Crayfish and Baitfish Culture in Wild Rice Paddies

by

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PROJECT OBJECTIVES

- To identify the influence of time of capture, crayfish size, sex, and eyestalk ablation on soft shell crayfish production
- To examine crayfish harvest in production-sized wild rice paddies under simulated commercial harvesting
- To examine the influence of crayfish densities on wild rice depredation
- To asses sucker production potential in wild rice paddies
- To assess the potential of aeration for influencing the growth and survival of baitfish and crayfish in wild rice paddies
- To assess the commercial viability of softshell crayfish production
- To transfer results of this research to potential entrepreneurs, fish farmers, and other interested persons

DESCRIPTION OF WORK PERFORMED

Soft Shell Crayfish Production

Experiments were conducted in spring, summer and fall since crayfish exhibit distinct changes in morphology and behavior over an annual cycle that influence natural molting cycles, and since these cycles could seriously influence the ability to produce soft shell crayfish. Crayfish were captured in rice paddies and returned to the laboratory for molting experiments. Typically crayfish were held in the laboratory for less that one month prior to conducting an experiment. Our work was conducted in the wet laboratory at NRRI. We built eight plywood trays 0.95 m wide, 2.45 m long and 0.15 m deep (3' by 8' by 6"). The trays were waterproofed with varnish and joints caulked with acetic-acid-based silicone caulk. Plastic lawn edging was nailed around the perimeters to reduce escape of the crayfish. Each tray had five dividers to allow for separation of six experimental groups of crayfish per tray. To allow for efficient drainage, holes were drilled through the dividers below the water line. Waste water drained from each tray through three pipes, and into city sewer lines.

Water was sprayed into each experimental unit by drilling holes in rigid ½" PVC pipe mounted along the edge of each tray. Water was pumped through the pipe using low head jet pumps. Six trays (36 experimental units) were set up to run from one head tank. Two other trays were connected directly to the cold water lines and were used in low temperature experiments. Both systems were flow through, unlike the recirculating systems often used by commercial soft shell operations in the South. We chose this design because our variable numbers of crayfish would put strains upon a recirculating biofilter, possibly resulting in toxic levels of ammonia building up

At the beginning of an experiment, a known number of crayfish of a given sex or age group were placed into each compartment. Each crayfish in an experimental group was then altered by surgically removing the X organs at the base of the eyestalks following the methods of Chen et al. 1992. Crayfish were immediately returned to the tray compartment from which they came. Each day thereafter for about 21 days, crayfish trays were examined at approximate six hour intervals and all live, dead, molting, and recently molted crayfish were counted in each of the compartments. Dead and molted crayfish were immediately removed from the trays. Separate compartments that contained non-ablated crayfish were maintained as controls during all of the experiments to allow comparison of molt rates of ablated crayfish with that of naturally molt cycles.

Simulated Crayfish Commercial Harvest

Crayfish were trapped continuously during the summer growing season when crayfish are out of their burrows and actively foraging in the paddies. Since most methods of capture utilize traps, these data were acquired to determine whether crayfish were trapable during the entire season and whether any distinct peaks or troughs occurred in their trapability. Variation in trapability could influence the quantity of crayfish that could be obtained at any given time during the harvest period. Other studies (Richards et al. 1995) have demonstrated that lake and stream dwelling Orconectid crayfishes exhibit sharp peaks in trapability in relation to temperature and molt cycles. Intensive crayfish harvest was assessed using 62 baited traps lifted twice a week in a 20 acre paddy in 1992 and 60 traps lifted approximately 4 times per week in a six acre paddy in 1993. Traps were 1/4" plastic mesh modified pillow traps and were baited with fish remains and artificial bait from a local processor.

Wild Rice Depredation

Enclosure Experiment

Crayfish in wild rice paddies were thought to have detrimental impacts on rice production because they consumed germinating plants. Personal communication with managers of Vomela Wild Rice Company suggested that crayfish at moderate populations would destroy wild rice primarily adjacent to the deeper ditches that ring each paddy, but higher densities of crayfish could destroy all the rice in a production paddy, some of which were up to 25 acres in size. There was some disagreement whether crayfish were the primary controlling force in this depredation. Direct observation of crayfish damage was prevented because crayfish are generally nocturnal and the water is stained. The impact of crayfish on wild rice needed to be quantified so that appropriate production/management strategies could be explored and true benefits or detriments of crayfish polyculture with wild rice could be assessed.

To determine the impacts of crayfish on wild rice, eighteen enclosures, two m^2 were placed in a two-acre wild rice paddy prior to flood-up in spring 1992. Three replicate enclosures were stocked with none, moderate and high densities of crayfish. Two size classes of crayfish were examined to determine if size played a role in crayfish depredation. Smaller crayfish were yearlings which averaged 2 inches and the larger crayfish averaged 2.75 inches.. Stocking rates were 0, 25 and 100 for small crayfish and 0, 5 and 20 for larger crayfish per two m^2 enclosure.

Enclosures were installed before the paddy was flooded in the spring. Prior to stocking, the enclosures were trapped to remove any crayfish which may have emerged from burrows within the enclosures. Crayfish were stocked 15 days after paddies were flooded. On June 15, after the wild rice stood up, the amount of vegetation in each enclosure was rated by visual inspection in one of four categories: 0 = no plants, 1 = few plants, 2 = many plants, and 3 = packed with plants. In addition, invertebrate samples were collected from each enclosure to determine if crayfish influenced benthic invertebrate density.

Mitigation Experiment

Attempts to mitigate the impacts of crayfish on wild rice were attempted in 1993. Our research suggested that crayfish only damage wild rice during a relatively short period during germination and early growth. After the plants stand up, little crayfish damage has been observed (personal communication with Vomela Wild Rice, Inc.). Gunderson and Kapuscinski (1993) also observed that young of the year crayfish, which hatch after wild rice has grown to the stand-up stage, have little impact on wild rice even at very high densities. We also found that crayfish tend to stay in the deeper ditches along the outside of the paddy during the day and migrate into the wild rice at night to feed. Therefore, it was hypothesized that wild rice damage might be mitigated by providing a more desirable food during the approximately three weeks that wild rice is most vulnerable to crayfish damage. A Wisconsin Department of Natural Resources laboratory study (Lorman, 1977) demonstrated that rusty crayfish consumption of aquatic macrophytes was reduced from 90% to 57% by the addition of liver as an alternate food source. The study also showed that the presence of liver also reduced consumption of plant roots by rusty crayfish.

A University of Minnesota experimental paddy that had sustained severe crayfish damage in 1992 was selected for the trial. Fifty pounds of 0.25 inch trout grower food was broadcast in two opposite corners of a square, one acre paddy, 4 to 5 times per week for three weeks in 1993. At the end of the trial, feeding was stopped and traps were set around the paddy to determine if the feeding had altered the distribution of crayfish. If it could be shown that crayfish were attracted to the part of the paddy where supplemental food was provided, then it might be possible to protect wild rice during its vulnerable stage and also make crayfish harvest easier and/or increase crayfish growth and survival. Because wild rice did not grow in this paddy in

1993 (due to crayfish depredation in 1992), we were unable to assess the direct impact of supplemental feeding on wild rice production.

Sucker Production Potential

Sucker production studies were conducted in drainable commercial wild rice paddies located off of State Highway 210 in Aitkin County , Minnesota. Paddies varied in size from 1 acre to 26 acres (Table 1). The paddy substrates are composed mostly of peat with varying amounts of clay also present in some paddies. Water for the paddies is pumped from the nearby Mississippi River. Each paddy is surrounded by a ditch for draining purposes. When flooded, the paddy is covered with about one foot of water and the ditch depth varies from 3 feet to about 5 feet. Paddies are flooded up in May and draining begins sometime during the middle of August. The amount of wild rice and other macrophytes growing in the paddys varies greatly depending upon germination success and other ecological and environmental factors. Some of the ditches become choked with cattails and reeds.

Table 1 Acreages of wild rice paddys used for white sucker growth and years used.

Paddy Number	Acreage	Year in Use
1	1	1992
2	2	1993
3	2	1992 , 1993
4	2	1993
5	2	1992 , 1993
6	6	1992 , 1993
12	12	1992 , 1993

White sucker fry (Catostomus commersoni) were transported in oxygenated plastic bags from the hatchery in Cass Lake , Minnesota to the wild rice paddies. The plastic bags were placed in the paddy water for a period of time prior to releasing to allow for temperature acclimation by the fry. In 1992 the fry were stocked on 5/28. Holes were poked in the bottom of the bag before being placed in the water to allow for pH acclimation. Some of the bags tipped over on their side and the oxygen escaped. This led to a fairly high initial mortality in some of the paddies.

Estimations of initial mortality were about 15% in experimental paddy one, 5% in experimental paddy three, 30% in experimental paddy five, 40% in the six-acre production paddy, and 50% in the twelve acre production paddy. Otherwise the paddies were stocked at the rate of 20,000 per acre in 1992 and at the rate of 30,000 per acre in 1993. Holes were not poked in the bottoms of the bags in 1993. Small thermometers were placed in the bags at the time the sucker fry were put in the bags at the hatchery. When the temperature in the bag had acclimated to the temperature of the paddy water, the fry were released. Observed initial mortality was extremely low and not measurable. The fry were stocked in the six and twelve acre paddys on 5/17 and the experimental paddies on 5/26 for the 1993 season. Ten fish were taken from each paddy at two week intervals during the growing season and preserved in 70 % ethyl alcohol for later analysis in the lab. Some sample dates are represented with less than ten fish as they were sometimes difficult to locate and capture. Lengths of the fish were measured and identification of stomach contents done for several gross taxonomic categories. At harvest time for the "93" season, fifty fish were preserved for the purpose of length and weight measurements.

Fish in experimental paddies two, three, four, and five received supplemental feed during the 1993 season. Super Sweet 3/32 inch trout pellets with not less than 41 % protein, not less than 10 % fat, and no greater than 4 % fiber were used. Each of the four paddys received feed at the rate of approximately 12.5 pounds per day for the period of June 15 through July 15, 18.75 pounds per day for the period of July 15 through August 1, and 25 pounds per day for the period of August 1 through August 15. Feed was broadcast in the ditch areas of the paddies, not onto the flat part where the rice was growing.

Zooplankton samples were taken on the same dates as the fish collection using a 5 inch diameter plankton net during the 1992 season and on 5/17, 6/2,6/10, and 6/18 of the 1993 season. No further plankton samples were taken during the 1993 season after the initial blooms subsided. Sets of three thirty foot horizontal tows were taken in each paddy in the ditch areas. Samples were preserved in 90 % ethyl alcohol and brought back to the lab for later identification of organisms. In 1992 the benthos was sampled using a 6 inch Wildco Petite Ponar. Samples were field washed using a 100 mesh to the inch sieve, preserved in 90 % ethyl alcohol, and returned to the lab for identification of organisms. Samples were taken on the flat area as well as in the ditches. In 1993, samples of the top two inches of the benthos were taken using a 1 inch core sampler only in the ditches and only on 6/23. This date represents our date of estimation as to when the suckers began to feed more from the benthos as suggested by a substantial reduction of plankton in the water column and the timing of the development of their inferior mouth. Water temperatures were monitored by use of max-min thermometers in 1993. One thermometer each was placed in the six and twelve acre paddies and an additional thermometer was placed in experimental paddy four to represent temperatures of the four experimental paddies. Water samples were taken from the paddys and returned to the lab for analysis in August of 1993.

In mid-August the water level of the paddies drops as they are drained in preparation for harvest of the rice. Harvest of the suckers was done when the water had drained off the rice paddy flat area but there was still three to four feet of water in the ditches. The entire ditch length of the smaller experimental paddies was seined but only representative stretches of the larger production paddies were seined and totals extrapolated from those data.

Aeration Evaluation

Water quality characteristics collected during 1991 indicated that dissolved oxygen frequently dropped to levels that would severely limit growth and survival of fish and crayfish. To assess the potential of wild rice paddies for the production of fish and crayfish it was important to evaluate the effects of aeration on the growth and production of both suckers and crayfish. Aeration was conducted in conjunction with sucker and crayfish production during 1992 and 1993.

During 1992, two paddies were aerated. A two-acre University of Minnesota experimental wild rice paddy was aerated using two, 2 hp, three phase, 230 volt Tornado aerators donated to the project by Aeromix Inc of Minneapolis. The aerators were placed in ditches on opposite sides of the paddy and their flow was directed along the ditches. A twelve acre production paddy was aerated using four aerators donated by Kasco Marine of Lakeland, Minnesota. Three of the Kasco aerators were ¾ hp, 115 volt surface type aerators. The fourth Kasco aerator was a 2 hp, 230 volt aerator that was used to direct a flow down one of the ditches. One of the ¾ hp surface aerators was installed near the 2 hp aerator to aerate the water that was being directed down the ditch. All of the aerators were placed in the ditches. Aerators were programmed to operate from 8:00 PM until 8:00 AM each day.

While it was not possible to aerate the entire ditch area in the twelve-acre paddy, refuge areas were created that would offer protection if D.O. dropped in other areas. It was not known if the suckers and crayfish would be able to detect these refuges during low D.O. events. Suckers were stocked in the aerated two-acre experimental paddy and in two other similar two-acre unaerated paddies. Suckers were also stocked in the aerated twelve-acre paddy and in an adjacent six acre unaerated production paddy. Crayfish were not stocked in any of the paddies, but were present in all of them because of natural reproduction.

The following year, 1993, three paddies were aerated. One, 2 hp Tornado aerator (described above) was installed in each of two, two-acre University of Minnesota wild rice research paddies. These two aerated paddies and two other two-acre paddies were stocked with suckers. The six-acre wild rice production paddy that was unaerated in 1992 and stocked with suckers, was again stocked with suckers, but was aerated in 1993 using the four Kasco aerators set up similar to the way they were set up in the twelve-acre paddy in 1992 (described above). The twelve-acre paddy that was aerated in 1992 was again stocked with suckers, but was unaerated during 1993. Aerators were programmed to run continuously during 1993. During both years sucker growth and production of suckers and crayfish were evaluated.

Commercial Viability of Soft Shell Crayfish Production

The use of eyestalk ablation to produce soft crayfish has obvious advantages and some drawbacks. In an attempt to visualize the important factors involved in the development of a viable business, a computer model was developed to allow input of many of the variables that influence profitability. The model does not include all the expenses that need to be examined prior to investing in a soft shell crayfish business, but it does provide a rough-cut estimate of potential income given a variety of scenarios. It is also useful in determining which factors are of greatest economic importance. Because our research showed that molt time can vary by species, time of year, maturity, sex and water temperature, three molting periods were selected. Ten-day, 14-day and 18-day molt cycles were selected because they represent observed molting periods for eyestalk ablated *Orconectid* species and they show the impact molt cycle has on business considerations.

The economic models were developed in a spread sheet format using QuattroPro and are designed to allow input of various variables that allow the examination of different production scenarios. All three models assume that one production unit will be stocked with ablated crayfish per day. Production units are three by eight foot trays that can be stocked with 20 pounds of eyestalk ablated crayfish. If more than 20 pounds of crayfish are stocked per day, the production unit consists of (lbs stocked per day)/20 number of trays.

RESULTS OF TECHNOLOGY OR PROCESS ASSESSED

Rice Paddy Physical and Chemical Characteristics

Wild rice paddies are characterized by a number of positive and negative features related to culture of fish and crayfish. The most important feature of wild rice production which determines the potential for polyculture of other aquatic species is water management. Paddies were typically flooded during mid April to mid May. Water was drawn from the Mississippi River and pumped via a number of connecting ditches to paddies where the water was pumped into individual paddies. Water control devices similar to stand pipes were blocked with boards to the desired paddy water level. Excess water was allowed to flow over the boards in the control structure to maintain the appropriate depth. Water levels were generally 12 to 18 inches on the paddy and three to six feet in the ditches that ring the paddy. Water levels were maintained in the paddies by periodic pumping through June. During July, paddies began to lose water through evaporation and leakage. Boards in the water control structures were pulled and the paddies and ditches drained from mid July to mid August. Water drains off the paddy and concentrates fish and crayfish in the ditches. Ditches also eventually become dry.

One advantage of wild rice paddy management is that water is available as early as April and water temperatures increase quickly. A disadvantage is that the water is shallow and water temperature fluctuates rapidly with air temperature changes. The water can also be subject to low D.O., especially when rice gets tall and blocks wind generated aeration. The wild rice grows so thick and the water gets so shallow on the paddy at times that the only usable area for fish is the ditches. An obvious advantage of wild rice paddies is that the water is drawn down which can facilitate easy harvest of fish and crayfish. A disadvantage, however, is the short growing season. Fish would have suitable water temperature for growth well beyond the draw-down management strategy for wild rice. Another disadvantage is that the ditches are not all suited to effective fish and crayfish harvest. Cattails, snags, and uneven mucky bottoms cause problems for seining and trapping although ditches could easily be modified for more efficient harvest.

Since water is pumped from the Mississippi River (and supply ditches which support a variety of fish and crayfish), water to fill paddies must be screened to prevent the introduction of unwanted species. Species introduced in this manner were primarily fathead minnows and crayfish, but bullheads, mud minnows, yellow perch and northern pike were also found. A number of predators also took their share of aquaculture production. Raccoons, mink, otters and skunks preyed upon crayfish especially when water levels began to drop. Birds such as great blue herons, and a variety of other waterfowl also were predators of fish and crayfish.

Wild rice paddies range in size from six acres to several hundred acres, but most paddies we worked in were six to 25 acres in size and were considered manageable for commercial scale aquaculture. Access to the paddies was a problem. During dry weather, access for most two and four wheel drive vehicles was excellent, but because the roads were made of clay, they became impassable for even four wheel drive vehicles after just a moderate rain. Electricity was not available to many of the paddies which limits aeration capabilities. Aeration, even when electricity was available, proved problematic at times due to power interruptions and clogging of aerators with wind blown debris.

Soil type of the paddies varied considerably. Some paddies had 12 to 24 inches of heavy black peat over clay, while other paddies were primarily clay with very little peat overlayment.

Analysis of water quality, averaged for the six paddies in August 1993, revealed that pH was 7.64, alkalinity was 207.1 ppm, dissolved inorganic carbon was 52.0 ppm and total organic carbon was 43.23 ppm. Total suspended solids ranged from 17.4 to 165.4 ppm and averaged 54.3 ppm. Ortho phosphorous ranged from 7.0 to 14.5 ppb and averaged 10.2 ppb. Ammonia and nitrate varied considerably from paddy to paddy. Ammonia ranged from 87.6 to 4920.3 ppb and averaged 2506.9 ppb. Nitrate ranged from 1.1 ppb to 2787.6 ppb and averaged 512.6 ppb (Table 2 contains water quality data for the six paddies).

Table 2 **Water Quality Analysis for Six Paddies in August 1993**

Paddy No.	Alkalinity ppm	DIC ppm	pH	TOC ppm	ortho-P ppm	TP ppm	TN ppm	NO3 ppm	NH3 ppm	TSS ppm
2	211.3	54.0	7.51	49.7	8.4	96.9	6564	2787	3710	17.4
3	200.6	50.2	7.62	53.2	7.0	414.5	5033	181.6	3657	49.6
4	239.3	59.8	7.74	65.3	14.5	322.1	6915	52.1	4920	29.9
5	161.2	40.3	7.53	42.9	10.1	282.3	6156	50.5	2572	27.4
6	235	58.7	7.98	26.7	10.6	278.0	2575	2.7	92.9	165.4
12	195.5	48.9	7.45	21.4	10.8	184.0	1647	1.1	87.6	36.0

Sucker Culture in Wild Rice Paddies

Zooplankton and Benthic Invertebrates

Zooplankton sampling data in 1992 showed that there was an initial pulse producing bloom early in the growing season followed by a marked decrease in the plankton numbers for the rest of the sample season. Experimental paddy number one (Fig. 1) did retain a few more numbers of copepods than did experimental paddies three or five (Figs. 2 & 3). The May 28th sample from the six-acre production paddy (Fig. 4) had numbers and types of organisms similar to the number one experimental paddy on the same date and the twelve-acre production paddy data showed no great assemblages of plankton at any time (Fig. 5). Cladocerans were most abundant in paddy three early in the season with counts of a little over 600 animals per liter. This is also the paddy that was receiving aeration.

Figure 2

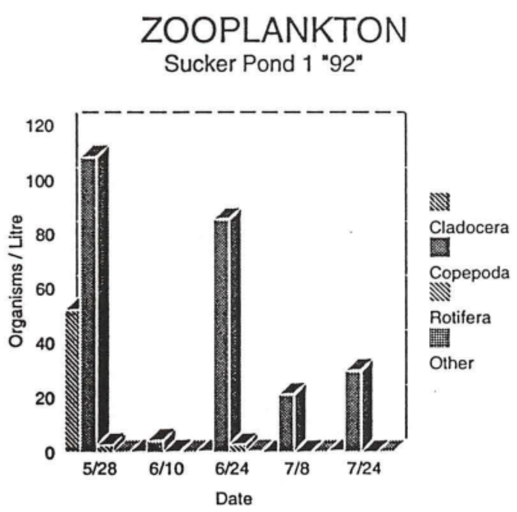


Figure 1

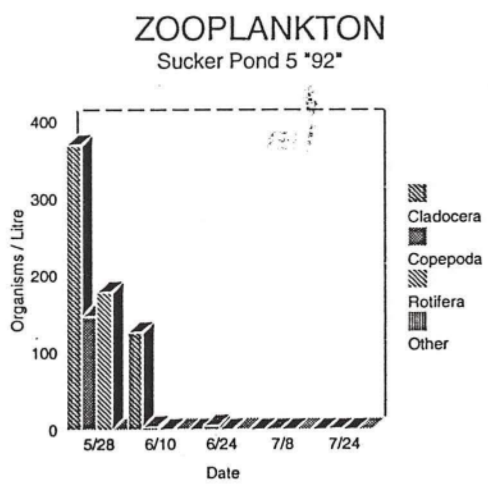


Figure 3

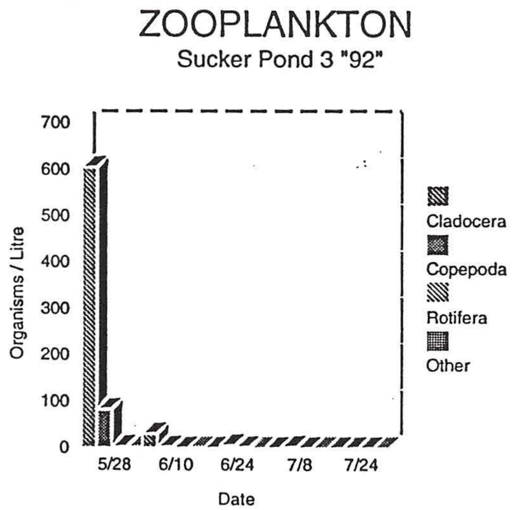


Figure 4

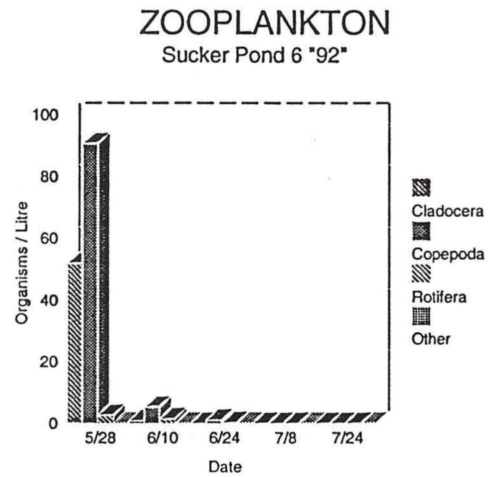
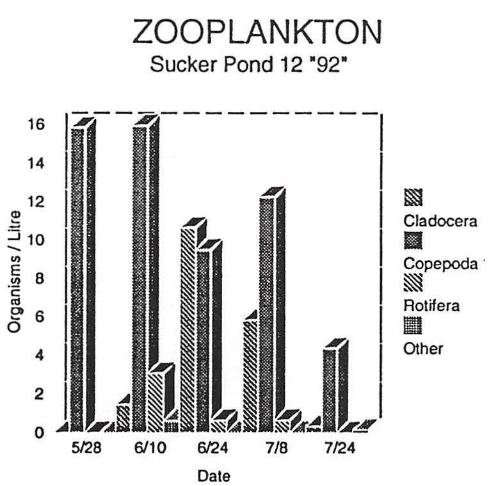


Figure 5



Analysis of zooplankton on the days that the sucker fry were stocked in the six and twelve acre-paddies in 1993 show that there was approximately three times as many cladocerans per liter in the six-acre paddy as there were in the twelve-acre paddy (Fig. 6). Copepod densities were approximately the same and the six-acre paddy had about 60% more total organisms per liter than the twelve-acre paddy. On 6/2 the six-acre paddy again had a great deal more plankton than did the twelve-acre paddy or any of the experimental paddies (Fig. 7). Number two and four paddies had greater densities than the other two two-acre paddies. The 6/10 analysis was of only the two acre-paddies. Paddies two and four had roughly seventeen and twelve times respectively the numbers of organisms that paddies three and five had (Fig. 8). Plankton analysis on 6/18 was of the six and twelve-acre production paddies. Paddy six had about three times the total organisms that paddy twelve had (Fig. 9).

Figure 6

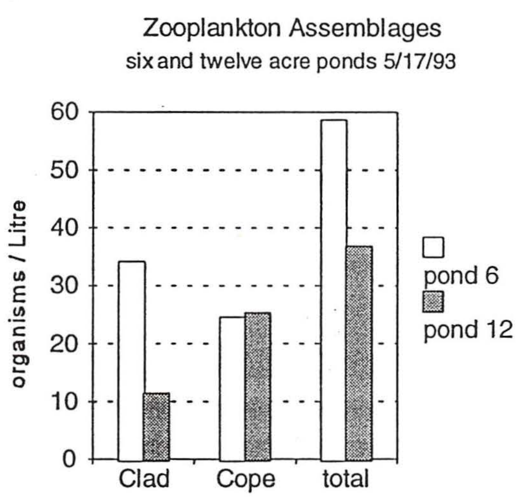


Figure 7

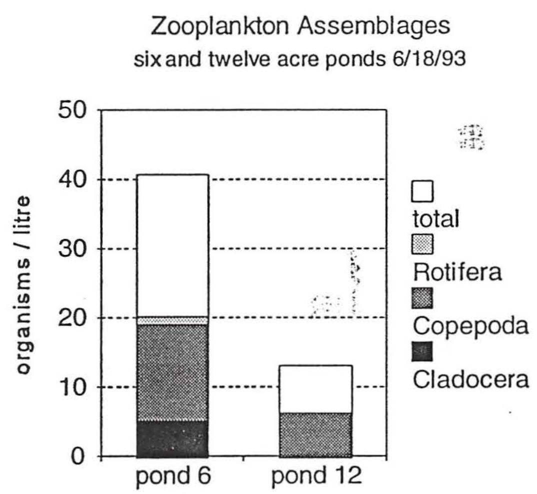


Figure 8

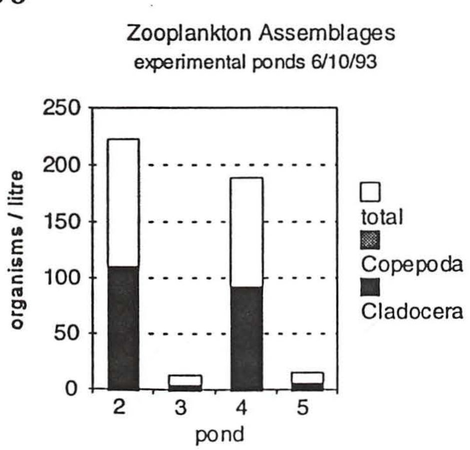
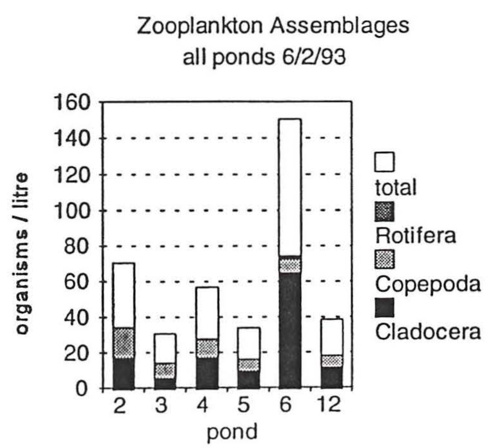


Figure 9



The primary benthic invertebrate found in the 1992 ponar samples was Chironomidae larvae (Figs. 10 - 14). There was a decline in the Chironomidae abundance for all paddies after the last week in June and the first week in July of the 1992 season. Although paddy five and the six acre-paddy seemed to have lower total abundances of organisms over the growing season than did the other paddies (Fig. 15), there was not a statistically significant difference between the paddies (P = 0.6465 for One-Way ANOVA). Benthic samples in 1993 revealed that paddy two and four had greater abundances of invertebrates than did paddies three and five and were primarily represented by oligochaetes and chironomids respectively (Fig. 16).

Figure 10

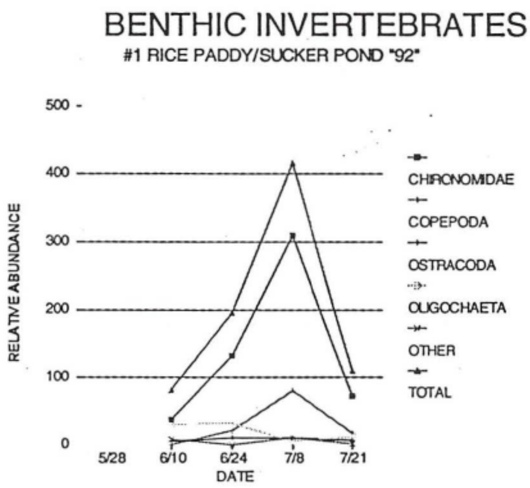


Figure 11

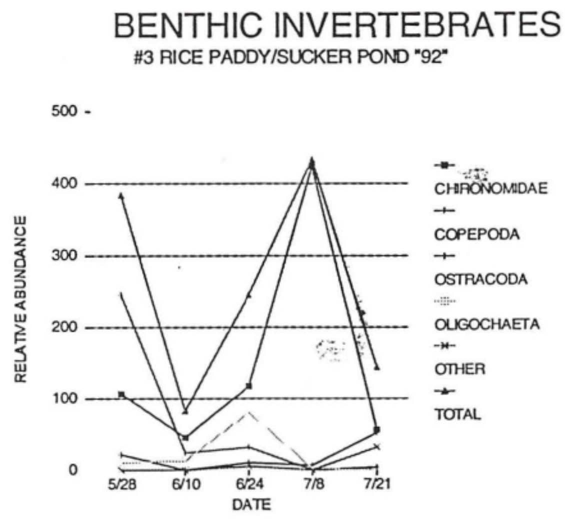


Figure 12

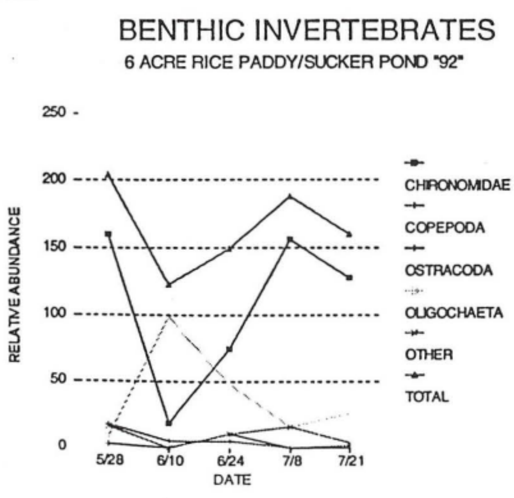


Figure 13

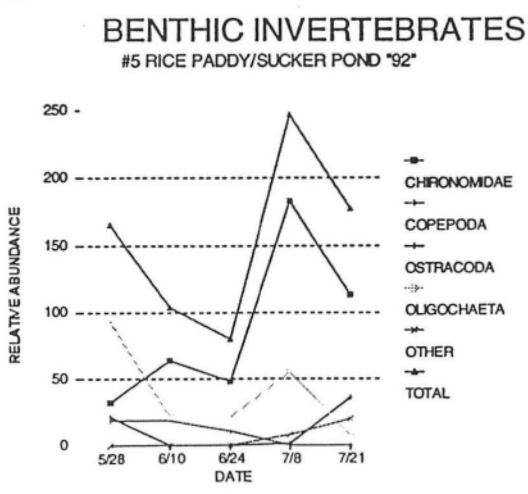


Figure 14

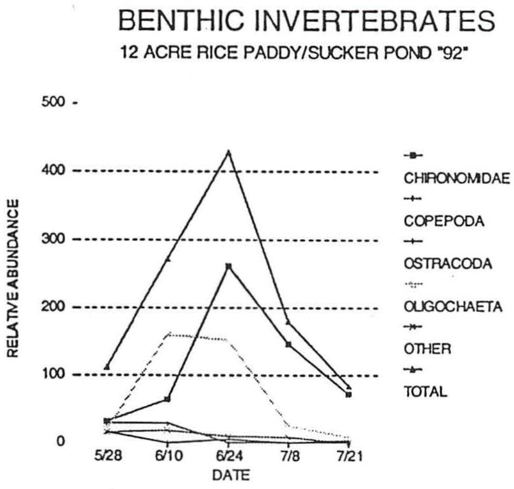


Figure 15

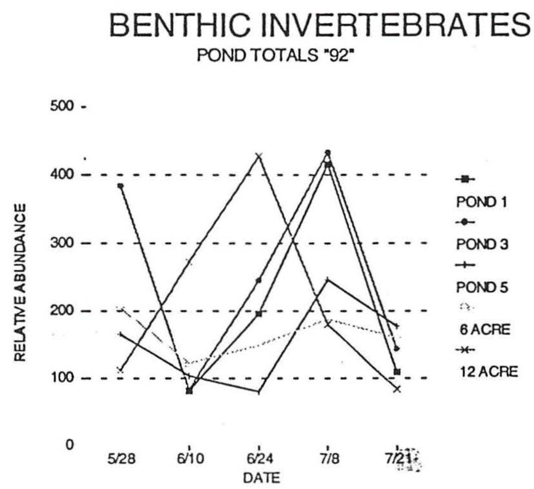
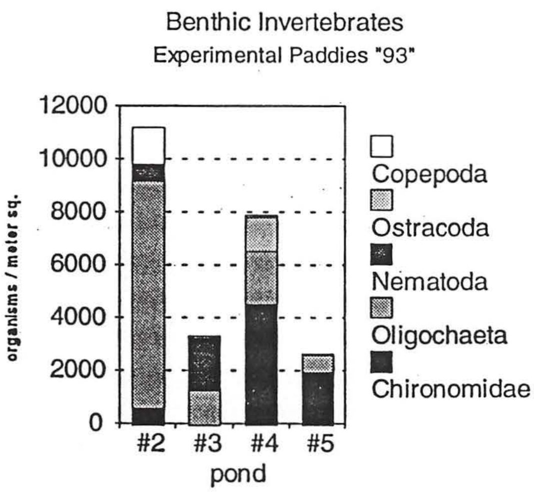


Figure 16



Minimum water temperatures did not differ significantly (P = 0.8528) among the three groups measured in 1993. Maximum water temperatures among the three groups did differ significantly however (P = <0.0001). Median values among paddy groups show that the experimental and six acre paddies were warmer than the twelve acre paddy (Table 3).

Table 3. Rank values of maximum temperatures in the three groups of sucker growth paddies in 1993.

Group	median	25%	75%
experimental	78	70	80
6 acre	76	70	80
12 acre	70	66.8	72.5

Differences in the median values among the three groups are greater than would be expected by chance (P = 0.01). Comparisons (Table 4) show the experimental paddies and the six acre paddy to differ from the twelve acre paddy.

Table 4. Pairwise multiple comparisons (Dunn's Method) isolating which paddy groups differ from the others with regard to maximum temperatures.

Comparison	P < 0.05
exp vs 12	yes
exp vs 6	no
6 vs 12	yes

Growth

Figure 17 depicts results of white sucker growth during the 1992 growing season. The two production paddies started out with the best growth but fell off during July. The only paddy that had fish of marketable size by harvest time was the number three experimental paddy. Stomach content analysis (Fig. 18) showed that these fish were taking advantage of the Chironomidae available in the benthos during the latter part of the season. Fish in paddy three also had fuller stomachs than fish in the other paddies on the last sampling date (Fig. 19). The fact that this paddy was aerated may have had a positive impact on the amount of food available to the fish and the general health of the fish, enabling them to take advantage of the food available. Of the two production paddies, the twelve-acre paddy had longer fish on the average than did the six-acre paddy. This was also the production paddy that was aerated. Stomach analysis showed that of all the paddies, that fish from the twelve-acre paddy had the second highest fullness rating. Gut content revealed (Fig. 20) that the organisms being consumed were primarily protozoans and not of the quality compared to Chironomids.

Figure 17

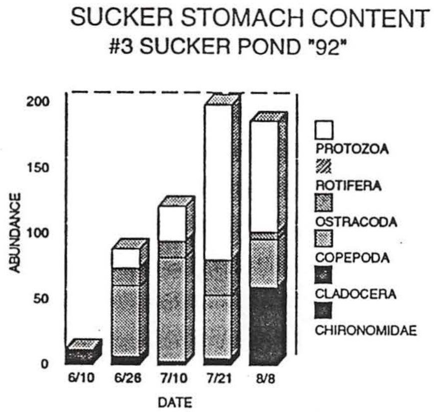


Figure 18

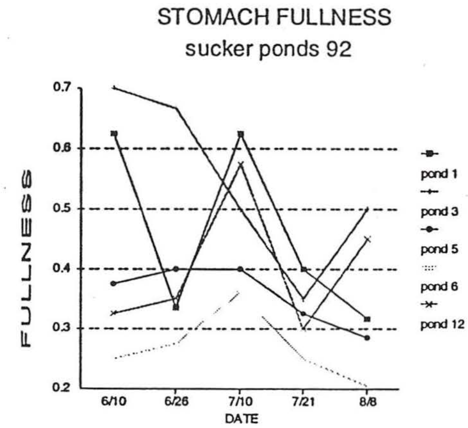
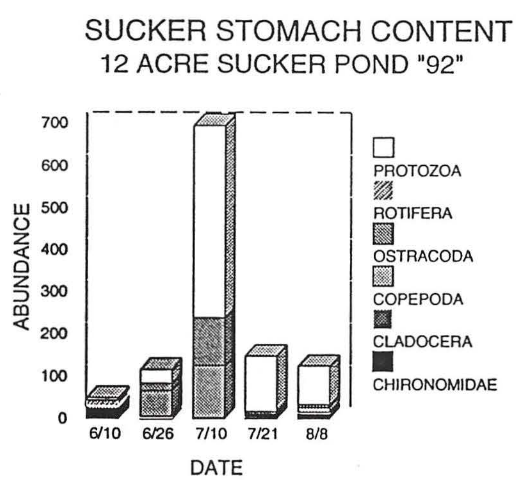


Figure 19



Overall production data show a tendency for the aerated paddies to have greater fish production than the unaerated paddies (Fig. 21). The greatest difference can be seen in the experimental paddies where there was three and six times the production in aerated paddy three than in unaerated paddies one and five respectively. Macrophyte cover was particularly heavy in paddy five which probably accounted for some fairly severe anoxic conditions at times. Although there was less production difference per acre between the six-acre and twelve-acre paddies, the difference is still fairly good with about a 20% increase in the aerated twelve-acre paddy over the unaerated six-acre paddy. There is also a little less confidence in these numbers because the entire paddy was not harvested. It is possible that we may have selected parts of the paddies to sample that would over or under represent the true numbers. The aeration does seem to be of great importance however. The two gallon estimate that represents the six-acre paddy is coupled with the smallest average sized fish of all five paddies. Higher productions in this industry don't carry a lot of weight if the product is not marketable. In some cases the fish could be overwintered in carry over ponds until the next spring, but if the fish are appreciably too small in the fall they still won't be of marketable size the following spring. Cooler water temperatures in the winter slow down metabolic rates in the fish and growth is slow. There are clear differences in production of fish and size of fish between the two aerated paddies, and of those two paddies the experimental paddy had greater numbers of zooplankton early in the season, greater average abundance of benthic invertebrates during the course of the growing period (257.9 vs 215.2), and stomach fullness was greater on the average (0.54 vs 0.40). This evidence points to the limiting factor of growth and production within aerated paddies to be food related. Supplemental feeding of white sucker minnows may be advantageous in terms of getting them to a marketable size and in great enough production numbers if cost can be contained to make it economically feasible.

Figure 20

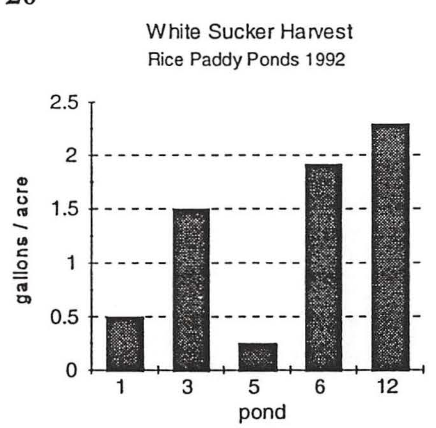
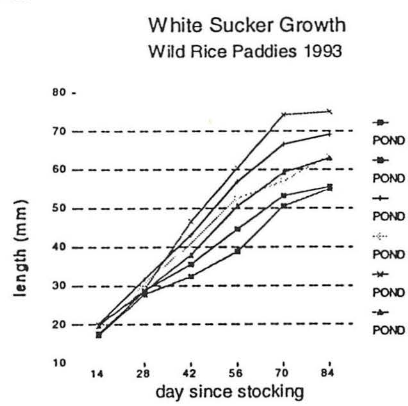


Figure 21



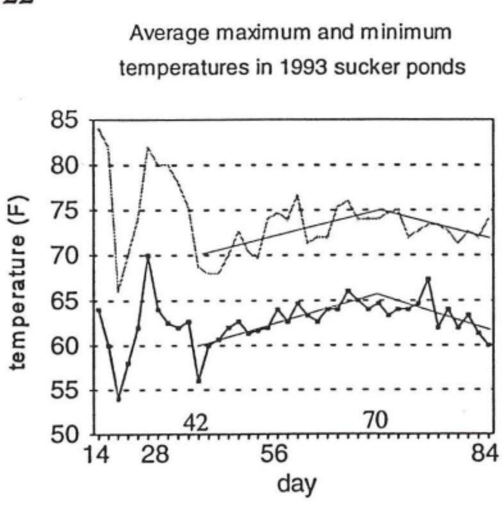
The experimental paddies averaged longer fish on day 84 of the 1993 growing season than did either the six acre or twelve-acre production paddies (Fig. 22). Paddy four accounted for the greatest growth overall, followed by paddy number two. Means of fish lengths between experimental paddies three and five are not significantly different nor are those between paddies six and twelve ($P > 0.05$). All other pairwise comparisons between paddies are significant (Table 5). The differences in the median values of sucker lengths between supplementally fed and unfed paddies are statistically significant ($P = < 0.0001$) and the median values of fish lengths between aerated and unaerated paddies are not statistically different ($P = 0.0795$).

Table 5. Matrix of Tukey pairwise comparison probabilities between sucker rearing paddies on day 84 of the 1993 season.

paddy	2	3	4	5	6	12
2	1.000					
3	0.003	1.000				
4	0.000	0.000	1.000			
5	0.000	0.884	0.000	1.000		
6	0.000	0.000	0.000	0.002	1.000	
12	0.000	0.000	0.000	0.001	1.000	1.000

Growth during the course of the growing season was fairly steady in all paddies. Between days 70 and 84 there was a general leveling off of growth in all paddies which may be due in part to a decrease in water temperatures during this period (Fig. 23).

Figure 22



Feeding

Stomach content analysis revealed that after trout pellet introduction, fish in supplementally fed paddies were feeding 90% or greater on pellets (Figs. 24 - 27). Even though stomachs of fish in paddies six and twelve were equally full or fuller than those in the experimental paddies (Fig. 28), quality of food ingested by fish in paddies six and twelve is evidently inferior to trout pellets. Fish in experimental paddies attained more growth with relatively less ingestion of forage. Day 42 and 56 analysis from paddy twelve shows the predominant food to be protozoans. Fish were evidently having a difficult time finding sufficient food. Day 42 analysis from paddy six also shows the predominant food to be protozoans. These findings suggest food resource as a limiting factor on growth.

Figure 23

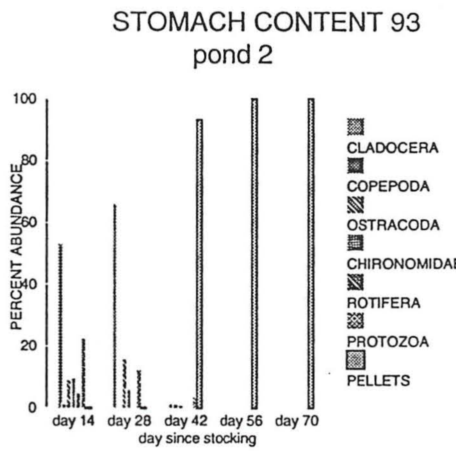


Figure 24

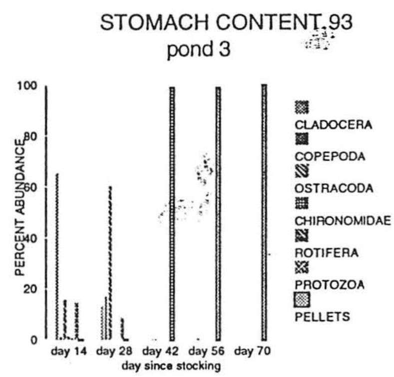


Figure 25

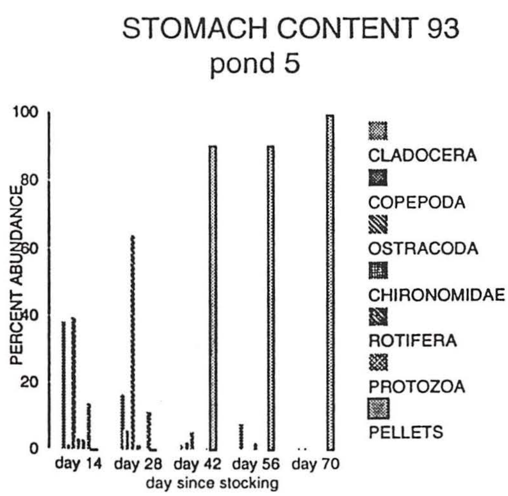


Figure 26

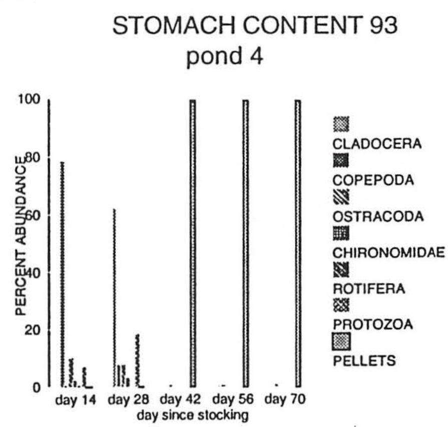


Figure 27

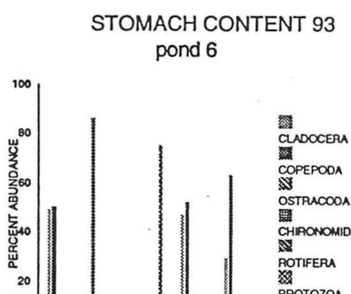


Figure 28

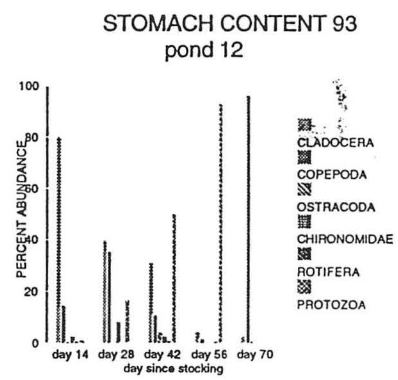
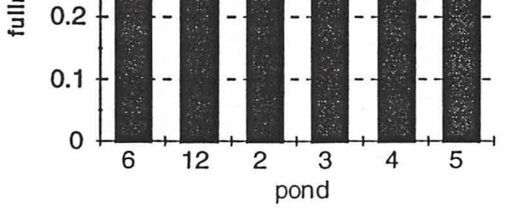


Figure 29



Production

Production data from experimental paddies show that the two aerated paddies produced more than twice the gallons of suckers as did the unaerated paddies (Fig. 31). Average gallons for the two aerated paddies is 21.9 gallons and the average for the unaerated paddies is 9 gallons. Production paddy twelve had more gallons of fish harvested (25.63 gallons) than production paddy six (22.554 gallons). Since paddy twelve was twice as big as paddy six, the actual production in paddy six is a little less than twice as much as paddy twelve. Production data converted to gallons per acre (Table 6) reveal that the aerated paddies produce more than twice as much on the average (8.55 gal./acre) as do the unaerated paddies (3.71 gal./acre). On calm and cloudy days these paddies undergo oxygen depletion that is addressed in part by aeration. The data also show that supplementally fed paddies produced about 2.5 times the average gallons per acre (7.72 gal./acre) as did the unfed paddies (2.95 gal./acre). Unfed paddy six had greater abundances of zooplankton on average (51.41/L) than did unfed paddy twelve (20.85/L). Aeration provides benefit to the fish as well as lower trophic organisms. Successful blooms of zooplankton translates into more food for the fish and greater production. A proper mix of feeding and aeration is important in the management of these paddies for production of sucker minnows.

Production in itself is mute if the fish don't reach marketable size. The average length of a light pike sucker minnow is 3.5 inches or almost 90 mm. The longest average lengths attained in this study was 75 mm or about 3 inches and that were attained in an unaerated paddy coupled with low production. Anoxic conditions may have provided high mortalities and consequently less competition between surviving fish for available resources. The data suggests that aeration is probably a must for sufficient production of white suckers in wild rice paddies and that supplemental feeding is important to production and growth. Questions that need to be answered are those addressing feed management and which environmental variables play a significant role in the growth and production of white sucker minnows.

Figure 30

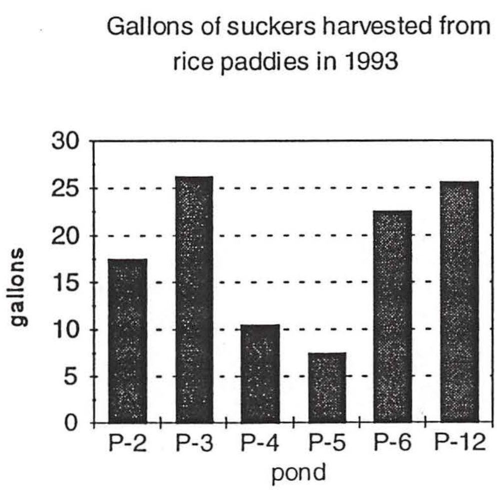


Table 6. Production of sucker minnows in Minnesota wild rice paddies in 1993.

paddy	2	3	4	5	6	12
gallons	17.51	26.25	10.50	7.50	22.55	25.63
gal. / acre	8.76	13.13	5.25	3.75	3.76	2.14

Crayfish

Soft Shell Crayfish Production

Results of the soft shell experimental trials indicated that ablation is an effective technique for producing soft shell Orconectid crayfish in controlled conditions.

Timing of Molts ---- During the first molting experiment in fall 1992, crayfish exhibited a distinct peak in molting activity between days 8 and 17 (Figure 27). Juvenile crayfish molted a few days earlier than adult males or females. There was no differences between the timing of molt between males and females during this period. After 18 days, molting activity had ceased.

During the second molting experiment (May 1993), a peak in molting period which lasted approximately three days was observed with both male and female crayfish (Figure 28). Male and female crayfish exhibited the same pattern and molting was completed within 18 days. Juvenile molting also peaked sharply. Juveniles completed molting by 14 days. Non ablated juveniles held under the same conditions had no distinct molting peaks.

During the third experiment (July 1993), a very distinct molting period was also observed between 8 and 17 days after ablation (Figure 29). Only adult males and females were used in this experiment. A control group held for the same period did not exhibit any peaks in molting activity. Molting times of males and females were similar, however, male molting peaked a couple days prior to females. As with the first and second experiment, molting was complete by the 18th day following ablation.

In all three experiments, the mean molting period for adults was less than 14 days (Table 7). The shortest period was in the fall trial with juveniles (9.5 days). Females and males had their shortest molting period during summer. Molt timing in summer was approximately 2 days shorter than the spring or fall experiment. Mean molt periods were very similar for both males and females in the spring and fall experiments.

Table 7. Mean time of molt (days) for ablated crayfish.

	Spring (Experiment 2)		Summer (Experiment 2)		Fall (Experiment 3)	
Crayfish Sex	Mean	SD	Mean	SD	Mean	SD
Male	12.1	1.8	10.4	2.1	12.6	1.7
Female	12.6	1.7	11.0	2.3	13.3	1.7
Juvenile					9.5	1.5

Figure 27

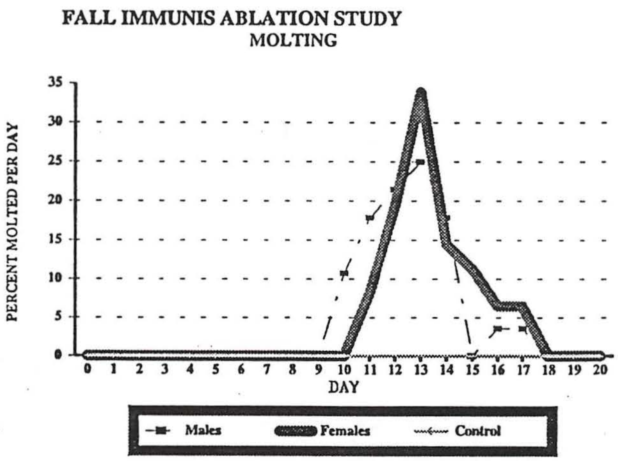


Figure 28

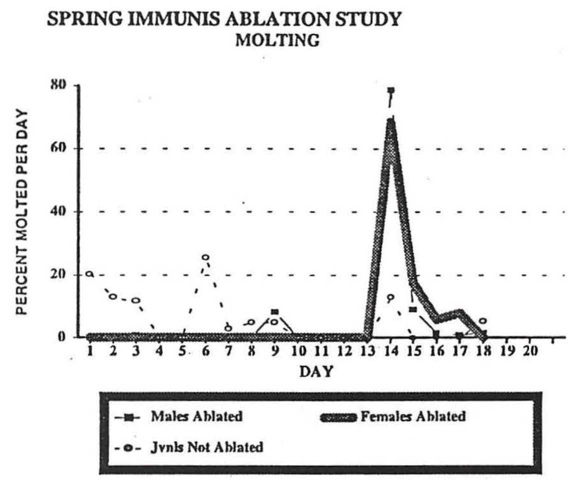
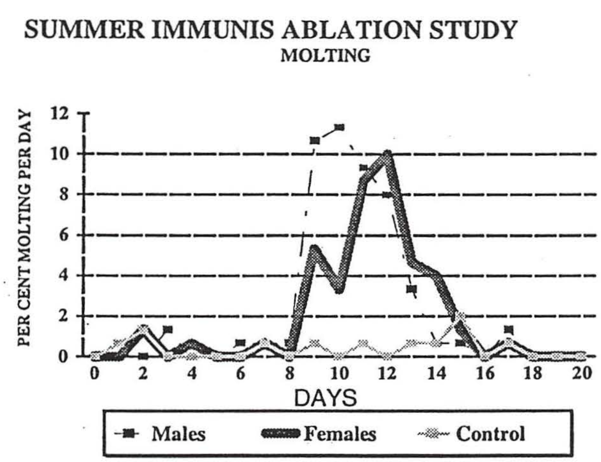


Figure 29



Molt Success -- Over 40% of adult ablated crayfish successfully molted in each of the experimental trials with the exception of males in the fall experiment which had an approximate 20% molt success. Approximately 50% of males in summer and females in fall and spring molted. Ablated juveniles had a 74% successful molt rate in the fall experiment.

Our observations suggest that molting success (or % mortality) are most strongly related to water quality. Although we did not run tightly controlled expedients to examine the influence of water quality, we did note that crayfish held in trays that were kept free of uneaten food and other organic materials had higher molt success. Consequently we examined the ability of females to molt without feeding during the November experiment to see if this might be a way to reduce the bacterial build up that occurs in the trays over time as uneaten food accumulates. The results of this experiment indicated that the unfed females had similar molt timing to fed females (Figure 27). Furthermore, the total % successful molts of the unfed females was 62.7%, which was considerable higher than the fed females.

Commercial Viability of Soft Shell Production

The use of eyestalk ablation to produce soft shell crayfish (as described earlier) has some advantages and some drawbacks. In an attempt to visualize the important factors involved in the development of a viable business, a model was developed to allow input of many of the variables that influence profitability. The model does not include all the expenses that need to be examined prior to investing in a soft shell crayfish business, but it does provide a rough-cut estimate of potential net income given a variety of scenarios. It is also useful in determining which factors are of greatest economic importance. Because this project showed that molt time of eyestalk ablated *Orconectid* species can vary by species, time of year, maturity, sex and water temperature, three molting periods were selected. Ten-day, 14-day and 18-day molt cycles were used because they represented observed molting periods for eyestalk ablated *Orconectid* species and they demonstrated the impact molt cycle had on net income. Each of the three molt periods were used to develop separate economic models.

A variety of scenarios were run for each of the three models to examine profitability of soft shell crayfish production using bilateral eye stalk ablation to induce molting. Each variable was examined for its relative impact on profitability.

By keeping other variables constant, it was found that the shortest molt cycle (10-day model) had the highest net income (Figure 30). Short molt cycle is achieved by using juvenile rather than mature crayfish and by increasing water temperature to optimum levels. Molt cycle is increased by using mature crayfish or lowering water temperature. Females tend to have a slightly longer molt cycle than males. When the number of trays was set at 40 for each of the three different models and all other parameters were held constant, the 10-day molt cycle resulted in significantly higher profitability than either the 14-day or 18-day molt cycles. While the 14-day molt cycle was more profitable than the 18-day model, the difference was not as pronounced as the difference between the 10-day and 14-day molt cycles. Length of the molt cycle is an important factor in determining net income.

By far the most important variable determining profitability was survival rates for the eye stalk ablated crayfish through the molt cycle (Figure 31). Our research has shown that these rates can be highly variable. Survival of ablated crayfish is determined by condition of crayfish prior to eye stalk ablation, water quality in the production facility, frequency of checking trays for newly molted crayfish, sex, size and maturity of crayfish, and skill of the ablator. Survival of crayfish can be increased by using crayfish in good condition; ones that have not been stressed during transportation or storage and ones that have not just recently undergone a natural molt in the wild. It is also important to check trays frequently because crayfish are cannibalistic and newly molted crayfish will be quickly consumed if they are not promptly removed from the trays.

Figure 30

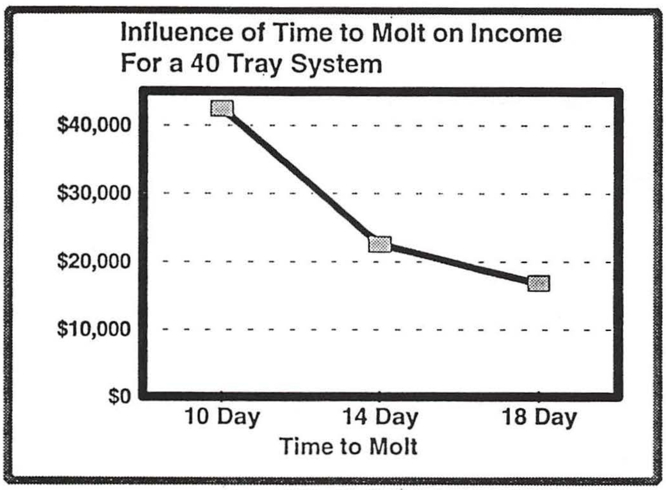


Figure 31

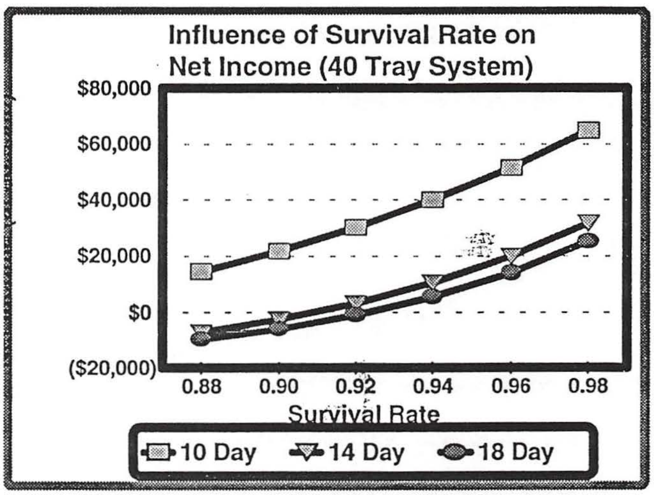


Figure 32

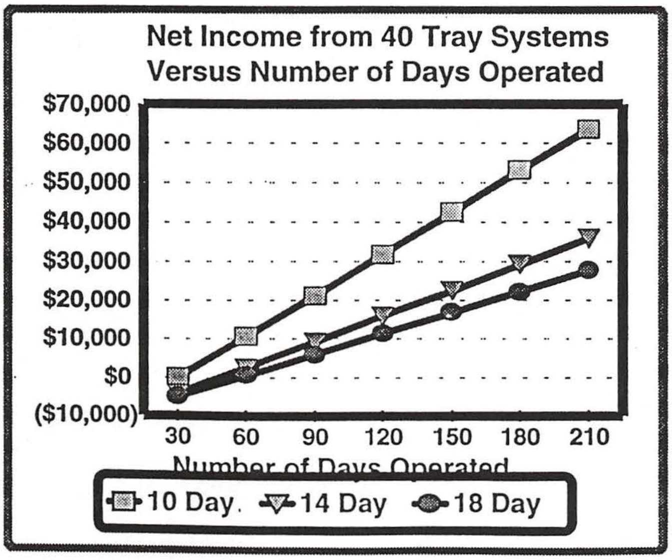


Figure 33

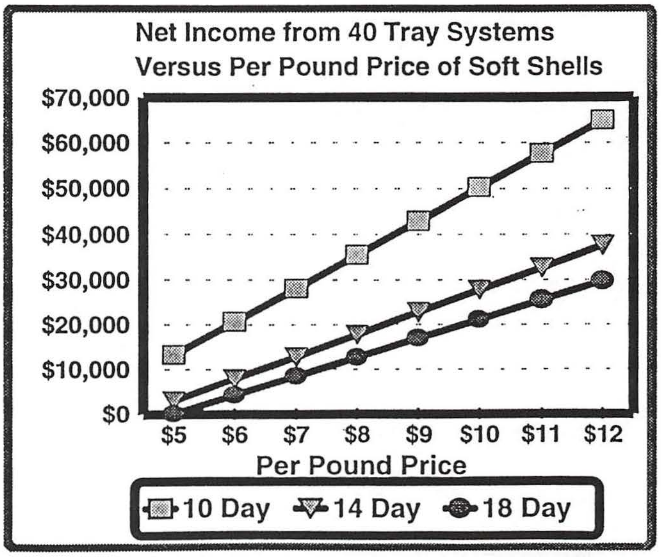
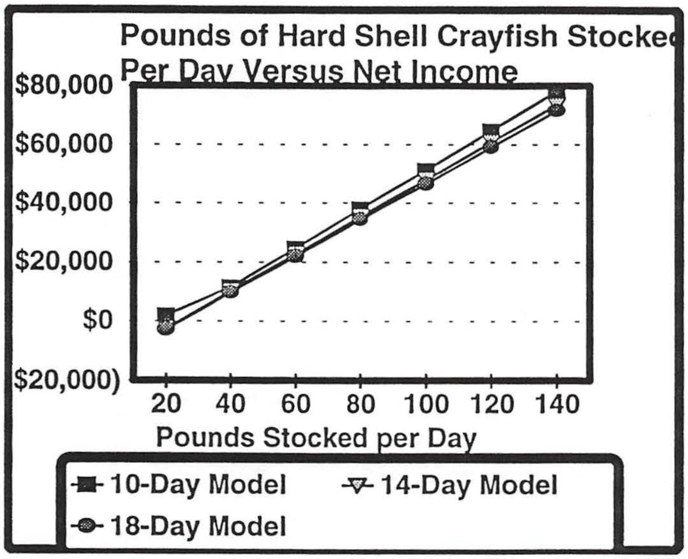


Figure 34



Number of days the facility is operated (Figure 32), the price paid for soft shell crayfish (Figure 33), and pounds of crayfish stocked per day (Figure 34) are also important in determining net income. Factors that were found to be less important to profitability were price of crayfish feed, cost of crayfish to stock production units (within reason), and cost of labor (within $2.00 per hour). Molting rates could be important depending upon values chosen, but within documented ranges, they were less important than survival rate.

Percent of soft shells produced from hard shells stocked varied in our laboratory studies from approximately 40 to 80 percent. By selecting molting and survival rates that resulted in a 60 percent return of soft shells, it appears that it would be profitable to produce soft shell crayfish at all three molt cycle lengths (10-days, 14-days, and 18-days) using eye stalk ablation and the production system described in this paper. It was estimated that net income would be $42,500, $22,500, and $17,000 for operating a 40 tray facility for 150 days (five months), producing about 60 percent soft shells from stocked hard shells, paying an employee $6.50/hr for 150 days and selling the product for $8.95 per pound. To show how sensitive the models are to price paid for the soft shell crayfish, the approximate net income at selling prices of $6.00 and $12.00 per pound were $20,500 and $60,000 for the 10-day model, $8,000 and $37,500 for the 14-day model, and $4,000 and $39,600 for the 18-day model, respectively.

In summary, it appears that production of soft shell crayfish by molt induction according to the model systems described in this paper would be profitable for a range of input variables that fall within limits observed in our lab studies. The model is designed only to provide a simple economic analysis of potential commercial viability. Information about current market demand and price must be thoroughly examined before investing in a soft shell crayfish business venture. Projected net income can be reduced by a number of factors not incorporated into this model. For example, if live soft shell crayfish are needed to meet the market demand and the product must be shipped a long distance to reach the market, losses from mortality during shipping will reduce profitability. It is recommended that a business development specialist be consulted and a detailed business plan be developed before starting a soft shell crayfish production business.

Crayfish Harvest, Distribution, Life History, and Response to Aeration

Through the course of this project a great deal has been learned about crayfish life history, growth, production, and behavior. Behavior of the papershell crayfish in Minnesota's wild rice paddies is very similar to the behavior of the red swamp crayfish (*Procambarus clarkii*) which annually produces a commercial harvest around 100 million pounds from aquaculture and wild in Louisiana each year. Both species burrow to escape harsh environmental conditions. In Louisiana, the red swamp crayfish burrows when water quality declines due to summer's heat, whereas, the papershell crayfish in wild rice paddies burrows in late summer to escape declining water levels and the onset of winter.

Papershell crayfish have been observed burrowing from the beginning of July until November. The majority of mature crayfish appear to burrow during the last two weeks of August even though water quality and level were maintained (Gunderson and Kapuscinski, 1993). Essentially, mature crayfish become unavailable after September 1. Young of the year crayfish delay burrowing longer than adults and can frequently be found through the month of September, concentrated in paddy ditches that have not completely dried and in water supply ditches.

Crayfish typically burrow along the edge of ditches that rings each paddy. They can be on either the paddy or the levy side of ditches. Occasionally, large numbers of crayfish have been observed burrowing throughout the paddy, far from the ditch or levy. It is generally thought that this happens when water is drawn down more rapidly than normal and there is a good stand of rice which visually hides the crayfish from predators. Crayfish burrow structure and depth were examined by filling the burrow with spray insulating foam. Excavation of the burrows after the foam hardened revealed that burrows normally extend down to and slightly below the water table. One or two crayfish may be present in a single burrow. Burrows are generally straight but may be slightly branched (see Huner, 1991, for a more complete description of crayfish burrowing). As water levels drop, crayfish continue to burrow to stay in contact with the water table. Burrows are generally capped with a mound of excavated soil 2 to 3 inches high.

Since crayfish damage has not been a problem in many wild rice growing areas other than in the Aitkin, Minnesota area, it is speculated that the soil type and water table level may allow for better crayfish over-winter survival than in other wild rice growing areas. Thermocouples were placed in crayfish burrows in fall 1992 to monitor temperature conditions in burrows. Burrows were selected from a variety of habitats and in two burrows thermocouples were placed near the entrance, the middle, and the bottom of the burrow. Results indicate that temperature near the bottom of all burrows never fell below 38 - 40 F during the winter even though temperatures near the entrance of the burrows approached freezing. Depth of burrows ranged from 63 cm (2 ft) to 127 cm (4 ft) and averaged 89 cm (2.9 ft). Temperatures were 2 to 5 degrees F warmer (depending on sample date) in areas of higher percentage of peat than in the more clay soils. It appears that crayfish in the studied paddies can find an environment thermally suitable for over-winter survival within 2 to 3 feet of the surface.

Crayfish emerged from burrows shortly after paddies are flooded each spring. Exact timing of emergence after flooding is not known because crayfish do not trap well in cold water. In years when water warmed quickly, however, crayfish were captured two weeks after flood up. Good catches were obtained in mid-April in 1990. Mature female crayfish appear to emerge from the burrow in berry (carrying fertilized eggs on their swimmerets) but some do not and may lay their eggs sometime after emergence. Berried female crayfish of other Orconectid species do not readily enter traps (Kutka et al, 1992). Papershell crayfish berried females do, however, trap as well as males in wild rice paddies.

Eggs hatch in late May. Juveniles remain with the female for a 2 to 3 molts after they hatch and usually leave the female by the end of May. Females undergo a molt following the dispersal of their young. It is thought that many of the larger, older females die during this molt, because they are not taken in traps after about the first of June. Young of the year crayfish seem to grow at different rates depending on food availability, their own density and the size of the adult population.

Gunderson and Kapuscinski (1993) found that young of the year crayfish in an experimental paddy with low crayfish densities and abundant food resources attained a size of 3.58 cm (CL) by the end of the first growing season. Crayfish from the same paddy one year later when crayfish densities were high only attained a size of 2.46 cm (CL) even though supplemental feed was provided. Young of the year crayfish in some wild rice production paddies do not even reach 2.0 cm (CL) in one growing season.

Young of the year crayfish in our aerated and unaerated control paddies also exhibited variable growth rates. Young of the year crayfish in the four, two acre experimental wild rice paddies, where suckers were stocked and supplemental food was supplied, attained an average size of 3.1 cm (CL) during the 1993 growing season.

Growth was significantly lower in wild rice production paddies where suckers were also stocked, but no supplemental feed was provided. Growth of young of the year crayfish in 1993 was the lowest in the aerated six-acre production paddy where there was no wild rice (due to crayfish depredation in 1992) and very little other aquatic vegetation. Young of the year crayfish in this paddy only grew to 1.97 cm (CL). Crayfish in the unaerated 12-acre production paddy (where a harvestable wild rice crop was produced) grew to 2.48 cm (CL).

Aeration did not seem to have an effect on young of the year growth during 1993 but effects were masked by differences in paddy wild rice production, crayfish density and sucker production. Growth was actually lower in the aerated six-acre paddy than it was in the unaerated 12-acre paddy. The six-acre paddy, however, was mostly devoid of any aquatic vegetation and there was a higher adult crayfish population than in the 12-acre paddy. Growth also did not seem to vary significantly among the two aerated and the two unaerated 2-acre experimental paddies. Young of the year crayfish reached 2.98 cm (CL) in the unaerated experimental paddies and 3.19 cm (CL) in the aerated experimental paddies. The effect of aeration on growth in the experimental two-acre paddies may have been masked by the higher crayfish and sucker densities in aerated paddies.

Both crayfish and sucker production, as estimated by end of season seining, seemed to be effected positively by aeration (see sucker results described above). The end of season harvest of crayfish from the two, two-acre aerated paddys was 118.5 pounds (average of the two paddies) compared to an average of 35.5 pounds harvested from the two, two-acre unaerated paddys, although production was highly variable in the aerated paddies. It appears that aeration influenced the amount of crayfish produced much more than the growth of crayfish in the two-acre experimental paddies. Production of crayfish in the aerated six-acre paddy could not be compared with crayfish production in the unaerated 12-acre paddy because the six-acre paddy was intensively trapped all season while the 12-acre paddy was harvested only at the end of the season. Also the end of season harvest of the six-acre paddy occurred on September 10, after most of the mature crayfish had already burrowed. All other paddies were harvested in late August, prior to most burrowing activity.

Intensive crayfish harvest by baited traps of a 20-acre paddy in 1992 and a six-acre paddy in 1993 reveal that trapping is not an effective method of crayfish removal. Crayfish catches seemed to reflect water temperature changes and molting cycles more than crayfish abundance. Catch rates in both 1992 and 1993 increased or remained stable through the summer rather than

Figure 35

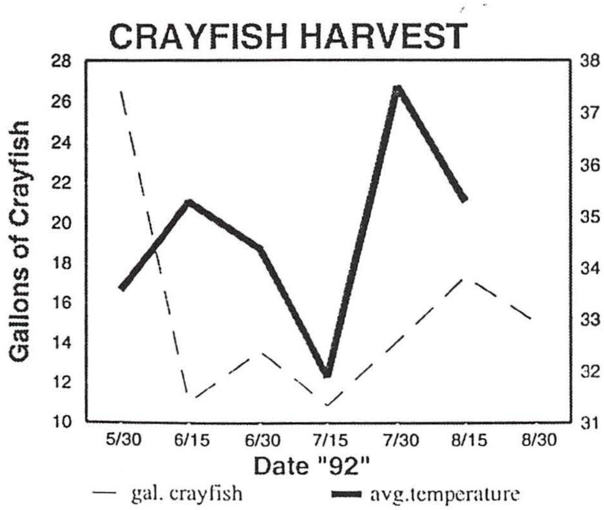
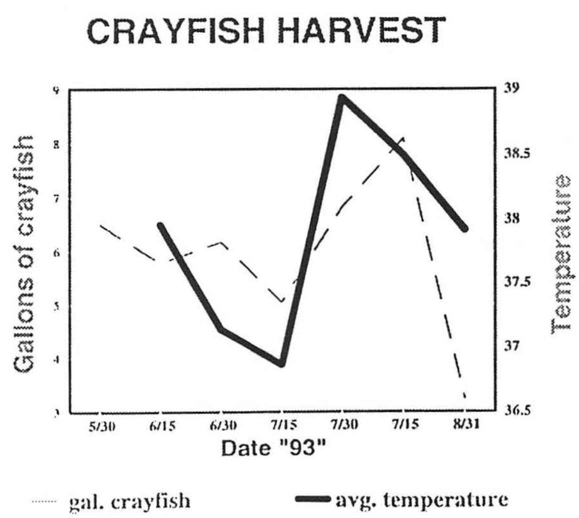


Figure 36



declining as a result of the intensive trapping effort. Approximately 1,425 pounds of crayfish were removed from a 20-acre paddy from May 4 until August 18, 1992. An average of 62 traps were lifted twice per week. Crayfish catch per trap averaged 0.86 pounds. Catch decreased during July when a period of cold weather reduced water temperatures (Figure 35), but then increased again when water temperatures increased. Trapping during 1993 again revealed that water temperature was an important determinant in crayfish trapping success (Figure 36). Unseasonably cool weather in early July, 1993 again caused a decline in catch rate which increased as temperatures increased in late July and early August. In 1993, 1,550 pounds of crayfish were removed from the six-acre paddy from May 14 to August 31. Approximately 60 traps were lifted 59 times (4.2 times per week) during 1993 for an average catch rate of 0.44 pounds per trap per lift.

Enclosures Results

Papershell crayfish had strong impacts on wild rice emergence and growth. No wild rice was present in enclosures with high density of either the large or small crayfish (Figure 37). Enclosures with moderate crayfish densities exhibited some wild rice growth and enclosures with no crayfish had much higher plant densities. Differences between control and crayfish treatments were apparent as early as one week after the beginning of the experiment.

Figure 37

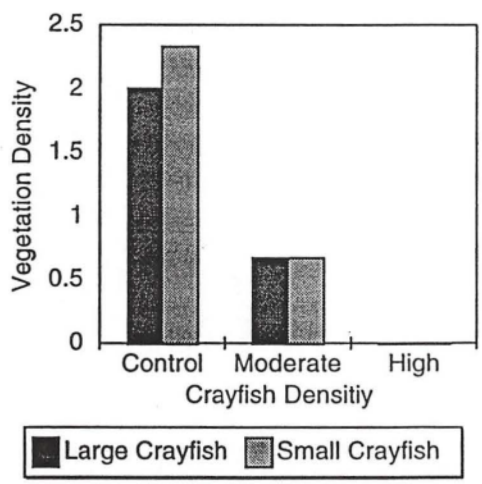
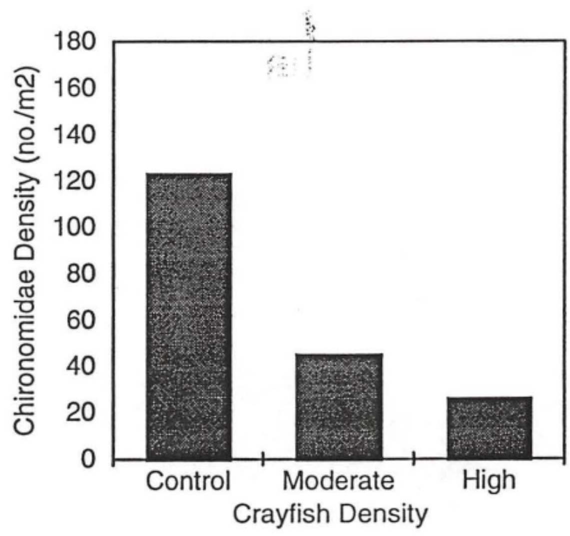


Figure 38



Similar trends were observed with the effects of crayfish density on benthic invertebrate abundance. Chironomids accounted for over 90% of the total abundance of invertebrates in the samples. Chironomid abundance in moderate and high density crayfish treatments was significantly lower ($p<0.05$) than controls (Figure 38).

The densities used in the enclosures are likely typical of areas near paddy ditches where crayfish are known to concentrate. Results of this experiment were consistent with our observations that the damage to wild rice in large paddies appears to be most apparent in the corners of the paddies where there is a large ditch area compared to the paddy area. In a subsequent experiment this same year by University of Minnesota wild rice investigators, wild rice was reseeded into exclosures and into the open paddy. Within the exclosure lush stands of wild rice grew, while outside the exclosures no wild rice emerged. We subsequently placed high densities of crayfish (approximately five times greater than our high density enclosures) into the enclosures after the rice became aerial, and observed no effects on the plants. Therefore, it appears that reseeding after a paddy has been damaged by crayfish may be ineffectual unless crayfish are removed. Also, it appears that after the rice plants become aerial, crayfish have little or no impact on the plant.

Crayfish damage to wild rice paddies is highly variable. Currently, we have insufficient data to predict which paddies will be impacted within a given year, but it does appear that small paddies may be more susceptible to major crop damage than larger paddies. Also, if crayfish abundance (or effects) can be reduced or minimized until the wild rice has become aerial, then damage to the crop will be eliminated or reduced. As a result, the following year (1993) we examined the possibility of trying to concentrate crayfish and provide them with an alternative food during the critical period until the rice became aerial. Results of that experiment follow.

Mitigation

The crayfish mitigation study was conducted in an effort to determine if by providing supplemental food, crayfish would preferentially feed on the supplemental food rather than feeding on the wild rice and whether supplemental feeding would concentrate crayfish in feeding areas. If crayfish could be concentrated in feeding areas and ate the provided feed rather than the wild rice, then it might be possible to protect wild rice during its three-week vulnerable stage and also make crayfish harvest easier and/or increase crayfish growth and survival.

Unfortunately, because of crayfish depredation the year before, there was not enough wild rice seed to produce a crop of wild rice and none grew anywhere in the one acre paddy in 1993. Crayfish densities in the paddy in 1993 were low and were not the cause of the crop failure. Therefore, we were unable to compare rice production in fed versus unfed areas of the paddy. Statistical analysis of the catch rates of crayfish in baited traps immediately following cessation of feeding did not show that crayfish were more concentrated in areas where feed was provided. Since distribution of crayfish in the paddy was not significantly altered due to our feeding of trout grower diet three times per week in two corners of the square paddy, we concluded that the crayfish in the test paddy did not respaddy to the food even though wild rice was absent and other food was likely limited.

Further effort needs to be directed at this mitigation effort. There have been no studies of crayfish food preferences which offered wild rice seedlings as a choice. We offered trout grower diet because it was readily available and from our lab studies we knew crayfish consumed it, but we did not know if crayfish would prefer it over wild rice seedlings. We felt that lower cost supplemental foods (like straw, waste potatoes, etc.) could be tested if mitigation worked with the trout feed. Observed crayfish depredation in production paddies is generally found adjacent to the ditch (especially in ditch corners) that rings each paddy. If a low cost supplemental feed could be found which crayfish preferentially feed on, then it may be possible to protect the rice during the period that it is most vulnerable to crayfish depredation. Under this project, we did not have the resources to further test the use of supplemental feeding in mitigation of wild rice depredation.

BENEFIT TO MINNESOTA ECONOMIC DEVELOPMENT

It is too early to determine long term economic benefit to Minnesota of crayfish and sucker culture in wild rice paddies. New businesses have started and existing ones have expanded as a direct result of this project. Two crayfish businesses started in 1994 which used information generated from this research. One business is a direct outcome of this project and will focus on crayfish production in wild rice paddies. The other business used information about soft shell crayfish, tail meat production, and other information about crayfish generated by this project. These two businesses are expected to provide approximately 12 jobs (mostly part time).

Another company is marketing a product from soft shell crayfish nationally which was a direct outcome of our contact with the business. The development of a national market for a product that uses soft shell crayfish not only increased employment at the existing business, but has increased the demand for soft shell crayfish which is being filled by technology that we demonstrated in the lab and extended to other existing and potential businesses. A Wisconsin company extended its production season by three months in 1993 and incorporate the technology, that enabled him to do this, more fully into his operation in 1994. The technology and the tools used were developed as part of this project and were transferred to the business during our April 1993 hands-on crayfish workshop (see workshop description below).

MARKETING

The results of this research have been marketed and presented at a number of forums. A crayfish workshop entitled "Crayfish: A New Industry For Minnesota -- What Are The Options" was held in April, 1993. Because we wanted to present hands-on information and involve participants, we limited registration to the first 20 people. Information generated during the crayfish research project was presented. Evaluations of the workshop indicate that participants rated the workshop very highly. On a scale of one (poor) to five (excellent), the overall conference was rated 4.4, the quality of the information presented was rated 4.6, and the quality of the presentations was rated 4.4. All respondents indicated that the workshop was a valuable use of their time and 80% said that they would use information that was presented. Sixty percent also listed specific information that they would use. One participant subsequently reported that he extended his operating season by three months in 1993 as a direct result of this workshop.

Information from both the crayfish and the baitfish aspects of the project were presented at Aqua '94, Minnesota's eighth annual aquaculture conference. This conference, held in March 1994 in Alexandria was attended by 300 people. Baitfish and crayfish results of this project were also presented at Development '94, an alternative business opportunity conference which attracted about 2,000 attendees and was held in Detroit Lakes in February, 1994. Results of this project were also presented at national meetings in Orlando, Florida and New Orleans, Louisiana. Results of our soft shell crayfish research were also presented at conferences in Indiana (September 1994) and in Wisconsin (March 1995).

Throughout the project, information has been presented to individuals that have requested information about the project. A number of informational publications have also been developed to help transfer information about various aspects of the developing crayfish industry. Information about the project has been published in a number of newsletters (Sieche, NRRI Now, AURI's newsletter, Wild Rice Growers newsletter) to help make people aware of the project and our results.

FUTURE NEEDS/PLANS

- **Market Development.** Food markets in both the northern U.S. and Europe, and bait markets within the region must be developed and expanded if crayfish culture, wild harvest and soft shell production are to progress.

- **Product Development.** The development of a cost effective tail meat peeling machine would increase the ability to market crayfish from wild rice paddies as well as small wild caught crayfish as human food. Crayfish tail meat is delicious, convenient for the consumer and can be incorporated into a number of other products. One machine appears to be ready for commercial testing. A Minnesota business is incorporating soft shell crayfish into its product. This product will be the focus of a nationwide infomercial beginning fall 1995. Success of this product could help develop soft shell crayfish production in the state.

- **Transportation Techniques for Live Crayfish.** Markets for live crayfish exist in Europe for human food and in the north central U.S. for bait. Businesses attempting to ship crayfish into these markets have at times encountered severe crayfish mortality problems. Development of techniques to consistently ship live crayfish with low rates of mortality would help the viability of this industry.

- **Mitigation of Wild Rice Damage by Crayfish.** Although we were unable to demonstrate the effectiveness of using supplemental feeding of crayfish in wild rice paddies to reduce depredation on wild rice, we feel that this would be a fruitful area of exploration if the culture of crayfish in wild rice paddies becomes economically viable. Further research into management strategies to maximize economic output from a mixed culture system (bait fish and wild rice or crayfish and wild rice) would also be beneficial.

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