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The effects of bait type, trap-soak duration, and trap modification on harvest of red swamp crawfish

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THE EFFECTS OF BAIT TYPE, TRAP-SOAK DURATION, AND TRAP MODIFICATION ON HARVEST OF RED SWAMP CRAWFISH

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ABSTRACT

The effects of bait type, trap-soak duration, and a trap entrance modification were evaluated from February through May 2008 in a 1.29 ha crawfish (red swamp crawfish, *Procambarus clarkii*) pond in southwest Louisiana. Commercial pyramid traps with three entrance funnels, 1.9-cm square-mesh vinyl-coated welded metal wire, were used. In trial 1, crawfish catch was evaluated in traps baited with Atlantic menhaden (*Brevoortia tyrannus*), a formulated dry bait, or a menhaden+formulated bait mixture, each at 24-h and 48-h soak durations. In trial 2, the escape of marked crawfish was evaluated in the presence or absence of bait at 24-h and 48-h soak durations. In trial 3, the catchability of traps with modified entrances, designed to reduce crawfish escape, were evaluated at 24-h and 48-h trap-soak durations.

In trial 1, menhaden alone was the most effective bait in February and March, all baits were equally effective in April, and the formulated bait alone was most effective in May. Overall, crawfish catch per unit effort (CPUE) with a 24-h soak duration was 36% and 27% higher in number and weight than the 48-h soak. Mean crawfish size increased when trap-soak duration was increased from 24-h to 48-h. In trial 2, traps containing “no marked crawfish” caught significantly more crawfish in both number (37%) and weight (30%) than traps with marked crawfish indicating that the presence of crawfish in traps prior to baiting decreased catch. Mean crawfish escape from traps ranged from 29 to 34%, and the presence or absence of bait had no significant effect on escape; however, the mean escape rate following a 48-h trap-soak duration (39%) was nearly twice that of a 24-h soak (22%). Crawfish CPUE with modified traps was 20% higher with a 48-h trap-soak duration. Modification of the trap entrance funnels with plastic cable ties appeared to reduce the rate of crawfish egress from the traps between 24-h and 48-h.

INTRODUCTION

The Louisiana crawfish industry is the only large-scale freshwater crustacean aquaculture enterprise in North America, with an estimated 1,300 farmers harvesting nearly 50,000 MT of red swamp crawfish, *Procambarus clarkii* (Girard, 1852) and white river crawfish, *Procambarus zonangulus* (Hobbs & Hobbs, 1990) in 68,000 ha of managed impoundments, located principally in south-central and southwest Louisiana, USA (Louisiana State University Agricultural Center 2009). Producers use extensive cultivation practices in which self-sustaining populations of crawfish are maintained in earthen impoundments managed as temporary-wetlands to simulate the natural hydrological cycle in south-central Louisiana. Commercial procambarid crawfish aquaculture practices in Louisiana are reviewed by McClain et al. (2007).

Procambarid crawfishes in Louisiana production ponds are harvested commercially with traps baited with fish or formulated attractants, starting as early as November and often terminating by June. Maximum harvesting effort usually occurs in March, April, and May when the standing crop of harvestable size animals is highest, and traps during this period are usually baited and emptied several or more days per week (Romaire 1995; Romaire et al. 2004). Because of the extended harvest season and intense trapping effort, harvesting accounts for at least half of the total direct expense (TDE) in procambarid crayfish aquaculture systems. Bait (22-30% TDE) and labor (16-20% TDE) are also major costs (Boucher and Gillespie 2008).

Although numerous studies have been conducted by Louisiana State University Agricultural Center scientists to evaluate crawfish traps, baits, and trapping protocols with the goal of improving harvesting efficiency (Pfister and Romaire 1983; Romaire and Pfister 1983; Romaire and Osorio 1989; Belhadjali 1994; Huner et al. 1990; Beecher 1996), these studies were conducted with commercial traps constructed from 1.9-cm diameter twisted hexagonal mesh

(“hex mesh”) vinyl-coated poultry netting (wire). Traps made with hex-mesh poultry wire have now been largely replaced in the industry with traps made from 1.9-cm square-mesh welded wire, which provides superior catch (McClain et al. 2003). Thus, previous crawfish aquaculture harvesting recommendations based on the use of hex-mesh traps should be re-assessed with new studies conducted using traps made from square-mesh welded wire.

A problem common to all commercial procambarid crawfish traps evaluated to date is the escape of marketable crawfish after having entered a trap (Pfister and Romaire 1983). Rate of escape increases with trap-soak duration (defined as the time elapsed between baiting the trap and lifting it from the water and removing the catch) (Pfister and Romaire 1983). Different trap entrance funnel configurations designed to potentially minimize the escape of astacid crayfishes (Westman et al. 1978; Fjalling 1995) have been evaluated. These studies demonstrated that although some funnel entrance modifications reduced escape, they also often impeded the ingress of animals into the traps thereby resulting in no net increase in catch. The purpose of this research was to evaluate baits, crawfish escape rates, and a trap design with modified entrances, using commercial crawfish traps made from 1.9-cm square-mesh vinyl-coated welded metal wire, with the goal to identify more cost-efficient trapping protocols that could be extended to the commercial crawfish aquaculture industry. Specific objectives were addressed in three harvesting trials: (1) trial 1 - evaluate seasonal crawfish catch in commercial square-mesh pyramid traps baited with a fish bait, a formulated bait or a fish+formulated bait mixture each at 24-hour and 48-hour trap-soak durations; (2) trial 2 - to assess the retentive ability of commercial square-mesh pyramid traps in the presence or absence of bait at 24- and 48-hour trap-soak durations; and (3) trial 3 - to determine the catchability of commercial square-mesh traps with modified entrance funnels compared to standard commercial traps.

MATERIALS AND METHODS

Location and Management

The study was conducted in a 1.29-ha commercial crawfish pond (Figure 1) located in southwest, Louisiana, USA, 15 km southwest of Kaplan (29^{o}56'19.83"N, 92^{o}20'49.92"W) from February 19 through May 28, 2008. The pond had been managed as a single-crop production system (McClain et al. 2007) since 2004. In preparation for the three harvesting trials, the pond was drained slowly over 2 weeks starting July 1, 2007 to induce burrowing. No crawfish broodstock were added prior to draining because sufficient adult crawfish remained in the pond following harvest from the preceding production season. Japanese millet (*Echinochloa frumentacea*) was planted as forage for the crawfish by aerially seeding 39 kg seed per ha to the dry pond bottom on October 3, 2007. The pond was filled with surface water from an adjacent water drainage ditch to a mean depth of 69 cm on November 12, 2007, and water was added as needed to maintain water depth and sustain acceptable oxygen concentrations for the crawfish. Water temperature was recorded continuously at a depth of 35 cm with a continuous temperature datalogger (HOBO, BoxCar Pro version 4.0.7.0, Onset Computer Corporation, Bourne, MA, USA).

Traps were placed in the pond in February 2008 at a density of 50 per ha (64 traps in 1.29 ha), and as many as 64 traps were used in the harvesting trials. Traps were the commercial “pyramid” design (Romaire et al. 2004) with three entrance funnels and a 15-cm long by 18-cm diameter vertical trap extension (1.9-cm x 1.9-cm vinyl-coat square-mesh welded metal wire) attached to the basket (Figure 2). A plastic handle/anti-escape collar (15-cm long x 10-cm diameter) was attached to the extension. Overall trap dimensions were nominally 45-cm wide at the base x 70-cm high. The construction material was 1.9-cm square-mesh, 18-gauge

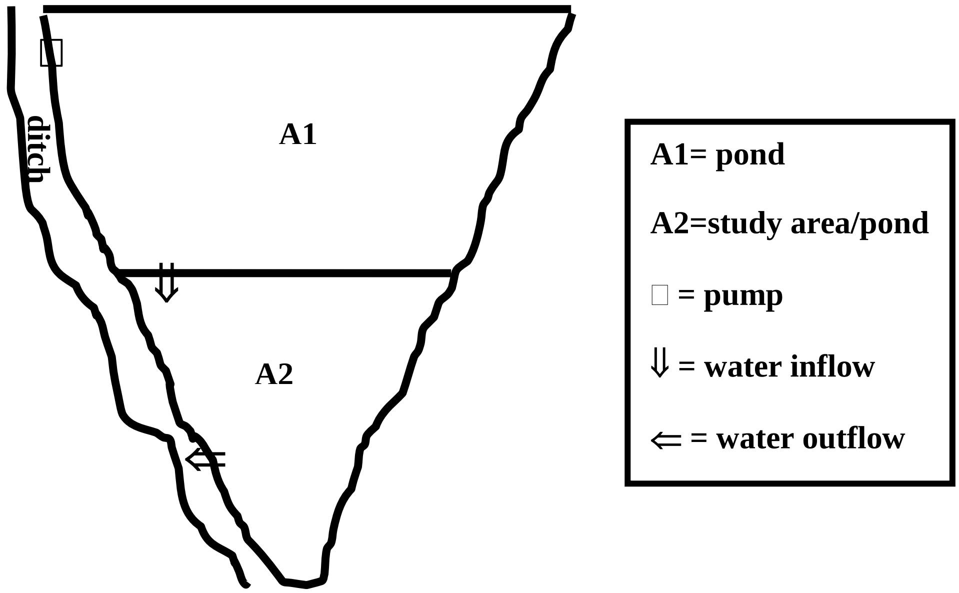

Figure 1. Schematic diagram of the 1.29 hectare crawfish pond (A2) used in the harvesting study. Pond A1 was included in the figure to depict how the study pond received its water from an adjacent drainage ditch.

Figure 2. Three-entrance-funnel pyramid trap used in the three crawfish harvesting trials.

diameter x 15-cm deep x 5.0-cm inner diameter. Crawfish traps were placed in rows with one row around the pond perimeter (34 traps), and four interior rows with 8, 9, 5, and 8 traps in these rows (30 traps). Spacing between individual traps and trap rows was about 8.6 m and 9 m, respectively. Traps were baited and harvested using a hydraulic powered rear-wheel boat (McClain et al. 2007). Baits were Atlantic menhaden (*Brevoortia tyrannus*) and/or commercially available formulated crawfish bait (Land-O-Lakes Crispy Crunch, Shreveport, Louisiana). Frozen menhaden was obtained from a local crawfish bait supplier weekly and was thawed and cut prior to use. Formulated crawfish bait was purchased weekly at a local feed store. Three separate harvesting trials were conducted, with each trial conducted once per week at three-week intervals, for a total of 15 weeks.

Bait Type x Trap-Soak Duration Trial

The bait type x trap-soak duration trial evaluated crawfish catch per-unit-trap effort (CPUE) for two baits (menhaden, formulated bait) and a bait combination (bait mixture) consisting of equal amounts of menhaden and formulated bait (menhaden+formulated bait), each at two trap-soak durations (24-h or 48-h soak), for a total of six bait type x trap-soak duration treatment combinations. The bait type x trap-soak duration trial was conducted at 3-week intervals from 20 February to 17 May for a total of 5 sample periods. The six treatment combinations were randomly assigned to 60 traps (with aid of a statistical random numbers table) with 10 replicates (traps) per treatment combination, and the treatments were re-randomized on each sampling date. A nominal bait quantity of 150 g per trap was used for both menhaden and formulated bait, and nominally 75 g each of menhaden plus formulated bait per trap for the menhaden+formulated bait combination for a total of 150 g (Beecher 1996). Traps were baited between 1000 and 1530 hours, and the content of each trap was emptied, after either 24-h or 48-

h, into individual containers and total weight (to the nearest gram) and number of crawfish in each trap were recorded. Mean size of crawfish per trap was determined by dividing the total weight of crawfish caught per trap by the number of crawfish in the trap.

Crawfish Retention Trial

The experimental treatments were as described in the "bait type x trap-soak duration" trial with the inclusion of a non-baited trap treatment. The eight bait x trap-soak duration treatment combinations were randomly assigned to 64 traps (8 replicate traps per bait x trap-soak duration combination), and re-randomized on each sampling date. Ten crawfish, with distinguishing marks to represent each of the 8 treatment combinations, were added, immediately prior to baiting, to each of four traps selected at random from the eight replicate traps assigned to each bait x trap-soak duration treatment combination. Marked crawfish were not added to the remaining four replicate traps. The experimental protocol was conducted at 3-week intervals from 7 March to 28 May for a total of 5 sample periods.

The traps were baited 1 day prior to implementation of the experimental trapping protocol to obtain 320 crawfish for marking. Each crawfish was marked with a non-toxic waterproof paint marker pen (Brite-Mark 40 valve action paint marker, ITW Mark-Tex, Olathe, KS 66061) with a symbol specific to each treatment combination, and a different color was used on each of the 5 sampling periods (Ramalho et al. 2008). Different color and symbol marks allowed for identification of marked crawfish that may have escaped, and entered other traps, from the same or previous repetition of the trial. Crawfish were marked on the dorsal plane of the carapace (Figure 3) and placed into the traps when bait was added. After the assigned trap-soak duration, traps were lifted, emptied, and the total weight and number of crawfish in each trap were recorded as well as the number of marked crawfish present in the trap. The number of

Figure 3. Marked crawfish used in trap retention trial. Different symbols represent a different bait x soak-duration treatment combination, and different colors represented study periods (weeks).

marked crawfish present in individual traps was used to determine the percentage escape rate at either 24-h or 48-h. When dead marked crawfish were found in the traps in which they were placed, the escape rate calculations were adjusted for death loss.

Modified Trap Trial

The modified trap trial compared the CPUE of the commercial style pyramid traps used in the preceding two trials (control traps) to traps with modified entrance funnels (experimental traps). The modified traps were identical to the control traps except each of the three inner funnel openings were modified by placing six, 10-cm long plastic cable ties (General Electric # 51229; GTIN # 00043180512291) on each funnel opening (Figures 4 and 5). Cable ties were anchored to the wire that formed the border of the inner funnel entrance, with the un-attached ends (“fingers”) angled toward the interior of the trap to form a flexible cone that narrowed the opening into the interior of the trap. The concept of the function of the cable ties is they would constrict the opening of the trap entrance funnels and thus minimize escape of animals that entered the trap, while not impeding ingress of crawfish into the trap.

Forty traps were used in the trial, 20 control traps and 20 experimental traps. All traps were baited with 150 g of the menhaden+formulated bait combination as described in the “bait type x trap-soak duration trial”. Ten randomly selected control traps and 10 experimental traps were emptied after a 24-h soak and the remainder emptied after 48-h. The content of each trap was emptied into a separate container and total weight and number of crawfish in each trap were recorded. The experimental protocol was conducted at 3-week intervals from 3 March 2008 to 28 May 2008 for a total of 5 sample periods, and on each sampling period the traps assigned to 24-h or 48-h soak durations were re-randomized.

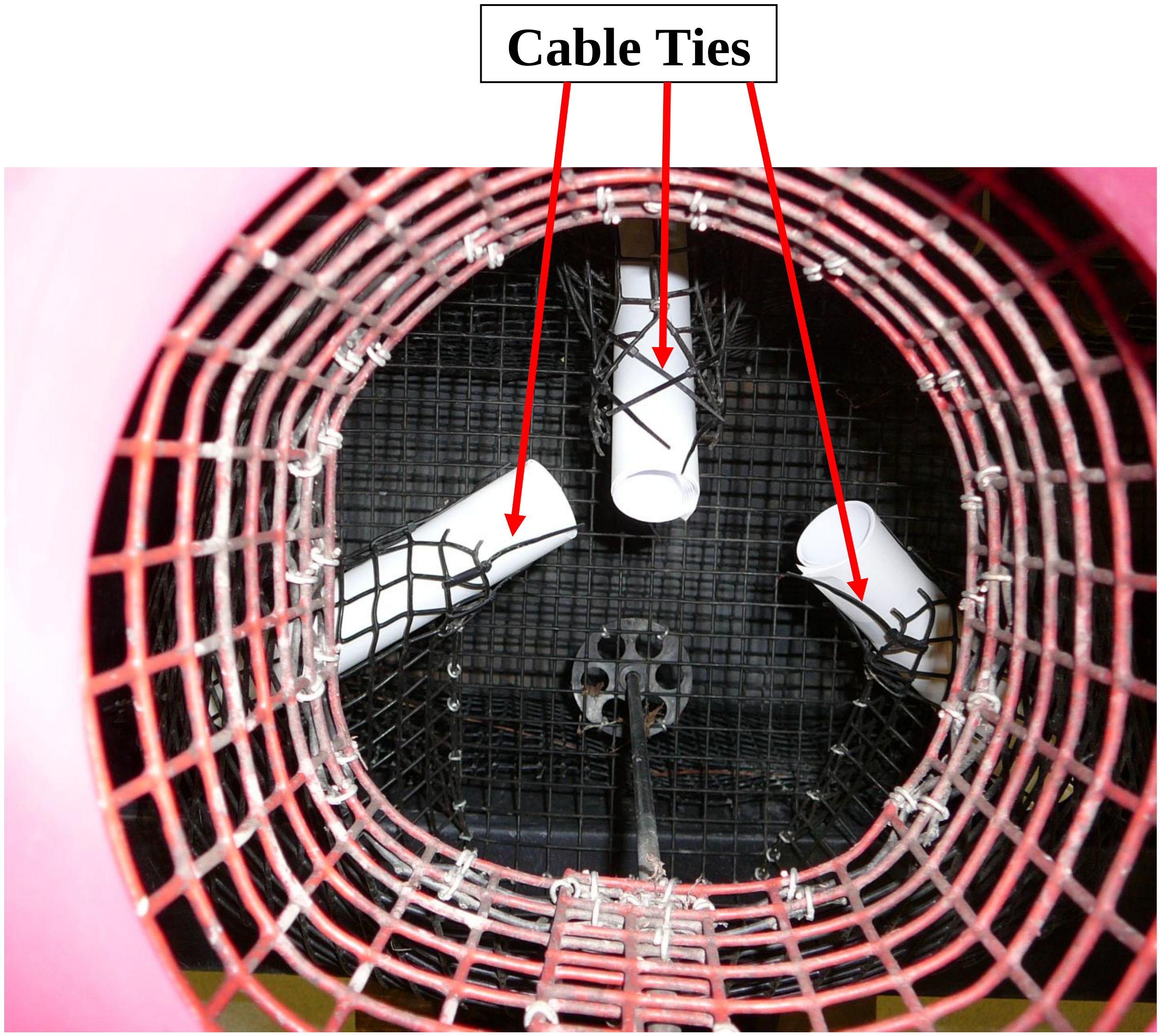

Figure 4. Interior of a modified three-funnel pyramid crawfish trap. White tubes demarcate the interior of the three entrance funnels. Black cable ties are attached along the circumference of the interior entrance funnels projecting inward into the trap.

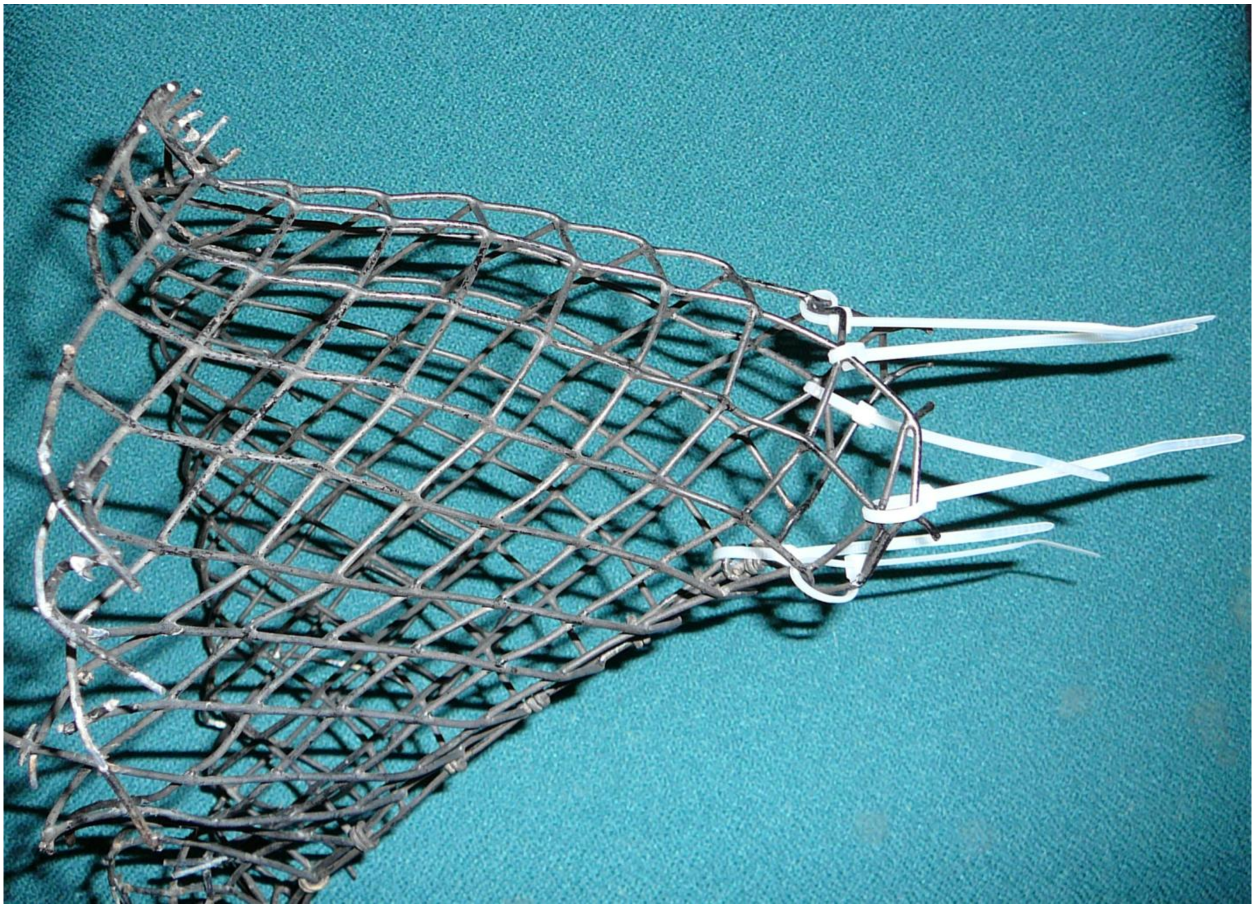

Figure 5. Modified entrance funnel removed from a three-funnel commercial pyramid trap. White cable ties are attached along the circumference of the interior entrance funnel for photographic purposes only. Black cable ties were attached to the three-funnel pyramid traps used in the modified trap trial.

Data Analysis

Data from the three trials were analyzed with the analysis of variance (ANOVA) using the general linear models (GLM) procedure with the Micro-SAS Statistical Software System (Version 9.1, SAS Institute, Cary, North Carolina, USA). The bait type x trap-soak duration trial was a completely randomized repeated measures design with a 3 x 2 factorial arrangement of treatments (main effects=bait type and trap-soak duration; repeated measure=week; experimental unit=trap). The crawfish retention trial was a completely randomized repeated measures design with a 4 x 2 x 2 factorial arrangement of treatments (main effects= bait type, trap-soak duration, and presence or absence of marked crawfish; repeated measure=week; experimental unit=trap). The modified trap trial was a completely randomized repeated measures design with a 2 x 2 factorial arrangement of treatments (main effects=trap type and trap-soak duration; repeated measure=week; experimental unit=trap). Response variables common to all three experimental trials were CPUE for number (number crawfish/trap/soak duration) and weight (g/ crawfish/trap/soak duration), and mean individual harvest weight or "size" (g/crawfish). In the crawfish retention trial, the percentage of marked crawfish that escaped, adjusted for the death of any marked crawfish in a trap in which it was placed, was also determined and used as response variable in the ANOVA. Duncan's New Multiple Range Test was used to test for statistical differences in treatment means in the experimental trials, and differences were declared significant at $\alpha \leq 0.05$. Additionally, for the crawfish retention trial, a simple linear regression analysis (PROC GLM) was conducted to determine if there was a relationship between the number of crawfish that entered traps (dependent variable) and the number of dead marked crawfish present in a trap (independent variable).

RESULTS

Bait Type x Trap-Soak Duration Trial

Mean daily water temperature ranged from 15.5^{o}C on 20 February to 21.7^{o}C on 16 May (Figure 6). Mean CPUE and individual mean harvest size was highest in February, and both catch and size progressively decreased through the harvesting season to termination of the trial in May (Figure 7).

Overall, traps baited with a combination of menhaden+formulated bait captured 16% more crawfish in both number and weight than formulated bait alone ($P < 0.05$; Table 1) but the CPUE for the menhaden+formulated bait mixture did not significantly differ from traps baited with menhaden, nor did the CPUE differ among traps baited with menhaden alone or formulated bait ($P>0.05$; Table 1). Mean size of crawfish was small, averaging near 10 g per individual crawfish. Bait type did not have any significant effect on mean individual harvest size of crawfish captured in pyramid traps ($P>0.05$). Although the menhaden+formulated bait combination had the overall highest catch, the efficacy of baits changed during the season, presumably in response to changes in water temperature (Figure 7) and crawfish population structure and density. Traps containing menhaden or menhaden+formulated bait had a 17 to 24% higher CPUE in February and March when water temperatures were cooler (15.5 to 17.2^{o}C). In contrast, traps with formulated bait had a higher CPUE than menhaden when used singly later in the season (Apr 25 and May 16) when water temperature was warmer (> 24^{o}C). On April 2, when water temperature was about 25^{o}C, all baits performed similarly relative to their ability to attract and retain crawfish with no bait being superior to any other.

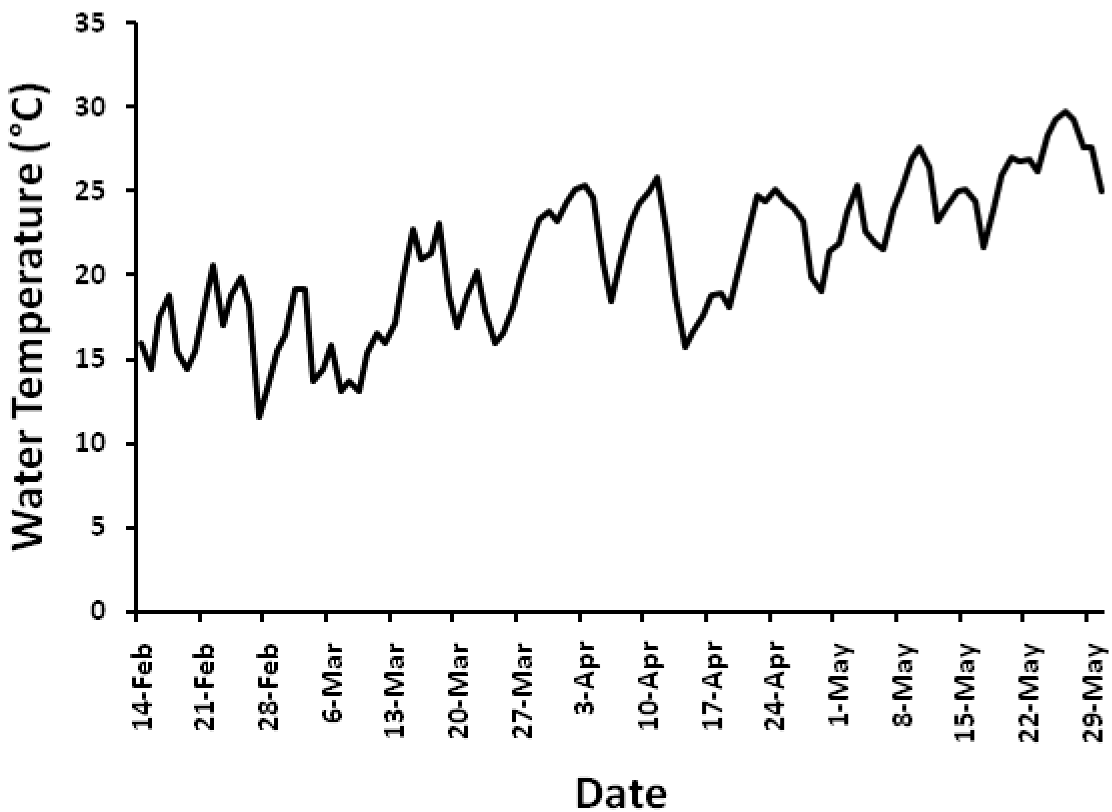

Figure 6. Mean daily water temperature in crawfish pond used in the three crawfish harvesting trials.

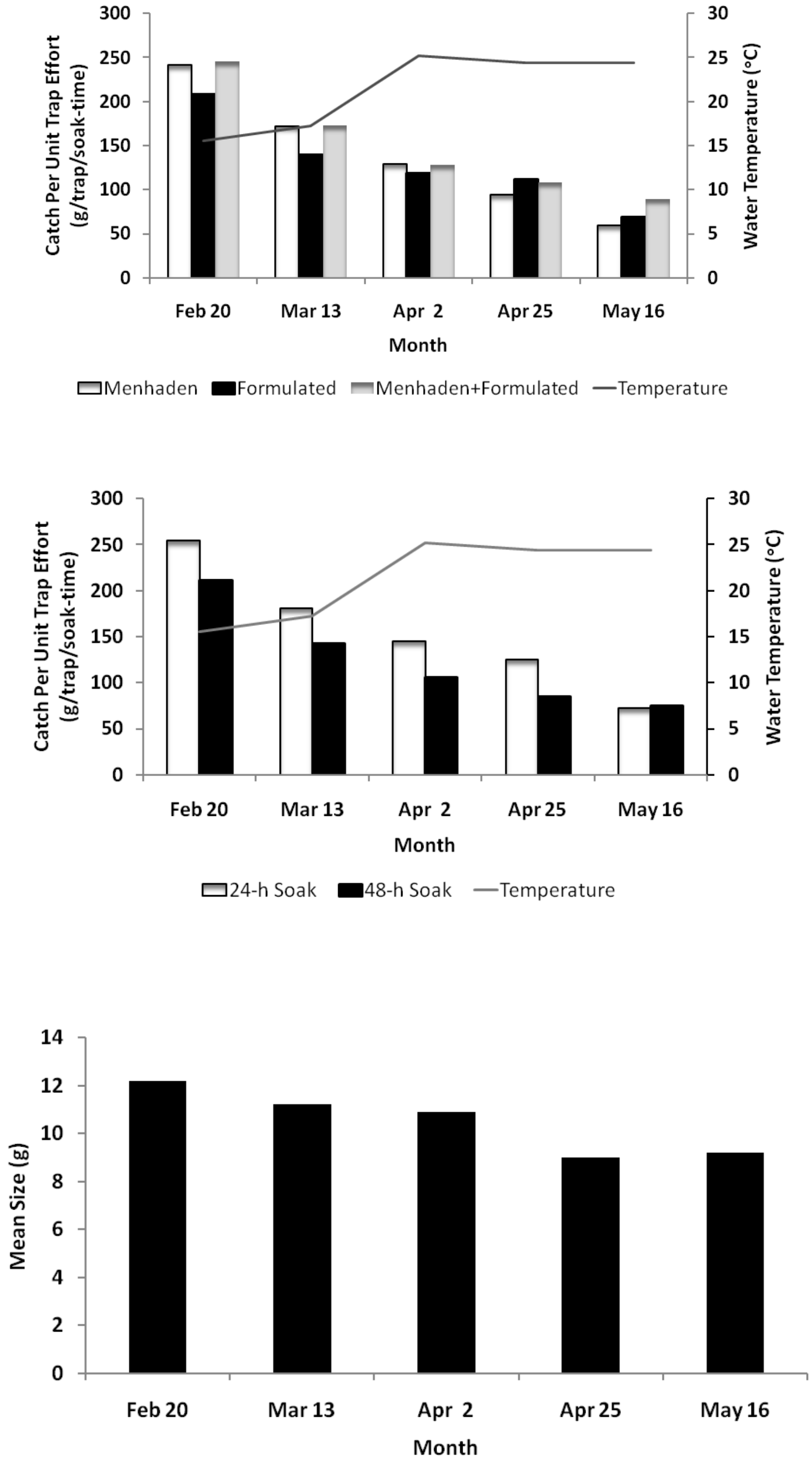

Figure 7. Temporal changes in crawfish catch per unit effort (weight/trap/soak) and mean individual harvest size in the bait type x trap-soak duration trial. Bait type was averaged over the two trap-soak durations, trap-soak duration was averaged over the three bait types, and crawfish size was averaged over bait types and trap-soak durations.

Table 1. Mean (±SD) crawfish catch per unit effort (number and weight of crawfish caught per trap per soak-duration) and mean individual harvest size of crawfish caught in 1.9-cm square-mesh pyramid traps in the bait type x trap-soak duration trial.

Bait Type	Soak Duration: 24 hours No/trap	24 hours Wt/trap (g)	24 hours Mean Size (g)	48 hours No/trap	48 hours Wt/trap (g)	48 hours Mean Size (g)	Grand Mean[1] No/ trap	Grand Mean[1] Wt/trap (g)	Grand Mean[1] Mean Size (g)
Menhaden +Formulated	16±7	167±87	9.9±1.7	12±5	129±71	10.9±1.7	14±7[a]	148±81[a]	10.4±1.7[a]
Formulated	14±7	141±71	9.8±1.7	10±5	114±69	11.1±2.0	12±6[b]	128±71[b]	10.5±1.9[a]
Menhaden	15±8	157±104	10.0±1.8	11±6	123±74	11.2±2.7	13±7[a,b]	140±91[a,b]	10.6±2.4[a]
Grand Mean[2]	15±7[x]			11±5[y]					
Grand Mean[2]		155±88[x]			122±71[y]				
Grand Mean[2]			9.9±1.7[x]			11.1±2.2[y]			

[1]Means with different superscript letters are significantly different at P $\leq$ 0.05, vertical comparisons only.
[2]Means with different superscript letters are significantly different at P $\leq$ 0.05, horizontal comparisons only.

Trap-soak duration had a significant influence on CPUE and mean crawfish harvest size throughout the trial, and its overall impact on CPUE was higher than for bait type. A 24-h trap soak, averaged across the three baits, resulted in a 36% and 27% higher CPUE in number and weight, respectively, than the 48-h soak ($P<0.05$; Table 1) and the higher CPUE observed with 24-h soaks was consistent among bait types from 20 February through 25 April, regardless of changes in water temperature and crawfish population dynamics (Figure 7). Overall, the mean CPUE (weight) declined nearly 21% and mean crawfish size increased 12% when the trap-soak duration was increased from 24 to 48-h.

Crawfish Retention Trial

Water temperature ranged from 15.5^{o}C on 29 Feb to 29.3^{o}C on 25 May (Figure 6). Mean CPUE was highest on 29 February, and then declined nearly 50% on 21 March where it remained relatively constant before increasing on the last sampling date in late May (Figure 8). Mean individual harvest size was largest in late February at initiation of the trial and size declined thereafter (Figure 8).

CPUE for the bait and trap-soak duration treatment combinations for traps containing no marked crawfish or 10 marked crawfish (Tables 2 and 3) was similar to that observed in the bait type x trap-soak duration trial. As anticipated, non-baited traps containing no marked crawfish had a significantly lower CPUE than baited traps with no marked crawfish and seldom averaged over 1 crawfish per trap (Tables 2 and 3). In traps containing no marked crawfish, the CPUE (number and weight) was 15 to 28% higher with the menhaden+formulated bait combination than with menhaden or formulated bait used singly ($P<0.05$), and no difference in CPUE was observed between menhaden and formulated bait ($P >0.05$; Table 2). In traps containing 10

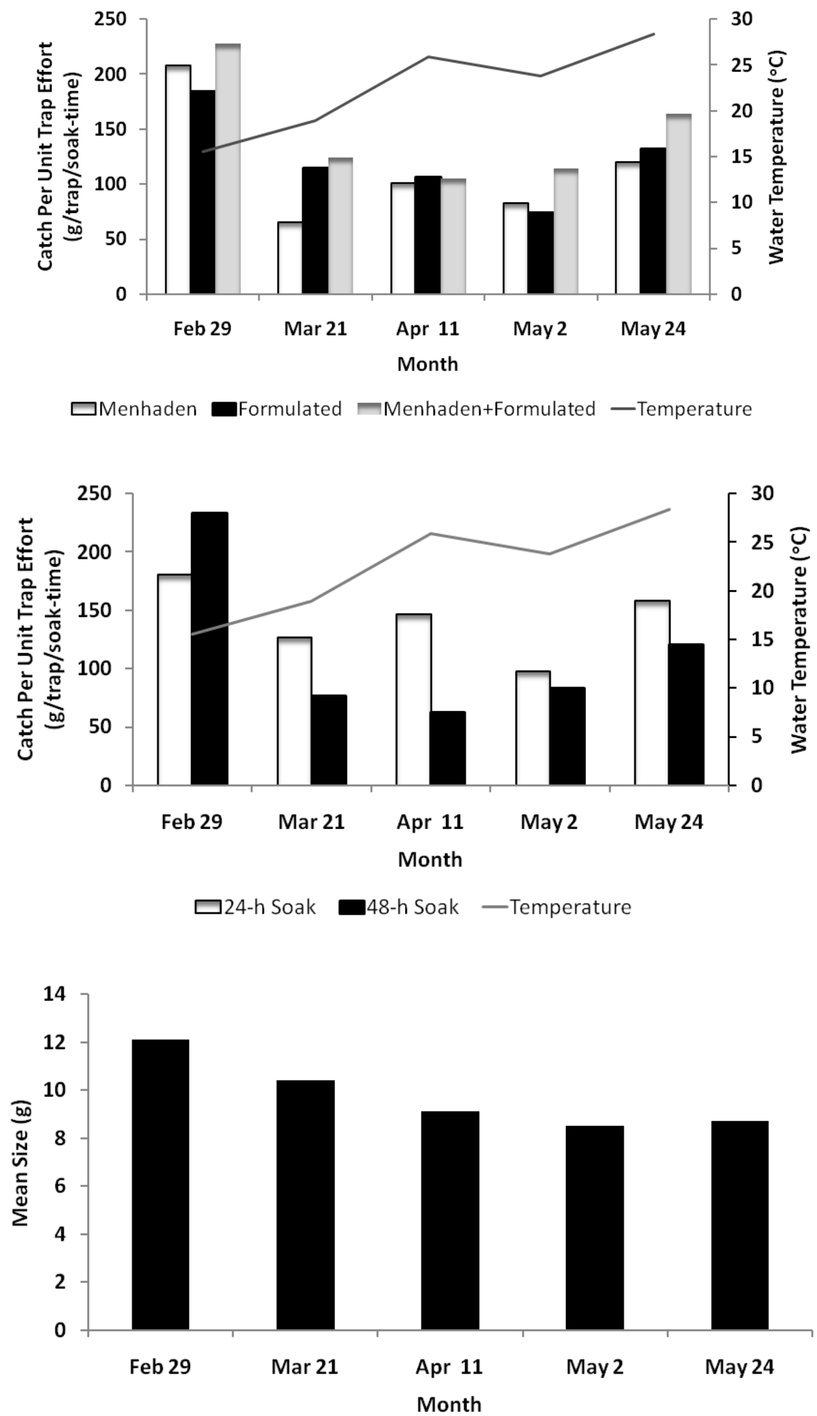

Figure 8. Temporal changes in crawfish catch per unit effort (weight/trap/soak) and mean individual harvest size in the crawfish retention trial. Bait type was averaged over the two trap-soak durations, trap-soak duration was averaged over the three bait types, and crawfish size was averaged over bait types and trap-soak duration.

Table 2. Mean (±SD) crawfish catch per unit effort (number and weight of crawfish caught per trap per soak-duration) and mean individual harvest size of crawfish caught in 1.9-cm square-mesh pyramid traps containing *no marked crawfish* in the crawfish retention trial.

	Soak Duration								
	24 hours			48 hours			Grand Mean[1]		
Bait Type	No/trap	Wt/trap (g)	Mean Size (g)	No/trap	Wt/trap (g)	Mean Size (g)	No/ trap	Wt/trap (g)	Mean Size (g)
Menhaden +Formulated	17±5	164±58	9.5±1.3	12±6	129±81	10.6±1.8	15±6[a]	147±71[a]	10.0±1.7[a]
Formulated	16±6	139±51	9.0±1.2	10±5	105±69	10.8±1.9	13±6[b]	122±62[b]	9.9±1.9[a]
Menhaden	13±7	121±73	8.9±2.0	11±6	109±79	9.8±1.8	12±6[b]	115±75[b]	9.4±1.9[a]
No Bait	1±1	8±11	9.0±2.5	1±1	13±9	10.5±5.4	1±1[c]	11±10[c]	10.0±4.5[a]
Grand Mean[2]	15±6[x]			11±6[y]					
Grand Mean[2]		141±63[x]			115±76[y]				
Grand Mean[2]			9.1±1.6[x]			10.4±1.9[y]			

[1]Means with different superscript letters are significantly different at P $\leq$ 0.05, vertical comparisons only.
[2] Note that that the grand means associated with 24-h and 48-h trap-soak durations do not include data from the non-baited traps; means with different superscript letters are significantly different at P $\leq$ 0.05, horizontal comparisons only.

Table 3. Mean (±SD) crawfish catch per unit effort (number and weight of crawfish caught per trap per soak-duration) and mean individual harvest size of crawfish caught in 1.9-cm square-mesh pyramid traps that initially contained 10 marked crawfish in the crawfish retention trial. The numbers in this table ***do not*** include the marked crawfish that were placed in the traps at the time of baiting.

	Soak Duration								
	24 hours			48 hours			Grand Mean[1]		
Bait Type	No/trap	Wt/trap (g)	Mean Size (g)	No/trap	Wt/trap (g)	Mean Size (g)	No/ trap	Wt/trap (g)	Mean Size (g)
Menhaden +Formulated	13±8	137±97	10.1±1.9	9±7	101±68	11.4±2.3	11±8[a]	119±85[a]	10.7±2.2[a]
Formulated	11±6	102±51	9.5±1.5	10±6	109±71	11.0±2.4	10±6[a]	105±61[b]	10.2±2.1[a]
Menhaden	7±4	68±45	9.2±2.0	7±4	74±46	11.6±4.3	7±4[b]	71±45[c]	10.4±3.5[a]
No Bait	1±1	5±8	10.4±4.6	1±1	10±13	10.7±6.6	1±1[c]	8±11[d]	10.6±5.8[a]
Grand Mean[2]	10±7[x]			9±6[y]					
Grand Mean[2]		102±73[x]			95±64[x]				
Grand Mean[2]			9.6±1.8[x]			11.3±3.1[y]			

[1]Means with different superscript letters are significantly different at P ≤ 0.05, vertical comparisons only.
[2] Note that that the grand means associated with 24-h and 48-h trap-soak durations do not include data from the non-baited traps; means with different superscript letters are significantly different at P ≤ 0.05, horizontal comparisons only.

marked crawfish, the CPUE with menhaden used singly was 32 to 40% lower than with formulated bait or the mixture of menhaden+formulated bait ($P<0.05$; Table 3). No difference in mean individual crawfish size was observed among bait types ($P>0.05$; Tables 2 and 3). Traps with menhaden+formulated bait tended to have slightly higher CPUE in all weeks of the trial, but not all differences were significant from the other two baits. In contrast to what was observed in the bait type x trap-soak duration trial, no discernible temporal shift in the CPUE in traps baited with menhaden or formulated bait singly was apparent with changes in water temperature with the exception of the first sampling date in late February in which CPUE was slightly higher in traps containing menhaden (Figure 8). In traps with no marked crawfish, the CPUE in number and weight was 36% and 23% higher, respectively, with a 24-h trap soak compared to a 48-hour soak ($P<0.05$), and the mean size of crawfish caught with a 48-h soak were significantly larger (Table 2). However, in traps containing marked crawfish no difference in the CPUE (in weight) was observed between 24-h and 48-h soaks ($P>0.05$), but the mean size of crawfish captured were larger with 48-h soaks ($P<0.05$; Table 3).

Traps containing no marked crawfish caught significantly more crawfish in both number (37%) and weight (30%) than traps with marked crawfish (calculations excluded the contribution of number and weight of marked crawfish) suggesting that the presence of crawfish in the traps when baited decreased the ingress of crawfish into the traps. The percentage of marked crawfish that escaped from traps was not significantly influenced by bait type or the absence of bait ($P>0.05$) and it ranged from 29 to 34% (Table 4). In contrast, the mean percentage of marked crawfish that escaped following a 48-h soak (39%) was nearly double that of a 24-h soak (22%; $P<0.05$). Nearly 58% of marked crawfish escaped from traps in mid-April when the mean water temperature was $25.9^{o}C$ and the fewest number of crawfish that escaped (19 to 22%) occurred

Table 4. Percentage of marked crawfish escaping after 24-hour and 48-hour trap-soak durations with different bait types in the crawfish retention trial. Escape percentages were adjusted for marked crawfish that died while in the traps.

Bait	Soak Duration		
	24 hours	48 hours	Grand Mean[1]
	% Escaped	% Escaped	% Escaped
Menhaden+Formulated	18±15	40±26	29±24[a]
Formulated	23±21	37±26	30±24[a]
Menhaden	19±17	39±23	29±22[a]
No Bait	30±23	39±25	34±24[a]
Grand Mean[2]	22±19[x]	39±25[y]	

[1]Means with different superscript letters are significantly different at P ≤ 0.05, vertical comparisons only.
[2]Means with different superscript letters are significantly different at P ≤ 0.05, horizontal comparisons only.

in February and March when water temperatures were coolest, ranging from a daily mean of 15.5°C to 18.9°C (Figure 9).

Modified Trap Trial

Water temperature ranged from 13.2°C on 7 March to 27.6°C on 28 May (Figure 6). No consistent temporal pattern in the CPUE was evident in the modified trap trial. Mean CPUE was highest in late March and late May (Figure 10), and mean individual harvest size was highest at initiation of the harvest trial in early March and at study termination in late May (Figure 10). The modified trap caught 19% more crawfish by number than the control traps ($P<0.05$) but no difference in CPUE (weight) was noted between the modified and control traps ($P>0.05$; Table 5). Although the CPUE in weight did not differ significantly between control and modified traps, a slightly higher CPUE (weight) was observed in modified traps on all sampling dates except in April (Figure 10). The mean individual size of crawfish caught with the modified traps was slightly smaller than those in the control traps but the difference in size was not statistically significant ($P>0.05$). As observed in the bait type x trap-soak duration and crawfish retention trials, the CPUE in both number and weight was significantly higher with a 24-h soak than with a 48-h soak (Table 5) and the highest differences in CPUE between 24-h and 48-h trap-soak durations occurred in March and late May (Figure 10). Overall, the CPUE at 24-h was 33% higher in number and 32% higher in weight than at 48-h ($P<0.05$; Table 5), and mean harvest size of crawfish retained after a 48-h soak was slightly larger than with the 24-h soak ($P<0.05$; Table 5). The CPUE in modified traps declined 24% and 17% in number and weight, respectively, from 24-h to 48-h, whereas the CPUE in control traps decreased 35% and 31% in number and weight, respectively, from 24 to 48-h (Table 5).

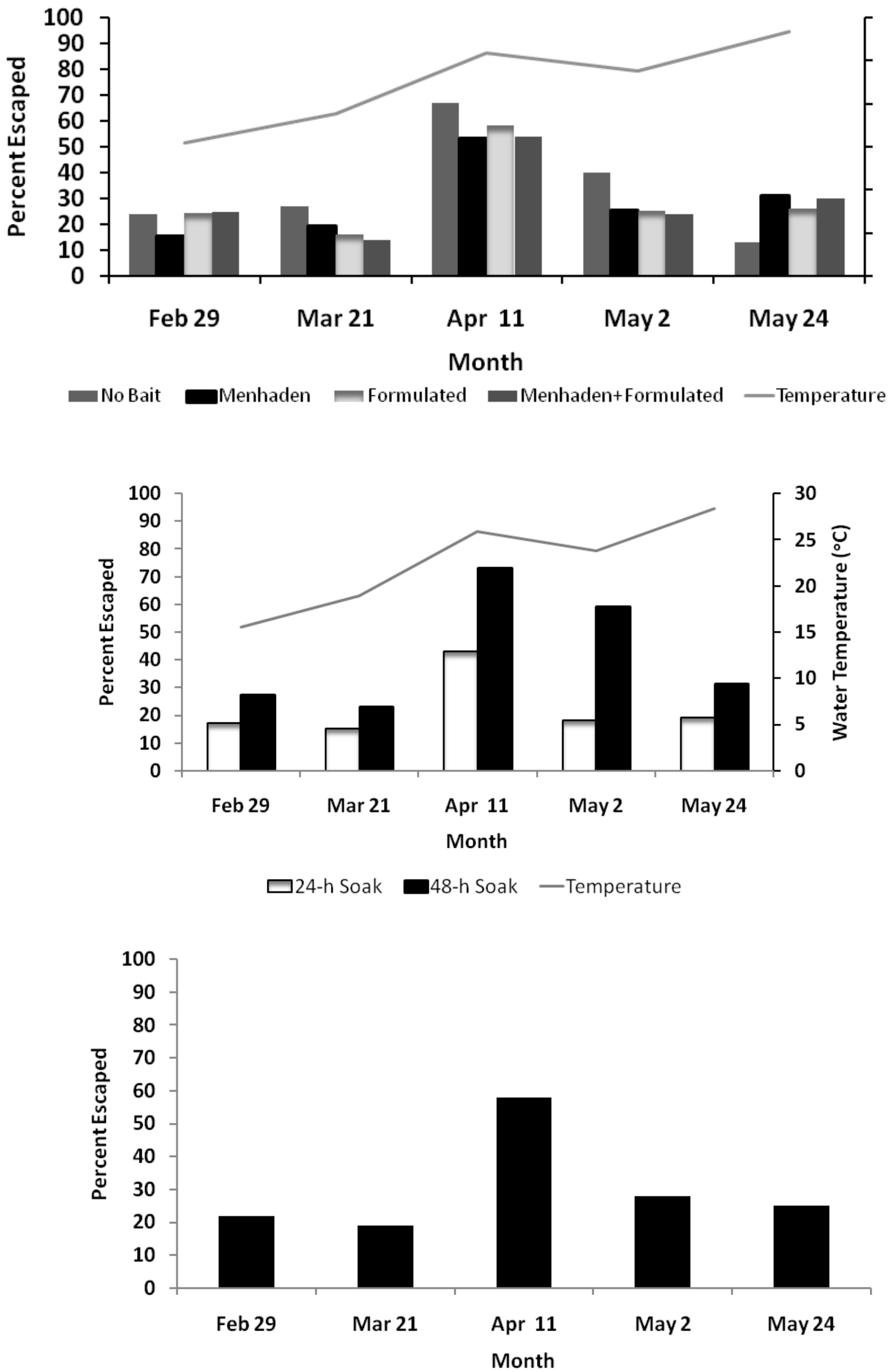

Figure 9. Temporal changes in percentage of marked crawfish that escaped from traps, as affected by bait type and trap-soak duration in the crawfish retention trial. Bait type was averaged over the two trap-soak durations, soak duration was averaged over the three bait types and non-baited traps, and bottom graph was the escape rate averaged over all bait types and trap-soak durations.

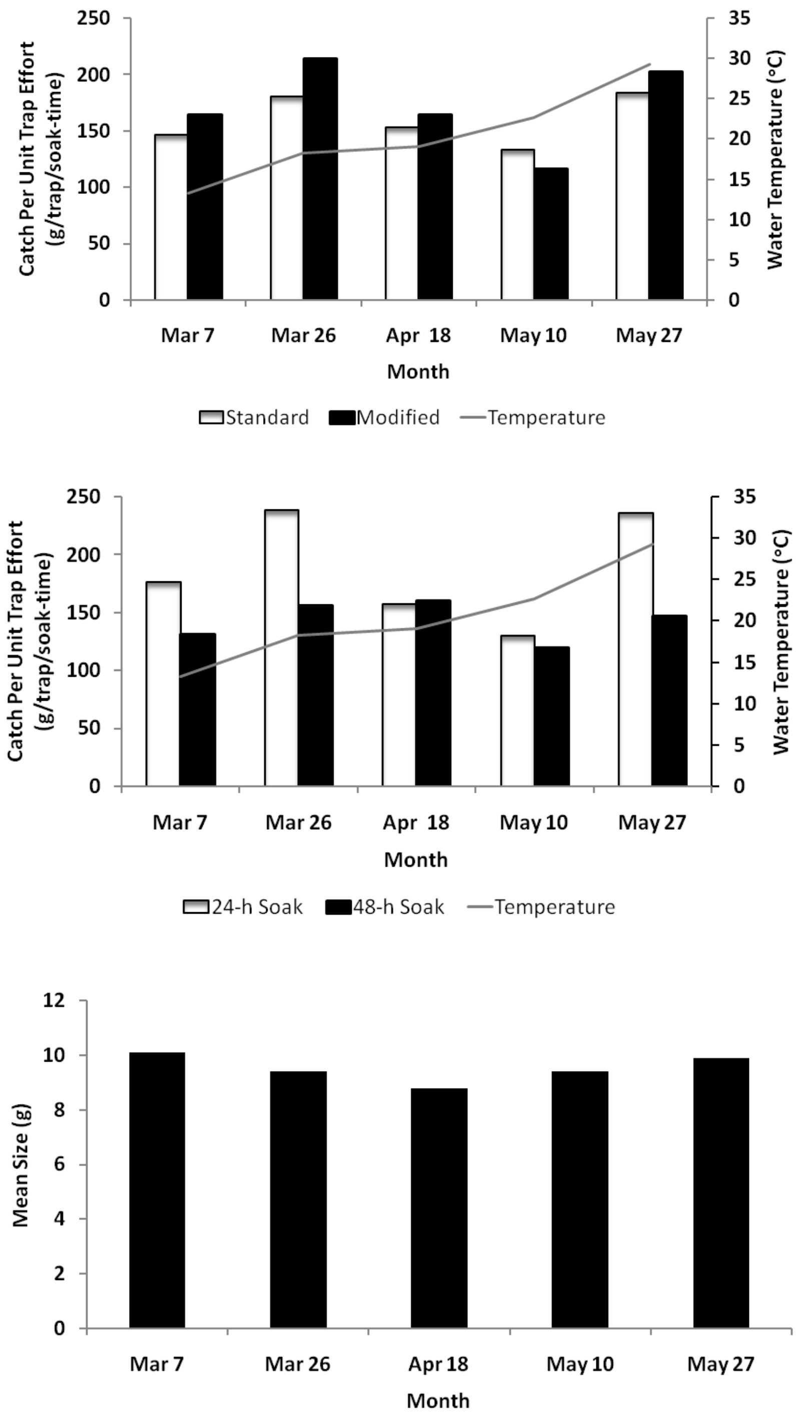

Figure 10. Temporal changes in crawfish catch per unit effort (g/trap/soak) and mean individual harvest size in the modified trap trial. Trap type was averaged over the two soak durations, soak duration was averaged over the two trap types, and crawfish size was averaged over trap types and soak durations.

Table 5. Mean (±SD) crawfish catch per unit effort (number and weight of crawfish caught per trap per soak duration) and mean individual harvest size of crawfish caught in 1.9-cm square-mesh pyramid traps with modified entrance funnels (modified trap) and non-modified (control trap) entrance funnels in modified trap trial.

	Soak Duration								
	24 hours			48 hours			Grand Mean[1]		
Trap Type	No/trap	Wt/trap (g)	Mean Size (g)	No/trap	Wt/trap (g)	Mean Size (g)	No/ trap	Wt/trap (g)	Mean Size (g)
Control	20±8	189±83	9.6±1.3	13±5	130±52	10.1±1.1	16 ± 8^{a}	159 ± 75^{a}	9.9 ± 1.2^{a}
Modified	21±8	187±78	8.8±0.9	16±7	156±64	9.6±1.1	19 ± 8^{b}	172 ± 73^{a}	9.2 ± 1.1^{a}
Grand Mean[2]	20 ± 8^{x}			15 ± 6^{y}					
Grand Mean[2]		188 ± 80^{x}			143 ± 59^{y}				
Grand Mean[2]			9.2 ± 1.2^{x}			9.9 ± 1.1^{y}			

[1]Means with different superscript letters are significantly different at $P \leq 0.05$, vertical comparisons only.
[2]Means with different superscript letters are significantly different at $P \leq 0.05$, horizontal comparisons only.

DISCUSSION

Bait Type x Trap-Soak Duration Trial

The menhaden+formulated bait combination and menhaden used alone were generally more effective attractants than formulated bait alone within the range of water temperatures encountered in this study. Menhaden was most effective at water temperatures less than 20^{o}C and the menhaden+formulated bait combination was slightly more effective at higher water temperatures. These findings are comparable to those reported in other procambarid crawfish bait studies (Romaire and Osorio 1989; Huner et al. 1990; Huner and Paret 1995; Beecher 1996), with the exception that other investigators reported formulated bait to be significantly more effective than fish baits at temperatures generally exceeding 20^{o}C and this was not evident in this trial. It is possible that the formulated bait would have been more effective in warmer water if the density of harvestable crawfish in the pond was higher and size of crawfish larger. The previously cited studies reported higher CPUE in weight and number, and larger sizes of crawfish than were observed in this study. Crawfish mastication of bait may be an important factor in the release and dispersion of attractants, particularly formulated baits that are manufactured to be relatively water stable. The low CPUE in this trial in combination with the small size of crawfish harvested could have reduced the concentration of attractants released from the formulated bait. I usually observed residual formulated bait remaining in the traps when they were lifted from the water after 24-h soaks, although little or no formulated bait residue was observed after 48-h soaks, indicating most of the formulated bait had either dissolved or been consumed.

Huner and Paret (1995) speculated that the chemoattractants present in fish baits are possibly more water soluble and more easily dispersed than in formulated baits. Although to my

knowledge there is no research that has compared attractant dispersal from fish baits and formulated baits, either in the presence or absence of crawfish, it is possible that in this study the low density of harvestable crawfish had some “negative” influence on the effectiveness of the formulated bait used. It is also equally possible that the formulated bait used in this study was not a particularly effective attractant. The ingredient compositions of formulated baits probably differ among feed mills, and formulated baits can differ in their ability to attract crawfish (McClain and D’Abramo 2006). Crawfish bait formulations are proprietary to the companies that manufacture them and formulations can potentially change with each production run.

Gizzard shad (*Dorosoma cepedianum*) is a freshwater clupeid, similar to Gulf menhaden, and it is widely used as a bait in the Louisiana crawfish industry. Romaire and Osorio (1989) reported that a gizzard shad+formulated bait combination increased crawfish catch as much as 28% over that obtained with formulated bait alone and 43% more than with gizzard shad at water temperatures of 16 and 20^{o}C. Huner and Paret (1995) reported that gizzard shad+formulated bait combinations were most effective in March, that bait combinations, gizzard shad or formulated bait used singly were comparable in April, and formulated baits were most effective in May. Beecher (1996) observed that that gizzard shad used singly was the most effective and profitable bait for attracting *Procambarus* spp. from January through March when temperatures were cooler than 20°C; formulated bait was superior in April and May when nominal temperatures exceeded 20°C; and a gizzard shad+formulated bait combination was an effective attractant over a wide range of temperatures (February through May). This bait trial began in late February when water temperatures were increasing and this may explain why the best overall CPUE was found with the combination bait. Also, as reported in other bait studies with *Procambarus*, use

of particular bait type had no influence on the size of crawfish attracted to and retained in traps (Romaire and Osorio 1989; Huner et al. 1990; McClain and D'Abramo 2006).

The 24-h trap soak caught more crawfish than the 48-h soak and the comparative difference in CPUE did not appear to be influenced by water temperature, apparent changes in the population density of harvestable crawfish, or the type of bait used. Although other procambarid crawfish harvesting studies have investigated trap-soak duration, this is one of the first studies investigating trap-soak duration using pyramid traps made from square-mesh welded wire. Romaire and Osorio (1989) reported that crawfish catch from March through May was 30% higher in 12-h soaks compared to 24-h soaks when using 1.9-cm hex-mesh stand-up pillow traps with two entrances, the standard trap used in the commercial crawfish industry when that study was conducted. Pfister and Romaire (1983), in a study in which 10 different trap designs were evaluated from March through May, reported that maximum catch of crawfish per trap occurred 6 to 12 hours after baiting the traps, and no further increase in catch was obtained by allowing the traps to soak longer. Lawson and Romaire (1991) found no consistent reduction in crawfish CPUE with 48-h soaks, compared to 24-h soaks, in three experimental procambarid crawfish ponds in which 1.9-cm hexagonal mesh stand-up pillow traps were used. Romaire (1997) reported that in a study using 1.9-cm hex-mesh three-funnel pyramid traps no significant differences were observed in crawfish CPUE (weight) in January and February with gizzard shad or a commercially formulated bait between 24-h and 48-h soaks, but in warmer waters (March and April) the CPUE was slightly higher with formulated bait with 48-h soaks compared to 24-h soaks, and no change in CPUE between the two soak durations was noted with gizzard shad. McClain and D'Abramo (2006) reported that the CPUE in both number and weight from March through June with 1.9-cm hex-mesh 3-funnel pyramid traps was higher with 48-h soaks with two

formulated baits (one commercial and one experimental) but catch decreased with gizzard shad and another brand of commercially formulated crawfish bait with 48-h soaks.

In this trial, 48-h soaks caught consistently larger crawfish than with 24-h soaks and this difference in size is generally consistent with observations from other studies and anecdotal reports from commercial crawfish producers. Romaire and Pfister (1983) reported that mean individual weight of crawfish caught during 24-h and 12 h nocturnal soaks were larger than those caught during 4-, 6-, or 12-h diurnal soaks. In contrast, McClain and D'Abramo (2006) observed no difference in mean size of crawfish retained in traps after 24-h or 48-h soaks, but the crawfish caught in their study (mean size > 24 g) were considerably larger than the mean size of crawfish caught in this trial (< 14 g). It is generally assumed that larger crawfish have a more difficult time escaping than do smaller animals.

Crawfish CPUE decreased consistently from late Feb through mid-May in this trial, and this observation contrasts with most other studies that report an increase in procambarid crawfish catch in late spring (Belhadjali 1994; Beecher 1996). The pond was severely forage deficient (visual observation) because of delayed planting of the forage crop, exacerbated by insect damage. Additionally, it appeared that the population density was relatively low and the crawfish were severely stunted, and these factors could in part be responsible for the decrease in CPUE as the harvest season progressed. White spot syndrome virus (WSSV) was also suspected as potentially having some negative effect on catch and harvest size. White spot syndrome virus was found in 76% of commercial crawfish ponds sampled in Vermilion Parish, Louisiana, in May 2007 (Baumgartner et al. 2009), and crawfish in my study pond exhibited clinical symptoms of WSSV in late April and May, including lethargy when handling individual crawfish and the occasional presence of dead adult crawfish floating along the pond perimeter.

Crawfish Retention Trial

As was observed in the bait type x trap-soak duration trial, the menhaden+formulated bait combination in this trial was overall a better attractant than menhaden or formulated bait used singly, CPUE was higher with a 24-h trap-soak duration, and harvested crawfish were larger with 48-h soaks. Menhaden seemed not to be as effective (compared to formulated bait singly) in this trial compared to the bait type x trap-soak duration trial. Fish bait was purchased weekly and it possible that the quality of the fish bait was not as high or factors such as changes in water temperature affected the effectiveness of the fish bait (Beecher 1996).

The presence of crawfish in traps at the time of baiting significantly reduced the CPUE of "new" crawfish that entered the traps by about one-third, and these observations were relatively consistent across bait types and trap-soak durations. *P. clarkii* and other species of crawfishes are socially aggressive and agonistic (Gherardi 2002) and presence of crawfish in a trap at the time the trap is baited in some way may either reduce the rate of ingress of crawfish into the traps or increase the rate of egress of "new" crawfish from the traps. No significant statistical correlation was found between the number of dead marked crawfish in traps and the number of new crawfish that entered the trap ($P>0.45$; $df=158$; $r^2=0.0036$). Thus, it would appear that dead or decomposing marked crawfish present in the traps had no influence on the ingress of new crawfish into the traps.

The reduced catch observed in traps in which marked crawfish were added to estimate escape rates from traps has a potentially important ramification relative to commercial harvesting. Following the days that crawfish farmers do not re-bait after emptying traps, some crawfish will congregate in the non-baited traps over the several days that can elapse before the traps are re-baited. Observations from this study suggest that it might be beneficial to the overall

crawfish catch to empty the traps of any crawfish that entered before re-baiting. Further research should be conducted to investigate in the relationship between the number and size of crawfish present in traps and their effects on impeding the ingress of crawfish into a trap and potential egress of crawfish from a trap.

Huner and Paret (1995) reported that formulated baits used singly was less attractive to crawfish than a gizzard shad+formulated bait combination, but they contented crawfish were retained longer in traps with only formulated bait because the formulated bait persisted; whereas with a shad+formulated bait combination crawfish consumed the bait more quickly and thus were more likely to escape after the bait was depleted. Observations on crawfish escape rates from this trial do not support this contention. The percentage of marked crawfish escaping from traps did not differ with formulated bait or menhaden used singly compared to the menhaden+formulated bait combination. Non-baited traps were initially expected to have a significantly higher rate of escape of marked crawfish than with baited traps. Although non-baited traps did have slightly higher escape rates, it was not statistically different from baited traps. Some producers use a higher amount of bait per trap under the assumption that it will enhance catch by reducing the escape rate of crawfish. They assume that if "food" (bait) remains in the trap before it is emptied, crawfish will not leave, but data from this trial would seem to refute this contention. Clearly, the optimal baiting strategy is to use the least amount of bait that provides the maximum catch taking into consideration the value of the crawfish and the cost of the bait.

Trap-soak duration had a significant influence on the rate of crawfish escape from traps, with escape rates associated with a 48-h soak (39%) nearly double that of a 24-h soak (22%), and this observation is reflected in the consistently lower CPUE in traps associated with a 48-h soak.

Although limited research has been conducted on the escape of procambarid crawfishes from traps, the findings from this trial are generally consistent with those previously reported. Pfister and Romaire (1983) reported that the number of crawfish escaping from traps increased significantly as the soak-duration increased from 12 to 48-h, and furthermore, they reported an average 20% and 39% of marked crawfish escaped from 10 different trap designs made from 1.9-cm hex-mesh poultry wire, after 24-h and 48-h soaks, respectively. These results are nearly identical to my observations with 1.9-cm three-funnel square-mesh pyramid traps.

Modified Trap Trial

The relatively high rates of crawfish escape from commercial traps, particularly with a 48-h trap-soak duration demonstrate the potential economic gain that could be achieved by modifying existing traps to retain a higher percentage of market-size crawfish. Although crawfish that escape from traps may be potentially caught at a later date, maximum profit can be achieved by capturing all marketable crawfish with as few trap sets as possible over the course of an entire trapping season. Traps that reduce the escape of market-size crawfish could increase net profit largely by reducing the cost of harvest labor and bait, two of the highest costs in procambarid crawfish aquaculture (Boucher and Gillespie 2008).

Although no statistical difference in either CPUE or mean individual crawfish size was observed between control and modified traps with 24-h soaks, the modified traps caught nearly 20% more crawfish by weight with 48-h soaks. Although modified traps increased crawfish catch with a longer soak, the catch was comprised of a higher number of smaller and potentially less valuable crawfish. Thus, it appears that the increase in catch observed at 48-h was associated with a larger number of smaller crawfish having a more difficult time escaping from the traps with the modified entrance funnels. Anecdotal observations by crawfish researchers

(Romaire, personal communication) indicate that the most likely source of crawfish escape is via the entrance funnels. Strategic attachment of plastic cable ties inward around the circumference of the inner entrance funnel appears to have reduced the number of crawfish that escaped through the entrance funnels. However, crawfish retention trials were not conducted with the modified trap so the mechanism by which a higher catch was attained after a 48-h soak with modified traps must be elucidated in future research.

Crawfish trap designs have evolved throughout the years to increase catch efficiency, and most advances in the Louisiana crawfish industry have been the product of industry development. Previous research on crawfish traps has focused on the relationship between the number of trap entrance funnels and catch (Bean and Huner 1978; Westman et al. 1978; Pfister and Romaire 1983). Fjalling (1995) reported that a relatively simple modification to the entrance funnels of traps used to capture signal crayfish (*Pacifastacus leniusculus*) in Sweden increased capture efficiency. Campbell and Whisson (2002) reported that modification to "standard" trap entrance funnels with a cloth mesh entrance that closed after crawfish passed through it, increased the retentive ability of traps used to capture Australian freshwater crawfish (*Cherax tenimanus*). However, other modifications to entrance funnels were not effective in reducing crawfish escape rates (Campbell and Whisson 2002).

The relative success of modifying crawfish trap entrance funnels by Fjalling (1995) and Campbell and Whisson (2002) to reduce crawfish escape provided impetus for me to investigate if a relatively simple modification to entrance funnels on commercial pyramid traps could be used to increase their catch efficiency. The hypothesis was that the constriction formed by the flexible "fingers" of the cable ties oriented to form more restriction upon exit, might minimize crawfish escape through funnel entrances once they were inside the trap, but not impede the

ingress of crawfish entering the trap through the restricted, but flexible, opening. This trial did show that the simple, inexpensive modification to pyramid trap entrance funnels with cable ties has some potential to increase catch efficiency of pyramid traps, particularly when 48-h trap-soaks are employed, but further research is needed. For example, different types of funnel entrance materials could and should be investigated as was done in Sweden and Australia. Additionally, further research could be conducted manipulating the number, length, and angle of the cable ties to enhance the retentive ability of traps for 24-h, 48-h or potentially longer soak durations. The low CPUE and small size of crawfish captured in this study could have significantly influenced the findings and general conclusions from this trial. Higher CPUE and larger size of marketable crawfish could have provided different results with modified traps. Additional research is needed to evaluate traps with modified funnel entrances in populations with higher densities and larger crawfish, more characteristic of those commonly observed in the Louisiana crawfish aquaculture industry.

CONCLUSIONS AND RECOMMENDATIONS

1. The efficacy of menhaden and formulated crawfish baits was dependent on water temperature. Menhaden used alone was generally effective when water temperatures were less than 20°C (February/early March). A menhaden+formulated bait combination appeared to be most effective at water temperatures ranging from 20 to 25°C (March/April). Formulated bait appeared to be slightly, but insignificantly more effective at water temperatures exceeding 25°C (May). Additional research should focus on a myriad of bait combinations because different types of fish and bait formulations are available, and bait availability, particularly with fish baits, can vary during the crawfish harvest season.
2. A 24-h trap soak consistently caught more crawfish than a 48-h soak and the comparative difference did not appear to be significantly influenced by bait type or water temperature. However, the increase in catch associated with a 24-h trap-soak duration appeared to be a result of traps retaining a larger number of smaller crawfish which could potentially be problematic in regards to crawfish marketability at certain times during the season. Future research with square-mesh three-funnel pyramid traps should focus on investigating additional trap-soak durations of less than 24-h, possibly 36 h, and soak durations exceeding 48-h, particularly if combined with additional research with traps with entrances modified to reduce escape. Additionally, more research is needed to clarify if optimal trap-soak durations differ among different bait types, bait mixtures, and bait formulations.
3. The presence of crawfish in traps at the time of baiting appears to reduce the ingress of crawfish into the traps or may increase the egress of new crawfish via escape perhaps from aggressive and agnostic behavior of crawfish already present in the trap. These findings suggest that it would potentially be beneficial for trappers to empty the traps of any crawfish

that are present immediately prior to re-baiting. Research should be conducted to investigate if the relationship between the number and size of crawfish present in traps and their effects on potentially controlling the rate of ingress into traps or egress of crawfish from traps, with and without bait.

4. The type of bait used in these harvesting trials did not appear to have a significant influence on the rate of crawfish escape from traps, but soak-duration did have a significant effect on crawfish escape, with 48-h soaks having nearly twice the number of crawfish escaping (39%) compared to 24-h soaks (22%). This observation explains the decrease in crawfish catch with 48-h trap soaks in all three harvesting trials. Additionally, non-baited traps did not have significantly more crawfish escaping than baited traps, thus at least partially refuting the theory that presence of bait in traps significantly reduces crawfish escape. Future research should be conducted to investigate crawfish escape and modes of escape, to include varying the number and size of marked crawfish in test traps, evaluating crawfish escape with different baits and bait quantities as well as varying soak-durations. Additionally, crawfish escape rates should be investigated in ponds containing larger quantities and sizes of crawfish that were present in this study over the course of a harvesting season in order to assess the impact of changes in temperature as well as population density and size structure.

5. Slight modification to the three entrance funnels on square-mesh pyramid traps with plastic cable ties resulted in 20% increase in crawfish catch (weight) with 48-h soaks but not with 24-h soaks. However, the additional catch appeared to be the result of the modified traps retaining a large number of smaller crawfish. Simple, inexpensive modification to pyramid trap entrance funnels with cable ties has some potential to enhance crawfish catch particularly when using 48-h soak harvesting strategies, but further research is needed. The number,

length, and angle of the cable ties attached to the inner entrance funnel should be varied. Other types of materials that can be added to, or in place of, pyramid trap entrance funnels should be evaluated. The crawfish pond used in this study had a low population of harvestable crawfish that were severely stunted and the population structure of crawfish in the pond could have significantly influenced the findings of this trial. Further studies with traps with modified funnel entrances designed to potentially reduce the escape of marketable crawfish should be conducted in ponds with higher standing crops of harvestable crawfish of acceptable ($\geq$ 20 g) or desirable market size ($\geq$ 30 g).

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VITA

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