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EVALUATION OF SAMPLING GEAR FOR PREDICTING HARVEST SIZE, YIELD AND INCIDENCE OF STUNTING IN CRAWFISH PONDS

A Dissertation

Submitted to the Graduate Faculty
of the Louisiana State University
and Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Forestry, Wildlife, and Fisheries

by
Jimmy L. Avery
B.A., University of Mississippi, 1980
M.S., Delta State University, 1982
December 1997

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ACKNOWLEDGMENTS

I wish to express my sincere gratitude to Dr. Robert P. Romaire, Professor of Fisheries, for serving as my major professor during the preparation of this dissertation and advancing my knowledge of crawfish research and production. I would also like to thank Dr. Robert C. Reigh, Professor of Fisheries, for his guidance and patience during my graduate studies and early research efforts. I am especially grateful to Dr. W. Ray McClain, Adjunct Associate Professor of Fisheries, for his collaboration and providing the data for analysis. I also wish to express my appreciation to the other members of my graduate committee; Drs. James W. Avault, Jr., Professor Emeritus of Fisheries, Terrence R. Tiersch, Associate Professor of Fisheries, and William B. Stickle, Jr., Professor of Zoology and Physiology, for reviewing this manuscript and supporting its completion.

I would gratefully like to acknowledge the support of my administration; especially Drs. Jack L. Bagent, Director of the Louisiana Cooperative Extension Service, Albert J. Ortego, Division Leader, and Kenneth J. Roberts, Project Leader, without which I could not have reached this goal. I also would like to thank research associates; Mrs. Sandra Malone, Vernon Pfister, and Jay Stander, and graduate student, Ken Couch, for their assistance during this and earlier research efforts.

This dissertation is the culmination of seven years of graduate studies and various research efforts. I could not have continued through the various set-backs without the patience and support of my family. Part of this accomplishment belongs to my loving parents, Sue and Bob Avery, who have always encouraged and inspired me to succeed. To my loving wife Bethe, I will never be able to fully express my

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appreciation for your sacrifices and willingness to assume most of the responsibilities of maintaining our family. To my daughters, Lauren and Elizabeth, thank you for allowing me to trade some of our time together for this accomplishment.

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ABSTRACT

Dip-nets, test traps and experimental drop samplers were evaluated for their potential to predict crawfish (*Procambarus* spp.) yields and size distribution at harvest. Field studies were conducted at the Rice Research Station, LSU Agricultural Center, Crowley, Louisiana, between 1991 and 1996 in 82 (0.16 - 0.2 ha) earthen impoundments. Fields were managed to simulate rice-crawfish systems typical of the southwestern and south-central Louisiana.

Multiple linear regression analysis was used to determine the relationship among catch-per-unit-effort (CPUE) of sampling gear (alone and in combination) with respect to yield in weight (kg/ha), yield in number (crawfish/ha) and size distribution at harvest. Relative abundance of crawfish as determined by each gear was compared to size distribution at harvest to develop predictive capabilities for assessing the potential of ponds to yield sub-marketable ("stunted") populations.

Ponds with recruitment during October to December were shown to yield 800 to 1,000 kg/ha, based on December dip-net sweeps of 0.25 to 1.5 crawfish/sweep or a December test trap catch of 0.5 to 11 crawfish/trapset. At higher sampling CPUE rates, yields began to decline. The CPUE of all three gear were statistically correlated to yield in number (crawfish/ha).

Regressions models predicted a smaller size harvest with increasing number of crawfish caught per sample. Dip-net sweep models predicted < 30% of total yield in weight would be $\geq$ 21g when mean monthly catch during November through February was > 1.5 crawfish/sweep. Test trap critical thresholds for "stunted" populations ranged from > 4 crawfish/trapset in November to > 9 crawfish/trapset in February. Drop

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sampler models predicted "stunted" populations when catch exceeded 13 crawfish/m^2 during November through February.

Multiple gear assessments within a pond did not produce a significant improvement over the predictive capability of the gear when used alone. An empirical relationship existed among the number of crawfish caught with one gear and the number of crawfish caught with another gear. This relationship changes as the season progresses due to the effect of size on vulnerability to different gear.

Additional research is needed to evaluate the reliability of drop sampler devices to accurately reflect crawfish standing crop and biomass.

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INTRODUCTION

Louisiana produces, processes, and consumes 80% of all freshwater crawfishes produced for human consumption in the United States of America (Huner 1994). In Louisiana, crawfish are commercially cultivated in 45,069 ha of ponds (Louisiana Cooperative Extension Service 1997), and also are harvested from non-managed riverine habitats. The two species of economic importance are red swamp crawfish (*Procambarus clarkii*) and white river crawfish (*P. zonangulus*) with the majority of the catch composed of red swamp crawfish (Avault and Huner 1985).

Procambarid crawfishes are cultured in shallow earthen impoundments from early fall (September/October) through early summer (May/June). Crawfish that were not harvested during the preceding production season serve as broodstock and produce young for the following season. By mid-April, early maturing crawfish mate and begin burrowing in preparation for reproduction. Ponds are typically drained in late May/June to cultivate vegetation, and remaining crawfish either burrow or perish. Under normal culture conditions, crawfish must survive in burrows for 4 to 5 months. Peak spawning occurs in the burrows during August and September (Gonul 1995).

Forages such as rice (*Oryza sativa*) or sorghum-sudangrass hybrids (*Sorghum bicolor)* are generally planted during summer while ponds are drained. Forage crops serve as the basis for a detrital food web for crawfish. When the ponds are flooded in September/October, adult and juvenile crawfish from the preceding season and recently hatched juveniles or young-of-the-year (YOY) exit burrows and begin to feed and grow. This initial range of age classes and subsequent reproduction results in multiple waves of recruitment during the ensuing production cycle (Romaire and Lutz 1989). If water

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temperature and dissolved oxygen are favorable, juvenile crawfish hatched in burrows can attain marketable size in 3 to 4 months. Once sufficient crawfish reach a marketable size, harvesting begins with baited, wire mesh traps (1.9 cm hexagonal mesh). Although some producers begin harvesting operations as early as November, the majority of the catch is concentrated from March through May (Romaire 1995). Management of crawfish ponds and different production scenarios are reviewed by de la Bretonne and Romaire (1989), Huner and Barr (1991), and Avery and Lorio (1996).

Prior to the development of export markets for large *P. clarkii* (> 30 g) in the late 1980s (Roberts and Dellenbarger 1989), producers were paid a single price, regardless of crawfish size. Because there was no marketing advantage for producing larger animals, commercial crawfish producers typically focused on maximizing total yields. Likewise, research efforts were directed towards increasing total production. As producers became more proficient at increasing juvenile recruitment and survival, stunting of populations became an increasing problem because of overcrowding.

Stunted crawfish populations are distinguished by slow growth or a cessation of growth at less than the desired market size of 20 g or larger (Avault et al. 1975, Jarboe and Romaire 1995). Typically, stunted populations exhibit a high percentage of the harvestable animals less than 18 g. Production of stunted crawfish populations can have a devastating economic effect on producers because of poor marketing opportunities for small crawfish.

Marketing developments in the Louisiana crawfish industry caused a shift in production priorities in the late 1980s. A decline in the supply of crawfish in Europe created markets for Louisiana crawfish (Huner 1989). The export market demanded

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select crawfish of the largest size and a premium was paid for those >30 g. The recent development of import competition with domestic crawfish abdominal meat has also caused producers to concentrate on production of larger crawfish. Imports of inexpensive crawfish tail meat from China have risen to an estimated 2,400 MT in 1996 (Anonymous 1996). This low cost product has eliminated some marketing opportunities for small crawfish, normally utilized for processing of the abdominal meat.

To effectively segregate crawfish for different market outlets, various grading processes have been developed. Grading allowed not only the segregation of crawfish for export but also allowed greater development in domestic markets, and grading according to size has become a standard industry practice (Moody 1989). The industry has now developed a market-based grading system in which producers are paid a higher price for larger crawfish. The Louisiana Crawfish Farmers Association formally adopted the following grade categories: jumbo, > 30 g/crawfish; large, 23-30 g; medium, 18-22 g; and peeler, 8-18 g. Most processors use only three size grades: large, $\geq$ 32 g; medium, 21-31 g; and small, < 21 g. A recent survey indicated prices paid to producers for graded crawfish ranged from $1.74-2.25/kg for large, $0.90-1.23/kg for medium, and $0.44-0.93/kg for small grades (Landreneau 1995). The survey also revealed that only 27% of farm-raised product fell into the largest size grade, with 32% meeting medium grade, and 41% grading as small. The percentage of small crawfish harvested is often much higher for some producers.

After the establishment of a grading system for Louisiana crawfish, development of management techniques to increase production of crawfish exceeding 21 g has

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become a high priority for producers. Although food resources are an important component of crawfish aquaculture, population density is probably the single most important factor regulating crawfish growth and harvest size in commercial ponds (Villagran 1993, Jarboe and Romaire 1995, McClain and Romaire 1995). Unfortunately, producers have little control over reproductive success and are not able to predict production yields. Recruitment and survival of juveniles are highly unpredictable and mostly unmanageable under current production practices. It is only after juveniles are large enough to be retained by the trap that producers have a good indication of production potential.

Several recent studies have investigated methods to control population densities in ponds (Jarboe 1989, Jarboe and Romaire 1995, McClain 1995c, McClain and Romaire 1995, Kryiacou 1996). Additional research is needed to determine more precisely the cause/effect relationships of various production variables and their interaction on crawfish growth and harvest size. To accurately determine these relationships, refinement in the assessment of many producer-related variables are needed. For example, to better examine the effects of population density on crawfish growth, a more accurate measurement of population density and structure is needed.

There are two established methods for estimating relative population density and population structure in crawfish ponds. Dip-net sampling is widely used by Agricultural Extension Service agents, researchers and producers to estimate recruitment and relative juvenile abundance of crawfish in commercial ponds. Dip-net sampling consists of dragging a long handled dip-net along the pond bottom for a short distance to sample juvenile crawfish. Farmers use test traps to assess population

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structure, as reflected in catch-per-unit-effort (CPUE), to justify the initialization of harvesting. Test traps are standard commercial traps that are baited, allowed to collect crawfish, and emptied to count captives after a 24-hour soak period. A third non-established method (drop samplers) has been used in research during the last 6 years to assess crawfish standing crop and biomass (McClain and Romaire 1995). The drop sampler is a remotely operated device that is dropped onto the pond bottom catching all crawfish in a 0.5 m^2 area. However, the efficiency of using these three sampling gear as a management tool to predict yield, harvest size, and the potential of a population to stunt remains to be determined. Improving protocols for better in-pond assessments would aid in the development of more precise prediction guidelines useful to producers.

Regression analysis is a statistical procedure that establishes the relationship among two or more quantitative variables so that one variable can be predicted from the other. Regression analysis serves three major purposes: (1) description, (2) control, and (3) prediction. The descriptive purpose for this study was to examine the empirical relationship among the number of animals caught with each sampling gear (alone and in combination) with crawfish yield and size distribution at harvest. By developing a statistical relationship between crawfish production and these sampling gear estimates, the establishment of critical thresholds for control measures could be developed. If this statistical relationship can be defined, producers and researchers could more accurately predict yield and size distribution at harvest.

A limited number of independent variables (x) can be included in a regression model. A central problem therefore, is choosing a manageable set of independent variables that provides the best explanation of the variation in the dependent or response

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variable (y). A producer usually does not have the capability to assess variables such as periodic changes in food resources (biomass and nutritional quality). Producers typically monitor water quality parameters (dissolved oxygen and water temperatures) only when there is some physical indication of poor conditions. However, producers and Agricultural Extension Service agents do routinely monitor population structure with dip-net sweeps and test traps.

The specific objectives of this study were (1) to evaluate the use of estimates of relative density, standing crop, and crawfish biomass to predict the potential of a population to become stunted, (2) to evaluate the statistical relationship of the number and/or weight of crawfish caught by the three sampling gear (used alone or in combination) with crawfish yield and size distribution at harvest, and (3) to develop a set of multiple linear equations to predict crawfish yield and size distribution at harvest.

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LITERATURE REVIEW

Overcrowding is probably the single most important factor affecting crawfish size at harvest. The abundance of juvenile crawfish in ponds is difficult to manage and density depends on many factors including the quantity of broodstock that burrow in spring (Gonul 1995), the physiological condition and general health of crawfish before burrowing (Thune and Scott 1986), ovarian development in mature females (de la Bretonne and Avault 1977), survival of broodstock in burrows, and juvenile survival after ponds are flooded (Huner 1978, Gonul 1995). A density of approximately 10 crawfish/m^2 or less will generate acceptable yields while still achieving optimum size distribution at harvest under typical forage-based conditions of commercial culture (Lutz and Wolters 1986, Villagran 1993, McClain 1995a, McClain 1995b, McClain and Romaire 1995).

During the first 2 months after flooding, mature females which have spawned or are preparing to spawn are referred to as "holdover" crawfish from the previous season. Young-of-the-year crawfish present in the first several weeks after flooding are referred to as primary recruitment classes. Immature crawfish survive the summer in burrows but do not reproduce until after fall flooding. These juveniles mature, burrow and spawn 2 to 5 months after ponds are flooded, producing secondary recruitment classes in winter and early spring (de la Bretonne and Avault 1977). This condition of population dynamics is referred to as multiple recruitment. Multiple recruitment classes have been reported in managed impoundments (Romaire 1976, de la Bretonne and Avault 1977, Huner 1978) but the number of classes was not quantified. Romaire and

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Lutz (1989) reported four to five primary recruitment classes 5 weeks post-flooding and significant recruitment in spring.

The effects of varied population structures, nutritional factors, or their interactions on production parameters have not been fully appraised. The main reason is that accurate assessment of crawfish density and food availability in flooded impoundments is not easily attainable. Relative estimations of population density and size structure have been obtained in research by use of mark-recapture sampling methods (Romaire 1976, Jarboe 1989), a seine (Momot and Romaire 1982, Romaire and Lutz 1989), small-mesh traps (Romaire 1976, Chien 1980, Johnson 1980, Miltner 1980, Paille 1980, Jarboe 1989, Niquette and D'Abramo 1991), large-mesh traps (Johnson 1980, McClain 1995a, McClain 1995b, McClain 1995c, McClain and Romaire 1995), dip-nets (de la Bretonne and Romaire 1989, Jarboe 1989, Gonul 1995, Kryiacou 1996), or drop samplers (McClain and Romaire 1995), but these have not yet been verified or correlated with production outcomes.

Romaire (1976) reported densities that ranged from 7 to 12 crawfish/m^2 of *P. clarkii* exceeding 45 mm TL in late November based on mark-recapture estimates. Abundance of smaller juveniles was not estimated and thus these densities underestimated total abundance of juveniles. Jarboe and Romaire (1995) reported *Procambarus* sp. densities of 8 to 18/m^2 in experimental pond populations in November based on a combination of mark-recapture estimates and dip-net sweep (DNS) counts. Romaire and Lutz (1989) reported densities of from 3 to 25 crawfish/m^2 in commercial procambarid aquaculture ponds based on seine haul samples. In these three studies,

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moderate to severe stunting of crawfish occurred in the ponds, resulting in a significant percentage of the harvest being less than commercially desirable size.

Two types of traps with different mesh sizes have been used to evaluate crawfish population densities. Small-mesh traps (1.9 - 6.4 mm square mesh) have been used to evaluate juvenile ($\geq$ 45 mm TL) density (Romaire 1976, Chien 1980, Johnson 1980, Miltner 1980, Paille 1980, Jarboe 1989, Niquette and D'Abramo 1991). Standard commercial traps (1.9 cm hexagonal mesh) have been used to evaluate number of harvestable animals ($\geq$ 75 mm TL) (Johnson 1980, McClain 1995a, McClain 1995b, McClain 1995c, McClain and Romaire 1995). Dip-net sweeps and test trap catch have been used by researchers to estimate crawfish densities relative to other ponds (Jarboe 1989, Jarboe and Romaire 1995, McClain 1995c, McClain and Romaire 1995, Kryiacou 1996).

There has been little standardization in the techniques used to take dip-net sweeps or how DNS catch is quantified. Miltner (1980) used five, two-sweep dips at regular intervals on each long side of the pond, giving a total of 10 DNS per pond. Miltner estimated the area covered by each sweep to be approximately 0.5 m^2. Density as determined by DNS was not reported in that study but was combined with test trap catches to produce a graph of length-frequency versus time. Jarboe (1989) made DNS by pulling the dip-net a distance of 1.2 m in six locations in each pond with four sweeps made along the pond periphery and two sweeps made in the center of the pond. He estimated the area sampled by a DNS to be approximately 0.5 m^2 and reported the density of crawfish of less than 40 mm TL as number of crawfish/m^2. Niquette and D'Abramo (1991) made four, 1 m DNS around the periphery of each pond. Juveniles

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collected by DNS were reported as "total number of juveniles collected monthly." Romaire (1976), Paille (1980), Momot and Romaire (1981) and Kyriacou (1996) made 10 DNS along the margin of the pond.

Kryiacou's (1996) DNS covered an area of about $0.33/m^2$ and he extrapolated the number of crawfish caught per sweep to population densities ranging from 27 to $33/m^2$ in October to 85 to $115/m^2$ in December (based on nocturnal DNS counts). Although diurnal DNS caught, on average, about half the number of crawfish that nocturnal DNS did, both sampling periods were highly correlated with yield and harvest size in that study. Because *Procambarus* is more active at night (Huner and Barr 1991), Kryiacou suggested that nocturnal DNS may provide a more accurate representation of absolute population density.

Gonul (1995) reported that highest juvenile abundance sampled from October through December in two experimental crawfish ponds (2 to 2.5 ha in size) occurred in December and averaged 4.5 juveniles per diurnal DNS. The yield of crawfish from the two ponds averaged 1,959 kg/ha and 43% of the harvest were >23 g. McClain (1995c) conducted an identical study to Kryiacou (1996) at the Rice Research Station, Louisiana Agricultural Experiment Station, Crowley, Louisiana. McClain's experimental ponds were not overpopulated; DNS counts for October through March were consistently ≤1 crawfish per diurnal DNS. In McClain's study, more than 86% of the crawfish exceeded 22 g and the mean total yield was 1,458 kg/ha.

Drop samplers are a relatively new sampling technique for estimating crawfish populations. The development of this gear arose from the need to estimate the standing crop both in numbers and biomass based on a sample taken from a unit area (m^2).

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Dr. James T. Davis, Extension Fisheries Specialist at Texas Cooperative Extension Service, Texas A&M University, College Station, Texas, experimented with a galvanized garbage can with the bottom removed. He would move through a pond, trying to disturb as little of the pond bottom as possible, then push the can into the pond bottom surface. After bailing the water out of the can, he would collect the crawfish. Dr. Ray McClain, Crawfish Production Researcher, Louisiana Agricultural Experiment Station's Rice Research Station, LSU Agricultural Center, Crowley, Louisiana, later refined the gear into a stationary unit that could be remotely operated to minimize disturbance of crawfish being sampled.

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MATERIALS AND METHODS

STUDY SITE AND POND MANAGEMENT

The data for this study was supplied by Dr. W. Ray McClain and research associates located at the Louisiana Agricultural Experiment Station Rice Research Station. Field studies were conducted at the Louisiana Agricultural Experiment Station Rice Research Station, Crowley, Louisiana, between 1991 and 1996 in 82 experimental (0.16 - 0.2 ha) earthen impoundments. The soil (pH, 5.4; organic content, 1.34%) was a Crowley silt loam. Well water (pH, 7.7; total alkalinity, 270 mg/L as $CaCO_3$; and total hardness, 195 mg/L as $CaCO_3$) was supplied to each field via irrigation canals.

This research included 5 consecutive crawfish production seasons. The production cycle overlaps a portion of two successive calendar years that begins in October when the permanent flood is applied and concludes when the pond is drained the following May. Therefore, each reported research season begins in the year cited (i.e., 1991 or 91) but terminates in May of the following year.

Fields were managed to simulate rice-crawfish systems typical of the south-central region of Louisiana. Low-leveed (0.5 to 0.75 m high) ponds were built with a rice-levee plow and were rebuilt each year. Rebuilding levees was necessary due to the small size of the levees, erosion, damage, and rice harvesting. This is in contrast to "permanent" ponds that do not rebuild levees each year. Additional management strategies were based on the experimental treatments imposed on individual ponds. Research ponds had several experimental treatments being investigated each season. Sampling gear was utilized to collect data specific to each treatment. Additional

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observations were collected for this study to correlate variables collected from several years, over several environmental conditions and treatment results.

The effect of supplemental feeding (FEED) on crawfish yield was evaluated in four ponds during 1991. Burning of combine tailings (BURN), resulting in decreased forage biomass, was also a treatment in 1991. The effects of reducing crawfish populations (RED) within the production season by use of small-mesh traps (SMT), urea toxicity (TOX), or partial draining of the pond in either December (DEC), January (JAN), or February (FEB) was a major research effort during 1993, 1994, and 1995. Stocking undersize crawfish into a rice crop (or field) that did not contain a population of crawfish (RLY) was evaluated in 12 ponds during 1995.

Several forage-base strategies were used during the 5 years evaluated. For the purposes of this study, the term "main crop" (MC) refers to the practice of relying on the unharvested vegetative material of rice (R), sorghum-sudangrass (SS), or a mixture (MIX) of the two established solely for use as crawfish forage substrate. The use of vegetative regrowth following the harvest of rice grain is referred to as "ratoon crop" (RC).

Planting of main crop (mid-summer) and ratoon crop rice (early spring) followed standard recommended practices (Bollich 1987). Mars, a medium grain rice variety commonly planted for grain and crawfish forage, was planted 3 of the 5 years. When Mars became unavailable, closely related rice varieties such as Orion and Bengal were planted. Where rice growth was insufficient to establish an initial forage base, a sorghum-sudangrass hybrid (Pioneer 855F) was planted into the same seed bed.

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Sorghum-sudangrass or a mixture of sorghum-sudangrass and rice was also used as a primary forage base (MC).

After flooding for crawfish in early-to-mid October, all fields were maintained with an mean water depth of 25 to 32 cm. Dissolved oxygen (DO) and water temperature were monitored 3 to 5 days/week. Fields were flushed with fresh water only when early morning DO levels dropped below 2.0 mg/L. Table 1 depicts pertinent annual variables of the study including number and sizes of ponds, harvest data, management strategies, and forage crops (McClain et al. 1992, 1993, 1994, 1995, 1996).

SAMPLING PROTOCOL

Sampling protocols were consistent from year to year. Dip-net sweep counts were used to quantitatively sample young-of-the-year (YOY) crawfish. The dip-net had a 107-cm long wooden handle and the net was 16-mm diamond mesh, 40.6-cm long x 30.5-cm wide x 30.5-cm deep (area = 1240 cm^2) (Figure 1). Ten DNS counts were taken once per week in the afternoon from each pond (0.16 to 0.20 ha) along the margin without a specific sampling pattern. The dip-net was pulled along the pond bottom and covered an area of about 0.6 m^2. Samples were not taken from the interior of the pond because vegetation was too thick to pull the net along the bottom effectively. Dip-net sampling is generally selective for crawfish less than 40 mm total length (TL) because larger animals can more easily avoid the net (Romaire 1976). Animals larger than 63 mm were occasionally caught with the dip-net but were not counted in the sample because their catch was incidental and would have inflated daily totals. Mean number of crawfish per dip-net sweep $\leq$ 63 mm TL was recorded and the animals were returned to the pond.

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Table 1. Annual experimental conditions for crawfish production studies (1991 to 1996). Rice Research Station, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Crowley, Louisiana.

	Crawfish Season					
Annual Variables	1991	1992	1993	1994	1995	1995
Number of Ponds	20	10	12	16	12	12
Size of Ponds (ha)	0.16	0.16	0.16	0.20	0.20	0.20
Permanent Flood	1-Oct	1-Oct	4-Oct	5-Oct	17-Oct	17-Oct
Crawfish Harvest	3 Feb - 20 May	19 Jan - 7 May	21 Feb - 26 May	1 Mar - 31 May	21 Feb - 17 May	21 Feb - 17 May
Trapping Days	58	48	42	50	50	49
Traps / ha	74	62	62	64	64	64
Total Trapsets (no/ha/season)	4298	2964	2594	3211	3211	3147
Management Strategy[1]	CON, FEED, or BURN	CON or RLY	CON or RED	CON or RED	CON or RED	CON or RLY
Forage Crop[2]	MC-R, RC-R, SS, or MIX	MC-R or RC-R	MC-R	RC-R	MC - MIX	RC-R
Mean Peak Forage Biomass (g/m²)	393	361	425	770	130	467
Rice Variety	Mars	Mars	Mars	Mars	Bengal	Orion
Sorghum-sudangrass Variety	Pioneer 855F	-	-	-	Pioneer 855F	-

[1] CON = Conventional, FEED = Supplemental feed, BURN = Burning of tailings, RLY = Previous relay crawfish into rice crop, RED = Density reduction

[2] MC = Main crop, R = Rice, SS = Sorghum-sudangrass, MIX = Mixture of rice and sorghum-sudangrass, RC = Ratoon crop

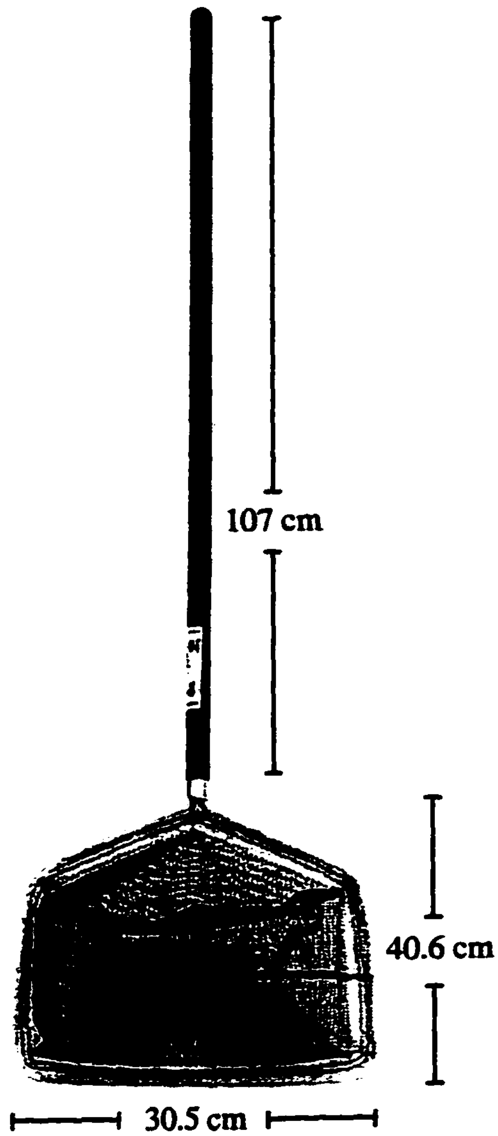

Figure 1. Dip net sampling device used to collect young-of-the-year crawfish.

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Test traps were used weekly to sample larger crawfish from flood-up until harvest. Test traps are generally selective for crawfish larger than 75 mm TL although crawfish as small as 65 mm can be retained if they are mature or the catch per trap is high. Traps used were commercial pyramid traps (1.9 cm hexagonal mesh) with three entrance funnels (Figure 2) set at a density of 20 to 25 traps/ha (4 traps/pond). All traps were baited with formulated bait (Purina Jumbo, Purina Mills, Inc., St. Louis, MO), menhaden (*Brvoortia patronus*), or gizzard shad (*Dorosoma cepedianum*) on the day prior to sampling (24-h baited set) and emptied of crawfish the following morning. The mean number of crawfish/trapset was recorded and the animals were returned to the pond.

An experimental drop sampling device (DRPS) designed to minimize gear bias was placed within 13 ponds over five production seasons to estimate population densities. The device was a galvanized metal cylinder 46 cm high with 0.5 m^2 end area that functioned by sliding up and down on three legs (Figure 3). The drop sampler was held upright in a locked (set) position that suspended it slightly above the water. One end of a rope was attached to a lock mechanism (trigger), and the other was positioned on a nearby levee. After several hours (or overnight), the device was operated by tripping the trigger, whereby the unit fell rapidly, entrapping any crawfish within the cylinder. Pond water was pumped from the cylinder and crawfish were retrieved. Each DRPS was operated at approximately 0800 hours and 1600 hours on Tuesdays and Thursdays. The drop sampler was placed in a pond and moved to a different location within the pond after several samples disturbed the bottom.

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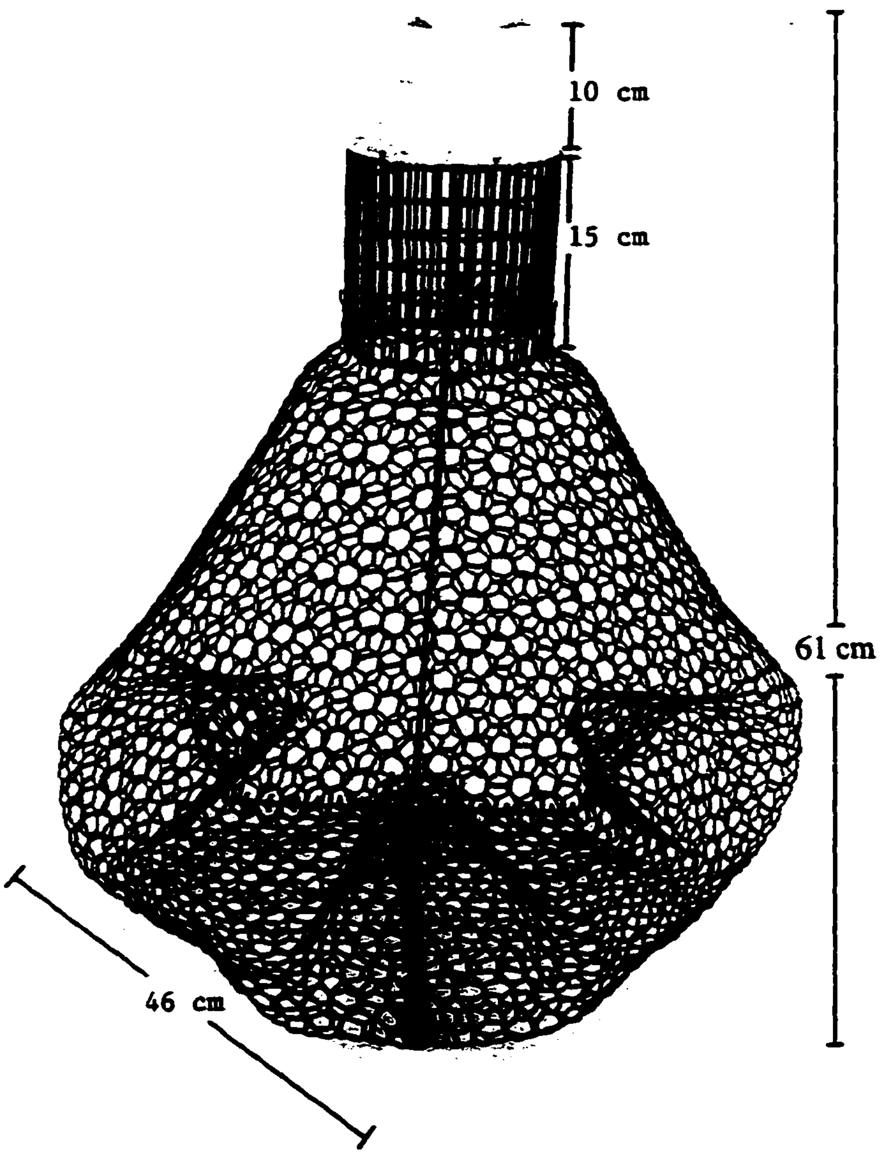

Figure 2. Standard commercial pyramid trap (1.9 cm hexagonal mesh) with three entrance funnels used as a test trap and to harvest marketable crawfish.

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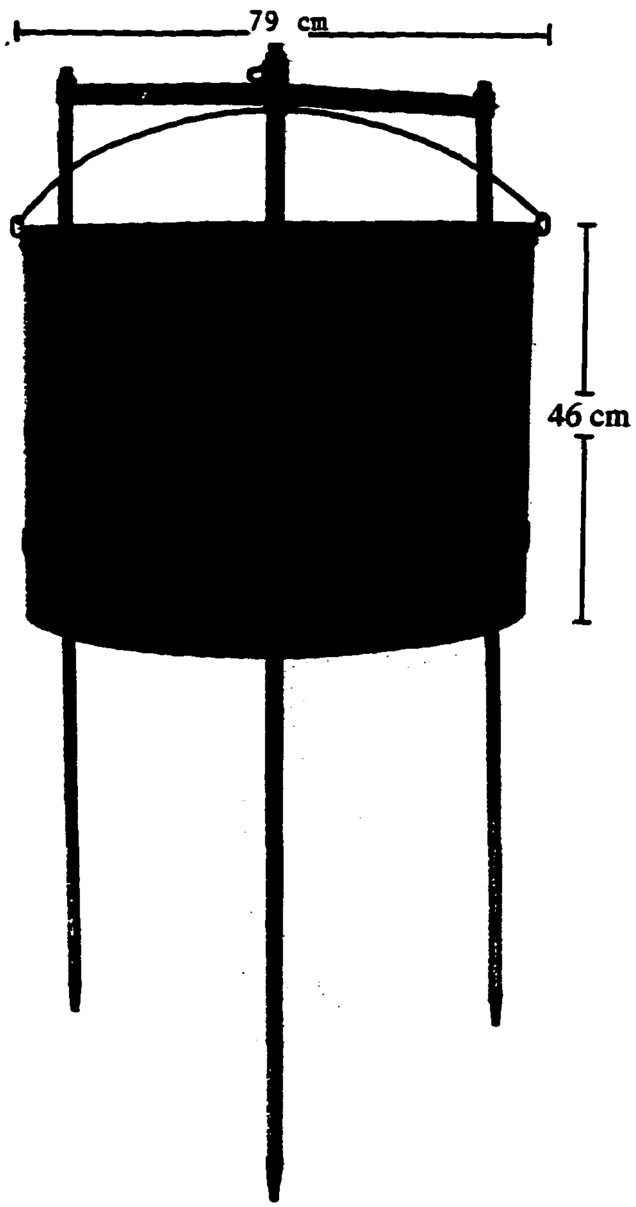

Figure 3. Drop sampling device (0.5m^2 end area) designed by Dr. W. Ray McClain, Louisiana Agricultural Experiment Station's Rice Research Station, LSU Agricultural Center, Crowley, Louisiana.

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HARVESTING PROTOCOL

Crawfish harvesting effort (trapsets/ha/year) varied from year to year (Table 1) based on the population of harvestable crawfish and environmental conditions. Total trapping effort was consistent for all ponds during the study year. Harvesting began when test traps reached a catch-per-unit-effort (CPUE) of 0.22 kg crawfish/trap and ceased when CPUE fell to 0.11 kg/trap.

Crawfish were harvested with pyramid style traps (1.9 cm hexagonal mesh) typically used in crawfish aquaculture (Romaire 1995). Traps were set in designated linear trapping lanes 2 m wide and 14 m apart, at densities ranging from 62 to 64 traps/ha. Traps were baited with 0.11 to 0.14 kg of formulated bait (Purina Jumbo, Purina Mills, Inc., St. Louis, MO), menhaden (*Brvoortia patronus*), or gizzard shad (*Dorosoma cepedianum*) per trap and emptied 3 to 5 days/week.

All harvested crawfish were mechanically graded at the research laboratory with the use of a passive, water-based grader as described by Rollason and McClain (1995) and sorted into three market size categories. Size distribution data were reported as percentage of the weight harvested for the particular size category. The largest category contained crawfish 32 g or larger, the medium category contained crawfish that were 21 to 31 g, and the smallest size category contained crawfish less than 21 g.

RELATIVE DENSITY, STANDING CROP, AND BIOMASS ESTIMATES

Raw Data Analysis

Raw data were recorded using Microsoft Excel™ (Vers. 4.0, and 5.0) spreadsheet software. Yearly data from individual ponds were summarized and mean monthly values were determined for dip-net sweeps (crawfish/sweeps), test trap catch

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(crawfish/trapset), and drop sampler catch in number (crawfish/0.5m^2) and biomass (g crawfish/0.5m^2). Monthly means were used in the analysis of this data. Although biweekly (twice per month) and weekly means could have been constructed, the amount of variation due to environmental influences on CPUE for weekly and biweekly means could have negatively impacted the predictive capabilities of the models developed. The procedures that may be developed to address population structure management are not likely to be time sensitive such that yield predictions can not be made from monthly sampling gear CPUE means.

Criteria for Identifying Stunted Crawfish Populations

In order to evaluate the potential of ponds to produce stunted populations, a criteria for identifying stunted populations was established. Populations with excessive amounts of crawfish $\leq$ 21 g during the spring harvest season can have devastating economic effects for the producer. Based on personal observations and discussions with other Area Aquaculture agents with the Louisiana Cooperative Extension Service (Dwight Landreneau, Area Agent, Louisiana Cooperative Extension Service, District 2, Crowley, Louisiana, May 1997 and Thomas Hymel, Area Aquaculture Agent, Louisiana Cooperative Extension Service, Iberia parish, Louisiana, May 1997), harvested crawfish populations were qualitatively grouped by the percent of total yield in weight $\geq$ 21 g.

Ponds in which < 30% of the total yield in kg/ha was comprised of crawfish $\geq$ 21g were designated as "stunted." Ponds which produced 30 to 49% of the total yield in kg/ha of crawfish $\geq$ 21 g were designated as "acceptable." Ponds exhibiting a size distribution at harvest of 50% or more of the total yield being comprised of animals $\geq$ 21 g were designated as "desirable".

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Relative Density Estimates

The relative density estimates for the 82 ponds used in this study were reported as mean monthly dip-net sweep counts (crawfish/sweep) and mean monthly test trap catch (crawfish/trapset).

Treatment Effects and Year-to-Year Variation

To determine if original treatment effects or year-to-year variation had an effect on relative density estimates based on DNS and TT catch, the 82 ponds used in this study were categorized by treatment effect (ponds receiving conventional management practices or ponds receiving either density reduction treatments or supplemental feed) and production season (1994 production season or all other production seasons). A mean monthly relative density was determined for all 82 ponds. Due to the possible treatment effects of density reduction or supplemental feed, these were separated from the conventional treatments for comparison. The 1994 production season also warranted special consideration due to the low number of crawfish caught with DNS and TT from October through March and the corresponding large yields in weight (kg/ha) and large proportion of crawfish ≥ 32 g and ≥ 21g.

Identifying Stunted Populations with DNS and TT

To determine if relative density estimates could be used to identify stunted populations, the 82 ponds were qualitatively grouped by the percent of total yield in weight ≥ 21 g. A monthly grand mean (± standard deviations) of the sampling gear CPUE was calculated by totaling the individual monthly CPUE means and dividing by the number of ponds in the qualitative group. These relative density profiles were constructed for dip-net sweeps and test trap catch.

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Crawfish Standing Crop and Biomass Estimates

Mean monthly standing crop estimates and mean monthly crawfish biomass estimates from the 13 ponds containing drop sampler were reported as number of crawfish per m^2 and grams of crawfish biomass per m^2, respectively.

Identifying Stunted Populations with DRPS

Due to the small number of observations (n = 13) and the lack of any ponds meeting the criteria established for "acceptable" populations, a different set of criteria were used to separate ponds with drop sampler catch information. The 13 ponds in which drop samplers were evaluated were separated into three groups based on (1) similar recruitment patterns and (2) production season (1994, 1995, and 1991-1993).

REGRESSION MODELS

Data were analyzed using the general linear model procedure (GLM) of the Micro-SAS Statistical Software System (SAS version 6.10, SAS Institute, Cary, NC). A high level of statistical variability is expected in crawfish pond management studies that attempt to duplicate commercial management practices because recruitment, mortality, and environmental conditions are highly variable and difficult to control. For this reason, regressions were considered to have utility as a predictive instrument only when $\alpha \leq 0.05$ and when the coefficient of determination (r^2) or multiple coefficient of determination (R^2) was ≥ 0.25 (25% of variation in the dependent variable explained by the model) (Dr. James Geaghan, Professor of Experimental Statistics, Department of Experimental Statistics, Louisiana State University, Baton Rouge, Louisiana, April 1997).

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Individual Sampling Gear

Multiple linear regression analyses were conducted to determine the relationships among the mean monthly CPUE of individual sampling gear (y) with total crawfish yields in weight (kg/ha) and number (crawfish/ha) and size distribution at harvest. The independent variables (x) in these regressions were numbers of animals caught with each sampling gear and year (encompassing environmental and management factors). This study was based on observational data, therefore y and x should be considered as random variables.

Based on the non-linear relationship of crawfish density to yield and size distribution, both linear and curvilinear functions were used in the linear regression models. The year-to-year (annual) variation was expressed as a linear term in the models. The independent variable was the mean monthly sampling CPUE for each individual gear. The comparisons were conducted for all months that data were available to evaluate the relationship over the entire production season. The statistical model for the multiple linear regression of individual sampling gear CPUE with yields and size distribution at harvest is given by:

$$\gamma = \beta_o + \beta_1 x_1 + \beta_2 (x_1)^2 + \beta_3 x_2 + \epsilon_i \qquad (1)$$

where:

γ = dependent or response variable (yield in kg/ha, no/ha, % $\geq$ 32 g, % $\geq$ 21 g),

β_o = intercept,

$\beta_{1,2,3}$ = multiple linear regression coefficients,

x_1 = independent variable (no/sweep, no/trapset, no/m^2, g/m^2),

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x_2 = qualitative index of year (1, 2, 3, 4, or 5)

ϵ_i = residuals

The qualitative index of year was used to account for the year-to-year variation caused by environmental and treatment effects. Study years were assigned a qualitative index value of 1 for the 1991 season, 2 for 1992, 3 for 1993, 4 for 1994, and 5 for the 1995 season. A median year value was used to determine predicted response variables (yield in weight and number, and size distribution at harvest) for an "average year." Some months did not have all years represented (i.e., the 1995 season had no observations for October). When attempting to predict yields and size distribution from the October regression model, the index values were totaled and divided by the number of years represented. Using this example, October would have a median year value of 2.5 ((1+2+3+4)/4 = 2.5). When all years were reported, the median year value used for prediction purposes was 3.0 ((1+2+3+4+5)/5 = 3.0).

The CPUE (no/0.5m^2 and g/0.5m^2) of morning (800 hrs) drop sampler catch was compared to CPUE of afternoon (1400 hrs) drop sampler catch by month with the analysis of variance (ANOVA) using the General Linear Models Procedure (GLM) in SAS.

Sampling Gear Combinations

By utilizing the catch of each gear within the same pond, gear combinations could be regressed on yields and size distribution at harvest. Dip-net sweeps and test traps were used in all 82 of the ponds studied. The independent variable was the mean monthly sampling CPUE for each individual gear. The comparisons were conducted for all months that data were available to evaluate the relationship over the entire

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production season. The statistical model for the multiple linear regression of the combination of number of crawfish/sweep and number of crawfish/trapset with yields and size distribution at harvest is given by:

$$\gamma = \beta_o + \beta_1 x_1 + \beta_2 (x_1)^2 + \beta_3 x_2 + \beta_4 (x_2)^2 + \beta_5 x_3 + \epsilon_i \quad (2)$$

where:

γ = response variable (yield in kg/ha, no/ha, % $\geq$ 32 g, % $\geq$ 21 g),

β_o = intercept,

$\beta_{1,2,3,4,5}$ = multiple linear regression coefficients,

x_1 = first independent variable (no/sweep),

x_2 = second independent variable (no/trapset),

x_3 = qualitative index of year (1, 2, 3, 4, or 5)

ϵ_i = residuals

All three sampling gear were utilized in only 13 ponds during the study. Due to the low number of observations (n = 13), only linear functions were used in the regression of no/sweep, no/trapset, and no/0.5m^2 with yields and size distribution at harvest to allow for the maximum degrees of freedom for the error term in the regression model. The independent variable was the mean monthly sampling CPUE for each individual gear. The comparisons were conducted for all months that data were available to evaluate the relationship over the entire production season. The statistical model for the multiple linear regression is given by:

$$\gamma = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \epsilon_i \quad (3)$$

where

γ = response variable (yield in kg/ha, no/ha, % $\geq$ 32 g, % $\geq$ 21 g),

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β_o = intercept,

$\beta_{1,2,3,4}$ = multiple linear regression coefficients,

x_1 = first independent variable (no/sweep),

x_2 = second independent variable (no/trapset),

x_3 = third independent variable (no/0.5m^2),

x_4 = qualitative index of year (1,2,3,4, or 5)

$\in_i$ = residuals

Comparison of Individual Sampling Gear

The statistical relationship between the number of crawfish caught with different gear during the same time period was determined. If a consistent ratio could be determined, the sample catch with one gear could be used to estimate the catch in another gear. Three simple linear regression models were used; dip-net sweep counts (y) were compared to test trap catch (x), the number of crawfish caught by drop samplers (y) was compared to test trap catch (x), and the number of crawfish caught with drop samplers (y) was compared to dip-net sweep counts (x). The comparisons were conducted for the months of October through February because these months represent the period in which most corrective management techniques could be employed. The statistical model for the simple linear regressions are given by:

$$\gamma = \beta_o + \beta_1 x_1 + \in_1 \qquad (4)$$

where:

γ = response variable (no/sweep, no/trapset, no/m^2),

β_o = intercept,

β_1 = simple linear regression coefficient,

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x_i = independent variable (no/sweep, no/trapset, no/m^2),

ϵ_i = residuals

PREDICTIVE MODELS

Validation

To validate the regression models used to establish the relationship of yield (weight and number) and size distribution at harvest with dip-net sweep CPUE and test trap CPUE (equation 1), the data set of 82 observations was sub-divided into a model building set (n = 54, 66% of observations) and a validation set (n = 28, 33% of observations). The total number of observations in the drop sampler data set was too few to utilize this procedure. The validation set was used to evaluate the calculated percent deviation of predicted values from observed values. This validation procedure is referred to as "cross validation" (Neter et al. 1989). Four separate iterations were conducted for validation. The 54 ponds selected for the model-building sets and the 28 ponds selected for the validation sets were selected using random number generation from the PROC FORMAT procedure of the Micro-SAS Statistical Software System (SAS version 6.10, SAS Institute, Cary, NC).

The multiple regression coefficients obtained from the four model-building data sets were compared for consistency with the coefficients from the full data set regressions (82 ponds) for dip-net sweep catch (Appendix A) and test trap catch (Appendix B). The iteration that exhibited the most consistency between its coefficients and the full model coefficients was chosen to be used in the cross validation (Neter et al. 1989). The observed sample catch data from DNS or TT in the validation set was entered into the regression models developed from the corresponding model-building

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set to evaluate the predictive ability of the selected model. The criteria for determining the suitability of the validation was that predicted values had to be within 25% of actual values.

Predictions of Yield and Size Distribution

Full Data Set Models

Once validated, the full data set (n = 82 ponds) was used to develop predictive regression models for dip-net sweeps and test trap catch. Predictive regression models were developed by segregating the range of observed monthly CPUE means sample for DNS and TT, into eight separate values and entering these values into those monthly regression equations that met the combined significance requirements of $Pr>F \leq 0.05$ and $R^2 \geq 0.25$.

Predictive regression models were also developed for drop sampler catch in numbers and biomass although because of the small size of the data set (n = 13) the models could not be validated.

Models for Predicting Yield in Weight (kg/ha)

Two methods were used to predict crawfish yield in weight (kg/ha). The first method regressed either no/sweep or no/trapset on total yield in weight (kg/ha) using equation (1) excluding the 1994 data. The 1994 data was eliminated in this method because when compared to the other production seasons, the 1994 season exhibited non-conforming results.

The second method for predicting crawfish yield in kg/ha used a two step procedure as follows: (Step 1) models developed using equation 1 were used to predict the number of crawfish harvested based on either the dip-net CPUE or test trap CPUE;

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(Step 2) then the yield of harvested crawfish in weight (kg/ha) was determined by substituting the predicted yield in number from Step 1 into the following linear regression model:

$$\gamma = \beta_o + \beta_1 x_1 + \epsilon_i \quad (5)$$

where:

γ = response variable (kg/ha),

β_o = intercept,

β_1 = linear regression coefficient,

x_1 = independent variable (no/ha),

ϵ_i = residuals

Equation 5 was used to establish a yield in weight and yield in number relationship for 1994 (n = 16) and non-1994 (n = 66) harvest data.

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RESULTS

RANGE OF OBSERVED VALUES

Annual yield and size distribution at harvest was summarized for each pond (Table 2). The data set used in this study had a wide distribution of yield (kg/ha and crawfish/ha) and size distribution of crawfish harvested. Yields in kg/ha and crawfish/ha from the 82 ponds ranged from 263 to 1,827 kg/ha and 12,450 to 106,329 crawfish/ha (Figure 4) and were comparable to yields from the commercial sector. Size distribution at harvest ranged from 0.64 to 65.63% of total yield in weight for crawfish ≥ 32 g to 9.2 to 89% of total yield in weight for crawfish ≥ 21 g (Figure 5).

Catch data for the three sampling gear is presented in Table 3. Mean monthly DNS counts ranged from 0 to 2.2 crawfish/sweep. Mean monthly test trap catch (crawfish/trapset) ranged from 0.2 to 10.4 crawfish/trapset. Mean monthly drop sampler catch (no/0.5m^2) ranged from 0.1 to 10.8 crawfish/0.5m^2 while the mean daily drop sampler catch in g/0.5m^2 ranged from 0.3 - 96.6 g.

RELATIVE DENSITY, STANDING CROP, AND BIOMASS ESTIMATES

Relative Density Estimates

Treatment Effects and Year-to-Year Variation

Comparing the effects of different experimental treatments and year-to-year variation on relative density as estimated from DNS revealed two distinct patterns (Table 4). For all 82 ponds combined, conventional treatments, and reduction/feed treatment groupings, relative densities were high during October and November, decreased during December and reached a maximum during February. For these

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Table 2. Yield and size distribution at harvest information for crawfish production studies (1991 to 1996). Rice Research Station, Louisiana Agricultural Experimental Station, LSU Agricultural Center, Crowley, Louisiana.

Management Strategy[1]	Forage Crop[2]	Year	Trapsets/ha	Yield (kg/ha)	Yield (no/ha)	Size Distribution Avg. Wt. (g)	Size Distribution ≥32 g (%)[3]	Size Distribution ≥21 g (%)[3]
CON	MC-R	91	4,298	1,085	60,734	17.87	4.58	36.84
CON	MC-R	91	4,298	1,162	67,915	17.11	2.96	29.77
CON	MC-R	91	4,298	1,303	77,349	16.84	2.54	28.89
CON	MC-R	91	4,298	1,193	61,986	19.25	8.34	48.10
FEED	MC-R	91	4,298	1,193	63,470	18.79	5.13	44.28
FEED	MC-R	91	4,298	1,182	63,369	18.66	4.22	42.19
FEED	MC-R	91	4,298	1,599	91,712	17.44	2.77	33.71
FEED*	MC-R	91	4,298	1,777	106,329	16.71	2.58	28.81
BURN	RC-R	91	4,298	263	12,450	21.12	15.13	65.91
CON	MC-R	91	4,298	1,194	52,345	22.81	10.23	58.37
CON	MC-R	91	4,298	1,268	52,371	24.22	12.90	60.99
CON	RC-R	91	4,298	616	21,780	28.27	31.59	77.49
CON	MC-SS	91	4,298	854	49,372	17.30	3.78	39.40
CON	MC-SS	91	4,298	784	43,718	17.93	7.93	40.91
CON	MC-SS	91	4,298	1,416	81,952	17.28	3.39	32.69
CON	MC-SS	91	4,298	1,487	84,407	17.61	5.05	36.59
CON	MC-MIX	91	4,298	1,110	65,115	17.05	3.64	32.12
CON	MC-MIX	91	4,298	1,084	66,146	16.38	3.12	27.99
CON	MC-MIX	91	4,298	1,144	57,946	19.74	10.13	51.17
CON	MC-MIX	91	4,298	1,104	55,627	19.85	11.96	50.12
CON	MC-R	92	2,964	538	28,168	19.11	5.16	33.53
CON*	MC-R	92	2,964	774	46,660	16.59	1.68	16.70
CON	MC-R	92	2,964	730	44,440	16.43	1.15	15.48
CON	MC-R	92	2,964	609	37,537	16.23	1.26	14.55
CON	RC-R	92	2,964	836	41,406	20.19	12.49	45.08
CON	RC-R	92	2,964	877	44,141	19.86	10.51	43.84
RLY	RC-R	92	2,964	782	41,129	19.00	7.06	36.80
RLY	RC-R	92	2,964	822	43,767	18.77	7.72	36.22
RLY	RC-R	92	2,964	958	45,127	21.23	18.54	54.23

[1] CON = Conventional, FEED = Supplemental Feed, BURN = Burning of tailings, RLY = Previous relay into rice crop

[2] MC = Main crop, RC = Ratoon crop, R = Rice, SS = Sorghum-sudangrass, MIX = Mixture of rice and sorghum-sudangrass

[3] % of total yield (kg/ha)

* Ponds containing drop samplers

(table con'd)

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Management Strategy[1]	Forage Crop[2]	Year	Trapsets/ha	Yield (kg/ha)	Yield (no/ha)	Size Distribution Avg. Wt. (g)	≥ 32 g (%)[3]	≥ 21 g (%)[3]
RLY	RC-R	92	2,964	914	42,888	21.30	19.70	55.12
CON*	MC-R	93	2,594	989	65,592	15.07	1.92	13.41
CON	MC-R	93	2,594	1,264	80,739	15.66	1.67	16.63
CON	MC-R	93	2,594	1,118	66,880	16.72	3.13	23.03
CON	MC-R	93	2,594	962	57,946	16.61	2.33	20.15
RED-SMT	MC-R	93	2,594	875	57,304	15.27	1.70	10.50
RED-SMT	MC-R	93	2,594	790	54,439	14.51	1.76	9.65
RED-SMT*	MC-R	93	2,594	957	66,729	14.34	1.00	9.20
RED-SMT	MC-R	93	2,594	723	48,370	14.95	0.64	10.42
RED-TOX*	MC-R	93	2,594	1,107	46,241	23.93	33.58	67.38
RED-TOX	MC-R	93	2,594	1,022	45,036	22.69	29.15	64.95
RED-TOX	MC-R	93	2,594	1,046	45,774	22.85	28.55	66.65
RED-TOX	MC-R	93	2,594	628	24,310	25.82	45.63	73.24
CON	RC-R	94	3,211	1,191	37,781	31.52	63.56	88.61
CON*	RC-R	94	3,211	1,302	41,716	31.22	58.32	87.40
CON	RC-R	94	3,211	1,827	59,739	30.58	56.35	85.45
CON	RC-R	94	3,211	1,672	53,708	31.13	58.75	86.99
RED-DEC	RC-R	94	3,211	1,594	51,979	30.66	57.28	85.78
RED-DEC	RC-R	94	3,211	1,482	48,007	30.88	59.15	86.54
RED-DEC*	RC-R	94	3,211	1,261	38,947	32.37	62.48	88.15
RED-DEC	RC-R	94	3,211	1,565	53,367	29.33	52.22	83.67
RED-JAN	RC-R	94	3,211	1,676	55,209	30.37	57.53	85.62
RED-JAN	RC-R	94	3,211	1,601	50,376	31.79	61.27	87.82
RED-JAN	RC-R	94	3,211	1,392	44,075	31.57	61.08	88.24
RED-JAN*	RC-R	94	3,211	1,169	35,763	32.70	63.24	87.95
RED-FEB	RC-R	94	3,211	1,743	55,503	31.40	61.33	87.39
RED-FEB	RC-R	94	3,211	1,296	40,888	31.70	64.10	88.67
RED-FEB	RC-R	94	3,211	1,414	43,746	32.32	65.03	88.34
RED-FEB*	RC-R	94	3,211	1,138	33,775	33.68	65.63	89.00
RLY	RC-R	95	3,147	683	23,681	28.83	37.09	72.49

[1]CON = Conventional, RED = Density reduction, SMT = Small mesh trap, TOX = Urea toxicity, DEC = December drain, FEB = February drain, JAN = January drain' RLY = Relay into rice crop

[2] MC = Main crop, RC = Ratoon crop, R = Rice

[3] % of total yield (kg/ha)

* Ponds containing drop samplers

(table con'd)

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Management Strategy[1]	Forage Crop[2]	Year	Trapsets/ha	Yield (kg/ha)	Yield (no/ha)	Size Distribution Avg. Wt. (g)	Size Distribution ≥ 32 g (%)[3]	Size Distribution ≥ 21 g (%)[3]
RLY	RC-R	95	3,147	382	13,961	27.33	38.20	72.42
RLY	RC-R	95	3,147	346	12,900	26.79	32.79	65.77
RLY	RC-R	95	3,147	833	29,732	28.03	37.06	71.88
RLY	RC-R	95	3,147	728	24,237	30.05	40.44	74.74
RLY	RC-R	95	3,147	464	17,057	27.20	28.86	64.49
RLY	RC-R	95	3,147	581	20,848	27.89	32.21	67.29
RLY	RC-R	95	3,147	538	19,059	28.25	34.34	69.97
RLY	RC-R	95	3,147	450	15,914	28.27	38.20	72.31
CON	RC-R	95	3,147	741	26,545	27.92	40.48	73.89
CON	RC-R	95	3,147	802	27,876	28.76	36.86	72.55
CON	RC-R	95	3,147	404	16,052	25.17	34.02	66.27
CON	MC-Mix	95	3,211	772	41,501	18.60	3.54	20.84
CON	MC-Mix	95	3,211	679	36,114	18.80	4.49	22.90
CON*	MC-Mix	95	3,211	635	33,518	18.95	5.03	23.88
RED-DEC*	MC-Mix	95	3,211	665	35,558	18.70	4.26	22.61
RED-DEC	MC-Mix	95	3,211	655	33,970	19.27	5.07	23.67
RED-DEC	MC-Mix	95	3,211	550	28,346	19.42	5.90	27.02
RED-JAN*	MC-Mix	95	3,211	573	30,271	18.94	3.26	22.25
RED-JAN	MC-Mix	95	3,211	587	30,655	19.15	3.83	23.49
RED-JAN	MC-Mix	95	3,211	534	27,792	19.20	3.58	23.01
RED-FEB	MC-Mix	95	3,211	656	36,218	18.12	2.98	20.15
RED-FEB	MC-Mix	95	3,211	659	35,442	18.60	3.16	20.51
RED-FEB*	MC-Mix	95	3,211	608	31,514	19.30	4.75	24.85

[1] RLY = Relay into main crop, CON = Conventional, RED = Density reduction, DEC = December drain, FEB = February drain, JAN = January drain

[2] RC = Ratoon crop, R = Rice, MC = Main crop, MIX = Mixture of rice and sorghum-sudangrass

[3] % of total yield (kg/ha)

* Ponds containing drop samplers

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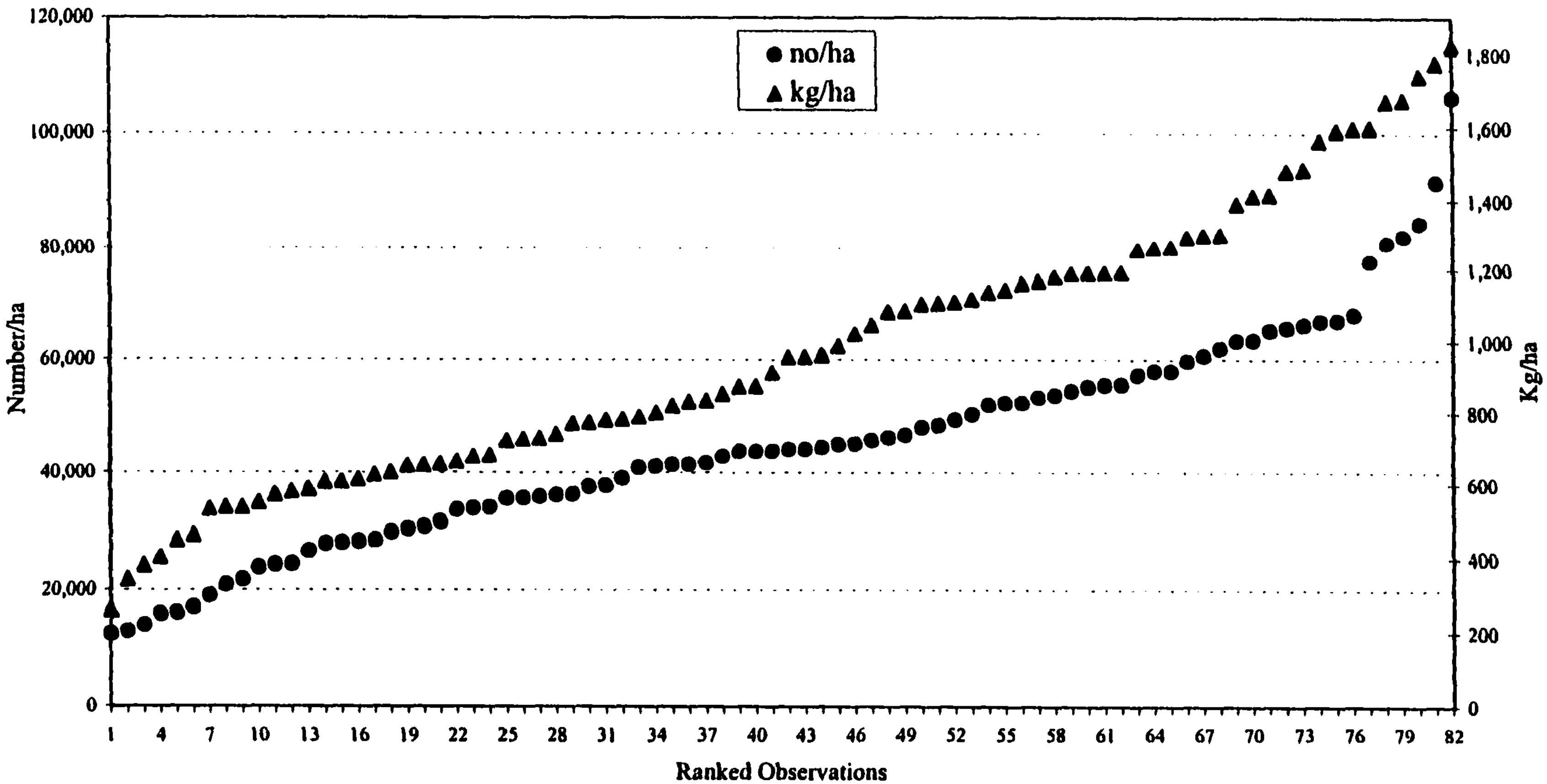

Figure 4. Crawfish yield distribution by weight (kg/ha) and individuals (crawfish/ha) ranked independently by observed values (scaled from low to high) for 82 experimental crawfish ponds (1991 to 1996). Rice Research Station, Crowley, Louisiana.

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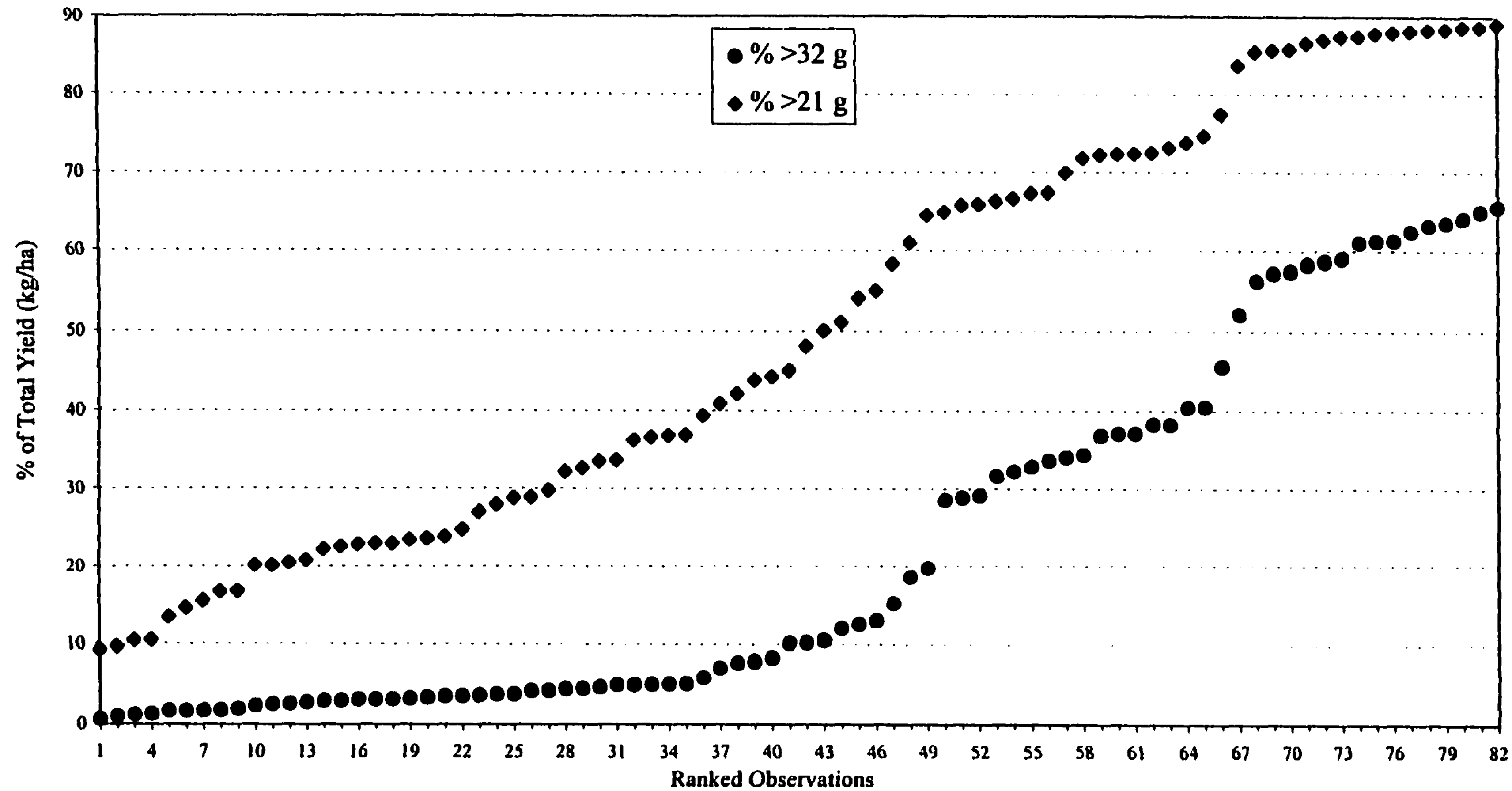

Figure 5. Crawfish size distribution at harvest (as % of total yield) ≥ 32 g and ≥ 21 g, ranked independently by observed values (scaled from low to high) for 82 experimental crawfish ponds (1991 to 1996). Rice Research Station, Crowley, Louisiana.

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Table 3. Monthly means (±SD) and minimum and maximum values (in parentheses) of monthly observations for dip-net sweep catch, test trap catch, and drop sampler catch for Rice Research Station crawfish studies (1991 to 1996).

Dip-net Sweep Catch (no/sweep)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
91/92	0.8 ± 0.5 (0.1-0.9)	0.6 ± 0.4 (0.1-0.7)	0.8 ± 0.5 (0.2-2.2)	0.6 ± 0.4 (1.8-0.6)	1 ± 0.7 (0.1-2.8)	1.0 ± 0.4 (0-1.6)	0.4 ± 0.2 (0-0.7)	[1]
92/93	1.0 ± 0.4 (0.4-1.6)	0.9 ± 0.2 (0.5-1.2)	0.6 ± 0.4 (0.3-1.6)	1.8 ± 0.6 (1.0-3.1)	1.6 ± 0.5 (1.0-2.4)	0.9 ± 0.2 (0.6-1.4)	0.6 ± 0.2 (0.3-1.0)	[1]
93/94	1.1 ± 0.7 (0.2-3.0)	2.2 ± 0.9 (1.1-4.6)	2.0 ± 0.5 (1.3-3.0)	1.9 ± 1.0 (0.9-4.2)	1.5 ± 1.0 (0.7-3.8)	1.1 ± 1.1 (0.1-3.8)	0.8 ± 0.5 (0.2-1.9)	0.3 ± 0.2 (0.1-0.8)
94/95	0.1 ± 0.1 (0-0.3)	0.3 ± 0.1 (0-0.4)	0.2 ± 0.1 (0-0.5)	0.1 ± 0.1 (0.1-0.4)	0.3 ± 0.1 (0.2-0.4)	0.2 ± 0 (0.1-0.3)	0.4 ± 0.1 (0.2-0.5)	0.5 ± 0.1 (0.3-0.8)
95/96	[1]	0.3 ± 0.2 (0-0.8)	0.1 ± 0.1 (0-0.3)	0.1 ± 0.1 (0-0.2)	0.4 ± 0.2 (0.2-0.8)	0.7 ± 0.3 (0.2-1.3)	0.1 ± 0.1 (0-0.2)	0 ± 0 (0-0.2)

Test Trap Catch (no/trapset)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
91/92	1.0 ± 0.7 (0-2.1)	0.9 ± 0.7 (0.2-2.2)	4.1 ± 3.3 (0.3-11.4)	7.1 ± 5.7 (0.5-21.7)	[1]	[1]	[1]	[1]
92/93	2.6 ± 0.9 (1.0-3.8)	4.0 ± 2.6 (1.8-8.9)	7.2 ± 8.2 (0.8-24.0)	6.9 ± 9.0 (0.5-24)	[1]	[1]	[1]	[1]
93/94	2.8 ± 1.0 (1.6-4.4)	5.4 ± 3.1 (1.7-11.7)	10.4 ± 5.9 (3.4-22.8)	4.6 ± 6.1 (0.3-21.3)	9.8 ± 10.4 (2.0-28.6)	[1]	[1]	[1]
94/95	0.3 ± 0.2 (0-0.6)	0.4 ± 0.2 (0.2-0.8)	1.1 ± 0.7 (0.3-2.5)	1.8 ± 0.8 (0.6-3.1)	2.0 ± 0.9 (0.8-3.8)	[1]	[1]	[1]
95/96	[1]	0.2 ± 0.2 (0-0.7)	0.5 ± 0.6 (0-2.8)	0.5 ± 0.4 (0.1-1.8)	1.7 ± 0.8 (0.5-3.0)	[1]	[1]	[1]

[1] No samples taken during this period

(table con'd)

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Drop Sampler Catch (no/0.5m²)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
91/92[1]	3.2	7.5	10.7	8.3	10.8	9.3	6.1	6.5
92/93[1]	9.8	8.1	6.4	9.6	7.4	6	6.6	4.8
93/94	2.4 ± 0.6 (1.9-3.1)	8 ± 1.4 (7.0-9.7)	8.9 ± 3.4 (6.5-12.8)	6.3 ± 4.0 (2.3-10.3)	8.5 ± 4.3 (4.8-13.3)	7.2 ± 6.4 (1.6-14.1)	3.7 ± 1.8 (1.7-5.3)	3.9 ± 1.8 (2.1-5.7)
94/95	0.1 ± 0.1 (0-0.2)	0.6 ± 0.2 (0.4-0.7)	0.6 ± 0.3 (0.4-1)	0.3 ± 0.2 (0.1-0.5)	0.5 ± 0.3 (0.1-0.8)	1.4 ± 0.3 (0.9-1.8)	2.4 ± 0.7 (1.5-3.0)	2.3 ± 0.8 (1.5-3.1)
95/96	[2]	2.5 ± 0.5 (1.9-3.0)	2.5 ± 1.4 (0.7-3.6)	0.7 ± 0.2 (0.5-0.9)	0.5 ± 1.2 (0.4-3.1)	2.3 ± 1.3 (0.5-3.4)	2.5 ± 0.4 (2.0-2.9)	2.3 ± 0.6 (1.5-2.8)

Drop Sampler Catch (g/0.5m²)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
91/92[1]	2.3	20.0	33.6	42.4	37.8	28.7	44.0	96.6
92/93[1]	9.3	13.9	14.0	38.8	32.0	34.0	46.4	37.7
93/94	3.1 ± 2.0 (0.9-4.7)	14.3 ± 5.6 (10.3-20.7)	19.1 ± 7.7 (11.8-27.1)	16.1 ± 12.2 (6.0-29.7)	27.8 ± 18.1 (12.9-48)	27.8 ± 19.7 (12.6-50.0)	23.9 ± 2.6 (22.0-26.9)	26.9 ± 1.7 (25.1-28.6)
94/95	0.3 ± 0.3 (0-0.7)	1.4 ± 0.7 (0.6-2.2)	1.5 ± 7.7 (11.8-27.1)	2.0 ± 1.4 (0.1-3.6)	3.1 ± 2.9 (0.6-6.7)	21.4 ± 6.1 (13.7-28.5)	53.9 ± 15.7 (31.6-64.9)	60.5 ± 21.6 (38.5-82.5)
95/96	[2]	2.2 ± 0.7 (1.4-2.9)	2.3 ± 1.5 (0.7-4.4)	2.2 ± 2.1 (0.4-4.6)	5.6 ± 3.7 (0.9-9.9)	11.4 ± 5.8 (3.2-16.8)	19.3 ± 0.7 (18.6-20.0)	20.0 ± 3.8 (15.7-24.7)

[1] Only one pond contained a drop sampler device

[2] No samples taken during this period

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Table 4. Mean (± SD) relative density estimates (crawfish/dip-net sweep) from dip-net sweep sampling gear for Rice Research Station crawfish studies (1991 to 1996) grouped by original treatment or year.

Treatments[1]	N	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
All	82	0.72 ± 0.62	0.72 ± 0.76	0.63 ± 0.73	0.69 ± 0.87	0.85 ± 0.75	0.77 ± 0.55	0.36 ± 0.33	0.23 ± 0.23
CON	49	0.84 ± 0.53	0.67 ± 0.59	0.61 ± 0.62	0.76 ± 0.90	0.88 ± 0.72	0.87 ± 0.41	0.36 ± 0.34	0.19 ± 0.25
RED or FEED	33	0.54 ± 0.70	0.81 ± 0.96	0.65 ± 0.89	0.58 ± 0.84	0.79 ± 0.81	0.61 ± 0.69	0.36 ± 0.32	0.26 ± 0.22
Non-1994	66	0.95 ± 0.58	0.83 ± 0.81	0.74 ± 0.78	0.82 ± 0.93	0.98 ± 0.78	0.90 ± 0.53	0.35 ± 0.37	0.13 ± 0.19
1994	16	0.13 ± 0.09	0.27 ± 0.11	0.20 ± 0.10	0.15 ± 0.09	0.30 ± 0.07	0.21 ± 0.05	0.37 ± 0.08	0.46 ± 0.15

[1] All = All 82 ponds combined, CON = Ponds receiving conventional management practices, RED = Ponds receiving density reduction treatments, FEED = Ponds receiving supplemental feed, Non-1994 = 1991, 1992, 1993, and 1995 observations, 1994 = 1994 observations

groupings, relative density decreased after harvesting was initiated 19 January through 21 February (Table 4). The 1994 treatment grouping had substantially lower relative densities during October through March. Initial densities decreased during December and January similar to other treatment groupings. Although harvesting did not begin until 1 March due to low CPUE, relative densities continued to increase during April and May.

Relative density for these groupings as estimated from TT also exhibited two distinct patterns (Table 5). For all treatment groupings except 1994, relative densities increased until December and then remained stable. The 1994 treatment group, while exhibiting substantially lower relative density, did not peak until February.

Identifying Stunted Populations

Ponds were separated into three qualitative groupings based on percent of total yield $\geq$ 21 g (Figure 6). This qualitative grouping of crawfish size distribution at harvest is based on the economic disadvantage of producing stunted populations (Table 6). To determine an estimated gross income per hectare, a mean yield was first determined for each qualitative grouping (Appendix C). Crawfish size distribution at harvest was classified as large, medium, or small to coincide with current processors' grading classifications. The mean price per kilogram for each grade (large, $2.00/kg; medium, $1.07/kg; and small, $0.69) was based on the price per kilogram as reported by Landreneau (1995).

Yield in weight (kg/ha) varied considerably within each qualitative grouping (Figure 7). Ponds with stunted populations produced yields ranging from 534 to 1,777 kg/ha. Pond with acceptable populations produced yields ranging from 538 to 1,599

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Table 5. Mean (± SD) relative density estimates (crawfish/trapset) from test trap sampling gear for Rice Research Station crawfish studies (1991 to 1996) grouped by original treatment or year.

Treatments[1]	N	Oct	Nov	Dec	Jan	Feb
All	82	1.37 ± 1.22	1.57 ± 2.38	3.67 ± 5.09	3.75 ± 5.37	3.70 ± 6.01
CON	49	1.39 ± 1.21	1.40 ± 2.32	3.36 ± 4.99	3.94 ± 5.68	3.35 ± 5.99
RED or FEED	33	1.34 ± 0.27	1.83 ± 2.49	4.13 ± 5.27	3.48 ± 4.96	3.97 ± 6.12
Non-1994	66	1.77 ± 1.19	1.85 ± 2.58	4.29 ± 5.49	4.23 ± 5.89	4.48 ± 7.13
1994	16	0.28 ± 0.19	0.44 ± 0.24	1.09 ± 0.67	1.80 ± 0.78	2.00 ± 0.89

[1] All = All 82 ponds combined, CON = Ponds receiving conventional management practices, RED = Ponds receiving density reduction treatments, FEED = Ponds receiving supplemental feed, Non-1994 = 1991, 1992, 1993, and 1995 observations, 1994 = 1994 observations

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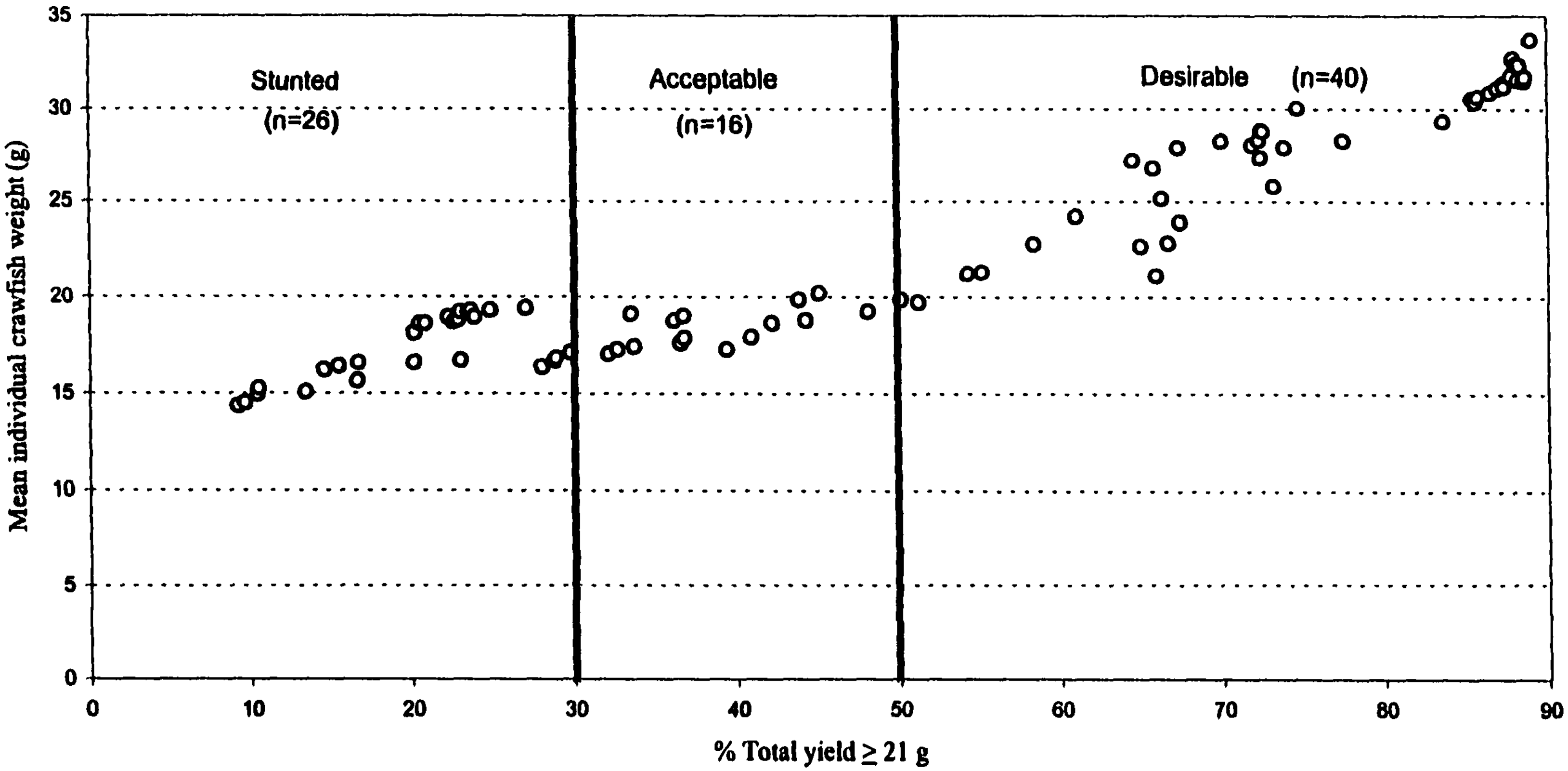

Figure 6. Assignment of "stunted", "acceptable", and "desirable" descriptors to crawfish populations based on size distribution at harvest (% total yield ≥ 21 g) for Rice Research Station crawfish studies (1991 to 1996).

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Table 6. Economic implications of different populations of crawfish based on size distribution at harvest for crawfish production studies (1991 to 1996). Rice Research Station, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Crowley, Louisiana.

			Mean Yield[1]	Size Distribution[2]			Estimated Gross Income[3]	Estimated Net Income[3]
Qualitative Grouping	% ≥ 21 g	N	(kg / ha)	% Large	% Medium	% Small	($ / ha)	($ / ha)
Stunted	9-29	26	828	2.9	17.1	80.0	653	-241
Acceptable	30-49	16	1,057	5.9	32.3	61.7	936	41
Desirable	50-89	40	1,038	41.6	33.0	25.4	1,408	513

[1] Mean yield for qualitative grouping

[2] % of total yield (kg/ha)

[3] See Appendix C

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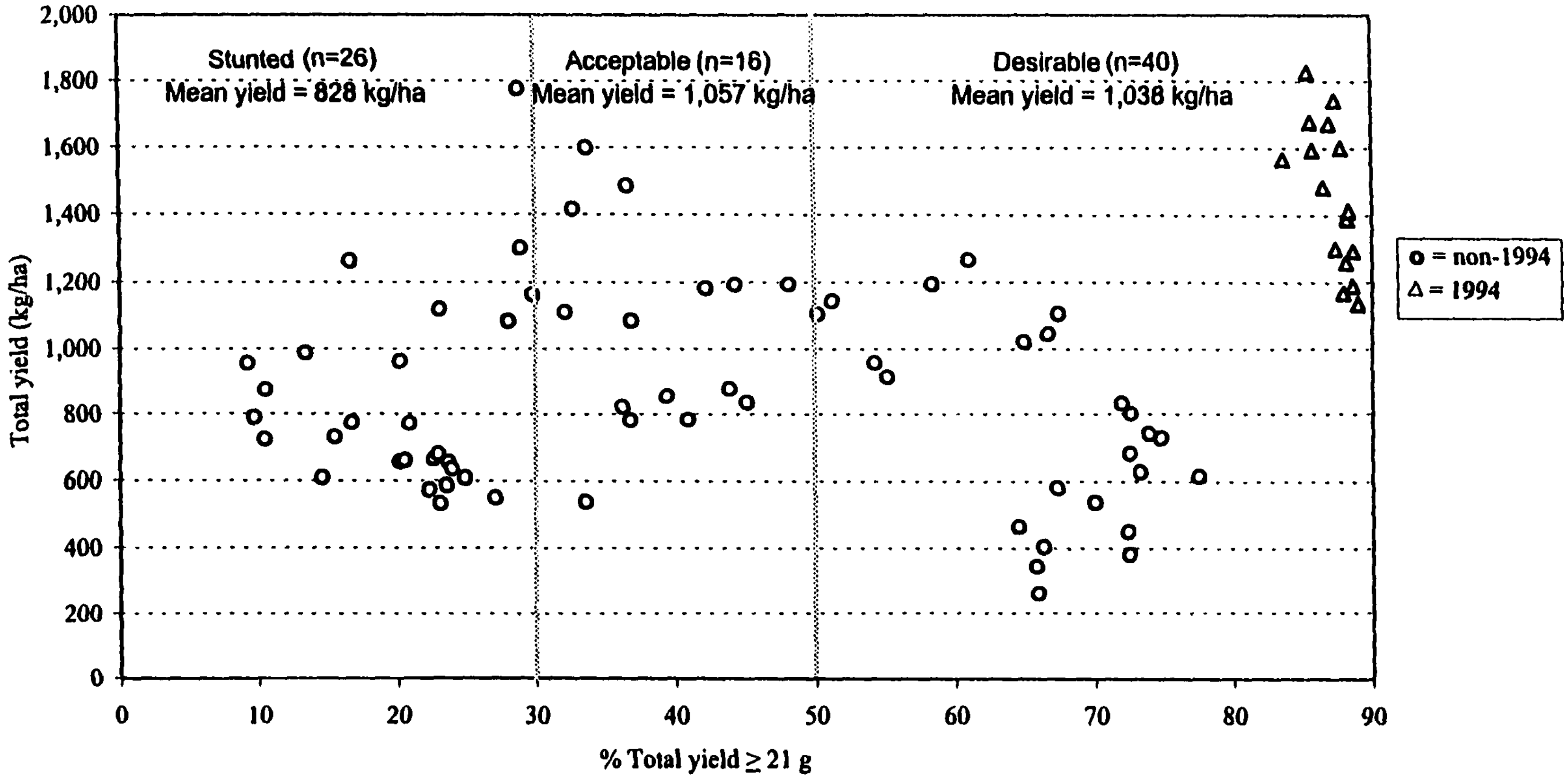

Figure 7. Crawfish yield (kg/ha) in ponds assigned as "stunted", "acceptable", and "desirable", Rice Research Station crawfish studies (1991 to 1996).

kg/ha. Ponds with desirable populations produced yields ranging from 263 to 1,827 kg/ha.

Stunted populations exhibited a primary peak of recruitment in October and November with a secondary peak in February (Table 7). Acceptable populations exhibited a similar recruitment pattern but with lower overall densities until late winter. Desirable populations had much lower relative densities for all months with highest recruitment in February and March peaking at 0.46 to 0.52 crawfish/DNS.

Relative density estimates for qualitative groupings of ponds based on mean monthly TT catches are presented in Table 8. Ponds which produced stunted populations had higher mean TT catch than acceptable or desirable populations during October through December.

Crawfish Standing Crop and Biomass Estimates

Identifying Stunted Populations

The 1994 season exhibited poor water quality during the critical first 17 weeks post-flood-up (Table 9). High water temperatures and high forage biomass led to low early morning dissolved oxygen and increased volume of water pumped to aerate ponds. The 1995 season was marked by low dissolved oxygen during the first 6 weeks post-flood-up and low temperatures during December, January, and February. Years 1991 to 1993 were similar in environmental conditions. Mean forage biomass for March of the 1994 crawfish production season (Ratoon Crop) was 282 g/m^2 while forage biomass in March of the 1995 crawfish production season (Main Crop) was only 21 g/m^2 (Table 10).

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Table 7. Mean (±SD) relative density estimates (crawfish/dip-net sweep) for Rice Research Station crawfish ponds grouped by % of total yield (kg/ha) ≥ 21 g.

Qualitative Grouping	% ≥ 21 g	N	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Stunted	9-29	26	1.10 ± 0.67	1.13 ± 0.99	0.87 ± 0.88	1.02 ± 1.17	1.15 ± 0.97	0.99 ± 0.74	0.46 ± 0.49	0.15 ± 0.23
Acceptable	30-49	16	0.97 ± 0.55	0.73 ± 0.34	0.71 ± 0.55	0.98 ± 0.67	1.29 ± 0.65	1.01 ± 0.24	0.48 ± 0.19	[1]
Desirable	50-89	40	0.39 ± 0.44	0.46 ± 0.58	0.45 ± 0.65	0.35 ± 0.56	0.47 ± 0.34	0.52 ± 0.36	0.24 ± 0.19	0.28 ± 0.23

[1] Missing cells represent no sampling during the time period

Table 8. Mean (±SD) relative density estimates (crawfish/trapset) for Rice Research Station crawfish ponds grouped by % of total yield (kg/ha) ≥ 21 g.

Qualitative Grouping	% ≥ 21 g	N	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Stunted	9-29	26	2.39 ± 0.97	2.64 ± 3.20	6.08 ± 7.12	4.96 ± 7.37	6.68 ± 9.15	[1]	[1]	[1]
Acceptable	30-49	16	1.35 ± 0.97	1.44 ± 0.96	4.11 ± 3.03	7.42 ± 5.57	[1]	[1]	[1]	[1]
Desirable	50-77	40	0.83 ± 1.14	0.93 ± 1.91	1.92 ± 3.27	1.51 ± 1.26	1.94 ± 1.03	[1]	[1]	[1]

[1] Missing cells represent no sampling during the time period

Table 9. Summary of selected mean environmental conditions after flood-up for crawfish studies (1991 to1996). Rice Research Station, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Crowley, Louisiana.

	Year				
Pond Conditions	1991	1992	1993	1994	1995
Mean Peak Forage Biomass (g/m^2)[1]	393.0	361.0	425.0	770.0	330.0
Morning Dissolved Oxygen (mg/L)[2]	6.1	6.8	6.9	2.8	5.8
Weekly Min Water Temp(°C)[2]	11.5	11.2	11.7	12.8	11.5
Water Pumped (million L)[3]	3.5	2.5	2.3	5.4	2.4
Flood-up Date	1 Oct	1 Oct	4 Oct	5 Oct	17 Oct

[1] Dry weight
[2] Mean for first 17 weeks post-flood-up
[3] Total for first 17 weeks post-flood-up

Table 10. Comparison of forage biomass values (g/m^2 dry weight) over time for 1994 and 1995 crawfish production seasons. Rice Research Station, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Crowley, Louisiana.

	1994	1995	
Month	Ratoon Crop[1]	Ratoon Crop	Main Crop[1]
November	770	524	137
December	680	506	146
January	587	515	85
February	442	435	44
March	282	208	21
April	81	107	11
May	0	0	0

[1] Density reduction treatments containing drop samplers

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Crawfish standing crop and biomass as determined by drop samplers is presented in Table 11 and Table 12, respectively. All ponds during 1991 to 1993 produced stunted populations except for the RED-TOX treatment in 1993. The 1995 season ponds showed similar recruitment patterns to the ponds of 1991 to 1993 but had much lower standing crops and crawfish biomass. The 1995 season ponds also produced stunted populations and lower yields in weight (kg/ha). Standing crop and biomass did not peak in the 1994 season ponds until April and May.

November standing crop estimates ranged from 13.89 to 19.33 crawfish/m^2 for 1991-1993 season ponds, 3.70 to 6.00 crawfish/m^2 for 1995 season ponds, and 0.71 to 1.36 crawfish/m^2 for 1994 season ponds. Biomass estimates for the 1995 and 1994 seasons were similar during the months of November through February but biomass was higher in the 1994 season ponds during March through May.

REGRESSION MODELS

Individual Sampling Gear

Dip-net Sweep Catch

A total of 18,730 dip-net sweeps were conducted for the 82 ponds in the study. Comparisons of regressions of yield in weight (kg/ha) with mean monthly DNS revealed that although the Pr>F values were significant for all months sampled, only April and May had R^2 values that were sufficiently high (≥ 0.25) to have acceptable predictive capability (Table 13). Although some YOY recruitment does occur during April and May, crawfish will likely not attain harvest size (75 mm TL, 10 to 15 g) before the ponds are drained in June. Dip-net sweep catches were highly correlated with yield in individuals (crawfish/ha) for all months except October.

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Table 11. Mean (±SD) standing crop estimates (crawfish/m^2) for Rice Research Station crawfish ponds (1991 to 1996) based on mean monthly drop sampler catch.

Treatment[1]	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Yield (kg/ha)
FEED	1991	6.33 ±7.07	14.90 ± 7.81	21.33 ± 6.87	16.50 ± 8.42	21.54 ± 8.69	18.63 ± 13.95	12.17 ± 7.90	13.00 ± 8.49	1,777*
CON	1992	19.50 ± 17.23	16.26 ± 12.01	12.71 ± 11.17	19.13 ± 8.68	14.75 ± 5.61	11.89 ± 6.06	13.28 ± 5.25	9.64 ± 4.16	774*
CON	1993	4.17 ± 6.38	19.33 ± 19.56	25.50 ± 14.39	20.67 ± 7.15	26.57 ± 9.61	28.23 ± 6.83	10.57 ± 7.35	11.38 ± 4.63	989*
RED-SMT	1993	6.16 ± 12.32	13.89 ± 16.66	14.86 ± 11.78	4.63 ± 5.71	15.00 ± 6.95	11.48 ± 5.78	7.87 ± 5.76	7.88 ± 5.73	957*
RED-TOX	1993	3.83 ± 6.17	14.94 ± 11.17	13.00 ± 7.92	12.76 ± 9.01	9.57 ± 7.44	3.26 ± 3.11	3.47 ± 3.02	4.13 ± 4.65	1,107
CON	1995	[2]	5.70 ± 5.09	7.17 ± 11.28	1.88 ± 5.32	6.22 ± 6.95	6.13 ± 6.99	5.67 ± 4.33	3.00 ± 2.70	635*
RED-DEC	1995	[2]	6.00 ± 12.87	4.17 ± 4.57	1.13 ± 2.18	3.34 ± 5.52	6.76 ± 5.82	4.67 ± 3.47	5.00 ± 7.04	665*
RED-JAN	1995	[2]	3.70 ± 9.95	1.33 ± 2.09	1.00 ±2.19	0.83 ± 1.91	0.93 ± 2.91	3.89 ±3.20	4.33 ± 5.11	573*
RED-FEB	1995	[2]	4.70 ± 6.00	7.00 ± 9.58	1.26 ± 2.39	1.77 ± 3.91	4.93 ± 5.73	5.78 ± 4.58	5.67 ± 4.71	608*
CON	1994	0	1.36 ± 2.64	2.00 ± 3.42	1.00 ± 1.85	1.59 ± 2.83	3.50 ± 4.54	6.00 ± 4.48	6.24 ± 3.66	1,302
RED-DEC	1994	0.29 ± 1.05	0.71 ± 1.45	0.71 ± 1.92	0.23 ± 0.86	0.25 ± 10.12	2.71 ± 3.47	2.96 ± 3.47	5.53 ± 2.62	1,261
RED-JAN	1994	0.14 ± 0.84	1.36 ± 3.59	1.23 ± 1.83	0.47 ± 1.37	0.50 ± 14.31	2.71 ± 2.99	5.82 ± 3.47	3.06 ± 2.41	1,169
RED-FEB	1994	0.29 ± 1.09	1.07 ± 2.36	1.00 ± 2.20	0.61 ± 1.77	1.40 ± 4.03	1.86 ± 3.00	4.61 ± 4.24	3.17 ± 2.46	1,138

[1] FEED = Supplemental feed, RED = Density reduction, TOX = Urea toxicity, CON = Conventional management practices, SMT = Small mesh trap, DEC = December drain, FEB = February drain, JAN = January drain

[2] Missing cells represent no sampling during the time period

* Stunted population

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Table 12. Mean (±SD) crawfish biomass estimates (g/m²) for Rice Research Station crawfish ponds (1991 to 1996) based on mean monthly drop sampler catch.

Treatment[1]	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Yield (kg/ha)
FEED	1991	4.6 ± 6.9	39.9 ±20.7	67.1 ± 27.9	84.8 ± 44.2	75.6 ± 30.8	57.4 ± 36.5	88.1 ± 35.7	193.2 ± 145.6	1,777*
CON	1992	18.5 ± 14.8	27.9 ± 18.6	28.0 ± 24.3	77.6 ± 32.7	64.0 ± 24.3	68.0 ± 34.6	92.7 ± 44.1	75.4 ± 32.5	774*
CON	1993	1.8 ± 3.2	41.4 ± 43.0	54.2 ± 30.8	59.4 ± 21.1	96.0 ± 59.0	100.0 ± 41.3	44.0 ± 30.6	57.1 ± 32.4	989*
RED-SMT	1993	7.6 ± 15.2	24.1 ± 28.9	37.1 ± 29.4	12.1 ± 16.3	45.1 ± 20.9	41.5 ± 20.9	45.9 ± 33.6	50.2 ± 36.5	957*
RED-TOX	1993	9.5 ± 16.4	20.6 ± 15.4	23.5 ± 19.8	25.0 ± 16.0	25.9 ± 21.0	25.2 ± 21.0	53.7 ± 46.8	54.3 ± 61.1	1,107
CON	1995	[2]	2.8 ± 2.7	8.8 ± 11.4	9.3 ± 25.3	19.8 ± 22.1	33.5 ± 37.8	40.0 ± 30.7	31.3 ± 28.5	635*
RED-DEC	1995	[2]	5.5 ± 11.8	4.2 ± 4.6	0.8 ± 1.5	11.5 ± 18.9	24.0 ± 18.9	37.2 ± 27.7	41.9 ± 59.0	665*
RED-JAN	1995	[2]	5.8 ± 15.6	1.4 ± 2.2	6.4 ± 14.9	1.8 ± 4.1	6.4 ± 16.9	37.6 ± 30.9	37.4 ± 26.2	573*
RED-FEB	1995	[2]	3.6 ± 4.6	4.1 ± 5.5	1.2 ± 2.1	11.2 ± 24.9	27.3 ± 39.2	39.9 ± 31.6	49.4 ± 41.0	608*
CON	1994	0	2.1 ± 4.8	3.5 ± 6.4	7.2 ± 13.4	8.5 ± 11.0	57.1 ± 73.9	129.8 ± 96.8	150.4 ± 87.4	1,302
RED-DEC	1994	1.4 ± 5.1	1.2 ± 2.5	2.4 ± 6.5	0.3 ± 1.2	1.2 ± 51.1	41.7 ± 51.1	63.1 ± 74.1	164.9 ± 77.7	1,261
RED-JAN	1994	0.4 ± 1.4	4.4 ± 11.6	2.9 ± 4.1	4.3 ± 10.3	1.7 ± 50.5	44.9 ± 50.5	129.5 ± 80.3	77.0 ± 60.1	1,169
RED-FEB	1994	0.4 ± 1.5	3.2 ± 7.1	3.0 ± 7.0	4.6 ± 12.6	13.4 ± 38.6	27.4 ± 38.6	108.6 ± 99.9	91.7 ± 71.3	1,138

[1] FEED = Supplemental feed, RED = Density reduction, TOX = Urea toxicity, CON = Conventional management practices, SMT = Small mesh trap, DEC = December drain, FEB = February drain, JAN = January drain

[2] Missing cells represent no sampling during the time period

* Stunted population

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Table 13. Level of statistical significance (Pr>F) and multiple coefficient of determination (R^2) for the multiple linear regression of crawfish yield and size distribution at harvest on mean monthly dip-net sweeps (no/sweep).

		Yield				Size Distribution[1]			
		kg/ha		no/ha		% ≥ 32 g		% ≥ 21 g	
Month	N	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2
October	58	0.0039*	0.2179	0.1153	0.1030	**0.0001***	**0.7870**	**0.0001***	**0.5913**
November	82	0.0261*	0.1112	**0.0001***	**0.4240**	**0.0001***	**0.2892**	**0.0001***	**0.2888**
December	82	0.0261*	0.1112	**0.0001***	**0.4267**	0.0001*	0.2226	0.0003*	0.1759
January	82	0.0112*	0.1317	**0.0001***	**0.3867**	**0.0001***	**0.2560**	0.0001*	0.2449
February	82	0.0174*	0.1212	**0.0001***	**0.4312**	**0.0001***	**0.3652**	**0.0001***	**0.3546**
March	82	0.0001*	0.2483	**0.0001***	**0.3884**	**0.0001***	**0.4689**	**0.0001***	**0.3578**
April	82	**0.0001***	**0.2542**	**0.0001***	**0.4886**	0.0001*	0.2387	0.0001*	0.1509
May	52	**0.0001***	**0.6917**	**0.0001***	**0.6316**	**0.0001***	**0.5676**	**0.0001***	**0.4650**

[1] % of total yield (kg/ha)

* Pr>F ≤ 0.05

Bold = Pr>F < 0.05 and R^2 > 0.25

The strongest correlations between DNS and the percentage of crawfish harvested (kg/ha) ≥ 32 g occurred during the months of October, November, February, and March (Table 13). January also met the established criteria for use in the predictive model. Monthly correlations between DNS and the percentage of crawfish harvested (kg/ha) ≥ 21 g exhibited similar coefficients to the percentage of crawfish harvested (kg/ha) ≥ 32 g, however R^2 values were slightly lower for % ≥ 21 g.

Test Trap Catch

A total of 10,230 test trapsets were conducted for the 82 ponds. Monthly comparisons of test trap catch to yield in weight (kg/ha) revealed that February was the only monthly mean with a sufficiently high R^2 to have predictive capability (Table 14). Test trap catch was positively correlated to yield of individuals (crawfish/ha) during all months sampled except October. During December, January, and February, the regressions of test trap catch with yield of individuals (crawfish/ha) had higher R^2 values (Table 14) than did comparisons of DNS to yield (crawfish/ha) during the same months (Table 13). Monthly comparisons indicated that R^2 values increased as the season progressed.

The regressions of test trap catch to the percentage of crawfish harvested (kg/ha) ≥ 32 g and ≥ 21 g revealed a potential predictive capability for October and February (Table 14). R^2 values for these models decreased as the season progressed except for a rise in February. This trend in R^2 values (decreasing with time) was the reverse of the trend for test trap catch comparisons to yield of individuals (increasing with time).

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Table 14. Level of statistical significance (Pr>F) and multiple coefficient of determination (R^2) for the multiple linear regression of crawfish yield and size distribution at harvest on mean monthly test trap catch (no/trapset).

		Yield				Size Distribution[1]			
		kg/ha		no/ha		% ≥ 32 g		% ≥ 21 g	
Month[2]	N	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2
October	59	0.0019*	0.2355	0.0814	0.1140	**0.0001***	**0.7639**	**0.0001***	**0.5874**
November	82	0.0369*	0.1025	**0.0001***	**0.3949**	0.0001*	0.2435	0.0003*	0.2112
December	82	0.0147*	0.1253	**0.0001***	**0.4714**	0.0001*	0.2310	0.0005*	0.2024
January	82	0.0016*	0.1763	**0.0001***	**0.5045**	0.0004*	0.2085	0.0103*	0.1340
February	51	**0.0007***	**0.2998**	**0.0001***	**0.6832**	**0.0012***	**0.2832**	**0.0005***	**0.3122**

[1] % of total yield (kg/ha)

[2] March, April, and May were not reflected in table because sustained harvesting began at that time.

* Pr>F ≤ 0.05

Bold = Pr>F < 0.05 and R^2 > 0.25

Drop Sampler Catch (Density)

The numbers of crawfish captured in morning drop samplers was not significantly different from afternoon values (monthly Pr>F values ranged from 0.1464 to 0.5477) (Table 15), thus the values were pooled and the pooled data set was used to generate monthly averages of crawfish density for each pond.

The number of crawfish caught with a drop sampler was positively correlated to yield in weight (kg/ha) during all months except May and yield in individuals (crawfish/ha) during all months (Table 16). The numbers of crawfish caught with a drop sampler was positively correlated to size at harvest (% $\geq$ 32g) during all months except January, April and May (Table 16). The numbers of crawfish caught with a drop sampler was positively correlated to size at harvest (% $\geq$ 21 g) only during October and November.

Drop Sampler Catch (Biomass)

The biomass of crawfish captured in morning drop samplers was not significantly different from afternoon values (monthly Pr>F values ranged from 0.3853 to 0.9136) (Table 17) so the values were pooled and the pooled data set was used to generate monthly averages for each pond.

The biomass ($g/0.5m^2$) of crawfish caught with a drop sampler was positively correlated to yield (kg/ha) during all months except October and March (Table 18). The biomass of crawfish caught with a drop sampler was significantly correlated to yield of individuals (crawfish/ha) during all months (Table 18). Crawfish biomass from drop sampler catches was positively correlated to size distribution at harvest (% $\geq$ 32 g and % $\geq$ 21 g) for November, February, April, and May.

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Table 15. Results of the analysis of variance (ANOVA) comparison of morning drop sampler catch (no/0.5m^2) with afternoon drop sampler catch (no/0.5m^2).

Month	N	Pr>F	Mean (no) ± SD	
			Morning	Afternoon
October	100	0.5587	1.94 ± 4.09	1.50 ± 3.37
November	266	0.1786	3.46 ± 4.42	2.77 ± 3.94
December	168	0.1640	4.05 ± 5.17	3.04 ± 4.28
January	230	0.1464	2.80 ± 4.81	2.03 ± 3.05
February	228	0.2876	3.50 ± 4.98	2.84 ± 4.33
March	236	0.3018	3.46 ± 4.65	2.92 ± 3.28
April	212	0.5477	3.06 ± 2.43	2.87 ± 2.35
May	146	0.4142	3.08 ± 2.44	2.78 ± 1.97

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Table 16. Level of statistical significance (Pr>F)and multiple coefficient of determination (R^2) for the multiple linear regression of crawfish yield and size distribution at harvest on mean monthly drop sampler catch (no/0.5m²).

		Yield				Size Distribution[1]			
		kg/ha		no/ha		% ≥ 32 g		% ≥ 21 g	
Month	N	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2
October	9	**0.0013***	**0.9461**	**0.0032***	**0.9237**	**0.0021***	**0.9357**	**0.0102***	**0.8776**
November	13	**0.0034***	**0.7663**	**0.0054***	**0.7391**	**0.0033***	**0.7666**	**0.0085***	**0.7110**
December	13	**0.0112***	**0.6916**	**0.0015***	**0.8067**	**0.0188***	**0.6527**	**0.0264***	**0.6238**
January	13	**0.0111***	**0.6925**	**0.0070***	**0.7235**	0.1449	0.4350	0.2290	0.3666
February	13	**0.0074***	**0.7197**	**0.0020***	**0.7920**	**0.0173***	**0.6590**	**0.0127***	**0.6827**
March	13	**0.0456***	**0.5723**	**0.0016***	**0.8023**	**0.0358***	**0.5961**	**0.0183***	**0.6545**
April	13	**0.0146***	**0.6723**	**0.0019***	**0.7936**	0.2119	0.3789	0.1401	0.4396
May	13	0.0784	0.5133	**0.0004***	**0.8587**	0.2110	0.3796	0.1783	0.4052

[1] % of total yield (kg/ha)

* Pr>F ≤ 0.05

Bold = Pr>F < 0.05 and R^2 > 0.25

Table 17. Results of the analysis of variance (ANOVA) comparison of morning drop sampler catch (g/0.5m^2) with afternoon drop sampler catch (g/0.5m^2).

Month	N	Pr>F	Mean (g) ± SD	
			Morning	Afternoon
October	100	0.9060	2.09 ± 4.84	1.96 ± 5.48
November	266	0.6951	5.16 ± 8.78	4.68 ± 11.02
December	168	0.9136	7.18 ± 11.03	6.99 ± 11.30
January	230	0.8201	7.57 ± 14.18	7.98 ± 12.87
February	228	0.3853	10.52 ± 16.83	12.60 ± 19.30
March	236	0.8121	21.56 ± 23.18	22.31 ± 25.51
April	212	0.5241	38.83 ± 36.74	35.65 ± 35.75
May	146	0.3640	37.99 ± 31.65	43.30 ± 38.43

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Table 18. Level of statistical significance (Pr>F) and multiple coefficient of determination (R^2) for the multiple linear regression of crawfish yield and size distribution at harvest on mean monthly drop sampler catch ($g/0.5m^2$).

		Yield				Size Distribution[1]			
		kg/ha		no/ha		% ≥ 32 g		% ≥ 21g	
Month	N	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2
October	9	0.0922	0.6953	**0.0009***	**0.9534**	0.0704	0.7282	0.1896	0.5846
November	13	**0.0021***	**0.7908**	**0.0010***	**0.8214**	**0.0297***	**0.6134**	**0.0222***	**0.6388**
December	13	**0.0066***	**0.7268**	**0.0001***	**0.9429**	**0.0521**	**0.5586**	0.3840	0.5894
January	13	**0.0178***	**0.6567**	**0.0069***	**0.7240**	0.1593	0.4216	0.1962	0.3908
February	13	**0.0071***	**0.7222**	**0.0041***	**0.7553**	**0.0281***	**0.6182**	**0.0152***	**0.6694**
March	13	0.0718	0.5234	**0.0071***	**0.7226**	0.5277	0.2091	0.5478	0.2006
April	13	**0.0291**	**0.6151**	**0.0014***	**0.8089**	**0.0077***	**0.7176**	**0.0120***	**0.6868**
May	13	**0.0008**	**0.8289**	**0.0002***	**0.8773**	**0.0028***	**0.7761**	**0.0082***	**0.7131**

[1] % of total yield (kg/ha)

* Pr>F ≤ 0.05

Bold = Pr>F < 0.05 and R^2 > 0.25

Sampling Gear Combinations

Dip-net Sweeps and Test Traps

Mean monthly dip-net sweep counts and test trap catch from the same pond regressed with the corresponding yield in weight (kg/ha) resulted in a predictive model with only for the month of October (Table 19). The trend of the coefficients were very similar to the coefficients of the two sampling gear when evaluated separately.

The combined sampling techniques of dip-net sweeps and test traps were significantly correlated to yield in individuals (crawfish/ha) during November, December, January, and February (Table 19). The trend of increasing R^2 values as the season progressed followed the same trend as the test trap method when used alone. The combination of dip-net sweeps and test traps in the same pond met the dual criteria of $Pr>F < 0.05$ and $R^2 \geq 0.25$ for size distribution at harvest (% $\geq$ 32 g and % $\geq$ 21 g) during October, November, January, and February (Table 19).

Dip-net Sweeps, Test Traps, and Drop Sampler (no/0.5m^2)

The combined sampling techniques of dip-net sweeps, test traps and number of crawfish caught with drop samplers was positively correlated to total yield in weight (kg/ha) and yield in individuals (crawfish/ha), during all months (Table 20). The combination of the three gear was positively correlated to size distribution at harvest (% $\geq$ 32 g and % $\geq$ 21g) during October, November, and February (Table 20).

Comparison of Individual Sampling Gear

Dip-net Sweeps and Test Traps

Mean monthly dip-net sweep count was compared to the mean number of crawfish caught by test traps for the corresponding month (Table 21). The monthly

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Table 19. Level of statistical significance (Pr>F) and multiple coefficient of determination (R^2) for the multiple linear regression of crawfish yield and size distribution at harvest on mean monthly dip-net sweeps and test trap catch.

		Yield				Size Distribution[1]			
		kg/ha		no/ha		% ≥ 32 g		% ≥ 21 g	
Month	N	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2	Pr>F	R^2
October	58	**0.0026***	**0.2903**	0.2530	0.1159	**0.0001***	**0.8666**	**0.0001***	**0.7251**
November	82	0.0957	0.1138	**0.0001***	**0.4251**	**0.0001***	**0.2907**	**0.0001***	**0.2972**
December	82	0.0283*	0.1492	**0.0001***	**0.4925**	0.0008*	0.2374	0.0018*	0.2191
January	82	0.0014*	0.2254	**0.0001***	**0.5297**	**0.0002***	**0.2696**	**0.0001***	**0.2843**
February	51	0.0010*	0.2459	**0.0001***	**0.6211**	**0.0003***	**0.2899**	**0.0001***	**0.2762**

[1] % of total yield (kg/ha)

* = Pr>F ≤ 0.05, **Bold** = Pr>F ≤ 0.05 and $r^2 \geq 0.25$

Table 20. Level of statistical significance (Pr>F) and coefficient of determination (r^2) for the simple linear regression of crawfish yield and size distribution at harvest with mean monthly dip-net sweep, test trap and drop samplers counts.

		Yield				Size Distribution[1]			
		kg/ha		no/ha		% ≥ 32 g		% ≥ 21 g	
Month	N	Pr>F	r^2	Pr>F	r^2	Pr>F	r^2	Pr>F	r^2
October	9	**0.0084***	**0.9462**	**0.0005***	**0.9866**	**0.0001***	**0.9967**	**0.0002***	**0.9929**
November	13	**0.0071***	**0.7974**	**0.0001***	**0.9570**	**0.0010***	**0.8780**	**0.0043***	**0.8221**
December	13	**0.0108***	**0.7731**	**0.0001***	**0.9482**	0.0798	0.6097	0.0982	0.5860
January	13	**0.0042***	**0.8228**	**0.0118***	**0.7681**	0.3562	0.3890	0.2844	0.4317
February	11	**0.0041***	**0.8967**	**0.0002***	**0.9620**	**0.0041***	**0.8966**	**0.0009***	**0.9383**

[1] % of total yield (kg/ha)

* = Pr>F ≤ 0.05, **Bold** = Pr>F ≤ 0.05 and $r^2 \geq 0.25$

Table 21. Simple linear regression models for the comparisons of three crawfish sampling gears (dip-nets, test traps, and drop samplers).

	Number / Dip-net Sweep (y) to Number / Test Trap (x)				
Month	N	Pr>F	r^2	Intercept	Number / Trap
October	58	0.0001*	0.2334	0.3837	0.2437
November	82	**0.0001***	**0.3042**	0.4468	0.1750
December	82	**0.0001***	**0.4059**	0.2937	0.0917
January	82	0.0001*	0.1772	0.4284	0.0684
February	51	**0.0001***	**0.7378**	0.2693	0.1002

	Number / Drop Sampler (y) to Number / Test Trap (x)				
Month	N	Pr>F	r^2	Intercept	Number / Trap
October	9	0.1351	0.2896	0.4961	1.1192
November	13	**0.0001***	**0.7450**	1.8886	0.7076
December	13	**0.0003***	**0.7042**	1.4676	0.5660
January	13	**0.0002***	**0.7346**	0.7405	0.4177
February	13	**0.0001***	**0.9016**	0.3545	0.4108

	Number / Drop Sampler (y) to Number / Dip-net Sweep (x)				
Month	N	Pr>F	r^2	Intercept	Number / Dip
October	9	0.1064	0.3289	0.4593	3.5100
November	13	**0.0009***	**0.6477**	0.7584	4.2806
December	13	**0.0010***	**0.6439**	1.5235	4.3815
January	13	**0.0012***	**0.6295**	0.9254	2.6027
February	11	**0.0001***	**0.9393**	-0.4599	4.4457

* Pr>F $\leq$ 0.05

Bold = Pr>F < 0.05 and r^2 > 0.25

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comparisons revealed Pr>F values = 0.0001 for all months and r^2 values ranged from 0.1772 to 0.7378. Dip-net sweep catch and test trap catch had r^2 values $\geq$ 25% during November, December, and February (Table 21). The ratio of number of crawfish/sweep to number of crawfish/trapset decreased from November to December but there was very little difference between December and February (Figure 8). Based on the regression models, for each crawfish caught with a test trap 0.62 crawfish were caught on average in a dip-net sweep in November, 0.37 crawfish in December, and 0.38 crawfish in February.

Drop Samplers and Test Traps

Drop sampler catch and test trap was positively correlated during all months sampled except October (Table 21). The ratio of number of crawfish/DRPS to number of crawfish/trapset decreased as the season progressed (Figure 9). Based on the regression models, for each crawfish caught with a test trap 2.60 crawfish were caught on average in a drop sampler in November, 2.03 crawfish in December, 1.16 crawfish in January, and 0.77 crawfish in February.

Drop Samplers and Dip-net Sweeps

Drop sampler catch and dip-net sweep catch was positively correlated during all months except October (Table 21). The ratio of number of crawfish/DRPS to crawfish/DNS did not vary considerably over the 4 months sampled (Figure 10). The slopes of the regression lines are similar for November, December, and February (4.28, 4.38, and 4.45, respectively). Based on these regression models, for each crawfish caught with a dip-net sweep 5.04 crawfish were caught on average in a drop sampler in

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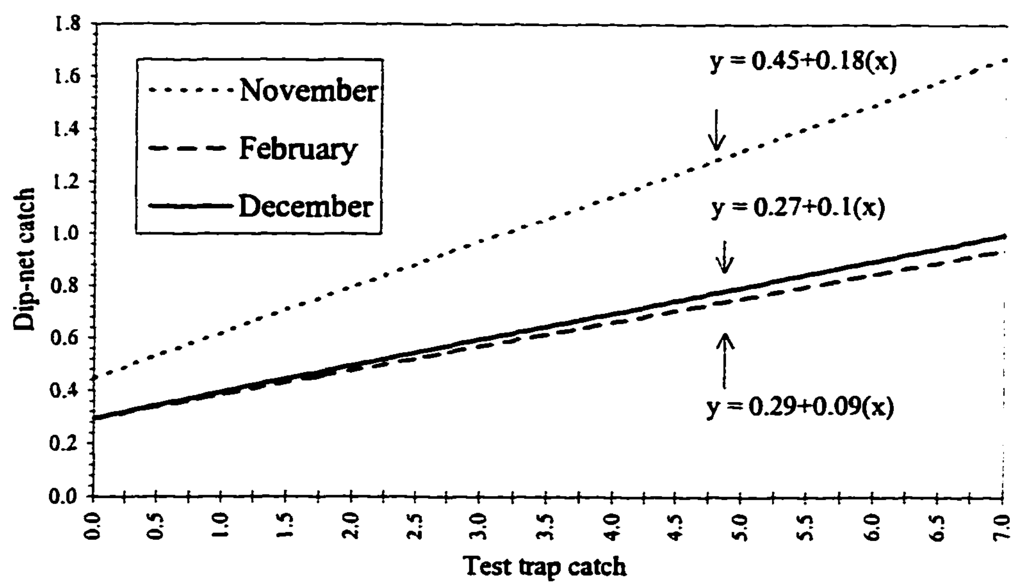

Figure 8. Simple linear regression of dip-net sweep catch (y) on test trap catch (x) for November, December and February.

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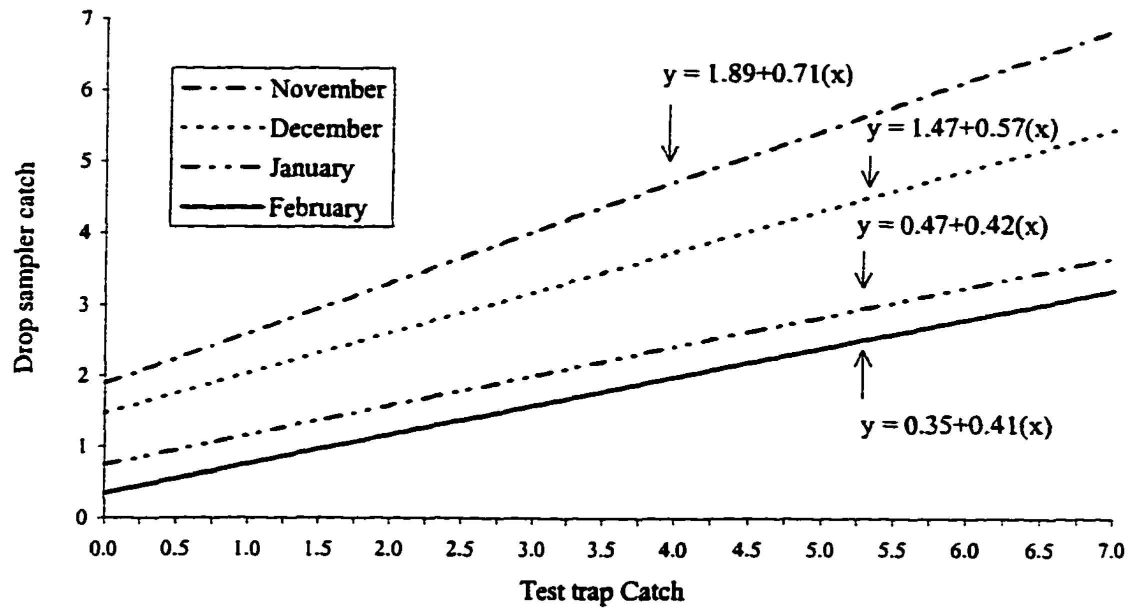

Figure 9. Simple linear regression of drop sampler catch (y) on test trap catch (x) for November to February.

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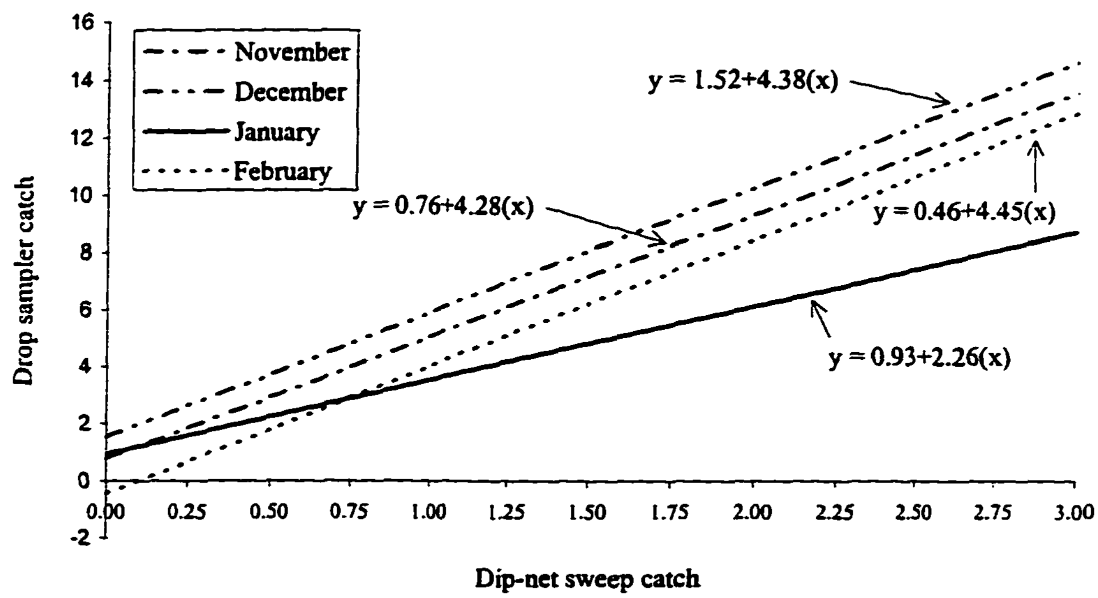

Figure 10. Simple linear regression of drop sampler catch (y) on dip-net sweep catch (x) for November to February.

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November, 5.90 crawfish in December, 3.53 crawfish in January, and 3.99 crawfish in February.

PREDICTIVE MODELS

Validation

Iteration 2 was chosen for cross validation of the dip-net sweep model and the test trap model based on the similarity of coefficients. The comparison of observed monthly means (for the validation data set) and predicted monthly means (as derived from the model building set) is presented in Table 22. There were no regression models for comparing DNS to yield in weight (kg/ha) that met the dual requirements of Pr>F $\leq$ 0.05 and R^2 values $\geq$ 0.25. Differences between the predicted mean number of crawfish harvested/ha and the observed mean ranged from -5.08% to -7.24%. Size distribution at harvest regression tended to over estimate crawfish in both categories (% $\geq$ 32 g and % $\geq$ 21 g).

Results of the test trap model cross validation is presented in Table 23. February was the only month in which the regression model had practical utility for prediction of yield in weight (kg/ha) by test trap catch. Predicted means for number of crawfish harvested/ha with test traps were similar to the means for number of crawfish harvested/ha as predicted by dip-net sweeps. Differences between the predicted mean % $\geq$ 32 g ranged from 8.18% to 16.27%. Predicted means for % $\geq$ 21 g were higher than actual means by 10.30 to 16.71%.

Predictions of Yield and Size Distribution

The linear coefficients, range of observed values, and median year information for the prediction models are presented in Appendix D.

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Table 22. Cross validation of model to predict crawfish yield and size distribution at harvest from mean monthly dip-net sweeps.

		Yield						Size Distribution[1]					
		kg/ha			no/ha			% ≥ 32 g			% ≥ 21 g		
Month	N	Observed (Mean)	Predicted (Mean)	Difference (%)	Observed (Mean)	Predicted (Mean)	Difference (%)	Observed (Mean)	Predicted (Mean)	Difference (%)	Observed (Mean)	Predicted (Mean)	Difference (%)
Oct	19	*	*	*	*	*	*	25.59	28.48	11.27	52.43	57.33	9.34
Nov	28	*	*	*	45,398	42,231	-6.98	22.19	27.81	25.37	47.86	57.61	20.38
Dec	28	*	*	*	45,398	43,106	-5.05	22.19	23.95	7.96	*	*	*
Jan	28	*	*	*	45,398	43,045	-5.18	22.19	24.30	9.54	47.86	52.87	10.47
Feb	28	*	*	*	45,398	42,110	-7.24	22.19	25.11	13.20	47.86	54.52	13.93

[1] % of total yield (kg/ha)

* Regression did not meet Pr>F and R^2 criteria for significance

Table 23. Cross validation of model to predict crawfish yield and size distribution at harvest from mean monthly test trap catch.

		Yield						Size Distribution[1]					
		kg/ha			no/ha			% ≥ 32 g			% ≥ 21 g		
Month	N	Observed (Mean)	Predicted (Mean)	Difference (%)	Observed (Mean)	Predicted (Mean)	Difference (%)	Observed (Mean)	Predicted (Mean)	Difference (%)	Observed (Mean)	Predicted (Mean)	Difference (%)
Oct	20	*	*	*	*	*	*	24.49	28.43	16.09	50.85	56.09	10.30
Nov	28	*	*	*	45,398	42,598	-6.17	22.19	25.26	13.87	47.86	54.60	14.09
Dec	28	*	*	*	45,398	42,444	-6.51	22.19	25.79	16.27	47.86	55.86	16.71
Jan	28	*	*	*	45,398	42,053	-7.37	22.19	25.54	15.11	*	*	*
Feb	18	985	955	-2.97	40,926	38,346	-6.30	30.47	32.97	8.18	53.73	60.09	11.83

[1] % of total yield (kg/ha)

* Regression did not meet Pr>F and R^2 criteria for significance

Dip-net Sweep Model

There were no significant regressions for yield in weight (kg/ha) using dip-net data in the prediction model. The model was not able to predict a range of yield in individuals (crawfish/ha) similar to the observed range; however, the range of predicted values did exhibit an increase in yield with an increase in no/sweep (Table 24). November dip-net sweeps predicted a range of 43,099 to 53,745 crawfish/ha.

The percentage of total yield in the size categories ≥ 32 g or ≥ 21 g decreased with increasing crawfish/DNS. A change from 0.25/DNS to 1.0/DNS in November decreased the % ≥ 32 g from 28% to 15%. A November DNS of 0.5 predicted a size distribution of 53% ≥ 21 g. A November DNS of 1.5 predicted a harvest size distribution of only 30% ≥ 21 g.

A comparison of the observed percent of total yield ≥ 21 g and the predicted percent of total yield ≥ 21 g based on the November dip-net sweep regression is given in Figure 11. The November regression overestimated percent of total yield ≥ 21 g for ponds with less than 30% of total yield ≥ 21 g and underestimated percent of total yield ≥ 21 g for ponds with more than 60% of total yield ≥ 21 g. The mean percent deviation of predicted to observed values for this model was 32% with a minimum of -75% and a maximum of 211%.

Test Trap Catch Model

Test trap catch was not a good predictor of yield in weight (kg/ha) directly because many regression models were not statistically significant. November test traps predicted increasing yield of individuals (crawfish/ha) with increasing no/trapset (Table 25). October test trap catch revealed a decreasing size at harvest with increasing catch.

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Table 24. Predicted crawfish yields and size distribution at harvest based on mean monthly dip-net sweeps (no/sweep).[1]

		Yield (no/ha)			
No/Sweep	Oct	Nov	Dec	Jan	Feb
0.25	*	43,099	44,073	45,657	42,224
0.50	*	45,684	48,081	46,151	44,001
0.75	*	47,945	51,199	46,623	45,733
1.00	*	49,883	53,427	47,072	47,420
1.50	*	52,789	55,212	47,904	50,660
2.00	*	54,401	53,437	48,647	53,721
2.50	[2]	54,720	48,101	49,301	56,603
3.00	[2]	53,745	39,205	49,866	59,306

		Size Distribution (% ≥ 32 g)			
No/Sweep	Oct	Nov	Dec	Jan	Feb
0.25	34	28	*	25	35
0.50	27	23	*	22	27
0.75	21	19	*	20	20
1.00	16	15	*	18	14
1.50	9	10	*	13	6
2.00	6	6	*	10	1
2.50	[2]	4	*	7	0
3.00	[2]	4	*	6	3

		Size Distribution (% ≥ 21 g)			
No/Sweep	Oct	Nov	Dec	Jan	Feb
0.25	66	60	*	*	69
0.50	56	53	*	*	58
0.75	47	46	*	*	49
1.00	40	40	*	*	41
1.50	30	30	*	*	28
2.00	24	23	*	*	20
2.50	[2]	19	*	*	16
3.00	[2]	18	*	*	17

[1] Regressions for yield (kg/ha) did not meet Pr>F and R^2 criteria for significance
[2] The associated no/sweep was outside the range of observed values
* Regression did not meet Pr>F and R^2 criteria for significance

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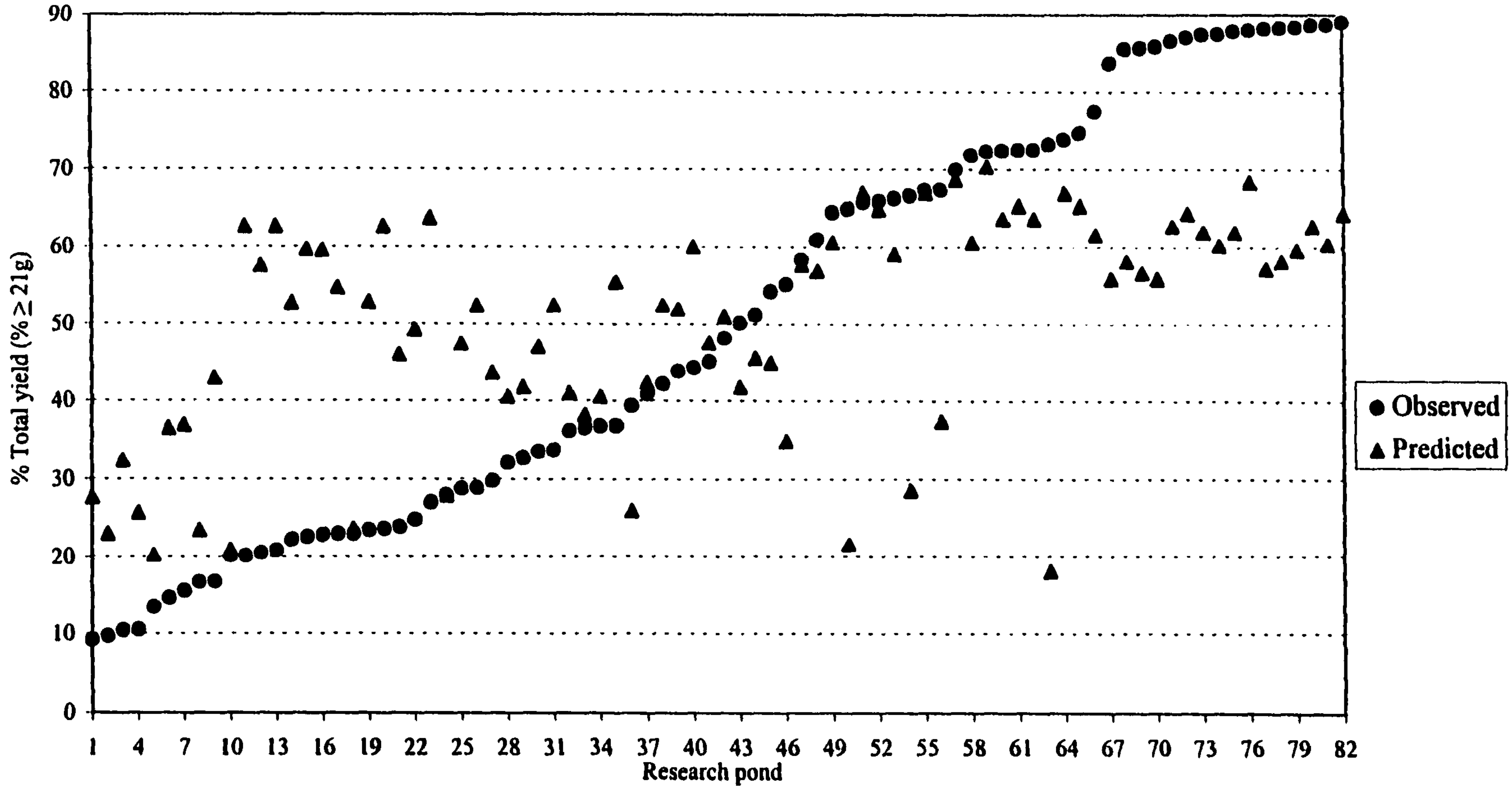

Figure 11. Comparison of observed size distribution at harvest (% $\geq$ 21g) with predicted size distribution at harvest (% $\geq$ 21g) based on November mean monthly dip-net sweep catch.

Table 25. Predicted crawfish yields and size distribution at harvest based on mean monthly test trap catch (no/trapset).[1]

		Yield (no/ha)			
No/Trapset	Oct	Nov	Dec	Jan	Feb
0.5	*	45,188	40,753	41,191	45,163
1.0	*	46,051	42,358	43,169	47,168
4.0	*	49,930	50,479	53,474	57,845
7.0	[2]	51,577	56,008	61,097	66,200
11.0	[2]	50,301	59,348	67,089	73,728
15.0	[2]	[2]	58,080	68,313	77,128
19.0	[2]	[2]	52,204	64,769	76,400
23.0	[2]	[2]	41,720	56,457	71,544

		Size Distribution (% $\geq$ 32 g)			
No/Trapset	Oct	Nov	Dec	Jan	Feb
0.5	32	*	*	*	64
1.0	25	*	*	*	60
4.0	7	*	*	*	36
7.0	[2]	*	*	*	17
11.0	[2]	*	*	*	-2
15.0	[2]	*	*	*	-13
19.0	[2]	*	*	*	-17
23.0	[2]	*	*	*	-13

		Size Distribution (% $\geq$ 21 g)			
No/Trapset	Oct	Nov	Dec	Jan	Feb
0.5	63	*	*	*	93
1.0	53	*	*	*	88
4.0	29	*	*	*	59
7.0	[2]	*	*	*	36
11.0	[2]	*	*	*	12
15.0	[2]	*	*	*	-2
19.0	[2]	*	*	*	-8
23.0	[2]	*	*	*	-5

[1] Regressions for yield (kg/ha) did not meet Pr>F and R^2 criteria for significance
[2] The associated no/sweep was outside the range of observed values
* Regression did not meet Pr>F and R^2 criteria for significance

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An October test trap catch of 1 crawfish/trapset predicted a size distribution at harvest of 25% $\geq$ 32 g and 53% $\geq$ 21 g. A test trap catch of 4 crawfish/trapset in October would indicate a potential of harvesting only 29% of total yield in kg/ha $\geq$ 21 g.

A comparison of the observed percent of total yield $\geq$ 21 g and the predicted percent of total yield $\geq$ 21 g based on the October test trap regression is given in Figure 12. The October regression overestimated percent of total yield $\geq$ 21 g for ponds with less than 30% of total yield $\geq$ 21 g and underestimated percent of total yield $\geq$ 21 g for ponds with more than 40% of total yield $\geq$ 21 g. The mean percent deviation of predicted from observed values for this model was 31% with a minimum of -54% and a maximum of 347%.

Models for Predicting Yield (kg/ha)

Neither dip-net sweeps nor test trap catch were a good predictor of yield in weight (kg/ha) per hectare directly when all five years were included in the study. Two alternative methods were used to predict yields in weight (kg/ha).

The first method regressed either no/sweep or no/trapset on total yield (kg/ha) using equation 1 but did not include the 1994 data. The statistical significance, range of observed values, median year values and the linear coefficients for prediction models based on non-1994 monthly dip-net sweeps and test trap catch are given in Table 26. By excluding the 1994 data, November to February dip-net sweeps and test trap catch regressions with yield in weight (kg/ha) were able to meet the dual requirements of Pr>F and R^2 established earlier. Using this method, November dip-net sweeps of 0.25 to 3 crawfish predicted a very narrow range of yield in weight (838 kg/ha to 995 kg/ha) (Table 27). However, December dip-net projections predicted a trend of increasing

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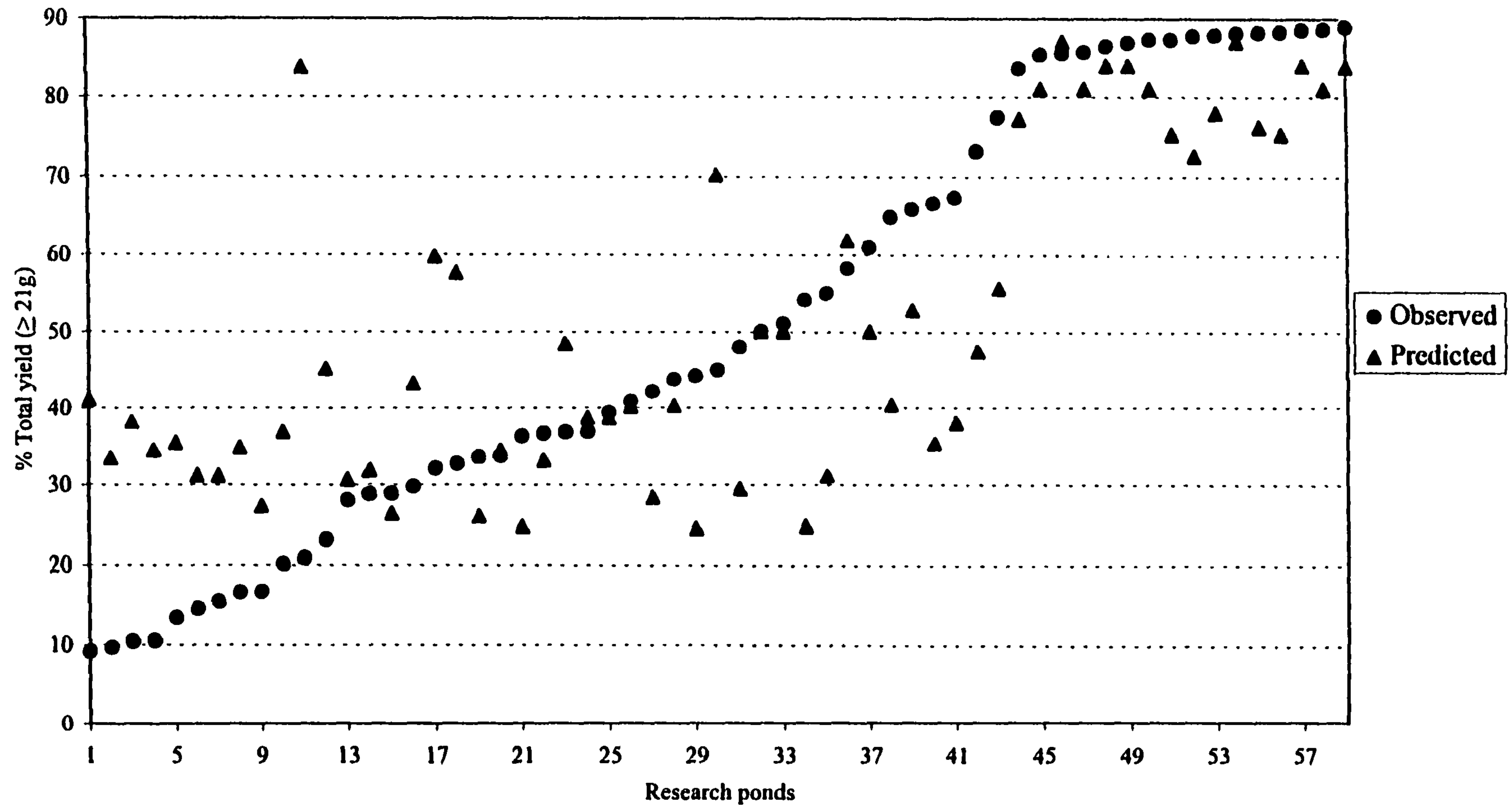

Figure 12. Comparison of observed size distribution at harvest (% ≥ 21g) with predicted size distribution at harvest (% ≥ 21g) based on October mean monthly test trap catch.

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Table 26. Statistical significance, min-max of observed values, and regression coefficients for the non-1994 dip-net sweep and non-1994 test trap predictive model equations. (Model: $Y = \beta_0 + \beta_1(X) + \beta_2(X^2) + \beta_3(M.Y.)$)

Gear[1]	Independent Variable (X)	Dependent Variable (Y)	Month[2]	Pr>F	R^2	N	Min-Max of X	M.Y.[3]	Regression Coefficients β_0	β_1	β_2	β_3
DNS	no/sweep	kg/ha	Nov	0.0001	0.3301	66	0 - 4.6	2.75	1021.0	205.1	-51.2	-84.0
DNS	no/sweep	kg/ha	Dec	0.0001	0.3799	66	0 - 3.0	2.75	869.9	474.9	-167.3	-54.0
DNS	no/sweep	kg/ha	Jan	0.0001	0.3022	66	0 - 4.2	2.75	1077.0	116.8	-30.3	-85.2
DNS	no/sweep	kg/ha	Feb	0.0001	0.3992	66	0.1 - 3.8	2.75	856.1	341.4	-68.4	-71.5
TT	no/trapset	kg/ha	Nov	0.0001	0.4393	66	0 - 11.7	2.75	1204.3	8.3	-0.4	-120.1
TT	no/trapset	kg/ha	Dec	0.0001	0.5105	66	0 - 24.0	2.75	1034.6	48.0	-2.3	-92.2
TT	no/trapset	kg/ha	Jan	0.0001	0.5088	66	0.1 - 27.0	2.75	980.8	50.6	-2.0	-78.3
TT	no/trapset	kg/ha	Feb	0.0001	0.6652	35	0.5 - 28.6	2.75	1161.8	57.1	-1.9	-130.9

[1] DNS = Dip-net Sweeps, TT = Test Trap catch

[2] October regressions did not meet Pr>F and R^2 criteria for significance

[3] Median year value

Table 27. Predicted crawfish yield (kg/ha) based on mean monthly non-1994 dip-net sweep and test trap catch data set.[1]

Dip-net Sweep Projection (kg/ha)				
No/Sweep	Nov	Dec	Jan	Feb
0.25	838	830	870	741
0.50	880	917	894	813
0.75	915	983	913	877
1.00	944	1,029	929	932
1.50	982	1,057	950	1,018
2.00	995	1,002	955	1,069
2.50	983	863	945	1,085
3.00	945	640	920	1,068

Test Trap Catch Projection (kg/ha)				
No/Trapset	Nov	Dec	Jan	Feb
0.25	878	804	790	830
0.50	882	827	814	857
0.75	900	937	936	1,000
1.00	911	1,007	1,022	1,108
1.50	913	1,036	1,081	1,200
2.00	[2]	994	1,077	1,231
2.50	[2]	880	1,008	1,201
3.00	[2]	694	876	1,110

[1] October regressions did not meet Pr>F and R^2 criteria for significance

[2] The associated no/trapset was outside the range of observed values

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until a catch of 1.5 crawfish/sweep. Projected yield in weight (kg/ha) decreased when crawfish/DNS exceeded 1.5. Test trap catch predictions were very similar to dip-net sweep predictions (Table 27). November test trap catches of 0.5 to 11 predicted yields of 878 kg/ha to 913 kg/ha. December yield projections peaked at 11 crawfish/trapset and then declined.

A comparison of the observed yield (kg/ha) and the predicted yield (kg/ha) based on the December non-1994 monthly dip-net sweep regression is given in Figure 13. The December regression overestimated yield (kg/ha) for ponds with yields < 500 kg/ha and underestimated yield (kg/ha) for ponds with yields > 1,200 kg/ha. The mean percent deviation of predicted versus observed values for this model was 10% with a minimum of -45% and a maximum of 252%.

The second method incorporated the 1994 data but estimated the yield in crawfish/ha first, then used the relationship of crawfish/ha to yield in weight (kg/ha) to predict total yield (kg/ha). The regression of yield in kg/ha (y) on yield in crawfish/ha (x) is presented in Figure 14. The regression of all seasons combined was used to predict yield in weight (kg/ha). Using this method, November dip-net sweeps of 0.25 to 3 crawfish/sweep predicted a range of yield differences of only 174 kg/ha (944 to 1,118 kg/ha) (Table 28). November test trap catches of 0.5 to 11 crawfish/trapset predicted yields of 975 kg/ha to 1,052 kg/ha.

Drop Sampler Model (no/0.5m^2)

The prediction models developed for drop sampler catch (no/0.5m^2) should be interpreted with caution. The models may be biased by the 1994 and 1995 seasons because eight of the 13 observations were from those 2 years. Only one sampler was

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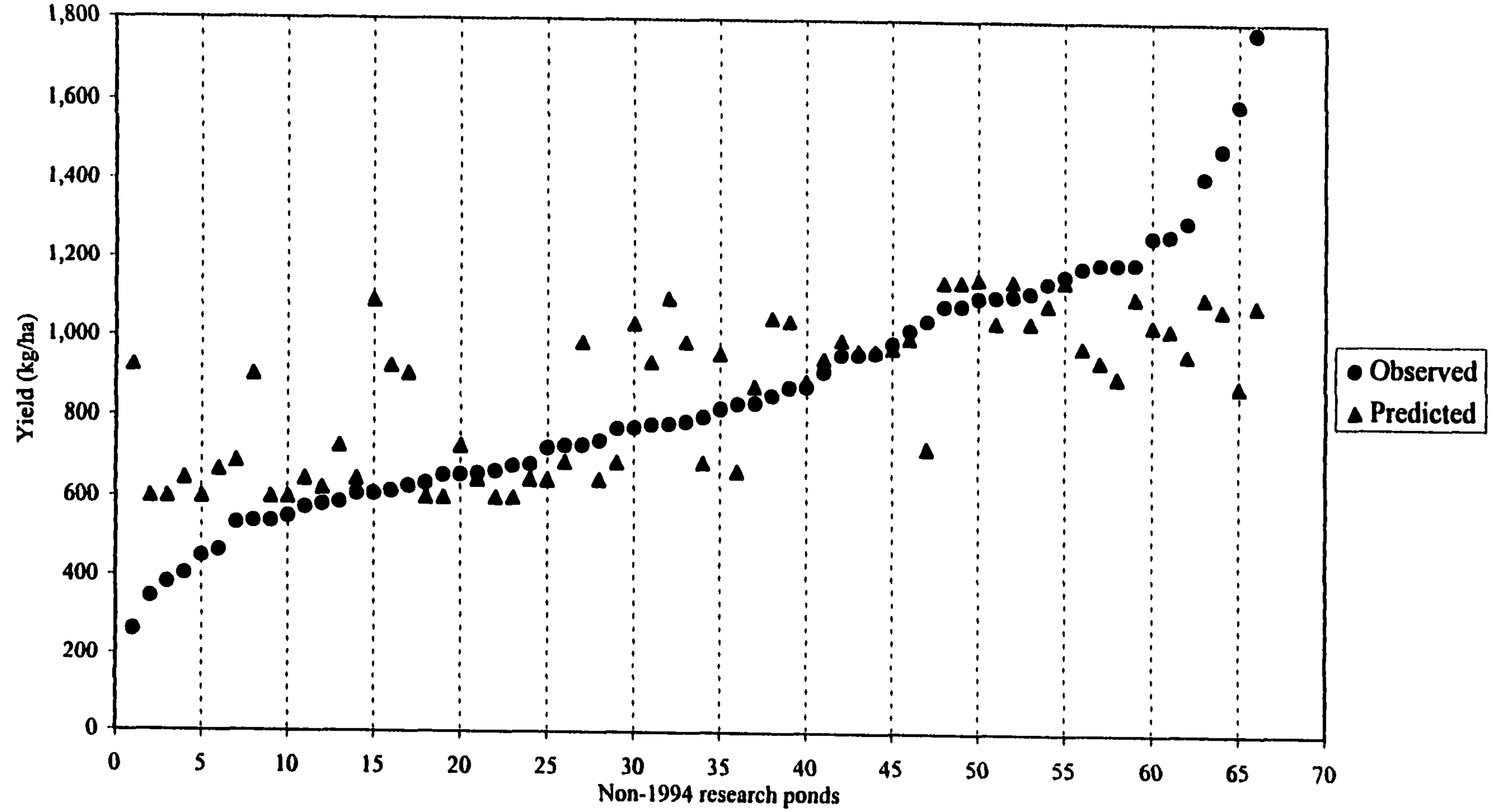

Figure 13. Comparison of observed yield (kg/ha) with predicted yield (kg/ha) based on non-1994 December mean monthly dip-net sweep catch (crawfish/sweep).

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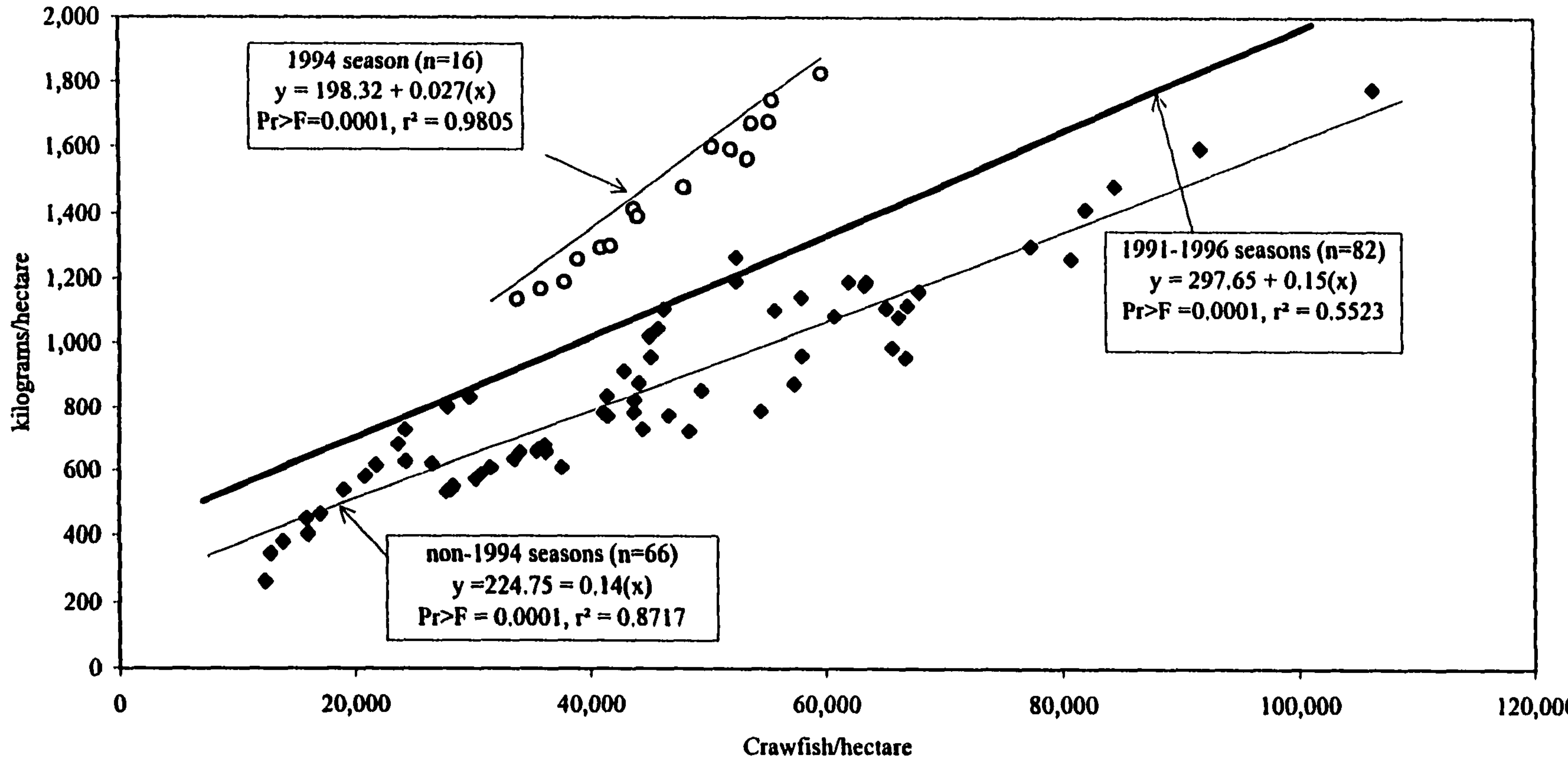

Figure 14. Regression of yield in kg/ha (y) on yield in crawfish/ha (x) for 1994, non-1994 and 1991-1996 crawfish production seasons. (Rice Research Station, Louisiana Agricultural Experiment Station, LSU Agriculutral Center, Crowley, Louisiana.)

Table 28. Predicted crawfish yield (kg/ha) based on yield in crawfish/ha[1] from dip-net sweep and test trap catch data.[2]

Dip-net Sweep Projection (kg/ha)				
No/Sweep	Nov	Dec	Jan	Feb
0.25	944	959	983	931
0.50	983	1,019	990	958
0.75	1,017	1,066	997	984
1.00	1,046	1,099	1,004	1,009
1.50	1,089	1,126	1,016	1,058
2.00	1,114	1,099	1,027	1,103
2.50	1,118	1,019	1,037	1,147
3.00	1,104	886	1,046	1,187

Test Trap Catch Projection (kg/ha)				
No/Trapset	Nov	Dec	Jan	Feb
0.5	975	909	916	975
1.0	988	933	945	1,005
4.0	1,047	1,055	1,100	1,165
7.0	1,071	1,138	1,214	1,291
11.0	1,052	1,188	1,304	1,404
15.0	[3]	1,169	1,322	1,455
19.0	[3]	1,081	1,269	1,444
23.0	[3]	923	1,145	1,371

[1] Yield (kg/ha) = 297.65 + (0.015*crawfish/ha)

[2] October regressions did not meet Pr>F and R^2 criteria for significance

[3] The associated no/trapset was outside the range of observed values

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used in years 1991 and 1992 and three samplers were used in 1993. Although some of the year-to-year variation is accounted for by the year variable in the model, the extreme variation in the 1994 and 1995 seasons could incorporate significant bias in predicting yield and size distribution in other years.

Predicted yield in weight (kg/ha) decreased as drop sampler catch (no/0.5m^2) increased (Table 29). This trend is the opposite of both of the alternate methods for predicting yield in kg/ha. All 5 months showed this same pattern. November drop sampler catches of 0.5 to 9 crawfish predicted yields of 1,537 kg/ha to 890 kg/ha.

The October regression model indicated that yield of individuals (crawfish/ha) decreased with increasing catch. This regression was probably biased due to 1995 not being included in the data (n=9). November predictions of yield of individuals did not increase as catch increased. Predicted yields (crawfish/ha) based on December catch increased as catch increased.

The percentage of total yield in the size categories $\geq$ 32 g or $\geq$ 21 g decreased dramatically as catch increased. A November drop sampler catch of 3 crawfish/0.5m^2 resulted in 24% of the crawfish $\geq$ 32 g and 50% $\geq$ 21 g. Drop sampler catches of 5 crawfish/0.5m^2 in November projected yields of only 3% $\geq$ 32 g and 26% $\geq$ 21 g. A comparison of the observed percent of total yield $\geq$ 21 g and the predicted percent of total yield $\geq$ 21 g based on the November drop sampler regression is given in Figure 15. The November regression overestimated percent of total yield $\geq$ 21 g for six out of eight ponds with less than 30% of total yield $\geq$ 21 g and underestimated percent of total yield $\geq$ 21 g for four of five ponds with more than 50% of total yield $\geq$ 21 g. However, six of 13 predicted values were within 9% of the observed values. The mean

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Table 29. Predicted crawfish yields and size distribution at harvest based on mean monthly drop sampler catch (no/0.5m²).

	Yield (kg/ha)				
no/0.5m²	Oct	Nov	Dec	Jan	Feb
0.5	1,758	1,537	1,449	1,491	1,499
1.0	1,611	1,471	1,382	1,418	1,424
3.0	1,114	1,242	1,159	1,167	1,168
5.0	769	1,069	1,009	981	987
7.0	574	952	930	860	880
9.0	530	890	924	804	848
11.0	[1]	[1]	989	[1]	[1]

	Yield (no/ha)				
no/0.5m²	Oct	Nov	Dec	Jan	Feb
0.5	70,418	52,477	48,283	57,192	49,023
1.0	71,341	54,314	48,343	58,085	49,180
3.0	71,857	59,638	49,497	60,481	50,500
5.0	67,293	61,722	52,115	60,997	52,924
7.0	57,649	60,566	56,197	59,633	56,452
9.0	42,925	56,170	61,743	56,389	61,084
11.0	[1]	[1]	68,753	[1]	[1]

	Size Distribution (% ≥ 32 g)				
no/0.5m²	Oct	Nov	Dec	Jan	Feb
0.5	54	69	67	*	70
1.0	42	58	60	*	62
3.0	2	24	35	*	34
5.0	-20	3	16	*	13
7.0	-23	-3	2	*	-3
9.0	-9	4	-6	*	-12
11.0	[1]	[1]	-8	*	[1]

	Size Distribution (% ≥ 21 g)				
no/0.5m²	Oct	Nov	Dec	Jan	Feb
0.5	89	98	95	*	100
1.0	72	87	88	*	91
3.0	18	50	60	*	59
5.0	-12	26	38	*	34
7.0	-18	16	21	*	16
9.0	-1	19	11	*	4
11.0	[1]	[1]	6	[1]	[1]

[1] The associated no/0.5m² was outside the range of observed values

* Regression did not meet Pr>F and R^2 criteria for significance

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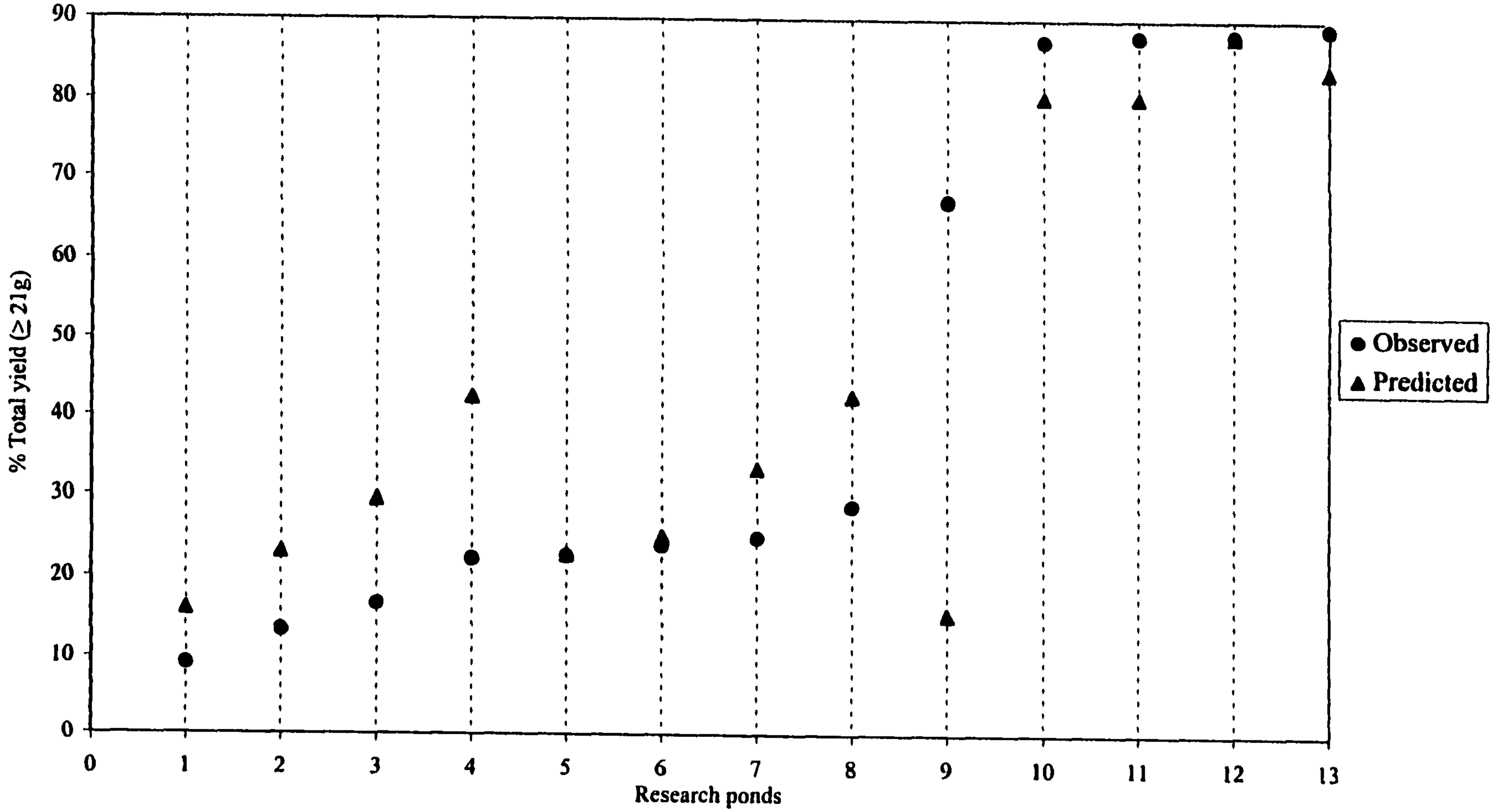

Figure 15. Comparison of observed size distribution at harvest (% ≥ 21g) with predicted size distribution at harvest (% ≥ 21g) based on November mean monthly drop sampler catch (no/0.5m²).

percent deviation for this model was 23% with a minimum of -77% and a maximum of 91%.

Drop Sampler Model ($g/0.5m^2$)

Projected yield in weight (kg/ha) decreased dramatically as drop sampler catch increased (Table 30). November drop sampler catches of 0.5 to 18 g of crawfish predicted yields of 1,662 kg/ha to 850 kg/ha.

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Table 30. Predicted crawfish yields and size distribution at harvest based on mean monthly drop sampler catch ($g/0.5m^2$).

Yield (kg/ha)					
$g/0.5m^2$	Oct	Nov	Dec	Jan	Feb
0.5	*	1,662	1,455	1,537	1,631
3.0	*	1,380	1,293	1,432	1,514
9.0	*	929	1,000	1,211	1,269
18.0	[1]	850	815	961	999
29.0	[1]	[1]	1,002	791	828
37.0	[1]	[1]	[1]	759	813
45.0	[1]	[1]	[1]	[1]	889

Yield (no/ha)					
$g/0.5m^2$	Oct	Nov	Dec	Jan	Feb
0.5	62,054	50,610	41,946	56,939	50,424
3.0	59,928	47,706	41,705	55,851	50,814
9.0	24,888	47,724	43,931	53,955	52,056
18.0	[1]	66,246	54,695	53,001	54,729
29.0	[1]	[1]	79,951	54,915	59,316
37.0	[1]	[1]	[1]	58,435	63,564
45.0	[1]	[1]	[1]	[1]	68,580

Size Distribution (% ≥ 32 g)					
$g/0.5m^2$	Oct	Nov	Dec	Jan	Feb
0.5	*	81	*	*	80
3.0	*	60	*	*	68
9.0	*	17	*	*	42
18.0	[1]	-19	*	*	11
29.0	[1]	[1]	*	*	-14
37.0	[1]	[1]	[1]	*	-22
45.0	[1]	[1]	[1]	[1]	-23

Size Distribution (% ≥ 21 g)					
$g/0.5m^2$	Oct	Nov	Dec	Jan	Feb
0.5	*	115	*	*	114
3.0	*	89	*	*	100
9.0	*	39	*	*	69
18.0	*	-4	*	*	32
29.0	*	[1]	*	*	3
37.0	*	[1]	[1]	*	-8
45.0	[1]	[1]	[1]	[1]	-10

[1] The associated $g/0.5m^2$ was outside the range of observed values

* Regression did not meet Pr>F and R^2 criteria for significance

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DISCUSSION

RELATIVE DENSITY, STANDING CROP, AND BIOMASS ESTIMATES

The negative economic impact of producing stunted crawfish can be substantial. The estimated gross income generated from experimental ponds in this data set in which more than 50% of the total yield in weight (kg/ha) was $\geq$ 21 g ("desirable") was 216% higher than the gross income generated from the harvest of a population in which less than 30% of the total yield in weight (kg/ha) was $\geq$ 21 g ("stunted"). This disparity in income is due to the higher value associated with large crawfish. The residual returns per hectare for rice and crawfish ranged from a loss of \$-241/ha for ponds with "stunted" populations (mean yield = 828 kg/ha) to a profit of \$513/ha for ponds with "desirable" populations (mean yield = 1,038 kg/ha). Lutz and Wolters (1986) estimated that gross revenue per hectare would be maximized at a density of 2 crawfish/m^2 based on yields in pools stocked at 1, 2, 4, 8, and 16 crawfish/m^2. In contrast, crawfish stocked at 16 crawfish/m^2 after 34 days of grow-out (mean weight = 6.3 g), would produce gross revenue of only \$6/ha. At stocking densities of 2 and 4 crawfish/m^2, gross revenue increased to \$360 and \$315 per hectare, respectively.

Nearly 50% of the 82 ponds evaluated in this study produced desirable populations and nearly 70% produced acceptable to desirable populations. Based on the extensive nature of the culture system used to produce procambarid crawfish, this percentage of larger size crawfish produced is very desirable. Based on personal observations, this level of large crawfish production was more consistent than is typically found in the commercial crawfish aquaculture industry.

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The range of yields within the qualitative groupings varied considerably. Stunted populations produced both low yields (534 kg/ha) and high yields (1,777 kg/ha). Although the mean yield for desirable populations was 1,038 kg/ha there were six ponds that produced less than 500 kg/ha.

It should be noted that the qualitative groupings developed for this study are based on an advantage in producing larger crawfish. If there is no incentive to produce larger crawfish then the producer would maximize gross income by using management strategies to increase total weight harvested. However, the producer with larger crawfish will usually have better marketing opportunities than possible with small crawfish.

Pond populations of *Procambarus* in 1991, 1992, and 1993 exhibited recruitment patterns similar to those reported by Romaire (1976), Momot and Romaire (1982), Lutz (1983), and Romaire and Lutz (1989) from experimental and commercial ponds with multiple waves of recruitment peaking during December through February. Relative density and standing crop began to decrease during March, April and May due to natural mortality, harvesting, and mature crawfish beginning to burrow. Romaire and Lutz (1989) also found young-of-the-year recruitment of *P. clarkii* was highest in the fall with lesser peaks in mid-winter and early spring. In their study, one commercial pond (17 ha) had four primary recruitment classes at 5 weeks after flooding (late October) and secondary recruitment classes in mid-November, mid-December, late January, and late March. In a second commercial pond (17.2 ha) they found five primary recruitment classes at 5 weeks after flooding (mid-November) and one secondary recruitment class appeared in early March. Momot and Romaire (1982) were

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able to differentiate distinct differences in procambarid population size structure by 6 and 12 weeks after flooding.

Relative densities as estimated by dip-net sweeps and test traps revealed that the recruitment patterns in 1994 were considerably different than any other year or treatment grouping. The poor water quality conditions in October and November in 1994 and 1995 probably killed early recruitment of the primary wave of young-of-the-year crawfish in October as evidenced by low crawfish standing crop and biomass during October through February. The 1994 season exhibited low survival of YOY through February after which late secondary recruitment waves resulted in dip-net sweeps higher than in other ponds and in other years. Late recruitment during the 1994 season was also evidenced by the increase in standing crop and biomass from January to February. These crawfish experienced rapid growth as evidenced by the increase in biomass from an mean of 5.6 g/m^2 in February, to 42.8 g/m^2 in March, and to 107.8 g/m^2 in April. This growth was possibly due to a low number of similar-sized animals with a large amount of available forage. The majority of the crawfish from the 1994 season were harvested in a 2-week period during May. This shows that ponds with a low primary wave of recruitment in November but high secondary recruitment in February may still reach economically advantageous populations if late season forage biomass remains sufficiently high and other environmental conditions remain favorable. Although standing crop estimates for 1995 ponds were very similar to 1994 ponds during April and May, suppressed growth due to low water temperatures and low forage biomass likely caused crawfish populations to stunt in 1995.

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This dramatic, late season increase in crawfish biomass is similar to the biomass increase experienced by McClain et al. (1997) and Lutz and Wolters (1986). McClain found that by relaying sub-marketable crawfish (mean weight = 13.5 g) to the improved environment of a rice field, crawfish were able to increase their weight by over 200% in 28 to 50 days (May through August). Lutz and Wolters (1986) found that juvenile crawfish (mean weight = 0.23 g) were able to reach a harvest weight of 13.3 g to 20.7 g in 34 days in pools stocked in May at 4 crawfish/m^2 and 1 crawfish/m^2, respectively.

Momot and Romaire (1982) observed population dynamics similar to those seen in the 1994 season in this study. During the first 12 weeks after flooding, an experimental pond contained the lowest relative density and < 15% of the crawfish were of harvestable size (> 75 mm) by December. The experimental pond had experienced a large population reduction between 4 and 6 weeks following initial flooding. Although the yield was lower than other five ponds in the study (1,429 kg/ha in a range of 2,211 to 1,429 kg/ha), the average weight per harvested crawfish was the highest.

November appears to be the first month in which a large enough separation in relative densities occurs to base an estimation on the potential of these ponds to produce stunted populations. Mean DNS counts of 0.5 to 0.75 crawfish/DNS in November resulted in economically advantageous populations whereas mean DNS counts in excess of 1.13 crawfish/DNS in November resulted in "stunted" populations. This DNS number is close to the 1.5 crawfish/DNS established by the predictive model as an indicator of stunted populations.

For the relative density estimates based on test traps, October estimates represent holdover crawfish emerging from burrows. The December peak in mean TT catch

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corresponds with juvenile crawfish being recruited into a size that will be retained in a trap. October appears to be a more appropriate month on which to base an estimation of the potential for a pond to stunt because (1) the standard deviations of mean relative density estimates (crawfish/trapset) are lower than November and (2) regression models revealed that only October and February test trap catch was positively correlated to size distribution at harvest. Based on these relationships, TT catch in excess of 2.39 crawfish/trapset in October resulted in stunted populations. The test trap predictive models projected that an October test trap catch of 4 crawfish/trapset indicated potential for yield of stunted populations.

Due to the lack of crawfish standing crop and biomass estimates for ponds that produce a size distribution at harvest of between 30 and 50% $\geq$ 21 g, estimating the threshold that would indicate yields of less than 30% $\geq$ 21 g is difficult. It appears from this study that ponds with November through February standing crop estimates in excess of 13 crawfish/m^2 and/or biomass in excess of 21 g/m^2 have the potential to stunt (less than 30% $\geq$ 21 g). Jarboe (1989) found that ponds with a population density of 16 to 18 crawfish/m^2 and biomass of 52.5 g/m^2 from November to January may have populations that stunt. Villagran (1993) found that pools stocked at an extrapolated rate of 13 crawfish/m^2 produced less than 30% of the total yield $\geq$ 21g.

PREDICTIVE MODELS

Validation

The best means of model validation is through the use of an independent data set or "new data." This option was not feasible because there was not a separate source of existing data and data from the 1996 - 1997 crawfish production season at the Rice

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Research Station was not yet available. These models will hopefully be validated by future studies and through verification in commercial settings.

The cross validations conducted for the dip-net model, to predict size at harvest ≥ 21 g, ranged from 9 to 20% deviation with observed values. This met the validation criteria ($\geq 25\%$ deviation) and allowed the model to be used. Comparisons of observed and predicted values based on the regression of November dip-net sweeps on percent $\geq$ 21 g showed considerable variation, however the thresholds derived from the model were consistent with relative density estimates.

The cross validations conducted for the test trap model, to predict size distribution at harvest ≥ 21 g, ranged from 10 to 17% deviation from observed values and met the criteria for validation ($\geq 25\%$ deviation).

Estimating Yields

Yield in Individuals (crawfish/ha)

The primary influences on the number of crawfish harvested from a population are size range of individuals in the population and overall harvesting effort. Standard commercial traps (1.9 cm hexagonal mesh) are generally selective for crawfish ≥ 75 mm TL (10 to 15 g), therefore smaller crawfish that have not reached a harvestable size by the end of the production season would not be harvested. If harvesting effort is too low (too few traps and/or trapping days), harvesting gear may become saturated resulting in fewer crawfish being harvested than potentially could be harvested. Additionally, mature crawfish may begin burrowing in late spring and are not susceptible to trapping. Thus the total number of crawfish harvested is a only a subset of the potential number of crawfish that could be harvested.

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Momot (1982) showed that it took about 2,600 trapsets/ha to remove 60% of the biomass of *Orconectes virilis* in two northwestern Ontario lakes. That level of harvesting effort was within the range of trapsets used during the five production seasons of this study. Momot and Romaire (1982) extrapolated that a harvesting effort of 6,000 trapsets/ha/season would be necessary to remove 80% of the procambarid crawfish populations from the Ben Hur Aquaculture Research Facility ponds used in their study. Yields in the Momot and Romaire study ranged from 2,211 to 1,429 kg/ha. Computer simulations indicate that 50 to 70% of the harvestable procambarid crawfish population in well managed ponds can be removed with trapping intensity comparable to those used in this study (2594 to 4298 trapsets/ha/season) (Dr. Robert Romaire, Professor, School of Forestry, Wildlife, and Fisheries, Louisiana State University, Baton Rouge, Louisiana, July 1997). However, little empirical field data are available on the amount of harvestable crawfish taken from stunted, acceptable, or desirable populations as defined by this study.

The ability to predict the number of crawfish that will be harvested from a pond has little utility to a commercial producer. The harvest parameters of interest are yield in weight (kg/ha) and percent of total yield that will bring a premium price, typically those ≥ 21 g. However, these two parameters are very closely related. The utility of this parameter was to determine if these sampling gear could accurately predict the number of crawfish harvested and if so, could the number of crawfish harvested be used to help predict total yield in weight (kg/ha)?

Dip-net sweeps and test trap catch were highly correlated to yield in individuals (crawfish/ha) during all months except October. The R^2 values for the regression of test

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trap catch on yield in individuals increased from November to February at which time test trap sample data were no longer taken. This improvement is because more crawfish attain a size that will be retained by the trap.

Drop sampler catch (no/0.5m^2 and g/0.5m^2) was correlated to yield in individuals (crawfish/ha) during all months sampled. It is surprising that DRPS catch is significantly correlated to yield in crawfish/ha in October because crawfish populations are not typically fully recruited until November or December (Romaire and Lutz 1989). Momot and Romaire (1982) found no appreciable difference in the size structure of six crawfish populations based on length-frequency histograms of crawfish sampled by dip-nets and seines at 2 and 4 weeks post-flooding.

Yield in weight (kg/ha)

Neither dip-net sweeps or test trap catch were good predictors of yield in weight (kg/ha) directly when all 5 years were included in the regression analysis. The main problem in predicting yields in kg/ha is that an increase in the number of crawfish harvested is not directly proportional to an increase in weight. For example, a 1991 control pond with sorghum-sudangrass hybrid as a main crop produced 43,718 crawfish that weighed a total of 784 kg/ha. However, a 1994 February density reduction pond with a ratoon crop of rice produced 43,746 crawfish that weighed a total of 1,414 kg/ha.

Villagran (1993) found that a stocking density of 5 to 35 crawfish/m^2 accounted for only 8% of the statistical variation associated with yield. The highest yield for a rice forage base pond in Villigran's (1993) study was obtained at a density of 10 crawfish/m^2 (1,880 kg/ha) and lowest yield at 5 crawfish/m^2 (1,085 kg/ha), an approximate reduction

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of 43%. No significant differences in mean yield were observed among the remaining densities (15 to 35 crawfish/m^2).

By excluding the 1994 data, December dip-net projections and test trap projections both predicted a trend of increasing yields with increasing CPUE until a threshold was reached then yields began to decline. For dip-net sweep catch, this critical threshold was 1.5 crawfish/sweep. December test trap models predicted yields would decline after a level of 11 crawfish/trapset.

By first estimating the yield in individuals (crawfish/ha), then using the relationship of crawfish/ha to yield (kg/ha), an estimate of yield (kg/ha) was achieved. Although the regression models developed by this procedure were highly significant, this procedure was not able to predict a range of yields in weight (kg/ha) that were similar to observed yields. An increase from the lowest observed values for DNS and TT to the highest observed values influenced the predicted yield by less than 200 kg/ha. This is due to predictions that were based on a mean year average and not specific years. Predicted and observed values would have been closer if individual years were used in the predictive models.

Drop sampler prediction models (no/0.5^2 and g/$0.5m^2$) revealed a dramatic decrease in predicted yield in weight (kg/ha) with increasing drop sampler catch. This dramatic trend does not accurately reflect the types of yield experienced in the full 82 pond data set or other research-based pond studies. The drop sampler models should be viewed skeptically due to the low sample size and the disproportionate representation of individual years that lie on the extremes of the yields and size distribution at harvest.

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de la Bretonne and Romaire (1989) reported that the relationship between diurnal DNS counts obtained 6 to 8 weeks post flood (generally corresponding to mid-November through December) and potential crawfish yield was as follows: 0 to 1 crawfish/DNS , 500 to 600 kg/ha ; 3 to 5 crawfish/DNS , 1,000 to 1,500 kg/ha , and 8 to 20 crawfish/DNS, 2,000 kg/ha or more. These relationships were based on observational data generally gleaned from years of experience but not verified through specific experimental design.

Data from the 15 experimental procambarid crawfish ponds evaluated by Kryiacou (1996) indicated that the relationship between yield and relative abundance, based on diurnal DNS in November, was as follows: 2 to 5 crawfish/DNS , 1,500 to 2,500 kg/ha ; 6 to 10 crawfish/DNS , 1,000 to 1,500 kg/ha ; and >10 crawfish/DNS , less than 1,000 kg/ha. Kryiacou's correlations of relative abundance to yield contradicted those predicted by de la Bretonne and Romaire (1989). Kryiacou's data illustrate the density-dependent relationship with size. As density increases as reflected in high DNS catch, yield in total weight (kg/ha) decreases because a higher percentage of the crawfish population did not attain a size that could be retained in a 1.9 cm mesh trap.

Based on this study of Rice Research Station crawfish ponds from 1991 to 1996, crawfish ponds that are experiencing an increase in recruitment during October through December will produce 800 to 1,000 kg/ha with December DNS of 0.25 to 1.5 crawfish/sweep or TT catch of 0.5 to 11 crawfish/trapset. Above these levels, yield will begin to decline.

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Estimating Size Distribution at Harvest

Size distribution at harvest showed a definite trend of decreased size with increased sampling gear catch. In general, larger crawfish or greater portions of large crawfish are inversely proportional to density. Other research studies have also observed an inverse relationship between size-at-harvest and initial densities in *P. clarkii* (Romaire et .al. 1978, Chien and Avault 1983, Mills and McCloud 1983, Lutz and Wolters 1986, Morrissy 1992, Villagran 1993, McClain 1995a, McClain 1995b, McClain and Romaire 1995). McClain (1995b) found that mean crawfish weights at 6 and 12 weeks declined as density increased from 2 to 18 crawfish/m^2 in enclosures containing rice-forage substrates. Villagran (1993) reported that mean crawfish weights after 171 days declined as density increased from 5 to 35 crawfish/m^2 in outdoor pools planted with rice and managed to simulate crawfish ponds.

How growth is affected at high densities has not been fully addressed. In forage-based production systems, it is likely that as crawfish density increases beyond some optimum density, food resources are depleted and nutritional shortages become a limiting factor. Villagran (1993) showed crawfish populations would stunt at densities of ≥ 5 crawfish/m^2 in forage deficient pools and at densities of ≥ 10 crawfish/m^2 in food sufficient pools. However, other studies have found crawfish growth to be density-dependent regardless of available food supply (Morrissy 1992 and McClain 1995a). A suspected cause or contributing factor is the social interaction/territorial restriction response that predominates in most species of crawfish (Lowery 1988).

The percentage of total yield ≥ 32 g or ≥ 21 g decreased with increasing dip-net sweep counts. At a relative abundance of 1.5 crawfish/sweep in November, less than

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30% of the total weight of crawfish harvested will be 21 g or larger. A harvest with such a small percentage of crawfish $\geq$ 21 g could have devastating economic effects on the producer.

Although the magnitude of crawfish caught with DNS was higher, Kryiacou (1996) also found that November DNS counts were highly correlated with harvest size. Kryiacou reported harvest size was inversely correlated to density based on both diurnal and nocturnal DNS counts, and at a relative abundance of $\geq$ 5 crawfish/DNS in November, less than 20% of crawfish harvested were 23 g or larger.

In this study, an October test trap catch of 1 crawfish/test trap predicted a size distribution at harvest of 53% $\geq$ 21 g while 4 crawfish/trapset would indicate a potential of harvesting only 29% of total yield in kg/ha $\geq$ 21g. It is somewhat surprising that the October regressions of test trap catch to size distribution were significant. Animals large enough to be retained in standard commercial traps during October are probably holdover adults and juveniles from the previous year. This would indicate that, in years with multiple recruitment classes, the amount of early potential broodstock is a good indicator of size distribution at harvest.

The drop sampler models also predicted decreasing size at harvest with increasing gear catch. A November drop sampler catch of 5 crawfish/0.5m^2 predicted a total yield of 26% $\geq$ 21g. A November drop sampler catch of 9 g/0.5m^2 predicted a total yield of 19% $\geq$ 21g.

<u>Sampling Gear Combinations</u>

Overall, correlation trends for the combination of DNS and TT in the same pond are similar to the correlations for the individual gear when used alone. The combination

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of these two methods was not a significant improvement in the predictive capability of the individual methods. It was theorized that by combining gear selective for crawfish < 63 mm (DNS) with gear that selected crawfish ≥ 75 mm (TT) a larger percentage of the variation in the model (R^2) could be explained. Since the R^2 values only improved slightly, the R^2 values of the density estimation terms in the model do not appear to be additive.

Comparisons of the combination of all three gear used in the same pond revealed only a slight improvement of the R^2 values when compared to regression of the number of crawfish caught with a drop sampler alone. For this reason, the additional effort of taking dip-net samples or running test traps when drop samplers are available would be of questionable utility.

<u>Comparison of Individual Sampling Gear</u>

The ratio of crawfish caught with a dip-net sweep to number of crawfish caught with a test trap decreased from November to December but did not change from December to February. This can be explained by more crawfish being recruited into the size that can be retained in the test trap. As YOY crawfish grow too large to be caught by the dip-net, they become large enough to be caught by the test trap. The number of crawfish large enough to be retained by a trap will continue to increase until they are removed from the pond through harvesting or succumb to natural mortality or predation.

The ratio of crawfish caught with a drop sampler to number of crawfish caught with a test trap decreased from November through February. As in the comparison of DNS and TT, more crawfish are being recruited into the size class to be retained by the test trap. This is supported by the fact that biomass estimates (g/m^2) are increasing at a

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faster rate than the standing crop estimates (crawfish/m^2) during November through February.

The ratio of number of crawfish caught with a drop sampler to number of crawfish caught with a dip-net did not vary considerably during the months sampled. As time progresses, less of the standing crop is vulnerable to dip-nets while drop samplers continue to sample all size classes equally.

LIMITATIONS OF SAMPLING GEAR

Dip-net Sweeps

Dip-net sweeps are generally used to monitor the presence of young-of-the-year (YOY) crawfish and the relative abundance of juveniles. The advantages of this type of sampling gear are low cost, portability, ease of operation, and quick assessment. Farmers, researchers and extension agents also can conduct many samples with little effort and inconvenience.

However, there are several limitations of this method to accurately reflect overall population dynamics. This is an active technique and the inherent bias may be due to size of vulnerable animals, area of the pond sampled, time of day the samples are taken, and variability among the sampling techniques of people taking the samples.

Dip-net sweeps typically select only small crawfish because larger animals can evade the net. Huner and Barr (1991) stated that as crawfish approach 50 mm TL they become difficult to catch with a dip-net. Romaire (1976) reported that dip-net sampling is generally selective for crawfish less than 40 mm TL. In this study, only juveniles that were too small to be captured by test traps were counted in the sample.

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Most researchers and farmers restrict dip-net samples to the periphery of the pond. Samples are typically not taken from the interior because vegetation early in the production season prevents use of the net along the bottom, and the population is disturbed by approaching the sample site. The margin of the pond is easy to access and allows sampling to be conducted from the levee or in shallow water where waders are not necessary. Niquette and D'Abramo (1991) suggested that the increased catch of juveniles in small mesh traps over dip-nets in March and May reflected the avoidance of shallow water by juveniles during the day, especially when cover was lacking. The authors suggested that in the absence of cover, young crawfish remained in deeper water or congregated in isolated patches of cover such as algae. Witzig et al. (1981) found that crawfish distribution was significantly affected by water depth, vegetation density, pond area, and time after flooding. Shallow water, dense vegetation, and center areas had higher mean yield of crawfish than did the deep water, light vegetation, and edge areas.

This could explain some low DNS counts in late season, forage-depleted ponds in this study. However, during October through January when DNS predictions have the most potential for assisting management decisions, crawfish were not exposed to conditions that would tend to congregate them into specific areas. The experimental crawfish ponds used in this study were precision land-leveled and did not have interior levees therefore depth varied only a few centimeters across the pond. Vegetation density was consistent due to exacting planting techniques and uniformity of seedbed.

Procambarid crawfish are typically most active at night (Huner and Barr 1991), suggesting that nocturnal dip-net sweeps might be better predictors of population

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density. Kyriacou (1996) found the relative abundance of juveniles determined from nocturnal (2000 to 2400 hours) DNS on average was double the counts obtained during diurnal (0900 to 1300 hours) sampling. Although the relative abundance was different for each sampling period, both were highly correlated with yield and size distribution at harvest. The increased catch of nocturnal DNS may be due to either a dispersal response of crawfish moving out of cover, or a concentration of crawfish along the margin for feeding or better water quality conditions. However, the increased nocturnal catch is not necessarily a better indicator of population structure. Although this variability due to time of day needs to be examined further, the adoption of sampling recommendations would be higher if farmers could incorporate these procedures during the normal daylight period when other farming activities are being conducted and labor is available.

Individual sampling techniques should be standardized as much as possible. For this study, the dip-net was plunged into the water at full arms length and aggressively dragged along the bottom while keeping the net as perpendicular to the bottom as possible. Each dip net sweep was estimated to cover an area of about 0.6 m^2 and it took approximately 4 seconds to take each sample.

Test Traps

Standard commercial crawfish traps are typically used to assess when to begin harvesting based on catch-per-unit-effort (CPUE) and to harvest marketable animals. Expanding the use of this gear to assess additional components of the population structure include the advantages that farmers already possess the equipment and they have a prior familiarity with the gear. The potential constraints of this sampling gear

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are daily variations in catch, more time and equipment are needed when compared to dip-net sampling, and the samples caught by this gear may require further processing (if determining total weight).

Trap catch may vary as much as 200% from day to day. The primary factors that influence the effectiveness of this technique to attract and hold crawfish are water temperature, population density and recruitment patterns (Romaire 1989). Harvest is usually lowest during January and February when temperatures are normally below 10° C. Harvest increases when temperatures range from 20 to 30° C (generally November to December and March to May in southern Louisiana) and when the standing crop of harvestable crawfish peaks (March through May). Molting cycles and the continuous recruitment of juvenile crawfish to harvestable size, and their removal through harvest results in much of the cyclic variation in daily catch. Additional factors that influence test trap catch include water quality (Hymel 1985, Araujo and Romaire 1989), type and quantity of forage (Romaire and Orosio 1989, Brunson 1989, McClain 1995b), and weather (Arajuo and Romaire 1989). To reduce the effect of daily variation on the predictive capability of test trap catch, catches should be averaged over longer periods of time (monthly) before management assessments are made.

<u>Drop Samplers</u>

Based on the strong correlation between drop samplers and yields and size distribution at harvest, the drop sampler shows potential for assessing population dynamics. However, two assumptions must be made for this sampling technique: (1) all size classes of crawfish are evenly distributed across the pond; and (2) all size classes are equally vulnerable to the gear.

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The first assumption is brought into question from the work of Witzig et al. (1981). However, for this study, the variation of crawfish populations due to different depths and vegetation densities was minimal. Although the weights of individual crawfish caught by drop samplers was not presented in this study, wide size ranges were represented in the samples.

Drop sampling devices offer several advantages over the other two gear evaluated. Most importantly, it allows for more in-depth analysis of population dynamics because all sizes of crawfish are sampled. A major component of the usefulness of this gear is that it samples a known area. Once the standing crop is estimated from the 0.5 m^2 sampled, the total standing crop for a pond can be extrapolated. Biomass can be determined for individual size classes and for the entire pond population.

However, drop sampling technology is more complicated than the other sampling gear and may be a more suitable research tool than a farm management tool. Drop samplers are not easily transportable from field to field. Obtaining multiple samples within a pond during one 24-hour cycle would require multiple units due to the pond bottom disturbance caused in relocating the units. Drop samplers also require more labor and equipment (pumps and batteries) than the other sampling gear and the samples require further processing (sorting and weighing).

LIMITATIONS OF MODEL

The predictive models and thresholds established by relative density, standing crop, and biomass estimates should be limited in their application to the types of production scenarios employed during this study and to the range of observations for the

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sampling gear evaluated. The study area and management strategies used in this study are typical of rice-crawfish rotational ponds of southwestern and central Louisiana. The Rice Research Station crawfish ponds are built on Crowley silt loam soils and are completely drained after harvesting is complete. The pond levees are destroyed after the soils are dry and are reconstructed just prior to planting rice. The combination of quick draining and removal of levees decreases the amount of holdover crawfish for the next season thereby reducing the chance of overpopulation.

All of the early recommendations concerning the effects of population dynamics on total production, have been based on studies conducted at the Ben Hur Aquaculture Research Facility, Louisiana Agricultural Experiment Station, LSU Agricultural Center, Baton Rouge, Louisiana. The Ben Hur crawfish ponds are located approximately 132 km east of the Rice Research Station and characterized by older-aged, permanent ponds with Sharkey clay soils. Ben Hur crawfish ponds are typified by high populations that are prone to stunting. These high populations are thought to be caused by increased burrowing activity caused by a large amount of levee/water interface of interior levees (Gonul 1995) and a prolonged, late draining period.

This difference in the two production systems (permanent ponds versus rotational ponds) is the major cause of the disparity of the range of sampling values for the two locations. Individual daily dip-net sweep values for this study ranged from 0 to 5.1 crawfish/sweep. Diurnal dip-net sweeps at the Ben Hur Aquaculture Research Facility have ranged from 1 to 30 crawfish/sweep (Kryiacou 1996). Test trap and drop sampler data is not available for comparison.

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CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. None of the predictive models developed were able to predict a range of yields (kg/ha) that were comparable to the observed yields for the experimental ponds in this study. The main problem in predicting yields (kg/ha) was that an increase in number of crawfish harvested is not directly proportional to an increase in weight. However, a threshold was determined above which yields declined. Based on Rice Research Station ponds in south-central Louisiana from 1991 to 1996, crawfish ponds that experienced an increase in recruitment during October through December produced 800 to 1,000 kg/ha with December dip-net sweep counts of 0.25 to 1.5 crawfish/sweep or a test trap catch of 0.5 to 11 crawfish/trapset. Above this level of catch, yields declined.
2. Dip-nets have potential utility for predictive capability but are limited by the size of vulnerable animals, area of the pond sampled, time of day the samples are taken, and variability among the sampling techniques of people taking the samples. Based on the findings from this study, dip-net sweep counts can be used to assess the potential of ponds to produce stunted populations but are not very accurate predictors of yield in weight. Dip-net sweeps should continue to be used as a qualitative assessment tool to monitor the presence of young-of-the-year crawfish and the relative abundance of juveniles until further refinements in their predictive capabilities can be investigated.
3. Test traps also have predictive capability but are limited by the variation in catch attributed to water temperature, population density and recruitment patterns, water

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quality, type and quantity of forage, and weather. Like dip-nets, test traps appear to have the capability to predict whether populations will stunt but further refinement of test trap sampling protocols are needed.

4. Dip-net sweeps, test trap catch, and drop sampler catch were statistically correlated to yield in individuals (crawfish/ha) which showed that they provide a relatively good index of relative population density of harvestable size crawfish.
5. Dip-net sweeps, test trap catch, and drop sampler catch predicted a decrease in the percentage of total yield ≥ 32 g and ≥ 21 g as the number of crawfish caught with each gear increased. In general, larger crawfish or greater proportions of large crawfish were inversely proportional to relative density, as estimated by dip-net sweeps, test trap catch, and drop sampler catch.
6. November and February dip-net sweeps of ≥ 1.5 crawfish/sweep predicted that less than 30% of the total weight of crawfish harvested would be 21 g or larger. These predictions were supported by relative density estimates during the same months of > 1.10 crawfish/sweep in ponds with stunted populations. Based on predictive models and relative density estimates, critical thresholds to predict stunted populations are presented in Table 31.
7. October test trap catch of ≥ 4 crawfish/trapset predicted that less than 30% of the total weight of crawfish harvested would be 21 g or larger. Based on predictive models and relative density estimates, critical thresholds to predict stunted populations are presented in Table 31.
8. Based on drop sampler catch, it appears that ponds with standing crops in excess of 13 crawfish/m^2 and/or biomass in excess of 24 g/m^2 during November through

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Table 31. Critical thresholds for predicting size distribution at harvest based on dip-net sweep, test trap catch, and drop sampler catch in southwestern and central Louisiana crawfish ponds.

	Dip-net (crawfish/sweep)			
Qualitative Grouping[1]	Nov	Dec	Jan	Feb
Stunted	> 1.5	> 1.5	> 1.5	> 1.5
Acceptable	0.75 - 1.5	0.75 - 1.5	0.75 - 1.5	0.75 - 1.5
Desirable	< 0.75	< 0.75	< 0.75	< 0.75
	Test Trap (crawfish/trapset)			
Qualitative Grouping[1]	Nov	Dec	Jan	Feb
Stunted	> 4	> 8	> 7	> 9
Acceptable	1 - 4	2 - 8	2 - 7	2 - 9
Desirable	< 1	< 2	< 2	< 2
	Drop Sampler (crawfish/m^2)*			
Qualitative Grouping[1]	Nov	Dec	Jan	Feb
Stunted	> 13	> 13	> 13	> 13
Acceptable	6 - 13	8 - 13	8 - 13	8 - 13
Desirable	< 6	< 8	< 8	< 8

[1] Stunted = < 30% of total yield (kg/ha) $\geq$ 21 g, Acceptable = 30-49% of total yield (kg/ha) $\geq$ 21 g, Desirable = $\geq$ 50% of total yield (kg/ha) $\geq$ 21 g

* Extrapolated from crawfish/0.5m^2

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February have the potential to stunt. However, ponds that have low standing crops in November could reach economically advantageous populations if late season forage biomass remains sufficiently high. Based on predictive models and standing crop estimates, critical thresholds to predict stunted populations are presented in Table 31.

9. Using multiple types of sampling gear within the pond did not significantly improve the predictive capability of the same gear when used alone. This would suggest that the amount of variation explained by each of the gear terms in the model is not additive.

10. An empirical relationship existed between the number of crawfish caught with one gear and the number of crawfish caught with another gear. This relationship changed as the season progressed and can be attributed to the change in mean size of the crawfish and resulting change in vulnerability to each gear. This empirical relationship can be used to extrapolate the catch of one gear from the catch of another gear.

RECOMMENDATIONS

1. The predictive models and thresholds established by relative density, standing crop, and biomass estimates should be limited in their application to the types of production scenarios employed during this study and to the range of observations for the sampling gear evaluated. The study area and management strategies used in this study are typical of rice-crawfish rotational ponds of southwestern and south-central Louisiana.

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2. The predictive models and thresholds developed in this study should be validated by new data sets from similar research conditions and tested in commercial settings. These gear should be incorporated into crawfish production management verification trials in Louisiana and their predictive capabilities evaluated on commercial crawfish farms.
3. Specific sampling protocols for each sampling gear should be investigated beyond the procedures used in this study.
4. The potential for drop samplers to assess population dynamics is high. The ability to sample all size classes from a known area would allow in-depth analysis of recruitment patterns, size structure, species composition, mortality rates and rates of sexual maturity. However, additional research is needed to evaluate the reliability of this gear to accurately reflect the standing crop and biomass of crawfish in a commercial production pond.
5. Further research is needed to evaluate the potential of using test traps to assess yield in individuals (crawfish/ha) and size distribution at harvest. This gear is familiar to crawfish producers and management recommendation adoption rates could be high if prediction models are refined. The use of small mesh (6.4 mm to 12.7 mm) traps in combination with standard commercial traps to assess population structure should also be investigated.
6. Density, as reflected by the catch-per-unit effort of these gear, only accounted for approximately 30 to 40% of the variation in yield explained by the models developed. Additional research is needed to assess other variables such as forage

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quantity and quality, water quality, and timing of flood-up that can be used to develop better descriptive models of population dynamics.

7. A concentrated effort should be made to establish an expected range of yields for each of the commercial production scenarios currently used in the Louisiana crawfish industry. Reported mean yields for commercial production systems have been limited to anecdotal data.

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APPENDIX A: CROSS VALIDATION ITERATIONS FOR THE DIP-NET PREDICTION MODEL

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Table 32. Cross validation iterations for the dip-net prediction model.

	Yield (kg/ha)														
	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
Month	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	58	0.0039	0.2179	39	0.0968	0.1633	39	0.0800	0.1734	37	0.1718	0.1387	36	0.1595	0.1472
Nov	82	0.0261	0.1112	54	0.1677	0.0953	54	0.0975	0.1173	54	0.0134	0.1913	54	0.1327	0.1050
Dec	82	0.0261	0.1112	54	0.1615	0.0969	54	0.0926	0.1195	54	0.0054	0.2219	54	0.1327	0.1050
Jan	82	0.0112	0.1317	54	0.1113	0.1122	54	0.0621	0.1351	54	0.0121	0.1946	54	0.1017	0.1158
Feb	82	0.0174	0.1212	54	0.1618	0.0968	54	0.1128	0.1116	54	0.0165	0.1839	54	0.0411	0.1508
Mar	82	0.0001	0.2483	54	0.0177	0.1814	54	0.0054	0.2222	54	0.0047	0.2268	54	0.0204	0.1763
Apr	82	0.0001	0.2542	54	0.0047	0.2266	54	0.0035	0.2365	54	0.0004	0.3051	54	0.0001	0.4675
May	52	0.0001	0.6917	32	0.0001	0.7304	33	0.0001	0.7584	33	0.0001	0.6538	36	0.0001	0.6912

	Yield (no/ha)														
	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
Month	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	58	0.1153	0.1030	39	0.3324	0.0916	39	0.1956	0.1239	37	0.1512	0.1464	36	0.1595	0.1472
Nov	82	0.0001	0.4240	54	0.0001	0.4085	54	0.0001	0.4463	54	0.0001	0.4766	54	0.1327	0.1050
Dec	82	0.0001	0.4267	54	0.0001	0.4169	54	0.0001	0.4265	54	0.0001	0.4540	54	0.1327	0.1050
Jan	82	0.0001	0.3867	54	0.0001	0.3513	54	0.0001	0.4061	54	0.0001	0.3912	54	0.1017	0.1158
Feb	82	0.0001	0.4312	54	0.0001	0.4196	54	0.0001	0.4993	54	0.0001	0.4594	54	0.0411	0.1508
Mar	82	0.0001	0.3884	54	0.0001	0.3551	54	0.0001	0.4013	54	0.0001	0.4039	54	0.0204	0.1763
Apr	82	0.0001	0.4886	54	0.0001	0.4388	54	0.0001	0.4890	54	0.0001	0.5020	54	0.0001	0.4675
May	52	0.0001	0.6316	32	0.0001	0.7454	33	0.0001	0.7888	33	0.0001	0.6222	36	0.0001	0.6912

(table con'd)

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Size Distribution (% ≥ 32 g)

Month	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	58	0.0001	0.7870	39	0.0001	0.8166	39	0.0001	0.8329	37	0.0001	0.7566	36	0.0001	0.8456
Nov	82	0.0001	0.2892	54	0.0001	0.4259	54	0.0001	0.3969	54	0.0003	0.3122	54	0.0001	0.3613
Dec	82	0.0001	0.2226	54	0.0005	0.2972	54	0.0011	0.2733	54	0.0127	0.1931	54	0.0318	0.1603
Jan	82	0.0001	0.2560	54	0.0002	0.3204	54	0.0001	0.3316	54	0.0066	0.2152	54	0.0233	0.1715
Feb	82	0.0001	0.3652	54	0.0001	0.4393	54	0.0001	0.4345	54	0.0003	0.3139	54	0.0006	0.2912
Mar	82	0.0001	0.4689	54	0.0001	0.4655	54	0.0001	0.5148	54	0.0001	0.3837	54	0.0001	0.4324
Apr	82	0.0001	0.2387	54	0.0008	0.2809	54	0.0004	0.3041	54	0.0207	0.1759	54	0.0014	0.2642
May	52	0.0001	0.5676	32	0.0010	0.4335	33	0.0001	0.6367	33	0.0002	0.4945	36	0.0001	0.5367

Size Distribution (% ≥ 21 g)

Month	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	58	0.0001	0.5913	39	0.0001	0.6185	39	0.0001	0.6191	37	0.0001	0.5821	36	0.0001	0.6770
Nov	82	0.0001	0.2888	54	0.0001	0.4227	54	0.0001	0.4106	54	0.0001	0.3759	54	0.0001	0.3620
Dec	82	0.0003	0.1759	54	0.0013	0.2677	54	0.0086	0.2065	54	0.0172	0.1824	54	0.0632	0.1344
Jan	82	0.0001	0.2449	54	0.0005	0.2967	54	0.0002	0.3273	54	0.0040	0.2321	54	0.0285	0.1643
Feb	82	0.0001	0.3546	54	0.0001	0.4249	54	0.0001	0.4428	54	0.0002	0.3291	54	0.0022	0.2509
Mar	82	0.0001	0.3578	54	0.0001	0.3560	54	0.0001	0.4095	54	0.0016	0.2603	54	0.0005	0.2978
Apr	82	0.0001	0.1509	54	0.0053	0.2226	54	0.0046	0.2271	54	0.0554	0.1395	54	0.0796	0.1255
May	52	0.0001	0.4650	32	0.0093	0.3320	33	0.0001	0.5355	33	0.0014	0.4097	36	0.0007	0.4094

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APPENDIX B: CROSS VALIDATION ITERATIONS FOR THE TEST TRAP PREDICTION MODEL

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Table 33. Cross validation iterations for the test trap prediction model.

	Yield (kg/ha)														
	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
Month	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	59	0.0019	0.2355	39	0.2197	0.1171	39	0.0293	0.2240	37	0.4068	0.0830	37	0.1366	0.1523
Nov	82	0.0369	0.1025	54	0.0909	0.1202	54	0.0935	0.1191	54	0.0177	0.1814	54	0.1368	0.1038
Dec	82	0.0147	0.1253	54	0.0167	0.1835	54	0.0265	0.1670	54	0.0028	0.2438	54	0.0404	0.1514
Jan	82	0.0016	0.1763	54	0.0049	0.2254	54	0.0149	0.1875	54	0.0004	0.3049	54	0.0009	0.2774
Feb	51	0.0007	0.2998	32	0.0113	0.3224	33	0.0004	0.4628	32	0.0062	0.3521	35	0.0089	0.3081

	Yield (no/ha)														
	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
Month	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	59	0.0814	0.1140	39	0.2360	0.1128	39	0.2430	0.1110	37	0.1136	0.1630	37	0.1393	0.1512
Nov	82	0.0001	0.3949	54	0.0001	0.3676	54	0.0001	0.4174	54	0.0001	0.4110	54	0.0001	0.3940
Dec	82	0.0001	0.4714	54	0.0001	0.5071	54	0.0001	0.4903	54	0.0001	0.5424	54	0.0001	0.4812
Jan	82	0.0001	0.5045	54	0.0001	0.4882	54	0.0001	0.5454	54	0.0001	0.5573	54	0.0001	0.4938
Feb	51	0.0001	0.6832	32	0.0001	0.7912	33	0.0001	0.7589	32	0.0001	0.7206	35	0.0001	0.6616

(table con'd)

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	Size Distribution (% ≥ 32 g)														
	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
Month	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	59	0.0001	0.7639	39	0.0001	0.6505	39	0.0001	0.8431	37	0.0001	0.6345	37	0.0001	0.6953
Nov	82	0.0001	0.2435	54	0.0010	0.2763	54	0.0005	0.2952	54	0.0044	0.2290	54	0.0482	0.1448
Dec	82	0.0001	0.2310	54	0.0019	0.2562	54	0.0004	0.3026	54	0.0061	0.2178	54	0.0858	0.1225
Jan	82	0.0004	0.2085	54	0.0064	0.2162	54	0.0006	0.2895	54	0.0160	0.1849	54	0.0724	0.1292
Feb	51	0.0012	0.2832	32	0.0309	0.2679	33	0.0005	0.4519	32	0.0564	0.2327	35	0.0179	0.2739

	Size Distribution (% ≥ 21 g)														
	Full Model			Iteration 1			Iteration 2			Iteration 3			Iteration 4		
Month	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2	N	Pr>F	R^2
Oct	59	0.0001	0.5874	39	0.0001	0.4910	39	0.0001	0.6369	37	0.0001	0.5531	37	0.0001	0.5352
Nov	82	0.0003	0.2112	54	0.0019	0.2557	54	0.0015	0.2621	54	0.0017	0.2592	54	0.1116	0.1120
Dec	82	0.0005	0.2024	54	0.0044	0.2289	54	0.0009	0.2803	54	0.0028	0.2437	54	0.3338	0.0651
Jan	82	0.0103	0.1340	54	0.0668	0.1323	54	0.0037	0.2342	54	0.0950	0.1185	54	0.6016	0.0362
Feb	51	0.0005	0.3122	32	0.0199	0.2925	33	0.0001	0.5039	32	0.0337	0.2630	35	0.0199	0.2687

APPENDIX C: ESTIMATED COSTS AND RETURNS PER HECTARE, RICE-CRAWFISH DOUBLE CROP, OWNER OPERATORS, SOUTHWEST LOUISIANA, 1997

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Table 34. Estimated costs and returns per hectare, rice-crawfish double crop, owner operators, southwest Louisiana, 1997. (Boucher and Gillespie 1997)

ITEM	Stunted Population ($ / ha)	Acceptable Population ($ / ha)	Desirable Population ($ / ha)
Income			
Rice	1005	1005	1005
Crawfish	653	936	1408
Total Income	1658	1941	2413
Total Direct Expenses	1329	1329	1329
Total Fixed Expenses	300	300	300
Total Specified Expenses	1629	1629	1629
Allocated Cost Items			
Overhead (owner)	159	159	159
Land (oppor. costs)	111	111	111
Residual Returns	**-241**	**41**	**513**

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APPENDIX D: LINEAR REGRESSION COEFFICIENTS OF THE DIP-NET SWEEP, TEST TRAP CATCH, AND DROP SAMPLER CATCH PREDICTION MODELS

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Table 35. Linear regression coefficients for the dip-net sweep, test trap and drop sampler predictive model equations. (Model: $Y = \beta_0 + \beta_1(X) + \beta_2(X^2) + \beta_3(M.Y.)$)

	Independent	Dependent		Min-Max		Regression Coefficients			
Gear[1]	Variable (X)	Variable (Y)	Month	for X	M.Y.[a]	β_0	β_1	β_2	β_3
DNS	no/sweep	no/ha	Nov	0 - 4.3	3.0	59121	12279	-2587	-6310
DNS	no/sweep	no/ha	Dec	0 - 3.0	3.0	54475	21373	-7121	-5100
DNS	no/sweep	no/ha	Jan	0 - 4.2	3.0	66165	2109	-178	-7008
DNS	no/sweep	no/ha	Feb	0 - 4.0	3.0	58283	7375	-358	-5960
DNS	no/sweep	% ≥ 32 g	Oct	0 - 1.9	2.5	13.50	-34.51	8.21	11.34
DNS	no/sweep	% ≥ 32 g	Nov	0 - 4.3	3.0	20.57	-21.46	3.94	4.11
DNS	no/sweep	% ≥ 32 g	Jan	0 - 4.2	3.0	16.08	-12.26	1.57	4.04
DNS	no/sweep	% ≥ 32 g	Feb	0 - 4.0	3.0	37.99	-36.88	7.75	1.81
DNS	no/sweep	% ≥ 21 g	Oct	0 - 1.9	2.5	62.12	-47.59	10.65	5.93
DNS	no/sweep	% ≥ 21 g	Nov	0 - 4.3	3.0	65.67	-34.08	5.74	0.93
DNS	no/sweep	% ≥ 21 g	Feb	0 - 4.0	3.0	85.82	-47.84	8.90	-1.94
TT	no/trapset	no/ha	Nov	0 - 11.7	3.0	65136	1913	-124	-6958
TT	no/trapset	no/ha	Dec	0 - 24.0	3.0	53982	3427	-144	-4969
TT	no/trapset	no/ha	Jan	0.1 - 27.0	3.0	49632	4180	-149	-3498
TT	no/trapset	no/ha	Feb	0 - 27.0	3.0	74944	4204	-129	-10617
TT	no/trapset	% ≥ 32 g	Oct	0 - 4.4	2.5	6.21	-15.98	1.96	13.17
TT	no/trapset	% ≥ 32 g	Feb	0 - 27.0	3.0	107.35	-9.07	0.24	-12.89
TT	no/trapset	% ≥ 21 g	Oct	0 - 4.4	2.5	53.47	-25.24	3.49	8.42
TT	no/trapset	% ≥ 21 g	Feb	0 - 27.0	3.0	137.33	-10.95	0.28	-12.85
DRPS	no/0.5m²	kg/ha	Oct	0 - 9.6	2.5	3044.08	-323.65	18.86	-451.50
DRPS	no/0.5m²	kg/ha	Nov	0.4 - 9.7	3.0	2589.22	-142.20	6.95	-327.56
DRPS	no/0.5m²	kg/ha	Dec	0.4 - 12.8	3.0	2376.94	-147.44	9.01	-285.41
DRPS	no/0.5m²	kg/ha	Jan	0.1 - 10.3	3.0	2755.80	-158.24	8.14	-395.79
DRPS	no/0.5m²	kg/ha	Feb	0-10.0	3.0	2630.67	-165.23	9.33	-350.40
DRPS	no/0.5m²	no/ha	Oct	0 - 9.6	2.5	123743	2798	-635	-21826
DRPS	no/0.5m²	no/ha	Nov	0.4 - 9.7	3.0	92251	4282	-405	-13938
DRPS	no/0.5m²	no/ha	Dec	0.4 - 12.8	3.0	77757	-155	183	-9814
DRPS	no/0.5m²	no/ha	Jan	0.1 - 10.3	3.0	99805	2138	-235	-14541
DRPS	no/0.5m²	no/ha	Feb	0-10.0	3.0	78985	108	138	-10017
DRPS	no/0.5m²	% ≥ 32 g	Oct	0 - 9.6	2.5	73.20	-28.74	2.24	-2.05
DRPS	no/0.5m²	% ≥ 32 g	Nov	0.4 - 9.7	3.0	110.88	-24.24	1.75	-10.00
DRPS	no/0.5m²	% ≥ 32 g	Dec.	0.4 - 12.8	3.0	114.62	-15.30	0.71	-13.32
DRPS	no/0.5m²	% ≥ 32 g	Feb	0-10.0	3.0	134.73	-16.78	0.76	-19.01
DRPS	no/0.5m²	% ≥ 21 g	Oct	0 - 9.6	2.5	133.64	-38.65	2.95	-10.31
DRPS	no/0.5m²	% ≥ 21 g	Nov	0.4 - 9.7	3.0	150.82	-25.16	1.67	-13.52
DRPS	no/0.5m²	% ≥ 21 g	Dec	0.4 - 12.8	3.0	153.02	-16.80	0.72	-16.44
DRPS	no/0.5m²	% ≥ 21 g	Feb	0-10.0	3.0	181.18	-19.25	0.83	-23.82
DRPS	g/0.5m²	kg/ha	Nov	0.6 - 20.7	3.0	2902.80	-128.38	4.43	-392.49
DRPS	g/0.5m²	kg/ha	Dec	0.7 - 33.6	3.0	2386.06	-71.35	1.88	-298.72
DRPS	g/0.5m²	kg/ha	Feb	0.6 - 48.0	3.0	2781.33	-49.43	0.72	-375.17
DRPS	g/0.5m²	no/ha	Oct	0 - 9.3	2.5	132078	1204	-587	-23493
DRPS	g/0.5m²	no/ha	Nov	0.6 - 20.7	3.0	79254	-1641	137	-9286

[1] DNS = Dip-net Sweeps, TT = Test Trap, DRPS = Drop Sampler
[a] Median year value

(table con'd)

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Gear[1]	Independent Variable (x)	Dependent Variable (Y)	Month	Min-Max for x	M.Y.[a]	Regression Coefficients βo	β1	β2	β3
DRPS	g/0.5m²	no/ha	Dec	0.7 - 33.6	3.0	55553.00	-289.00	55.00	-4492.00
DRPS	g/0.5m²	kg/ha	Jan	0.1 - 42.4	3.0	2735.48	-44.18	0.61	-392.14
DRPS	g/0.5m²	no/ha	Jan	0.1 - 42.4	3.0	97851.00	-484.00	14.00	-13558.00
DRPS	g/0.5m²	no/ha	Feb	0.6 - 48.0	3.0	83280.00	135.00	6.00	-10975.00
DRPS	g/0.5m²	% ≥ 32 g	Nov	0.6 - 20.7	3.0	157.46	-9.41	0.20	-23.84
DRPS	g/0.5m²	% ≥ 32 g	Feb	0.6 - 48.0	3.0	141.93	-5.05	0.06	-19.84
DRPS	g/0.5m²	% ≥ 21 g	Nov	0.6 - 20.7	3.0	208.97	-11.20	0.24	-29.59
DRPS	g/0.5m²	% ≥ 21 g	Dec	0.7 - 33.6	3.0	192.88	-7.32	0.11	-27.53
DRPS	g/0.5m²	% ≥ 21 g	Feb	0.6 - 48.0	3.0	192.89	-5.96	0.07	-25.37

[1] DNS = Dip-net Sweeps, TT = Test Trap, DRPS = Drop Sampler

[a] Median year value

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VITA

Jimmy Lee Avery was born on October 23, 1958 in Greenville, Mississippi, the son of Venita Sue and Bobby Lee Avery. He attended Cleveland High School in Cleveland, Mississippi, and graduated in May 1976.

He was admitted into the University of Mississippi in September of 1976. In May of 1980 he graduated with a Bachelor of Arts degree in Zoology and a minor in Computer Science.

He was admitted into Delta State University at Cleveland, Mississippi, in June 1980. In August 1982 he graduated with a Master of Science degree in Interdisciplinary Biology with a specialization in fisheries. The title of his thesis was "Fisheries Assessment of Lake Bolivar County: a Weed-Infested Lake".

Upon graduation he was employed by the Mississippi State University, School of Veterinary Medicine, Field Research Laboratory, Stoneville, Mississippi, where he served as Research Associate in the field of channel catfish disease research.

In November 1985 he was hired by the Louisiana Cooperative Extension Service as an Aquaculture Area Agent for northeastern Louisiana. In July 1990 he was transferred to the State Office of the Louisiana Cooperative Extension Service to work statewide on aquaculture issues and is currently responsible for educational efforts in crustacean aquaculture.

He enrolled in the Graduate Program of the School of Forestry, Wildlife and Fisheries at Louisiana State University in September 1990, where he is currently a candidate for the degree of Doctor of Philosophy in Wildlife and Fisheries Science.

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DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Jimmy L. Avery

Major Field: Wildlife and Fisheries Science

Title of Dissertation: Evaluation of Sampling Gear for Predicting Harvest Size, Yield and Incidence of Stunting in Crawfish Ponds

Approved:

Robert P. Romaire
Major Professor and Chairman

[signature]
Dean of the Graduate School

EXAMINING COMMITTEE:

Robert C. Reigh

Terence Tiersch

William B. Stickle Jr.

James Avault

W. Ray McClain

Date of Examination:

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