and territorial organisms, the territory perceived by the crayfish has a direct effect on growth; the larger the area, the less the frequency of social interaction, and the better the survival and growth rate. The open pond bottom is the only substrate for crayfish in disked ponds. With a smaller substrate area and limited food, the number of aggressive encounters probably increase, resulting in a higher mortality from fighting and a diversion of energy from growth.

Goyert (1978) found significant differences in crayfish survival among substrates with 72.6% survival in a horizontal surface area[1], followed by 65% in a vertial surface area[2], and 54.6% in a control medium [3]. The substrate configurations of standing ponds versus disked ponds were comparable to those of surface area (vertically standing, uncut rice straw and horizontally lodged, cut rice straw) versus control in Goyert's experiment. Goyert (1978) concluded that the increased growth and survival can be attributed to the crayfish's ability to migrate from areas of high density (initially crowded bottom layer) to areas of low density (upper layers) via the substrate. By dispersing themselves among the multiple surface areas provided by the rice straw, the crayfish reduced the number of encounters and thus perceived a larger territory than actually existed.

(4) Food abundance: Crayfish were smaller in disked ponds than in baled or standing ponds, because food was less available. Since most of the rice straw was disked under, little substrate was left for periphyton. Rice straw in baled ponds reached a C:N ratio of 17:1 slightly earlier than in standing ponds; however, food availability was lower in baled ponds than in standing ponds. With less food and a higher population density in baled ponds than in standing ponds, crayfish were smaller in baled ponds. Consequently, baled ponds, as compared to standing ponds, had fewer harvestable crayfish. From the differences between potential yield and actual

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[1] Horizontal oriented loops of 26 cm wide window screen.

[2] Vertically oriented loops of 26 cm wide window screen.

[3] Gravel filter medium only.

yield in standing ponds (63 kg/ha) and baled ponds (9 kg/ha), the higher food availability in standing ponds was evident.

Further study is suggested on the polyculture of forage crops to increase food availability for crayfish. A combination of forage crops with different initial C:N ratios and decaying dynamics may sustain adequate nutrition, substrate, and periphyton throughout the whole growing season.

SUMMARY OF DISCUSSION

1. Flooding dates affected the rate of rice straw decay, periphyton establishment, and crayfish growth.
2. High water temperature due to early-flooding accelerated the metabolism of organisms, such as rice straw decay microflora, periphyton, and crayfish; but survival of crayfish was lowered because of reduced DO and increased aggressiveness of crayfish.
3. The disposals of rice straw physically determined attachment area for periphyton and the total amount of substrate and substrate configuration for crayfish. The substrate and its configuration affected crayfish population density and survival.
4. The differences of DO due to water temperatures and disposals of rice straw affected the change of the C:N ratio of rice straw and release of nutrients.
5. The bulk of food sources for crayfish is composed of decaying rice straw and periphyton. Periphyton biomass is mainly affected by attachment area, nutrients supply, and water temperature.
6. High population density adversely affected survival and growth which in turn resulted in the differences in yields.
7. The best overall combination of parameters for maximum crayfish production in kg/ha was from the treatment of early-flooding with standing rice.
8. The responses of environmental parameters and crayfish population dynamics to the treatments of disposals of rice straw and

flooding dates are generalized and summarized as below and in Fig. 16.

	Rice Straw Disposals			Flooding Dates	
	Baled	Standing	Disked	Early-Flooding	Late-Flooding
Rice Straw Decay	aerobic	partially aerobic	anaerobic	early	late
Water Temperature	-----	-----	-----	higher	lower
Amount of Rice Straw in Water at Measuring	middle	highest	lowest	lower	higher
Periphyton Attachment Area	middle	largest	smallest	-----	-----
Nutrient Supply	lowest	middle	highest	earlier higher	later lower
Periphyton Biomass	middle	highest	lowest	higher	lower
Rice Straw C:N Ratio	lowest	middle	highest	slightly lower	slightly higher
DO at Measuring	highest	lowest	middle	higher	lower
Amount of Substrate	middle	largest	smallest	-----	-----
Substrate Configuration	middle	best	poorest	-----	-----
Food Sources Quality and Quantity	middle	best	poorest	exhausted earlier	exhausted later
Growth	middle	fastest	slowest	faster	slower

	Rice Straw Disposals			Flooding Dates	
	Baled	Standing	Disked	Early-Flooding	Late-Flooding
Population Density and Survival	highest	middle	lowest	lower	higher
Yield	middle	highest	lowest	slightly higher	slightly lower

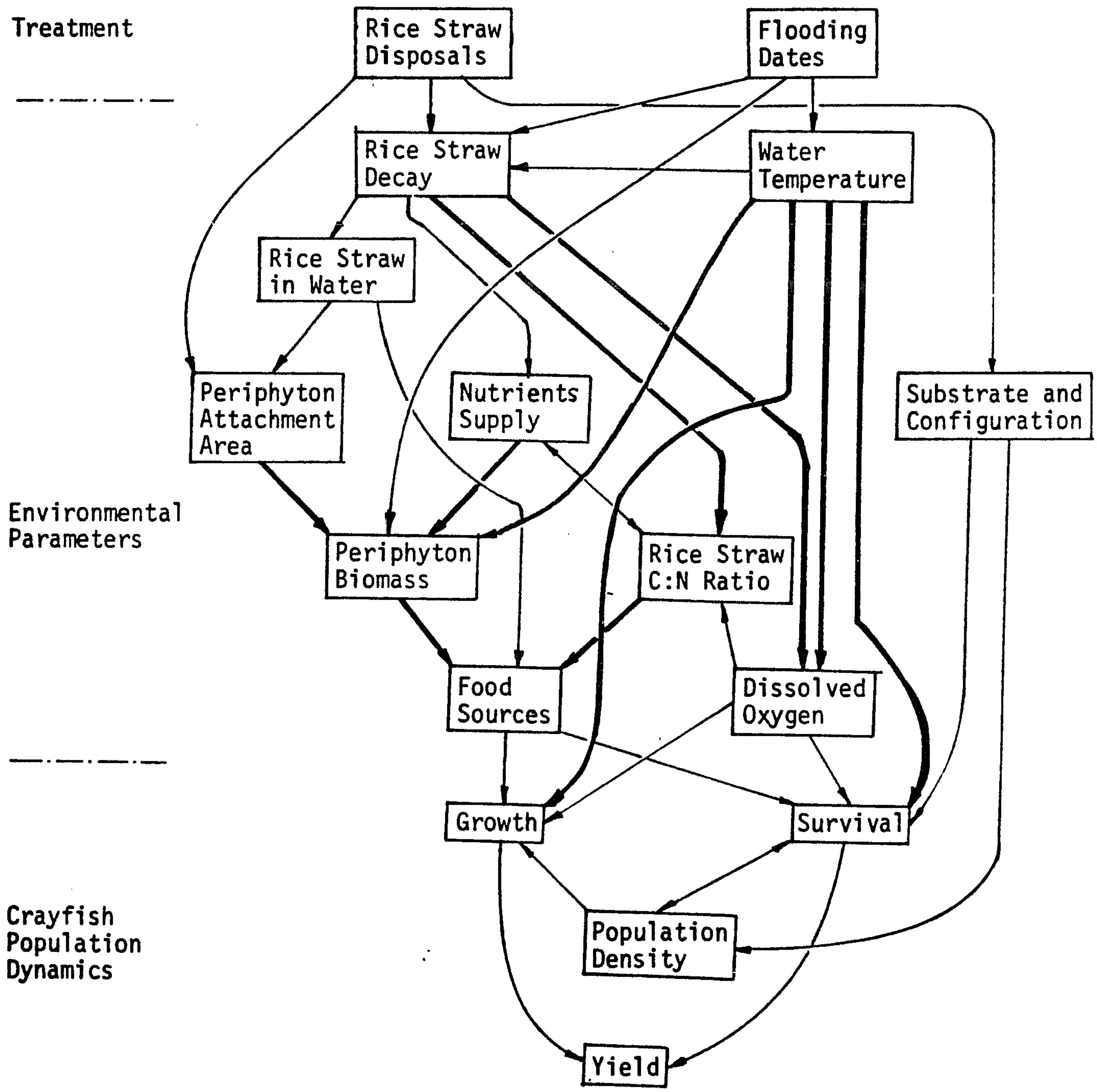

Fig. 16. The effects of treatments on environmental parameters and crayfish population dynamics. The thickness of the lines shows the relative magnitude of effects.

CONCLUSIONS AND RECOMMENDATIONS

1. Late fall flooding in this study had no significant effects on crayfish field. Delaying fall flooding until late October reduced oxygen depletion problems and increased crayfish survival. However, growth is delayed, and so is the time of marketing. Farmers may choose early flooding in order to reach the market ahead of wild-caught crop.
2. The nutritional value of forage can be improved by manipulating the decaying dynamics. Both the decaying forage and the attached periphyton play equally important roles in food supply. Temporary removal of rice straw from the pond at fall flooding reduce oxygen depletion problem. It is suggested that rice straw be put back into ponds after critical periods of low DO (low temperature days) to allow for establishment of periphyton and additional substrate. The cost of removing and returning rice straw should be compared to that of conventional circulation/ aeration techniques in the economic study.
3. It was evidenced that high population density in itself adversely affected survival and growth. It is suggested that intensive trapping start as soon as crayfish reach harvestable size. Removal of harvestable crayfish may reduce population density and food competition and increase survival and growth, and the yield.
4. The best management scheme to produce highest yield of crayfish calls for early flooding, with rice fodder left standing.

5. A combination of forage crops with different initial C:N ratios and decaying dynamics may sustain adequate nutritional food, substrate, and periphyton throughout the whole season.

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APPENDIX A - Figures and Tables Summarizing Data

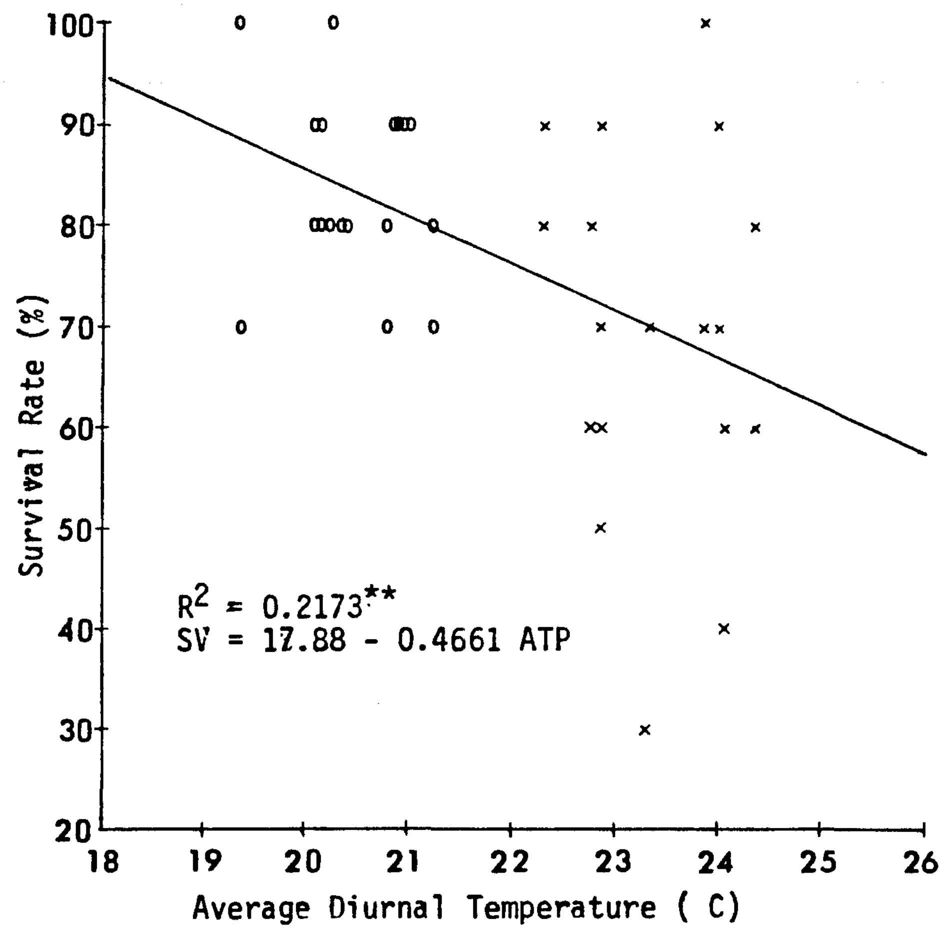


Fig. A-1. Relation of survival rate (SV) of crayfish to average diurnal temperature (ATP) during a 4-week period, 1978, Ben Hur Farm, LSU. Early-flooded ponds (×), Late-flooded ponds (o).

Note: Part of the variation explained by the regression, i.e., R^2, may be due to the time of flooding.

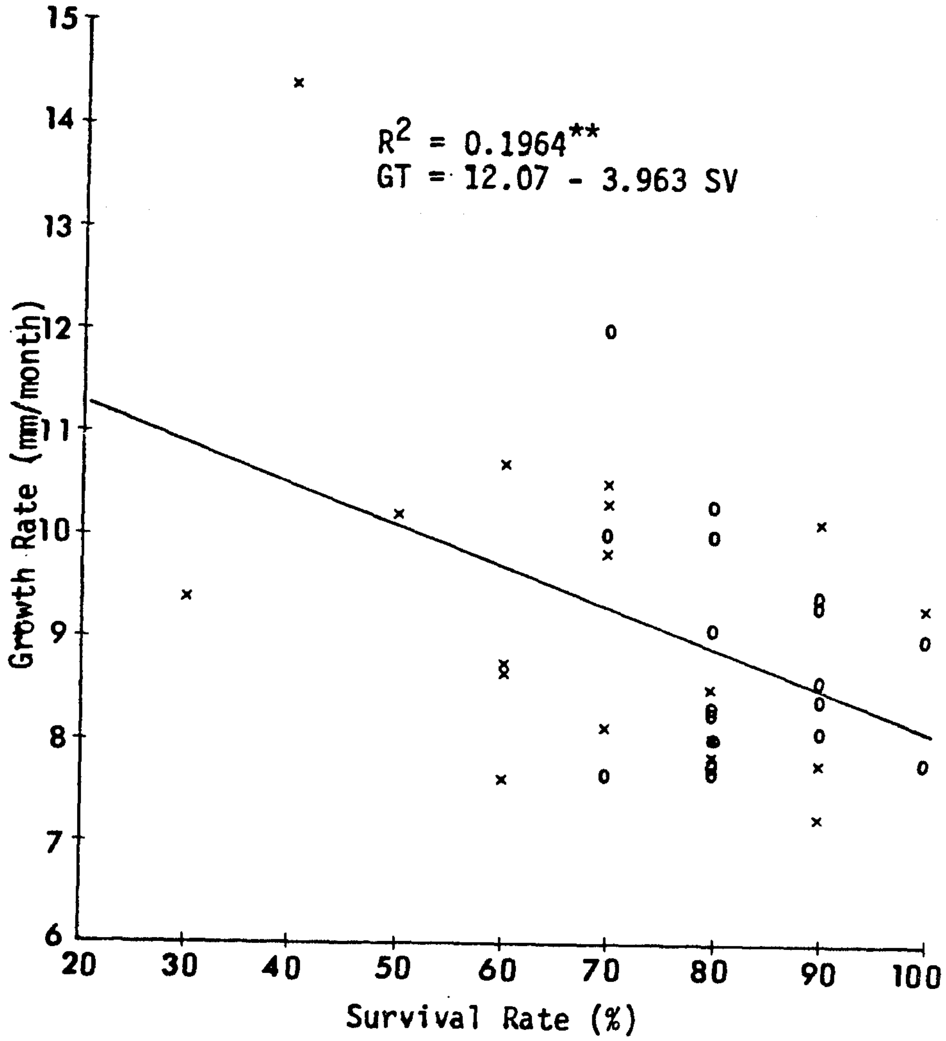


Fig. A-2. Relation of growth rate (GT) to survival rate (SV) of crayfish during a 4-week period, 1978, Ben Hur Farm, LSU. Early-flooded ponds (×), Late-flooded ponds (o).

Note: Part of the variation explained by the regression, i.e., R^2, may be due to the time of flooding.

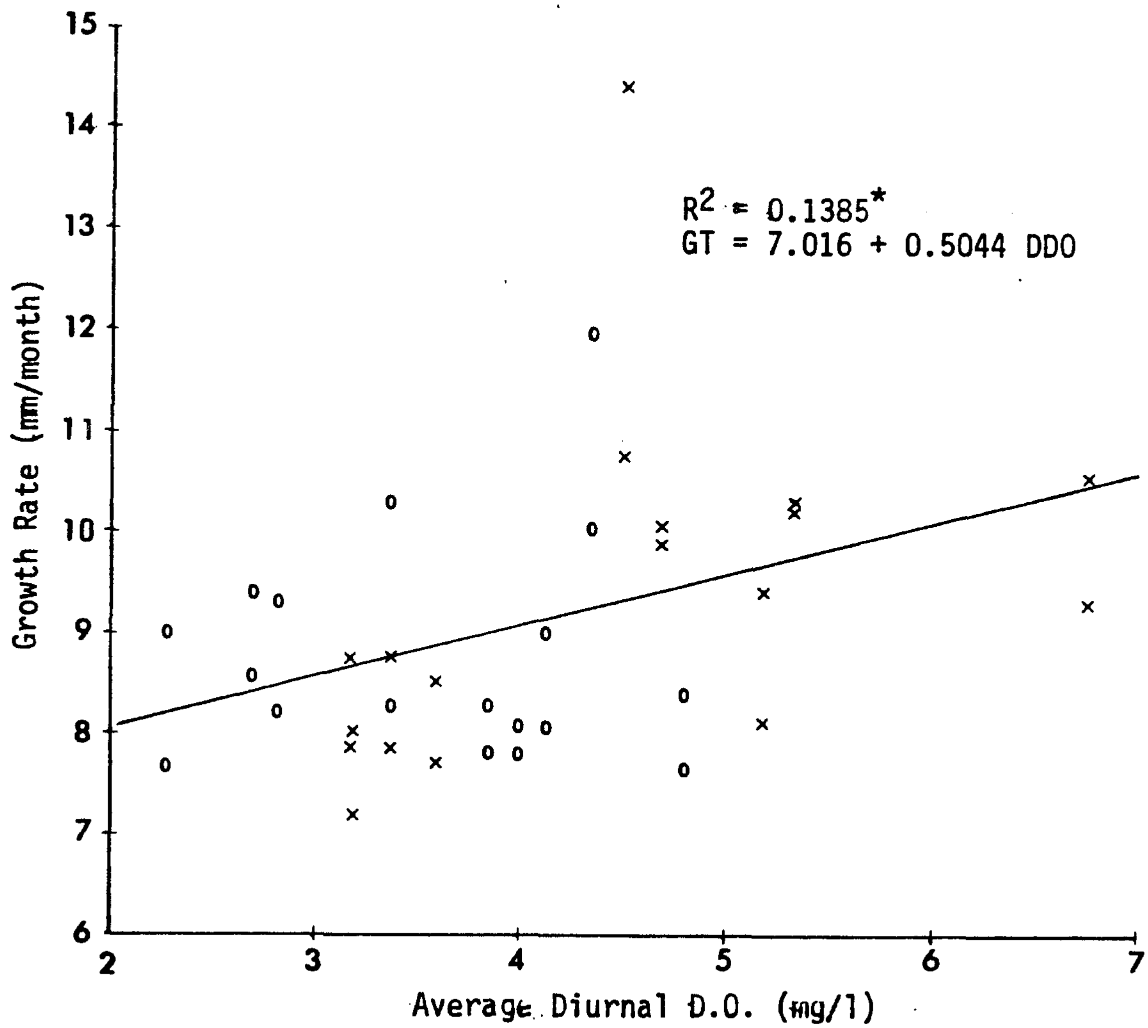


Fig. A-3. Relation of growth rate (GT) of crayfish to average diurnal dissolved oxygen (DDO) during a 4-week period, 1978, Ben Hur Farm, LSU. Early-flooded ponds (x), Late-flooded ponds (o).

Note: Part of the variation explained by the regression, i.e., R^2, may be due to the time of flooding.

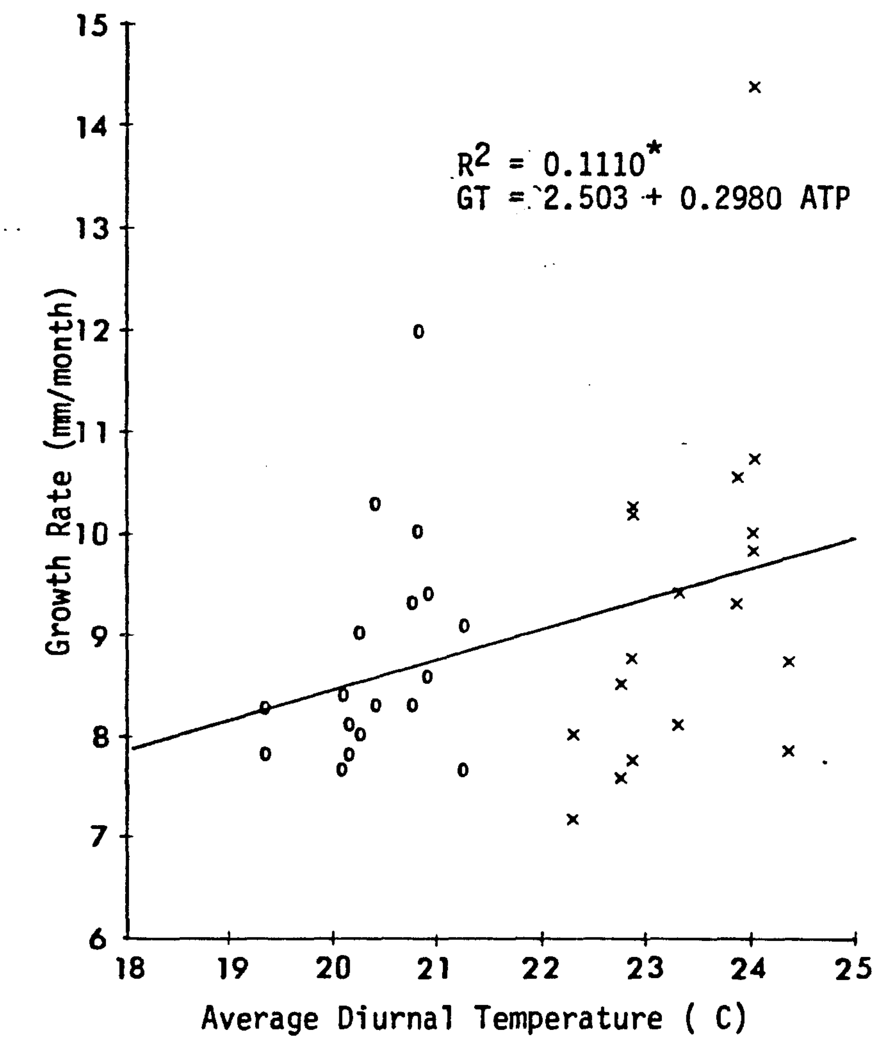
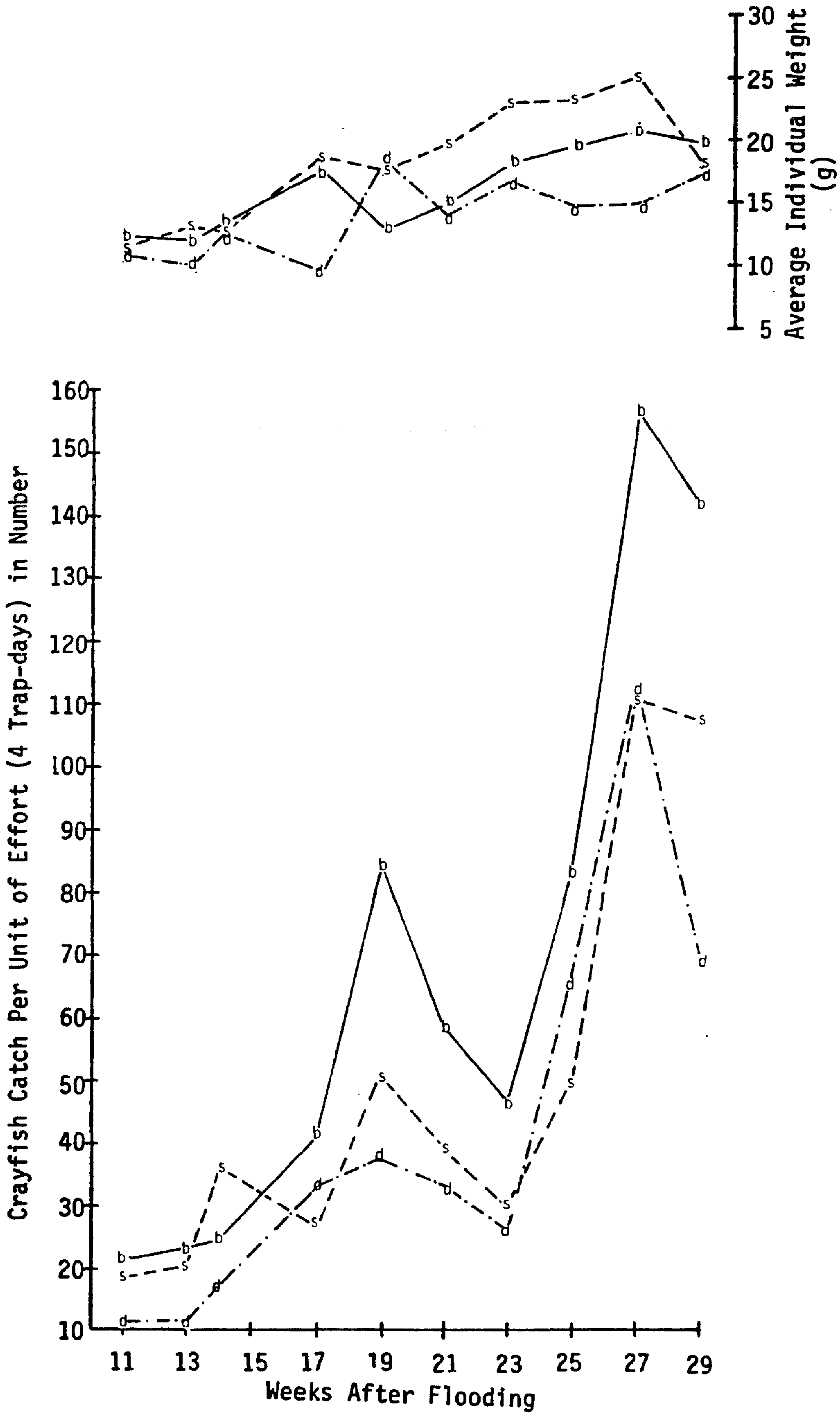


Fig. A-4. Relation of growth rate (GT) of crayfish to average diurnal temperature (ATP) during a 4-week period, Ben Hur Farm, LSU. Early-flooded ponds (×), Late-flooded ponds (o).

Note: Part of the variation explained by the regression, i.e., R^2, may be due to the time of flooding.

Fig. A-5. The catch per unit of effort (two traps/pond) and the size, in weight (g), of crayfish from baled ponds (b ——), standing ponds (s — —), and disked ponds (d —◦—), which were early-flooded on 20 September 1978, during 11th to 29th week post flooding, Ben Hur Farm, LSU.



30
25
20
15
10
5
Average Individual Weight
(g)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Crayfish Catch Per Unit of Effort (4 Trap-days) in Number
11
13
15
17
19
21
23
25
27
29
Weeks After Flooding

Fig. A-5

Fig. A-6. The catch per unit of effort (two traps/pond) and the size, in weight (g), of crayfish from baled ponds (b ——), standing ponds (s — —), and disked ponds (d —•—), which were late-flooded on 15 October 1978, during 7th to 25 week post flooding, Ben Hur Farm, LSU.

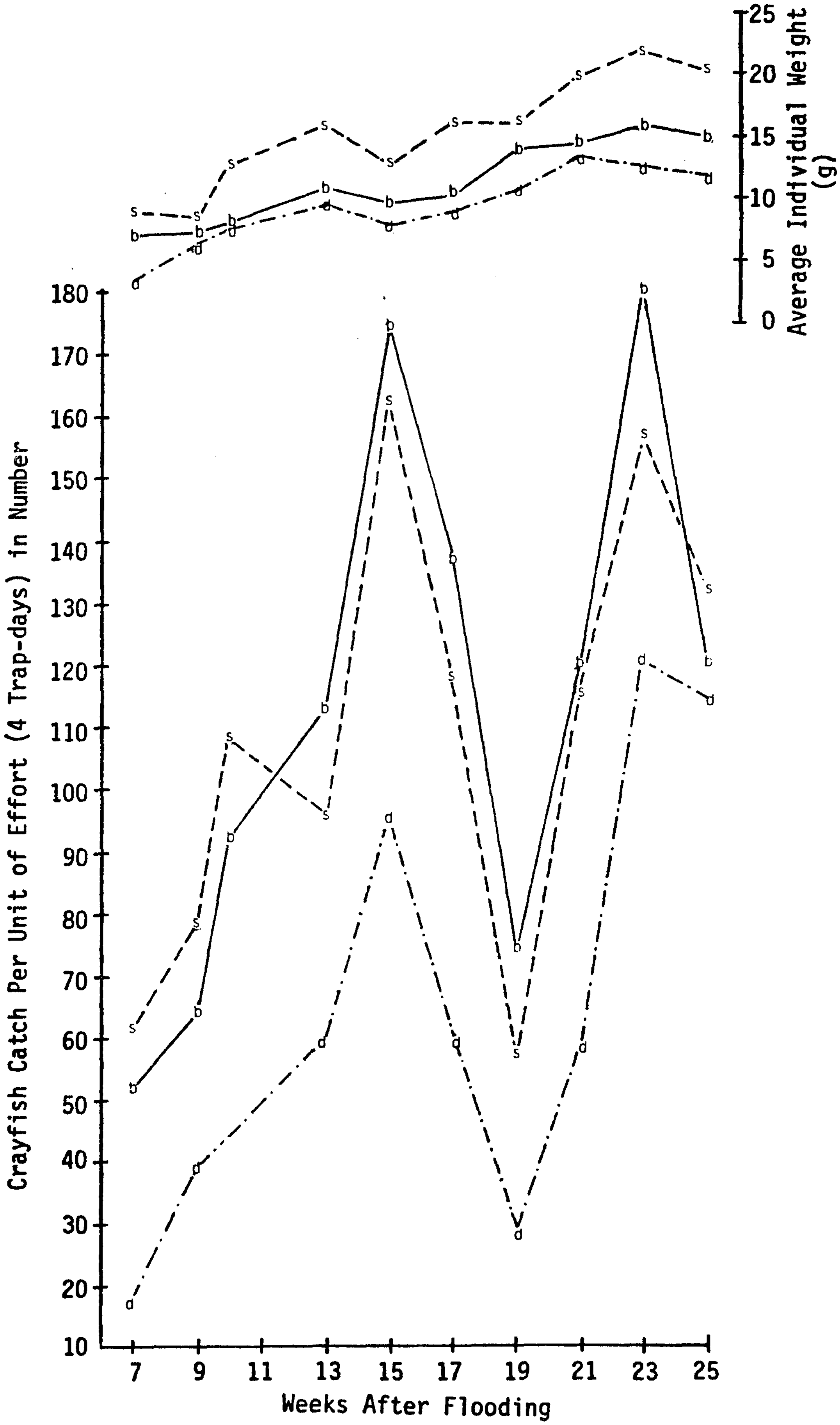

Average Individual Weight (g)
0
5
10
15
20
25
Crayfish Catch Per Unit of Effort (4 Trap-days) in Number
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
7
9
11
13
15
17
19
21
23
25
Weeks After Flooding

Fig. A-6

Fig. A-7. The yield (Y)-effort (X) curve of crayfish from baled ponds, (b ——, $Y=1212(1-e^{-0.2266X})^{3.2893}$), standing ponds (s – –, $Y=1672(1-e^{-0.1904X})^{3.0952}$), and disked ponds (d –·–, $Y=873(1-e^{-0.2312X})^{4.6206}$), which were early-flooded on 20 September 1978, during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

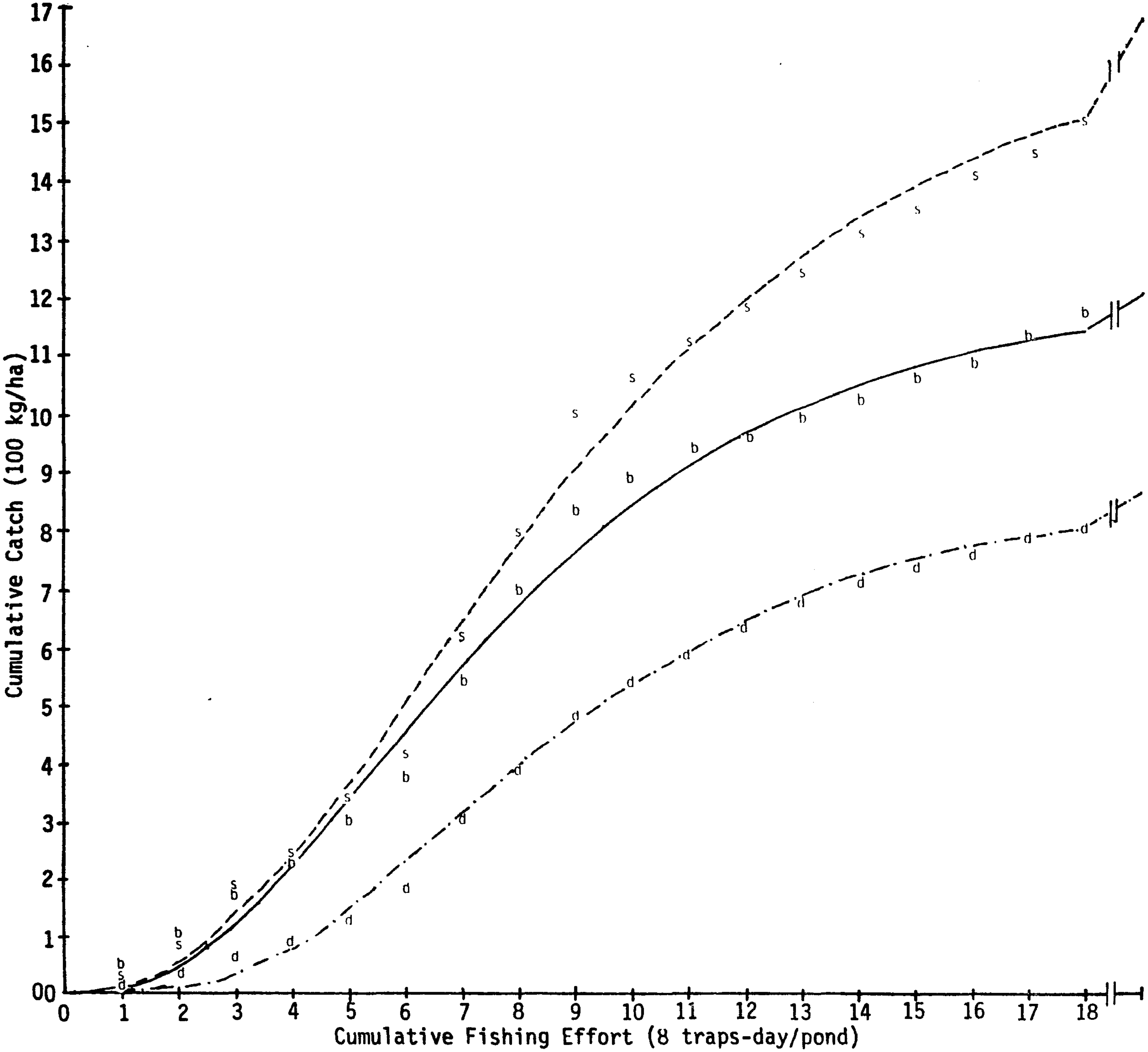

Cumulative Catch (100 kg/ha)
Cumulative Fishing Effort (8 traps-day/pond)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
00
s
b
d

Fig. A-7

Fig. A-8. The yield (Y)-effort (X) curve of crayfish from baled ponds (b ——, $Y=1144(1-e^{-0.3471X})^{7.1356}$), standing ponds (s — —, $Y=1527(1-e^{-).2422X})^{3.8019}$), and disked ponds (d —·—, $Y=793(1-e^{-).-902X})^{5.2483}$), which were late-flooded on 15 October 1978, during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

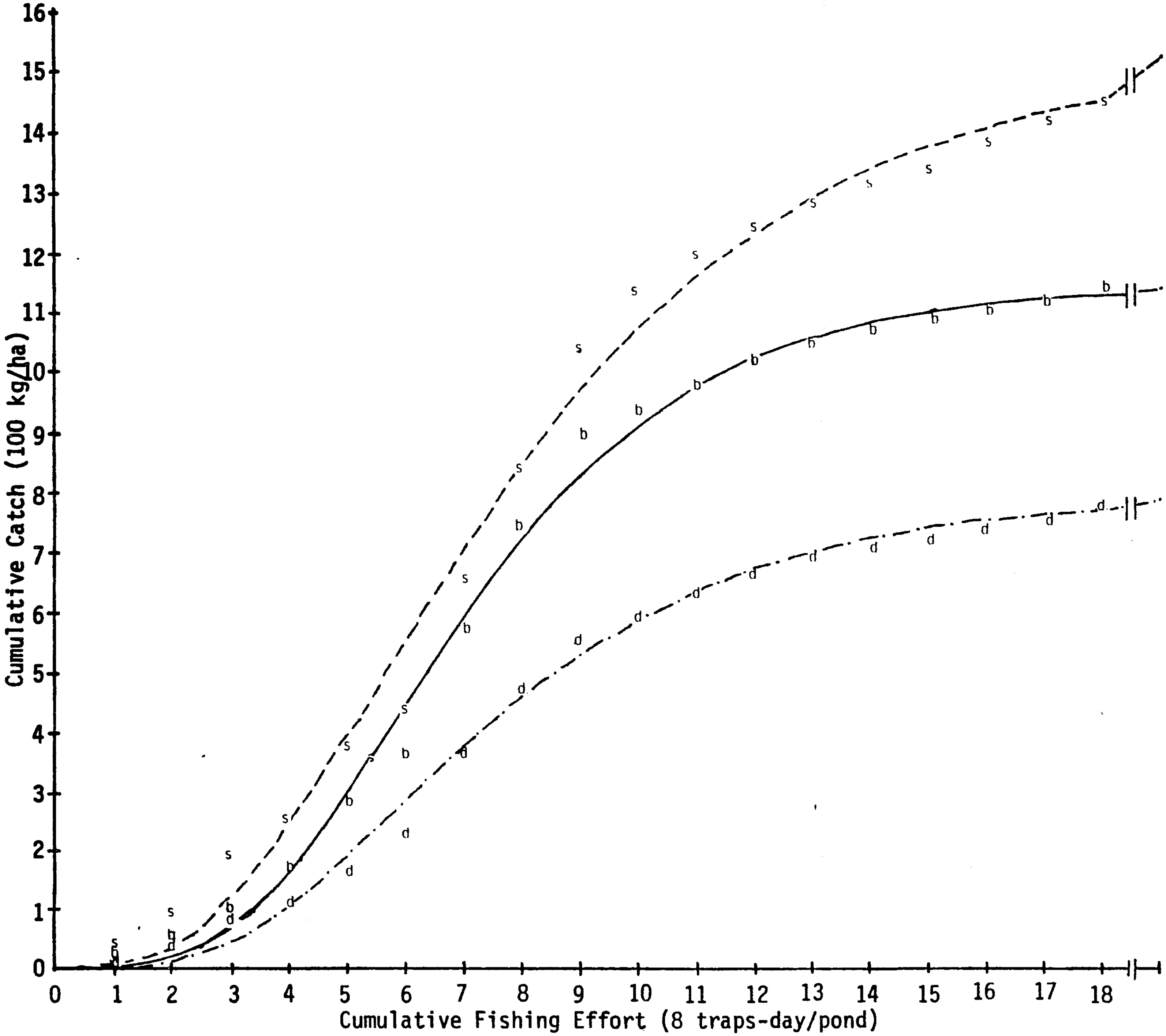

Cumulative Catch (100 kg/ha)
Cumulative Fishing Effort (8 traps-day/pond)

Fig. A-8.

Table A-1. Average diurnal DO, dawn DO, and diurnal temperature of ponds receiving six treatments of two flooding dates X three disposals of rice straw during the first weeks after flooding in 1978, Ben Hur Farm, LSU.

Diurnal DO (mg/l):

	Early Flooding [1]	Late Flooding [2]	Average
Baled [3]	5.7	4.1	4.9
Standing [4]	3.4	4.1	3.8
Disked [5]	4.2	2.6	3.4
Average	4.4	3.6	

Dawn DO (mg/l):

	Early Flooding	Late Flooding	Average
Baled	1.2	1.7	1.5
Standing	1.6	0.7	1.2
Disked	1.1	0.9	1.0
Average	1.3	1.1	

Diurnal Temperature (C):

	Early Flooding	Late Flooding	Average
Baled	23.4	20.2	21.8
Standing	22.6	20.2	21.4
Disked	24.1	21.0	22.6
Average	23.4	20.5	

[1] Ponds were flooded 20 September 1978.

[2] Ponds were flooded 15 October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Tabld A-2. Dawn dissolved oxygen and average diurnal temperature of ponds receiving six treatments of two flooding dates X three disposals of rice straw during the first 10 weeks after flooding in 1978, Ben Hur Farm, LSU.

Dissolved Oxygen (mg/l)

	Early-Flooded Ponds [1]			Late-Flooded Ponds [2]		
Week	Baled [3]	Standing [4]	Disked [5]	Baled	Standing	Disked
2	0.8	0.5	0.6	1.0	1.5	0.8
3	0.6	0.4	0.3	0.9	1.1	0.8
4	2.3	0.5	0.5	2.3	3.1	2.2
5	3.1	1.7	2.3	0.5	0.9	0.8
6	1.4	1.0	1.3	1.3	2.0	1.7
7	1.9	0.9	3.9	---	---	---
8	4.9	2.7	5.9	---	---	---
9	1.9	0.5	2.7	4.4	6.2	6.3
10	3.6	2.5	6.2	3.2	4.7	5.3
Average	2.3	1.2	2.6	2.0	2.8	2.5

Water Temperature (C)

	Early-Flooded Ponds			Late-Flooded Ponds		
Week	Baled	Standing	Disked	Baled	Standing	Disked
2	28.3	27.0	28.8	23.4	22.1	23.8
3	27.0	26.0	27.6	20.6	20.0	21.2
4	23.4	23.7	24.9	17.0	17.2	18.1
5	18.8	18.2	19.7	20.5	20.6	21.3
6	23.1	22.7	23.9	14.6	14.6	15.0
7	20.7	19.7	21.2	----	----	----
8	17.2	16.7	17.9	----	----	----
9	20.5	19.9	21.3	9.3	8.9	9.2
10	14.6	14.6	14.6	12.1	12.0	12.3
Average	21.5	20.9	22.2	16.7	16.6	17.2

[1] Ponds were flooded September 1978.

[2] Ponds were flooded October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Table A-3(a). The amount of NH_4^+-N, NO_2^-+NO_3^--N and total N (mg/l) from six treatments of two flooding dates X three disposals of rice straw from 16 October 1978 to 18 March 1979, Ben Hur Farm, LSU.

Sampling Dates	Dates of Flooding	Disposals of Rice Straw Baled [3]	Standing [4]	Disked [5]	Average
NH_4^+					
10/16/78	Early [1]	0.025	0.054	0.000	0.026
11/22/78	Late [2]	0.028	0.000	0.013	0.014
	Average	0.027	0.027	0.007	0.020
11/12/78	Early	0.028	0.000	0.013	0.014
12/18/78	Late	0.000	0.123	0.000	0.041
	Average	0.014	0.062	0.007	0.028
12/18/78	Early	0.000	0.007	0.053	0.020
1/19/79	Late	0.043	0.204	0.088	0.112
	Average	0.022	0.106	0.071	0.066
1/19/79	Early	0.180	0.063	0.038	0.094
2/19/79	Late	0.016	0.085	0.053	0.051
	Average	0.098	0.074	0.046	0.073
2/19/79	Early	0.025	0.029	0.023	0.026
3/18/79	Late	0.016	0.085	0.053	0.051
	Average	0.021	0.057	0.038	0.039
Average		0.036	0.065	0.034	0.045
NO_2^-+NO_3-N					
10/16/78	Early	0.000	0.003	0.277	0.093
11/22/78	Late	0.013	0.020	0.014	0.016
	Average	0.007	0.012	0.146	0.055
11/22/78	Early	0.050	0.010	0.023	0.028
12/18/78	Late	0.219	0.000	0.412	0.210
	Average	0.135	0.005	0.218	0.119
12/18/78	Early	0.023	0.020	0.067	0.037
1/19/79	Late	0.024	0.000	0.123	0.049
	Average	0.024	0.010	0.095	0.043
1/19/79	Early	0.004	0.135	0.037	0.059
2/19/79	Late	0.098	0.323	0.023	0.148
	Average	0.051	0.229	0.030	0.104

Tabld A-3(a). Continued.

Sampling Dates	Dates of Flooding	Disposals of Rice Straw Baled [3]	Standing [4]	Disked [5]	Average
2/19/79	Early	0.011	0.000	0.146	0.052
3/18/79	Late	0.075	0.000	0.008	0.028
	Average	0.043	0.000	0.077	0.040
Average		0.052	0.051	0.113	0.072
Organic-N					
10/16/78	Early	0.949	1.282	0.649	0.960
11/22/78	Late	0.885	0.952	0.996	0.944
	Average	0.917	1.117	0.823	0.952
11/22/78	Early	0.597	1.000	0.810	0.802
12/18/78	Late	0.595	0.758	0.759	0.210
	Average	0.596	0.879	0.785	0.753
12/18/78	Early	0.559	0.489	0.462	0.503
1/19/79	Late	0.746	0.544	1.025	0.772
	Average	0.652	0.516	0.744	0.637
1/19/79	Early	0.501	0.633	0.821	0.652
2/19/79	Late	0.529	0.524	0.640	0.564
	Average	0.515	0.579	0.731	0.608
2/19/79	Early	0.786	0.524	0.430	0.580
3/18/79	Late	1.002	1.003	0.706	0.904
	Average	0.894	0.764	0.568	0.742
Average		0.715	0.771	0.730	0.738
Total N					
10/16/78	Early	0.974	1.339	0.926	1.080
11/22/78	Late	0.905	1.004	1.035	0.981
	Average	0.940	1.172	0.981	1.031
11/22/78	Early	0.675	1.010	0.846	0.844
12/18/78	Late	0.814	0.860	1.171	0.948
	Average	0.745	0.935	1.009	0.896
12/18/78	Early	0.852	0.509	0.582	0.558
1/19/79	Late	0.813	0.748	1.236	0.932
	Average	0.698	0.629	0.909	0.745

Table A-3(a). Continued.

Sampling Dates	Dates of Flooding	Disposals of Rice Straw Baled [3]	Standing [4]	Disked [5]	Average
1/19/79	Early	0.685	0.831	0.896	0.804
2/19/79	Late	0.643	0.932	0.716	0.764
	Average	0.664	0.882	0.806	0.784
2/19/79	Early	0.822	0.553	0.599	0.658
3/18/79	Late	1.138	1.099	0.816	1.018
	Average	0.980	0.826	0.708	0.838
Average		0.805	0.889	0.883	0.859

[1] Ponds were flooded on September 1978.

[2] Ponds were flooded on October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Table A-3(b). The amount of PO_4^{3-}-P, and total P (mg/l) from six treatments of two flooding dates X three disposals of rice straw from 16 October 1978 to 18 March 1979, Ben Hur Farm, LSU.

Sampling Dates	Dates of Flooding	Disposals of Rice Straw: Baled [3]	Standing [4]	Disked [5]	Average
PO_4^{3-}-P					
10/16/78	Early [1]	0.017	0.024	0.015	0.019
11/22/78	Late [2]	0.123	0.025	0.103	0.084
	Average	0.070	0.025	0.059	0.051
11/22/78	Early	0.009	0.102	0.846	0.053
12/18/78	Late	0.055	0.027	0.041	0.041
	Average	0.032	0.065	0.045	0.047
12/18/78	Early	0.009	0.013	0.023	0.016
1/19/79	Late	0.001	0.008	0.044	0.018
	Average	0.005	0.011	0.036	0.017
1/19/79	Early	0.012	0.008	0.001	0.007
2/19/79	Late	0.023	0.022	0.005	0.017
	Average	0.018	0.015	0.003	0.012
2/19/79	Early	0.014	0.004	0.009	0.009
3/18/79	Late	0.111	0.063	0.052	0.075
	Average	0.063	0.034	0.031	0.043
Average		0.038	0.030	0.035	0.034
Total P					
10/16/78	Early	0.149	0.073	0.126	0.116
11/22/78	Late	0.164	0.108	0.109	0.127
	Average	0.157	0.091	0.118	0.122
11/22/78	Early	0.072	0.163	0.049	0.095
12/18/78	Late	0.060	0.173	0.133	0.122
	Average	0.066	0.168	0.091	0.108
12/18/79	Early	0.057	0.036	0.061	0.051
1/19/79	Late	0.098	0.056	0.108	0.087
	Average	0.078	0.046	0.085	0.070

Tabld A-3(b). Continued.

Sampling Dates	Dates of Flooding	Disposals of Rice Straw Baled [3]	Standing [4]	Disked [5]	Average
1/19/79	Early	0.059	0.040	0.055	0.051
2/19/79	Late	0.035	0.082	0.135	0.084
	Average	0.047	0.061	0.095	0.068
2/19/79	Early	0.058	0.104	0.071	0.078
3/18/79	Late	0.219	0.195	0.172	0.195
	Average	0.139	0.150	0.121	0.137
Average		0.097	0.103	0.102	0.101

[1] Ponds were flooded 20 September 1978.

[2] Ponds were flooded 15 October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Table A-4. Average rate of weight loss (%) of rice straw under six treatments with two flooding dates X three disposals of rice straw during five durations of decomposition, Ben Hur Farm, LSU.

Duration of Decomposition	Dates of Flooding	Disposals of Rice Straw: Baled[3]	Standing[4]	Disked[5]	Average
30 days	Early[1]	47.13	43.23	37.29	42.55
	Late[2]	26.33	24.73	19.00	23.66
	Average	36.73	33.98	28.60	
60 days	Early	53.68	49.31	42.06	48.35
	Late	40.16	27.05	25.31	30.84
	Average	46.92	38.18	33.69	
90 days	Early	61.14	51.76	45.51	52.80
	Late	55.95	33.82	28.53	39.44
	Average	58.55	42.79	37.02	
120 days	Early	68.44	54.87	44.98	56.10
	Late	57.80	58.58	39.37	51.92
	Average	63.12	56.73	42.17	
150 days	Early	79.15	68.81	52.84	66.93
	Late	74.98	64.45	45.03	61.49
	Average	77.07	66.63	48.94	

[1] Ponds were flooded 20 September 1978.

[2] Ponds were flooded 15 October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Table A-5. Initial survival rate (%) and growth (mm) of 16 mm juvenile crayfish under six treatments of two flooding dates X three disposals of rice straw during the first month after flooding, Ben Hur Farm, LSU.

0-14 days:

	Early Flooding[1]		Late Flooding[2]		Average	
	Survival	Growth	Survival	Growth	Survival	Growth
Baled[3]	78	6.9	95	3.8	87	5.4
Standing[4]	95	4.8	95	4.7	95	4.8
Disked[5]	85	5.7	96	4.3	91	5.0
Average	86	5.8	95	4.3		

15-28 days[6]:

	Early Flooding		Late Flooding		Average	
	Survival	Growth	Survival	Growth	Survival	Growth
Baled	83	2.9	87	4.6	85	3.8
Standing	81	3.2	87	4.5	84	3.9
Disked	79	4.6	89	4.4	84	4.5
Average	81	3.6	88	4.5		

0-28 days:

	Early Flooding		Late Flooding		Average	
	Survival	Growth	Survival	Growth	Survival	Growth
Baled	65	9.7	83	8.3	74	9.0
Standing	77	8.0	83	9.2	80	8.6
Disked	67	10.3	85	8.7	76	9.5
Average	70	9.3	84	8.7		

[1] Ponds were flooded 20 September 1978.

[2] Ponds were flooded 15 October 1978.

[3] Ponds where the rice straw was collected and piled into heaps on the bank.

[4] Ponds where the rice straw was left as was in the ponds.

[5] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

[6] The second 2 week survival rate = (The number of crayfish survived at the end of the fourth week) / (The number of crayfish survived at the end of the second week) X 100%.

Table A-6. The parameters of von Bertalanffy's growth curves [1] of crayfish from treatments with two flooding dates X three disposals of rice straw, Ben Hur Farm, LSU.

Dates Flooding		Disposals of Rice Straw: Baled [2]	Standing [3]	Disked [4]	Combined [5]
Early	L_∞	112.7	94.1	87.6	92.2
Flooding	to	-46.5	-3.6	-27.6	-16.2
(20/9/78)	k	0.0185	0.0947	0.0413	0.0550
Late	L_∞	92.8	131.5	72.5	82.7
Flooding	to	-18.9	-35.4	1.8	-7.8
(15/10/78)	k	0.0422	0.0171	0.2387	0.0896
Combined [6]	L_∞	101.5	95.4	77.4	
	to	-27.7	-9.1	-0.8	
	k	0.0286	0.0641	0.1337	

[1] von Bertalanffy's growth curve:

$$L_t = L_\infty \cdot (1-e^{-k\cdot(t-to)})$$

where Lt = length at age t in mm,
L_∞ = average maximum total length,
k = Brody's growth coefficient,
t = age, in weeks in this case,
to = theoretical adjustment parameter, which express the age when the length would have been zero.

[2] Ponds where the rice straw was collected and piled into heaps on the bank.

[3] Ponds where the rice straw was left as was in the ponds.

[4] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

[5] Data of disposals of rice straw combined then fit into growth curve.

[6] Data of flooding dates combined then fit into growth curve.

Table A-7. The average number (AVGN) per trapping and individual weight (AVGIW) of harvestable crayfish from six treatments of two flooding dates X three disposals of rice straw during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

Dates of Flooding		Disposals of Rice Straw: Baled [1]	Standing [2]	Disked [3]	Average
Early Flooding (20/9/78)	AVGN	161	221	126	169
	AVGIW	20.9	20.2	18.2	19.8
Late Flooding (15/10/78)	AVGN	188	209	137	178
	AVGIW	15.7	18.6	15.8	16.7
Average	AVGN	174	215	131	
	AVGIW	18.3	19.4	17.0	

[1] Ponds where the rice straw was collected and piled into heaps on the bank.

[2] Ponds where the rice straw was left as was in the ponds.

[3] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Table A-8. The parameters of yield-effort curves[1] from six treatments of two flooding dates X three disposals of rice straw, Ben Hur Farm, LSU.

Dates of Flooding		Disposals of Rice Straw Baled[2]	Standing[3]	Disked[4]	Average
Early	A	1212	1672	873	7251
Flooding	K	0.22657	0.19046	0.23117	0.20981
(20/9/78)	M	3.2893	3.0957	4.62055	3.41666
	lnM/K	5.2552	5.9329	6.62073	5.85608
Late	A	1144	1527	784	1127
Flooding	K	0.34711	0.24222	0.29019	0.29636
(15/10/79)	M	7.13559	3.80189	5.24826	5.35081
	lnM/K	5.66130	5.51358	5.71314	5.65950
Average	A	1166	1569	830	
	K	0.28739	0.22553	0.24848	
	M	4.85995	3.65851	4.51738	
	lnM/K	5.50133	5.75115	6.06863	

[1] Yield-effort curve:

$$Y = A \cdot (1-e^{-K \cdot x})^{M}$$

where Y = cummulative catch in weight,
x = cumulative fishing effort,
A = biological potential yield,
$\frac{\ln(M)}{K}$ = the time when peak catch starts,
K = determination value of curvature,
exp = natural logarithm.

[2] Ponds where the rice straw was collected and piled into heaps on the bank.

[3] Ponds where the rice straw was left as was in the ponds.

[4] Ponds where all the rice straw was disked underground about 5-7.5 cm deep.

Appendix B - Tables of Statisticsl Analysis

Tabld B-1. The analysis of variance of periphyton dry weight from periphyton samplers in ponds under six treatments of two flooding dates (FLD) X three disposals of rice straw (STR), during three durations of exposure (T), Ben Hur Farm, LSU.

Source	df	SS	MS	F
Treatments	17	53.50	3.14	4.83**
T	2	11.42	5.71	8.80**
STR	2	8.08	4.04	6.22**
FLD	1	17.72	17.72	27.30**
T*FLD	2	2.66	1.33	2.05ns
T*STR	4	6.32	1.58	2.43ns
FLD*STR	2	1.20	0.60	0.92ns
T*FLD*STR	4	5.90	1.48	2.27ns
Error	36	23.40	0.65	
Total	53	76.70		

Table B-2. The analysis of variance of rice straw weight loss after five periods of decomposition (T) under six treatments of two flooding dates (FLD) X three disposals of rice straw, (STR), Ben Hur Farm, LSU.

Source	df	SS	MS	F
Treatment	29	21117.56	728.19	51.38**
T	4	10677.31	2669.32	188.34**
FLD	1	3174.93	3174.93	224.01**
STR	2	5078.01	2539.00	179.14**
T*FLD	4	826.71	206.67	14.58**
T*STR	8	970.02	121.25	8.56**
FLD*STR	2	15.63	7.81	0.56ns
T*FLD*STR	8	374.96	46.87	3.31**
Error	60	850.38	14.17	
Total	89	21967.94		

Table B-3. The analysis of variance of the number of harvestable crayfish from six treatments of two flooding dates (FLD) X three disposals of rice straw (STR), and 18 trapping occasions (8 traps/pond) (T), during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

Source	df	SS	MS	F
Treatment	107	4279520	39996	4.62
T	17	3350102	197065	22.78**
FLD	1	6427	6427	0.74ns
STR	2	376632	188316	21.77**
T*FLD	17	169469	9969	1.15ns
T*STR	34	285566	8399	0.97ns
FLD*STR	2	20623	10312	1.19ns
T*FLD*STR	34	70700	2079	0.24ns
Error	216	1868452	8650	
Total	323	6147972		

Table B-4. The analysis of variance of catch per unit of effort in weight from six treatments of two flooding dates (FLD) X three disposals of rice straw (STR), and 18 trapping occasions (8 traps/pond) (T), during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

Source	df	SS	MS	F
Treatment	107	1979660402	18501499	5.61**
T	17	1570720064	9239539	28.01**
FLD	1	2067364	2067364	0.63ns
STR	2	208532426	104266213	31.60**
T*FLD	17	34854248	2050250	0.62ns
T*STR	34	139300609	4097076	1.24ns
FLD*STR	2	667251	333626	0.10ns
T*FLD*STR	34	712622772	688778	0.21ns
Error	216	2692283174	3299180	
Total	323			

Table B-5. The analysis of variance of average individual weight of harvestable crayfish from six treatments of two flooding dates (FLD) X three disposals of rice straw (STR), and 18 trapping occasions (8 traps/pond) (T), during 2 December 1978 and 29 May 1979, Ben Hur Farm, LSU.

Source	df	SS	MS	F
Treatment	107	4502.25	42.08	1.76**
T	17	2164.27	127.31	5.31**
FLD	1	762.31	762.31	31.82**
STR	2	311.22	155.61	6.49**
T*FLD	17	141.09	8.30	0.35ns
T*STR	34	589.02	17.32	0.72ns
FLD*STR	2	195.48	97.74	4.08*
T*FLD*STR	34	338.87	9.97	0.42ns
Error	216	5151.33	23.96	
Total	323	9653.58		

Table B-6. The analysis of variance of crayfish production (kg/ha) from six treatments of two flooding dates (FLD) X three disposals of rice straw (STR), Ben Hur Farm, LSU.

Source	df	SS	MS	F
Treatments	5	3833218413	766643682	3.78*
FLD	1	35369657	35369657	0.17ns
STR	2	3787767781	1893883891	9.33**
FLD*STR	2	10080975	5040488	0.02ns
Error	12	2435574957	202964579	
Total	17	6268793370		

VITA

Yew-Hu Chien was born on October 22, 1951, in Taipei, Taiwan, Republic of China. He attended National Taiwan Normal University High School and graduated in May, 1969.

In September, 1969, he enrolled at National Taiwan University, Taipei, Taiwan. In June, 1973, he graduated with a Bachelor of Science degree in Fishery Biology.

In July, 1973, he entered military service as a second-lieutenant in the artillery, ending the service in May, 1975.

In August, 1975, he entered the Graduate School at Louisiana State University in Baton Rouge and earned the Master of Science degree in Marine Sciences in 1978. Upon completion of the Masters degree, he was accepted into the doctoral program of the Department of Marine Sciences. He earned the Masters degree in Applied Statistics in May, 1980. He is now a candidate for the Degree of Doctor of Philosophy in the Department of Marine Sciences.

EXAMINATION AND THESIS REPORT

Candidate: Yew-Hu Chien

Major Field: Marine Sciences

Title of Thesis: EFFECTS OF FLOODING DATES AND DISPOSALS OF RICE STRAW ON CRAYFISH, PROCAMBARUS CLARKII (GIRARD), CULTURE IN RICE FIELD

Approved:

James W. Avault Jr.
Major Professor and Chairman

James G. Traynham
Dean of the Graduate School

EXAMINING COMMITTEE:

[signatures]

Kenneth L. Koonce

Date of Examination:

October 15, 1980