TOXICITY OF AMMONIA AND HIGH pH TO FRESHWATER SHRIMP, *MACROBRACHIUM ROSENBERGII*

By

David L. Straus

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in the Department of Wildlife and Fisheries
Mississippi State, Mississippi

May 1988

TOXICITY OF AMMONIA AND HIGH pH

TO FRESHWATER SHRIMP, MACROBRACHIUM ROSENBERGII

By

David L. Straus

APPROVED:

H. Randall Robinette, Ph.D.
Professor of Wildlife & Fisheries (Major Professor)

Robert D. Brown, Ph.D.
Professor of Wildlife & Fisheries (Department Head and Graduate Coordinator)

John M. Heinen, Ph.D.
Assistant Professor of Wildlife & Fisheries (Committee Member)

Warren S. Thompson, Ph.D.
Dean, School of Forest Resources

Jonathan W. Pote. Ph.D.
Assistant Professor of Agricultural & Biological Engineering (Committee Member)

Charley Scott, Ph.D.
Vice President for Graduate Studies

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. H. Randall Robinette for the opportunity to work under him and gain from his extensive knowledge in aquaculture. Committee members Dr. John Heinen and Dr. Jonathan Pote have given considerable input to my research, and I thank them both. Dr. Marvin Bond, Director of the Water Resources Research Institute, has been invaluable in funding this project. I am indebted to Carolyn Boyle for her extensive expertise in statistics, as I would have been lost without her help. Dr. Robert Thurston and Dr. Martin Hamilton of Montana State University and Dr. Craig Tucker of the Delta Branch Experiment Station have contributed much knowledge pertaining to toxicology and statistics. Viodelda Jackson and Dr. Randy MacMillan merit credit for contributing knowledge concerning ammonia and nitrite analyses. Mike Argo and the staff at MAFES computing have been extremely helpful. Employees of the South Farm Aquaculture Unit--Gary Fornshell, Pat Foley, and Jeff Collins -- have assisted me in various stages of my research and deserve many thanks. I would also like to thank Judy Coats, Richie Cooper, Pat Deliman, Mack Fondren, and Dr. Jim Tidwell for assistance and encouragement throughout my education at Mississippi State University. Special thanks go to my Mom and Dad who have played a very important role in my life; although I

haven't always shown them my love, I appreciate them immensely!

Most of all I thank God for the innumerable blessings He has bestowed on me throughout my life.

ABSTRACT

David L. Straus, Master of Science, 1988

Major: Wildlife Ecology, Department of Wildlife and Fisheries

Title of Thesis: Toxicity of Ammonia and High pH to Freshwater Shrimp, Macrobrachium rosenbergii

Directed by: H. Randall Robinette

Pages in Thesis: 116. Words in Abstract: 241.

ABSTRACT

Three size classes of Macrobrachium rosenbergii de Man (post-larval, juvenile, and sub-adult) were exposed at 29°C to four pH levels (8.5, 9.0, 9.5, and 10.0 for post-larvae and juveniles, and 9.0, 9.5, 10.0, and 10.5 for sub-adults) and four concentrations of un-ionized ammonia-nitrogen (0, 1, 2, and 3 mg/L NH_3-N), in a 4 X 4 factorial design. Post-larvae and juveniles were exposed for 72 h, while sub-adults were exposed for 24 h. LC_{50} and LC_{10} values were calculated using the trimmed Spearman-Karber method and probit analysis. Results indicated a synergistic toxic effect between NH_3-N and high pH. Juveniles were more tolerant of high pH and NH_3-N than post-larvae. Sub-adults were less tolerant than juveniles; this may have been due to stress from crowding during toxicity trials. In general, LC_{50} and LC_{10} estimates decreased approximately 0.5 pH units

from 6 h to 72 h exposures.

Field study tests in culture ponds indicated that high pH levels were associated with low concentrations of NH_3-N (<0.20 mg/L). High pH levels and excessive mortalities (>30%) occurred in some of these ponds, but data were not taken over the entire production period and, therefore, no correlation could be established. Based upon trimmed Spearman-Karber 72 h LC_{10} estimates, pH and un-ionized ammonia-nitrogen levels should not exceed 9.0 and 1 mg/L, respectively, for post-larvae, and should not exceed 9.5 and 0 mg/L, respectively, for juveniles. These estimates are especially applicable to re-circulating systems, but may also provide useful guidelines for pond culture.

Contents

Figures

Tables

Introduction

Interest in commercial culture of the giant Indo-Pacific freshwater shrimp, Macrobrachium rosenbergii de Man, has increased steadily since mass culture techniques were developed in the 1960's (Sandifer and Smith 1985). Mississippi possesses a climate suitable for seasonal production of freshwater shrimp. The state already has a large, economically important aquaculture industry (Tucker 1985), which will facilitate rapid commercialization of shrimp culture if it proves economically attractive. A major input and constraint in aquaculture is a water supply of suitable quantity and quality. Well water in some parts of Mississippi and elsewhere has an inadequate buffering system due to high alkalinity and low calcium hardness levels. Ponds filled with such water can experience high pH levels lethal to aquatic animals when dense phytoplankton blooms are present, because removal of carbon dioxide during photosynthesis causes carbonate ions to hydrolyze to bicarbonate and hydroxyl ions (Boyd 1979).

High pH also increases the toxicity of the ammonia released by metabolism of aquatic animals and microbes. Ammonia exists in both an un-ionized (NH_3) and an ionized (NH_4^+) form in aqueous solution. Toxicity to aquatic animals has been attributed primarily to the un-ionized form, which has been estimated to be 50 times more toxic

than the ionized form (Tabata 1962). The percentage of the total ammonia which is in the un-ionized form is principally dependent on pH. As pH rises, increasing amounts of ammonia exist in the un-ionized form because fewer hydrogen ions are available to protonate NH_3 to NH_4^+ (Thurston et al. 1979).

An un-ionized ammonia-nitrogen (NH_3-N) level of 0.10 mg/L reduced the growth rate of freshwater shrimp post-larvae (Wickins 1976). Mortalities of freshwater shrimp associated with high pH have been reported (AQUACOP 1979, Sandifer et al. 1983, Clardy et al. 1985). Toxicity of high pH to M. rosenbergii has been investigated (Sarver et al. 1979, Hummel 1986), but no toxicological studies have been done on both ammonia and high pH for this species.

Sandifer et al. (1983) stated that the preferred pH range for freshwater shrimp ponds is 6.5 to 9.0, which is also the preferred range for finfish ponds (Swingle 1957). Mortalities of freshwater shrimp associated with high pH have been reported in South Carolina waters with high total alkalinity ($\geq$180 ppm); however, mortality was apparently due to gill occlusion by precipitated calcium carbonate rather than to high pH itself (Sandifer et al. 1983, Sandifer and Smith 1985). AQUACOP (1979) reported that pH levels exceeding 10.5 resulted in mortalities of recently molted freshwater shrimp. Their discussion implied that un-ionized ammonia was probably the cause of death, but no evidence was presented that ammonia rather than high pH itself was the

cause. Freshwater shrimp ponds at Mississippi State University have exhibited extensive mortalities when pH levels were high (Clardy et al. 1985).

Studies have been performed on pH toxicity in fresh water to M. rosenbergii by Sarver et al. (1979) and Hummel (1986). However, Sarver et al. did not indicate whether ammonia levels were monitored, while Hummel reported that ammonia testing was done at the conclusion of several experiments. It is unclear whether it was high pH or high levels of un-ionized ammonia in combination with high pH which caused mortalities in these experiments.

Sarver et al. (1979) tested 72 h tolerances of post-larvae of three ages (newly-settled, 2 weeks post-settling, and 1 month post-settling) to three pH levels (9.0, 9.5, and 10.0) using two replicates (20 animals per replicate) per age group. Temperature was not specified but was probably 29°C, based on other information in the article. No animals died at pH 9.0, averages of 40-80% per age group died at pH 9.5, and all died at pH 10.0.

Hummel (1986) tested 96 h tolerances of post-larvae of unspecified size to ten pH levels ranging from 7.5 to 12.0 in 0.5-unit increments; each treatment was replicated twice with 30 animals per replicate. Temperature ranged from 28 to 29°C. Animals exposed to pH levels of 7.5 and 8.0 exhibited no mortalities, whereas animals at pH 8.5 and 9.0 exhibited 1% and 40% mortality, respectively. Tanks with

higher pH levels had 100% mortality. The 8 h LC_{50} for pH was estimated to be between 9.0 and 9.5; however, the type of analysis was not reported.

The present study was undertaken to determine the acute toxicity of higher pH and un-ionized ammonia-nitrogen in fresh water to post-larval, juvenile, and sub-adult freshwater shrimp for various exposure periods. In addition, pH and ammonia were monitored in freshwater shrimp culture ponds in order to have field observations for comparison with laboratory toxicity results.

Materials and Methods

Bioassays

Bioassays were performed on three size classes of shrimp: post-larvae, juveniles, and sub-adults. Static bioassays (CMTTAO 1975; APHA 1985) were carried out in eighteen tanks arranged in a randomized 4 x 4 factorial design with two control tanks per replication. Three replications were carried out for each size class. Post-larval and juvenile freshwater shrimp were exposed to pH levels of 8.5, 9.0, 9.5, and 10.0 $\pm$ 0.1, and sub-adults were exposed to pH levels of 9.0, 9.5, 10.0, and 10.5 $\pm$ 0.1. NH_3-N concentrations of 0, 1, 2, and 3 $\pm$ 0.25 mg/L were tested at each pH level. See Table 1 for a list of abbreviations and analytical methods used.

Bioassay tanks were 72 L glass aquaria (61 x 31 x 38 cm) bonded with silicone adhesive. Bottoms were painted black on the outside to enhance visibility of the shrimp. Transparent polystyrene covers prevented shrimp from jumping out. A plastic structure ("habitat"), constructed of 13 mm light louver grid material, was provided in each tank to allow the shrimp to distribute themselves better throughout the water column, thereby reducing the chances of cannibalism and stress associated with crowding (Figure 1). An airstone provided minimal aeration in each tank to avoid stripping ammonia while maintaining DO levels near 100%

Table 1. Abbreviations used in the text and methods used for measurement of water quality.

Abbreviations	
TAN	Total ammonia-nitrogen
NH_3-N	Un-ionized ammonia-nitrogen
NO_2-N	Nitrite-nitrogen
LC_{50}	An estimate of the median lethal concentration for the population at a given time
LC_{10}	An estimate of the concentration lethal to 10 percent for the population at a given time
DO	Dissolved oxygen

Parameter	Method
Temperature	Mercury thermometer
pH	Fisher Accumet pH meter (Fisher Scientific Company 1983)
DO	Dissolved oxygen meter (Yellow Springs Instrument Company Scientific Division 1986)
TAN	Colorimetric (phenate) method (APHA 1985)[a]
NH_3-N	Thurston et al. 1979 (calculated from measurements of total ammonia nitrogen, pH, and temperature)
NO_2-N	Colorimetric (sulfanilamide) method (APHA 1985)[a]
LC_{50} and LC_{10}	Determined by the trimmed Spearman-Karber method (Hamilton et al. 1977) and probit analysis (Finney 1971)

[a] A Bausch and Lomb Spectronic Model 2000 spectrophotometer was used.

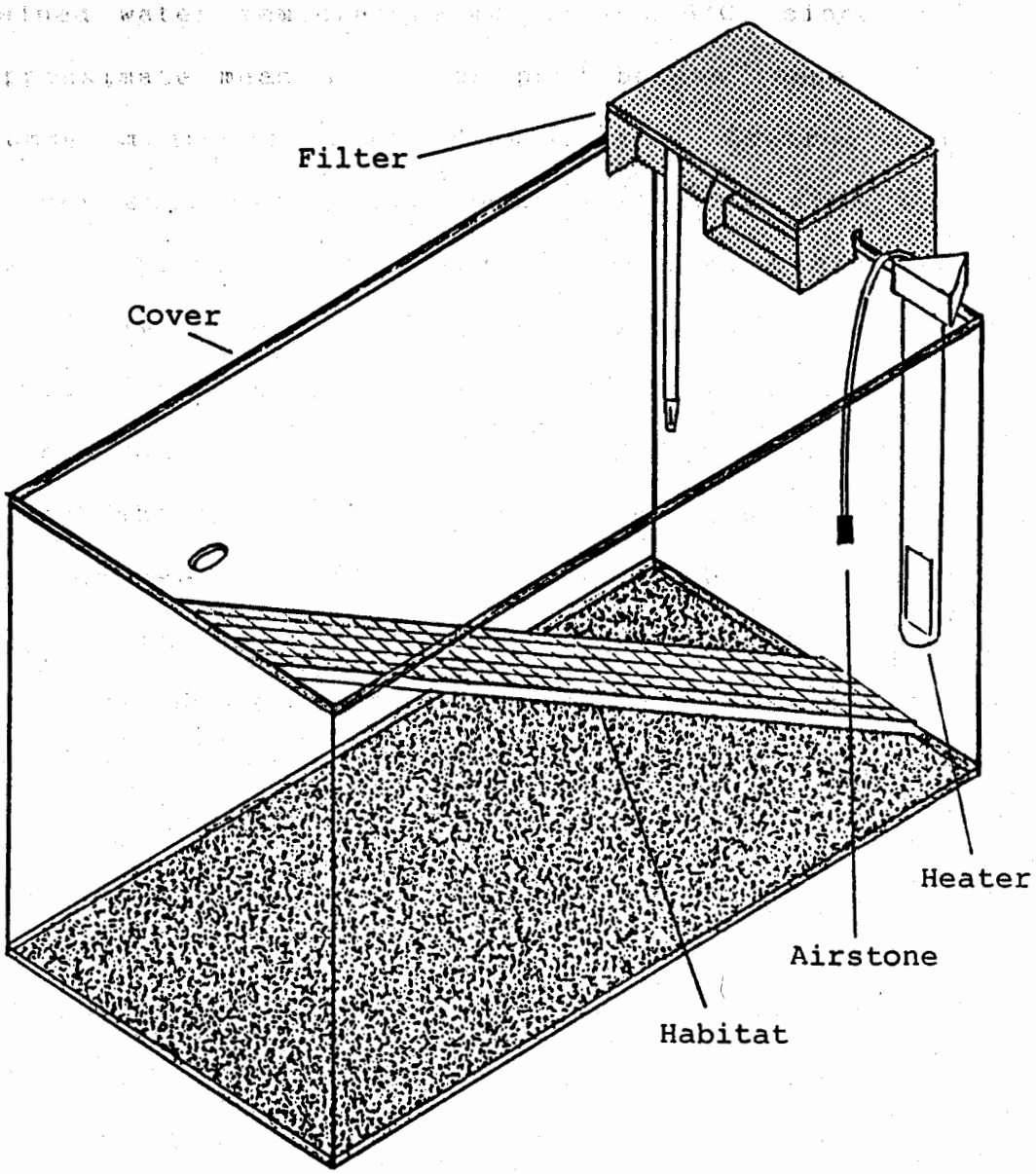

Figure 1. Bioassay system used for freshwater shrimp toxicity study.

saturation. An electric immersion heater in each tank maintained water temperature at 29 $\pm$ 0.5°C, since this is the approximate mean afternoon pond bottom temperature for the summer months in north Mississippi. Control and zero NH_3-N concentration tanks were provided with outside biological filters containing conditioned pea gravel to oxidize waste ammonia. A 16 h-light/8 h-dark light cycle was employed to simulate summer photoperiod conditions.

Tanks were filled with 60 L of local, unchlorinated well water which had been aerated for at least 24 h prior to use. Analyses of well water were obtained near the beginning and end of the testing period (Appendix A). Experimental pH values were achieved and maintained using 0.5 M NaOH and 0.5 M HCl. The pH was monitored several times daily (see Table 2) and adjusted as required. Control tanks did not receive any pH adjustment. NH_3-N concentrations were achieved using a solution of 1000 mg/L NH_4Cl, and were calculated using parameters of 29°C and percent NH_3-N of TAN at pH levels of 8.5, 9.0, 9.5, 10.0, or 10.5, according to individual treatments (Appendix B). In contrast, most ammonia toxicity studies have tested uniformly spaced levels of TAN, which results in non-uniformly spaced levels of NH_3-N.

NH_3-N concentrations were monitored regularly (Table 2). Appropriate volumes of tank water were exchanged with new 29°C water of the proper pH level when NH_3-N

Table 2. Water quality parameter monitoring schedules for freshwater shrimp bioassays.

Parameter	Monitoring intervals (h)	
	Post-larvae and juveniles[a]	Sub-adults[b]
pH	12[c]	3[c]
NH_3-N	24	6
NO_2-N	24	12
Temperature	24	12
DO	24	12

[a] Duration = 72 h.
[b] Duration = 24 h.
[c] pH levels were occasionally monitored more frequently.

concentrations increased to their upper permissible limits. NO_2-N concentrations were also monitored frequently (Table 2), to ensure that this would not be a source of stress or mortality to the test animals. See Appendix C for test parameter measurements. Post-larvae were obtained from the Aquaculture Unit of the Mississippi Agricultural and Forestry Experiment Station (MAFES), Mississippi State University, or were purchased from Blue Lobster Farms (Madera, CA). Juveniles and sub-adults were reared from post-larvae in nursery tanks and grow-out ponds, respectively, at the Aquaculture Unit. Sub-adults were moved to indoor holding tanks in the fall to avoid lethally low water temperatures and were held for 3 days to 4 weeks before bioassays. Shrimp were selected for approximate size uniformity and acclimated for 48 h without feeding in an aerated tank (303 x 50 x 25 cm) containing 29°C well water. The tank was equipped with a pea gravel biofilter and with habitats, polystyrene covers, and immersion heaters similar to those in the aquaria. Water quality in this tank was monitored frequently and was maintained by water exchanges if the biofilter did not perform adequately.

After pH and NH_3-N treatment levels had been adjusted in the experimental tanks, 20 post-larvae, 10 juveniles, or 10 sub-adults were stocked per tank between 0600 and 0800 h. Shrimp were first counted in groups of five into 300 ml of well water in 1 L plastic buckets (one per tank) until each

bucket held the 10 or 20 needed per tank. Then 300 mL of water was added to each bucket from the corresponding aquarium. Another 300 mL was added to each bucket about 1 min later, and then the animals were poured into the aquaria. A representative sample of 30 shrimp was similarly selected during this stocking procedure; these were not used in the experiment but were measured and weighed individually to obtain size estimates (Appendix D). Size class measurements are summarized in Table 3.

Shrimp were not fed during an experiment, in order to minimize variability due to nutritional and metabolic condition (CMTTAO 1975, APHA 1985). Molts and dead animals were recorded and removed when observed. Molting was rarely associated with mortality. The criterion used for death was a lack of movement after gentle prodding. Survivors were counted at 1, 3, 6, 9, 12, 24, 48, and 72 h for post-larvae and juveniles, and at 1, 3, 6, 9, 12, 15, 18, 21, and 24 h for sub-adults. The 72 h test period for post-larvae and juveniles was used instead of the standard 96 h bioassay because unstable levels of pH and NH_3-N, increased NO_2-N concentrations, and decreased DO were encountered in unfiltered tanks by 96 h. Tests for sub-adults were limited to 24 h, because their greater biomass caused similar deterioration of water quality in longer trials. In all tests, a replication was rejected if control survival averaged less than 90%. Results were tabulated and

Table 3. Post-orbital length and wet weight for each size class of freshwater shrimp.

Size Class	Size Parameters	Mean	SE	Range
Post-Larvae	Length (mm)	9.6	0.1	7-11
	Weight (mg)	12.9	0.4	6-21
Juveniles	Length (cm)	3.45	0.03	2.8-4.0
	Weight (g)	0.836	0.023	0.41-1.28
Sub-Adults	Length (cm)	7.56	0.05	6.8-8.9
	Weight (g)	10.18	0.25	6.9-16.8

n = 90 for each size class.

expressed as percent survival for each replication (Appendix E).

Field Study

Levels of pH, NH_3-N, and temperature were monitored daily from 6/25/87 to 7/26/87 in six freshwater shrimp research ponds involved in another study (Appendix F). Water samples were taken near 1600 h (approximately the time of highest pH) at a depth of about 30 cm and were analyzed immediately. Water temperature was monitored with a YSI Model 51B oxygen meter, while pH and NH_3-N were measured as for the bioassay tanks. These parameters were also recorded from other shrimp research ponds of the Aquaculture Unit which exhibited pH levels $\geq$10.0. Monitoring of ponds was done to gather water quality data from ponds which had high pH yet had good survival (c. >70%), for comparison with laboratory results. Attempts were made to maintain pH $\leq$10.0 in these ponds by flushing when levels attained 9.5, although this was not always possible.

Statistical Analyses for Bioassays

Percent survivals from the toxicity tests were analyzed using both probit analysis (Finney 1971) and the trimmed Spearman-Karber method (Hamilton et al. 1977), a parametric and a non-parametric method, respectively. Both tests estimate the LC_{50} of the toxicants, which is chosen because it is the quantile whose estimates have the lowest sampling variance (Gelber et al. 1985). The LC_{50} estimate is

standard for acute toxicity tests, but is not practical for culturists. Therefore, LC_{10} estimates were also calculated to provide practical guidelines for freshwater shrimp production.

Probit analysis is based on transformation of concentration levels so that the resulting relationship of concentration-mortality has a known functional form (Gelber et al. 1985). The probit transformation maps percent mortality into a probit value, which ranges from - infinity to + infinity; plotting the probit values against the logarithms of the concentrations gives a sigmoid-shaped curve (Gelber et al. 1985). Probit analysis requires data sets having at least 2 values that are not 0% and not 100%. This was not always the case in this study.

The non-parametric trimmed Spearman-Karber method is based on the monotonicity (increasing order) of the concentration mortality curve from which LC_{50} estimates are obtained (Gelber et al. 1985). The only requirement for this analysis is that at least one mortality proportion must be less than or equal to 50% and at least one must be greater than or equal to 50%.

Hamilton et al. (1977) compared the probit, logit and trimmed Spearman-Karber methods and concluded that the probit and logit models have deficiencies that are sufficiently important and "... should probably not be used for routine analyses of an extended series of bioassay

experiments". (Logit analysis is a parametric method which is rarely used in toxicity tests). Hamilton et al. (1977) also stated the importance of analyzing sets of bioassay data with a single statistical method when routine analysis is performed. Because of reliability and ease of use, the trimmed Spearman-Karber method was chosen as a superior analysis for this study. However, probit analysis (available from SAS Institute Inc., Cary, NC) was also carried out, for the sake of comparison with other studies using it.

An LC_{50} estimate is based on data from only a small portion of a particular species and does not coincide with the true LC_{50}, which is the concentration that would be lethal to exactly 50% of the entire species. Thus, a 95% confidence interval for the true value is usually computed along with its point estimate (Gelber et al. 1985).

The trimmed Spearman-Karber computer program (available from the United States Environmental Protection Agency, Athens, GA) was designed to calculate only LC_{50} values along with their respective confidence intervals. The LC_{10} values, which have much greater sampling variance and are therefore less reliable, were calculated by linear interpolation of the adjusted mortality proportions from the original program; confidence intervals would be too large to be useful for this estimate and thus are not reported.

Results

Appendices C, D, and E, contain data collected from individual replications during bioassays. Survival results of treatment combinations within replications for each size class were averaged for calculating LC_{50} and LC_{10} estimates. Survival among replications was generally consistent, as evidenced by small standard errors.

Tables 4-6 report percent survival (mean $\pm$ standard error) for each size class at each exposure period. Figures 2-4 show 3-dimensional graphs of the average survival percentages for each size class. Toxicity of NH_3-N increased substantially with increasing pH. Results indicate that both the sensitivity of animals to pH and the synergistic effect of pH and NH_3-N decreased from post-larvae to juveniles; however, sub-adults were less tolerant than juveniles.

Post-larval survival means exhibited substantial mortality ($\geq$25%) at 0 mg/L NH_3-N between pH levels of 9.0 and 9.5 at 9 h (Table 4). The 9 h exposure period also indicated post-larvae at pH 9.0 and NH_3-N concentrations of 0, 1, and 2 mg/L had survival averaging 98% which dropped to 68% at 3 mg/L. After 24 h at pH 8.5, post-larvae averaged 94% survival among concentrations of 0, 1, and 2 mg/L NH_3-N, but a synergistic effect apparent at 3 mg/L caused decreased survival of 33%. Results indicate that post-larval fresh-

Table 4. Mean percent survival ± standard error of post-larval freshwater shrimp over 3 replications.

Treatment combination*	Time (h) 1	3	6	9	12	24	48	72
8.5,0	98±0.02	98±0.02	98±0.02	100±0.00**	98±0.02	98±0.02	97±0.03	97±0.03
8.5,1	98±0.02	98±0.02	98±0.02	97±0.03**	98±0.02	98±0.02	97±0.02	97±0.02
8.5,2	100±0.00	100±0.00	100±0.00	100±0.00**	97±0.02	87±0.04	83±0.03	75±0.08
8.5,3	98±0.02	95±0.00	93±0.02	88±0.07**	77±0.09	33±0.24	13±0.13	5±0.05
9.0,0	100±0.00	100±0.00	98±0.02	97±0.03**	98±0.02	95±0.00	95±0.00	93±0.02
9.0,1	100±0.00	100±0.00	100±0.00	100±0.00**	100±0.00	100±0.00	100±0.00	92±0.03
9.0,2	98±0.02	98±0.02	97±0.02	97±0.03**	93±0.02	80±0.06	50±0.21	17±0.08
9.0,3	98±0.02	97±0.02	93±0.02	68±0.03**	53±0.19	18±0.18	2±0.02	0±0.00
9.5,0	98±0.02	92±0.06	78±0.14	65±0.30**	70±0.20	68±0.22	60±0.23	43±0.17
9.5,1	100±0.00	68±0.18	45±0.18	23±0.07**	37±0.20	13±0.13	5±0.05	0±0.00
9.5,2	97±0.03	47±0.24	13±0.11	3±0.03**	10±0.08	3±0.03	0±0.00	0±0.00
9.5,3	92±0.03	23±0.16	0±0.00	0±0.00**	0±0.00	0±0.00	0±0.00	0±0.00
10.0,0	90±0.05	27±0.19	2±0.02	0±0.00**	0±0.00	0±0.00	0±0.00	0±0.00
10.0,1	72±0.11	5±0.05	0±0.00	0±0.00**	0±0.00	0±0.00	0±0.00	0±0.00
10.0,2	75±0.10	0±0.00	0±0.00	0±0.00**	0±0.00	0±0.00	0±0.00	0±0.00
10.0,3	52±0.15	0±0.00	0±0.00	0±0.00**	0±0.00	0±0.00	0±0.00	0±0.00
Control 1	100±0.00	100±0.00	98±0.02	100±0.00**	98±0.02	97±0.03	97±0.03	97±0.03
Control 2	100±0.00	100±0.00	100±0.00	100±0.00**	100±0.00	100±0.00	100±0.00	98±0.02

* pH,mg/L NH_3-N.

** Survival was averaged over only 2 replications, because data were not recorded at 9 h during the first replication.

Table 5. Mean percent survival ± standard error of juvenile freshwater shrimp over 3 replications.

Treatment combination*	Time (h)							
	1	3	6	9	12	24	48	72
8.5,0	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
8.5,1	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
8.5,2	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
8.5,3	100±0.00	100±0.00	100±0.00	100±0.00	97±0.03	97±0.03	97±0.03	93±0.03
9.0,0	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
9.0,1	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
9.0,2	100±0.00	100±0.00	97±0.03	97±0.03	93±0.07	93±0.07	73±0.18	57±0.30
9.0,3	100±0.00	100±0.00	97±0.03	97±0.03	93±0.03	83±0.07	30±0.25	10±0.10
9.5,0	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
9.5,1	100±0.00	100±0.00	100±0.00	100±0.00	97±0.03	87±0.03	73±0.12	63±0.18
9.5,2	100±0.00	97±0.03	87±0.09	83±0.12	80±0.10	50±0.21	13±0.13	3±0.03
9.5,3	100±0.00	100±0.00	93±0.03	90±0.06	80±0.06	30±0.25	3±0.03	0±0.00
10.0,0	100±0.00	100±0.00	90±0.10	83±0.12	70±0.21	60±0.21	47±0.19	40±0.15
10.0,1	100±0.00	93±0.07	67±0.17	50±0.17	33±0.07	13±0.09	0±0.00	0±0.00
10.0,2	100±0.00	87±0.03	47±0.09	17±0.07	3±0.03	0±0.00	0±0.00	0±0.00
10.0,3	100±0.00	87±0.09	33±0.15	7±0.07	3±0.03	0±0.00	0±0.00	0±0.00
Control 1	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
Control 2	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00

* pH,mg/L NH_3-N.

Table 6. Mean percent survival ± standard error of sub-adult freshwater shrimp over 3 replications.

Treatment combination*	Time (h) 1	3	6	9	12	15	18	21	24
9.0,0	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	97±0.03	97±0.00
9.0,1	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
9.0,2	97±0.03	97±0.03	93±0.07	93±0.07	93±0.07	87±0.09	87±0.09	87±0.09	87±0.09
9.0,3	100±0.00	90±0.10	73±0.09	70±0.10	43±0.09	33±0.15	23±0.09	20±0.10	17±0.07
9.5,0	100±0.00	100±0.00	77±0.15	57±0.18	50±0.15	50±0.15	50±0.15	50±0.15	50±0.15
9.5,1	100±0.00	97±0.03	63±0.19	50±0.25	40±0.25	27±0.27	27±0.27	27±0.27	23±0.23
9.5,2	93±0.07	87±0.07	57±0.22	37±0.18	30±0.17	23±0.15	23±0.15	20±0.12	10±0.06
9.5,3	100±0.00	90±0.06	50±0.26	20±0.20	7±0.07	0±0.00	0±0.00	0±0.00	0±0.00
10.0,0	100±0.00	77±0.12	27±0.22	10±0.10	10±0.10	7±0.07	3±0.03	3±0.03	3±0.03
10.0,1	97±0.03	70±0.21	23±0.19	3±0.03	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00
10.0,2	100±0.00	67±0.17	23±0.19	7±0.07	3±0.03	3±0.03	3±0.03	0±0.00	0±0.00
10.0,3	100±0.00	73±0.13	27±0.07	10±0.06	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00
10.5,0	100±0.00	67±0.17	3±0.03	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00
10.5,1	100±0.00	53±0.26	17±0.17	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00
10.5,2	100±0.00	43±0.13	7±0.07	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00
10.5,3	100±0.00	47±0.27	7±0.07	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00
Control 1	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00
Control 2	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00	100±0.00

* pH, mg/L NH_3-N.

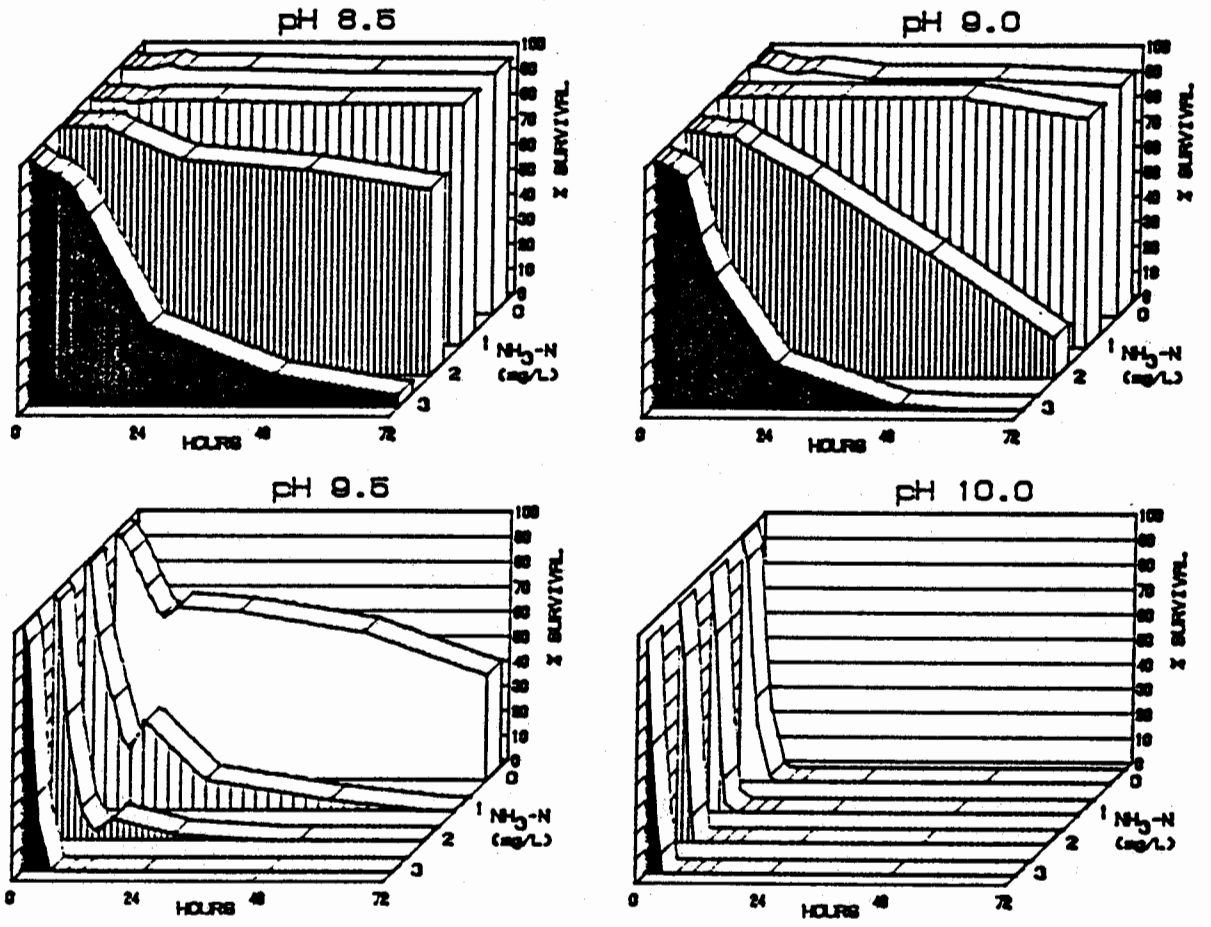

Figure 2. Three-dimensional graphs of mean post-larval freshwater shrimp survival over 3 replications at 1, 3, 6, 9, 12, 24, 48, and 72 hours.

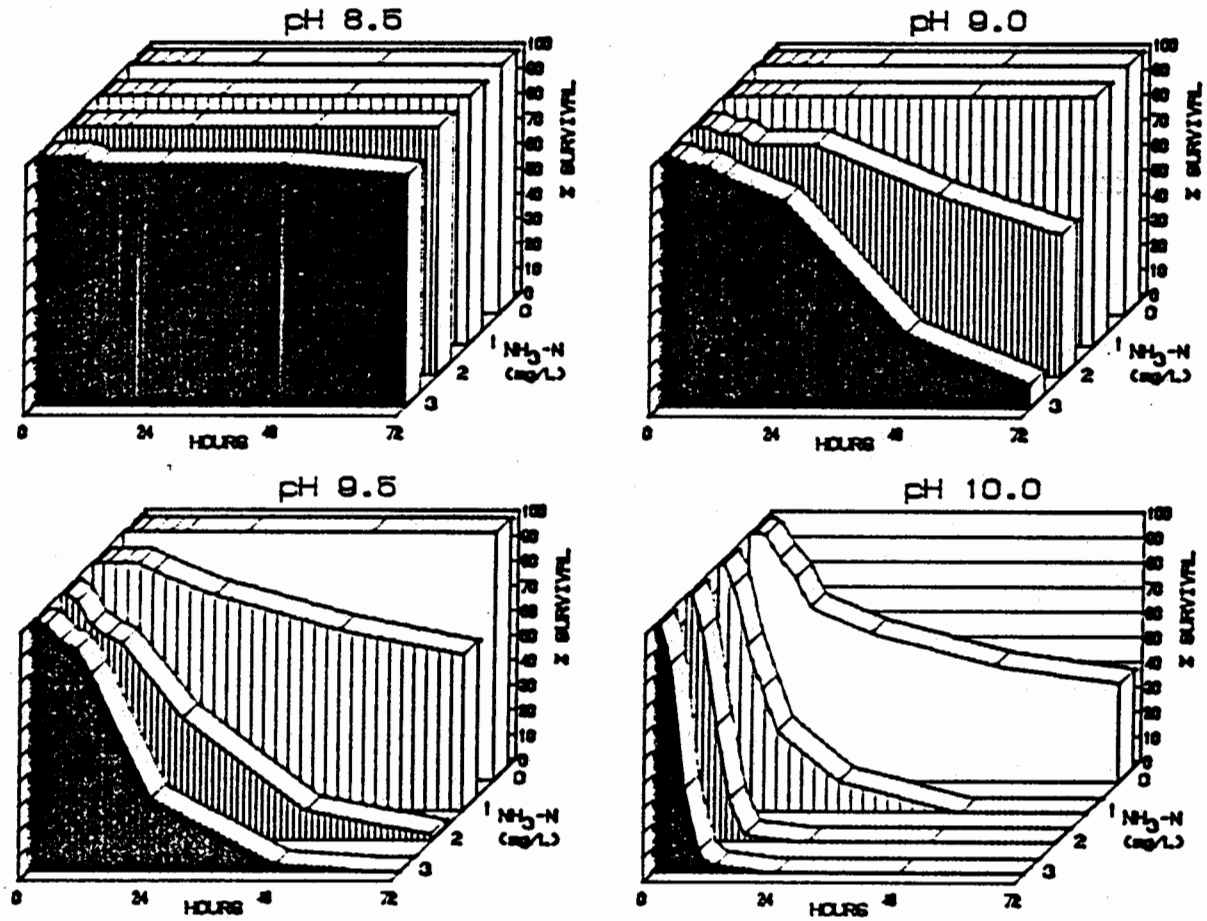

Figure 3. Three-dimensional graphs of mean juvenile freshwater shrimp survival over 3 replications at 1, 3, 6, 9, 12, 24, 48, and 72 hours.

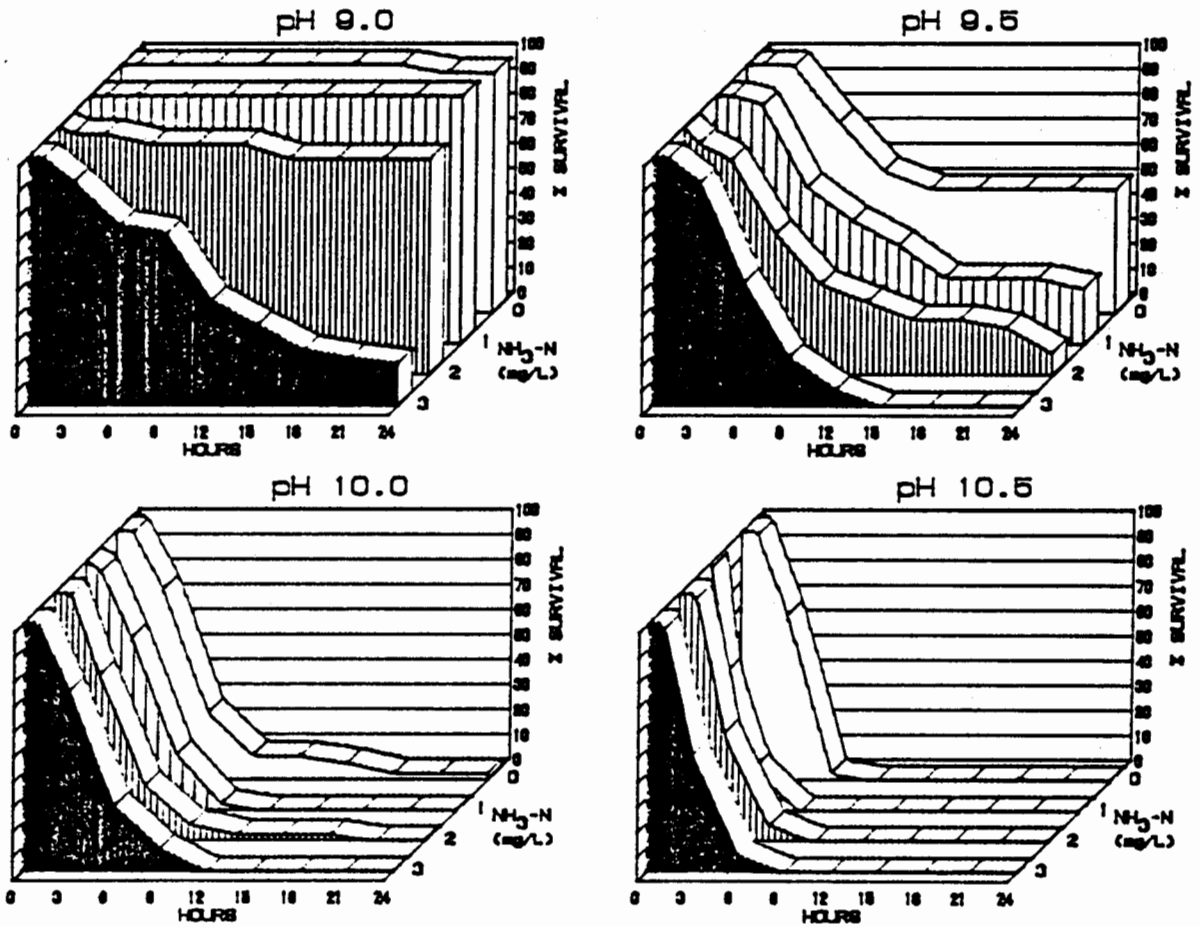

Figure 4. Three-dimensional graphs of mean sub-adult freshwater shrimp survival over 3 replications at 1, 3, 6, 9, 12, 15, 18, 21, and 24 hours.

water shrimp can tolerate pH levels up to 9.0 at 0 and 1 mg/L NH_3-N for 72 hours (Figure 2, Table 4); however, sensitivity to higher pH levels at 0 mg/L NH_3-N and synergistic effects at combinations of pH 9.0 and 2 mg/L NH_3-N or higher resulted in unacceptable mortalities. Observations show break-points in tolerance between 2 and 3 mg/L NH_3-N at exposure periods of 9 and 24 hours at pH levels of 9.0 and 8.5, respectively.

Juvenile freshwater shrimp exhibited considerable mortalities at the 9 h exposure period at pH 10.0 with survival of 83% at 0 mg/L NH_3-N, decreasing to 50% at 1 mg/L (Table 5). Mortality $\geq$25% was shown at 12 hours between pH levels of 9.5 and 10.0 at 0 mg/L NH_3-N; however, within pH 9.5 at 24 h, a synergistic effect was exhibited at 2 mg/L NH_3-N with substantial mortalities as opposed to 0 mg/L. As exposure increased to 48 h, a synergistic effect was seen at 1 mg/L NH_3-N at pH 9.5 with substantial losses as compared to 0 mg/L. Juvenile survival for 72 hours (Figure 3) clearly showed that 0 mg/L NH_3-N was tolerated at pH levels to 9.5, 1 mg/L was tolerated to pH 9.0, and 2 and 3 mg/L NH_3- N were tolerated only at pH 8.5. In the absence of NH_3-N, juveniles tolerated pH 9.5 to 72 h, but sustained >30% mortality at pH 10.0 and 12 h. Synergistic effects causing substantial mortalities were also exhibited at the 72 hour exposure period at pH 9.0 and 2 mg/L NH_3-N, as well as at pH 9.5 and 1 mg/L.

Sub-adult survival means exhibited decreased tolerance over 24 h (Table 6, Figure 4) compared to post-larvae and juveniles. Mortality $\geq$25% resulted at 6 h between pH 9.0 and 9.5 at 1 mg/L NH_3-N; however, within pH 9.0, NH_3-N concentrations of 0, 1, and 2 mg/L averaged 98% survival but at 3 mg/L, survival decreased to 73%. This mortality pattern continued over the 24 h period, with 87% survival at pH 9.0 and 2 mg/L at 15 h, but decreased to 17% survival at 3 mg/L NH_3-N and pH 9.0 at 24 h. Unacceptable mortality was also exhibited during the above mentioned time periods at 0 mg/L NH_3-N and pH 9.5. Results of sub-adult survival indicate that NH_3-N concentrations of 0, 1, and 2 mg/L can be tolerated at pH 9.0 through 24 h; however, higher levels of pH and/or NH_3-N caused substantial mortalities.

Trimmed Spearman-Karber results are reported in Tables 7-14 and probit analysis results are reported in Tables 15-18 as estimates of LC_{50} and LC_{10} values for pH levels and NH_3-N concentrations for each size class.

Trimmed Spearman-Karber post-larval LC_{50} estimates for pH ranged from 9.82 at 3 h and 0 mg/L NH_3-N to 8.71 at 72 hours and 2 mg/L NH_3-N (Table 7). Juvenile LC_{50} estimates for pH at similar exposure periods and NH_3-N concentrations were higher and ranged from 10.00 at 9 hours and 1 mg/L NH_3-N to 8.76 at 72 h and 3 mg/L NH_3-N (Table 8). Sub-adult LC_{50} estimates ranged from 10.44 at 3 h and 3 mg/L NH_3-N to 9.20 at 9 h and 3 mg/L NH_3-N (Table 9).

Table 7. Trimmed Spearman-Karber LC_{50} pH estimates (and 95% confidence intervals) utilizing post-larval freshwater shrimp survival means from 1 to 72 h at each NH_3-N concentration.

Time (h)	NH_3-N (mg/l) 0	1	2	3
1	--	--	--	--
3	9.82 (9.77-9.87)	9.60 (9.55-9.66)	9.47 (9.42-9.52)	9.34 (9.29-9.38)
6	9.64 (9.60-9.69)	9.47 (9.41-9.52)	9.29 (9.26-9.33)	9.23 *
9	9.55 (9.50-9.60)	9.35 (9.31-9.39)	9.25 (9.22-9.27)	9.08 (9.02-9.15)
12	9.59 (9.54-9.64)	9.42 (9.38-9.47)	9.26 (9.21-9.30)	8.96 (8.87-9.06)
24	9.57 (9.51-9.62)	9.30 (9.27-9.34)	9.17 (9.11-9.23)	--
48	9.53 (9.47-9.59)	9.26 (9.24-9.28)	8.95 (8.88-9.03)	--
72	9.43 (9.37-9.49)	9.21 (9.18-9.24)	8.71 (8.66-8.76)	--

* The 95% confidence interval was effectively infinite, and therefore, not useful.

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 8. Trimmed Spearman-Karber LC_{50} pH estimates (and 95% confidence intervals) utilizing juvenile freshwater shrimp survival means from 1 to 72 h at each NH_3-N concentration.

Time (h)	NH_3-N (mg/l) 0	1	2	3
1	--	--	--	--
3	--	--	--	--
6	--	--	9.96 (9.84-10.08)	9.86 (9.80-9.91)
9	--	10.00 *	9.75 (9.71-9.79)	9.73 (9.69-9.78)
12	--	9.86 (9.81-9.92)	9.64 (9.59-9.69)	9.63 (9.58-9.69)
24	--	9.75 (9.71-9.78)	9.46 (9.40-9.51)	9.30 (9.24-9.37)
48	9.97 *	9.61 (9.56-9.65)	9.17 (9.12-9.23)	8.89 (8.84-8.94)
72	9.91 *	9.56 (9.51-9.61)	9.04 (8.99-9.09)	8.76 (8.73-8.79)

* 95% confidence intervals were effectively infinite, and therefore, not useful.

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 9. Trimmed Spearman-Karber LC_{50} pH estimates (and 95% confidence intervals) utilizing sub-adult freshwater shrimp survival means from 1 to 24 h at each NH_3-N concentration.

Time (h)	NH_3-N (mg/l) 0	1	2	3
1	--	--	--	--
3	--	--	10.35 (10.19-10.51)	10.44 (10.27-10.62)
6	9.77 (9.70-9.84)	9.67 (9.58-9.77)	9.62 (9.55-9.70)	9.49 (9.37-9.62)
9	9.58 (9.52-9.63)	9.51 (9.46-9.56)	9.42 (9.36-9.48)	9.20 (9.13-9.26)
12	9.54 (9.48-9.60)	9.44 (9.39-9.49)	9.37 (9.31-9.42)	--
15	9.53 (9.47-9.58)	9.38 (9.34-9.42)	9.30 (9.24-9.35)	--
18	9.51 (9.46-9.56)	9.38 (9.34-9.42)	9.30 (9.24-9.35)	--
21	9.49 (9.44-9.55)	9.38 (9.34-9.42)	9.28 (9.23-9.33)	--
24	9.49 (9.44-9.55)	9.36 (9.32-9.40)	9.24 (9.21-9.27)	--

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 10. Trimmed Spearman-Karber LC_{10} pH estimates utilizing freshwater shrimp survival means of each size class at each NH_3-N concentration and exposure period.

Post-larvae

Time (h)	NH_3-N (mg/L) 0	1	2	3
1	10.00	9.67	9.66	9.52
3	9.52	9.14	9.08	9.04
6	9.20	9.08	9.04	9.02
9	9.11	9.05	9.04	--
12	9.14	9.07	9.02	--
24	9.09	9.05	--	--
48	9.07	9.04	--	--
72	9.03	9.01	--	--

Replications = 3, except only 2 at 9 h.

Juveniles

Time (h)	NH_3-N (mg/L) 0	1	2	3
1	--	--	--	--
3	--	--	9.85	9.88
6	10.00	9.65	9.35	9.52
9	9.79	9.60	9.25	9.50
12	9.67	9.55	9.12	9.12
24	9.62	9.38	9.03	8.75
48	9.59	9.18	8.68	8.55
72	9.58	9.14	8.62	8.52

Replications = 3.

Sub-adults

Time (h)	NH_3-N (mg/L) 0	1	2	3
1	--	--	--	--
3	9.72	9.63	9.35	9.25
6	9.22	9.14	9.04	--
9	9.12	9.10	9.03	--
12	9.10	9.08	9.02	--
15	9.10	9.07	--	--
18	9.10	9.07	--	--
21	9.07	9.07	--	--
24	9.07	9.06	--	--

Replications = 3.

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 11. Trimmed Spearman-Karber LC_{50} NH_3-N estimates (and 95% confidence intervals) utilizing post-larval freshwater shrimp survival means from 1 to 72 h at each pH level.

Time (h)	pH 8.5	9.0	9.5	10.0
1	--	--	--	--
3	--	--	1.48 (1.07-2.04)	--
6	--	--	0.29 (0.16-0.51)	--
9	--	--	0.05 (0.02-0.11)	--
12	--	--	0.15 (0.07-0.34)	--
24	2.64 (2.51-2.78)	2.43 (2.19-2.70)	0.05 (0.03-0.08)	--
48	2.41 (2.23-2.60)	1.86 (1.75-1.97)	0.02 (0.01-0.05)	--
72	2.18 (2.07-2.31)	1.45 (1.16-1.80)	--	--

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 12. Trimmed Spearman-Karber LC_{50} NH_3-N estimates (and 95% confidence intervals) utilizing juvenile freshwater shrimp survival means from 1 to 72 h at each pH level.

Time (h)	pH 8.5	9.0	9.5	10.0
1	--	--	--	--
3	--	--	--	--
6	--	--	--	1.77 (1.46-2.16)
9	--	--	--	0.38 (0.23-0.61)
12	--	--	--	0.12 (0.06-0.26)
24	--	--	2.02 (1.71-2.37)	0.03 (0.01-0.06)
48	--	2.48 (2.34-2.64)	0.81 (0.63-1.05)	--
72	--	2.02 (1.88-2.17)	0.54 (0.42-0.70)	--

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 13. Trimmed Spearman-Karber LC_{50} NH_3-N estimates (and 95% confidence intervals) utilizing sub-adult freshwater shrimp survival means from 1 to 24 h at each pH level.

Time (h)	pH 9.0	9.5	10.0	10.5
1	--	--	--	--
3	--	--	--	1.24 (0.02-95.43)
6	--	3.00 *	--	--
9	--	0.35 (0.03-4.05)	--	--
12	2.83 (2.64-3.04)	0.01 *	--	--
15	2.64 (2.51-2.78)	0.01 *	--	--
18	2.53 (2.44-2.62)	0.01 *	--	--
21	2.50 (2.42-2.58)	0.01 *	--	--
24	2.48 (2.41-2.55)	0.01 *	-	-

* 95% confidence intervals were effectively infinite, and therefore, not useful.

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 14. Trimmed Spearman-Karber LC_{10} NH_3-N estimates utilizing freshwater shrimp survival means of each size class at each pH level and exposure period.

Post-larvae

Time (h)	pH 8.5	9.0	9.5	10.0
1	--	--	--	0.01
3	--	--	0.09	--
6	--	--	--	--
9	2.82	2.24	--	--
12	2.35	2.08	--	--
24	1.73	1.41	--	--
48	1.50	1.15	--	--
72	1.32	1.03	--	--

Replications = 3, except only 2 at 9 h.

Juveniles

Time (h)	pH 8.5	9.0	9.5	10.0
1	--	--	--	--
3	--	--	--	1.50
6	--	--	2.50	0.01
9	--	--	1.71	--
12	--	--	1.41	--
24	--	--	0.77	--
48	--	1.37	0.38	--
72	--	1.23	0.28	--

Replications = 3.

Sub-adults

Time (h)	pH 9.0	9.5	10.0	10.5
1	--	--	--	--
3	3.00	1.78	--	--
6	2.15	--	--	--
9	2.13	--	--	--
12	2.06	--	--	--
15	1.77	--	--	--
18	1.77	--	--	--
21	1.77	--	--	--
24	1.77	--	--	--

Replications = 3.

-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 15. Probit analysis LC_{50} pH estimates utilizing freshwater shrimp survival means of each size class at each NH_3-N concentration and exposure period.

Post-larvae

Time	NH_3-N (mg/L)			
(h)	0	1	2	3
1	*	*	*	*
3	9.85	9.59	9.47	9.30
6	9.60	9.45	9.31	9.14
9	9.54	9.34	9.25	9.00
12	9.55	9.41	9.23	8.87
24	9.53	9.30	9.07	*
48	9.48	9.24	8.89	*
72	9.39	9.16	8.70	--

Replications = 3 except only, 2 at 9 h.

Juveniles

Time	NH_3-N (mg/L)			
(h)	0	1	2	3
1	--	--	--	--
3	--	--	*	--
6	--	--	9.98	9.88
9	--	--	9.73	9.70
12	--	9.90	9.60	9.59
24	--	9.75	9.45	9.28
48	--	--	9.18	8.91
72	--	--	9.05	8.76

Replications = 3.

Sub-adults

Time	NH_3-N (mg/L)			
(h)	0	1	2	3
1	--	--	*	--
3	*	10.47	10.35	10.54
6	9.78	9.77	9.64	9.47
9	9.59	9.52	9.43	9.21
12	9.56	--	9.38	*
15	9.54	--	9.31	--
18	9.52	--	9.31	--
21	9.50	--	9.28	--
24	9.50	--	9.23	--

Replications = 3.

* Estimated values were outside test parameter range.
-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 16. Probit analysis LC_{10} pH estimates utilizing freshwater shrimp survival means of each size class at each NH_3-N concentration and exposure period.

Post-larvae

Time (h)	NH_3-N (mg/L) 0	1	2	3
1	*	9.65	9.66	9.35
3	9.36	9.19	9.20	8.91
6	9.21	9.10	9.10	8.81
9	9.25	9.00	9.08	8.60
12	9.18	9.08	8.91	*
24	9.12	9.02	8.63	*
48	9.05	8.97	8.47	*
72	8.97	8.91	*	--

Replications = 3 except only, 2 at 9 h.

Juveniles

Time (h)	NH_3-N (mg/L) 0	1	2	3
1	--	--	--	--
3	--	--	9.90	--
6	--	--	9.37	9.42
9	--	--	9.32	9.39
12	--	9.63	9.23	9.10
24	--	9.47	9.11	8.85
48	--	--	8.84	8.59
72	--	--	8.77	8.53

Replications = 3.

Sub-adults

Time (h)	NH_3-N (mg/L) 0	1	2	3
1	--	--	*	--
3	9.87	9.70	9.39	9.25
6	9.34	9.12	9.01	*
9	9.23	9.23	9.02	*
12	9.19	--	9.02	*
15	9.20	--	*	--
18	9.23	--	*	--
21	9.16	--	8.97	--
24	9.16	--	8.97	--

Replications = 3.

* Estimated values were outside test parameter range.
-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 17. Probit analysis LC_{50} NH_3-N estimates utilizing freshwater shrimp survival means of each size class at each pH level and exposure period.

Post-larvae

Time (h)	pH 8.5	9.0	9.5	10.0
1	*	*	*	*
3	*	*	2.66	0.72
6	*	*	1.63	--
9	*	*	1.26	--
12	*	*	1.44	--
24	*	*	1.23	--
48	*	2.82	1.10	--
72	*	2.33	--	--

Replications = 3 except only, 2 at 9 h.

Juveniles

Time (h)	pH 8.5	9.0	9.5	10.0
1	--	--	--	--
3	--	--	--	*
6	--	*	*	2.82
9	--	*	*	1.82
12	--	*	*	1.39
24	--	*	*	1.14
48	--	*	2.32	--
72	--	*	2.12	--

Replications = 3.

Sub-adults

Time (h)	pH 9.0	9.5	10.0	10.5
1	--	--	--	--
3	*	*	*	2.59
6	*	*	*	*
9	*	1.54	*	--
12	*	1.17	0.23	--
15	*	1.08	0.12	--
18	*	1.08	0.00	--
21	*	1.08	--	--
24	*	1.05	--	--

Replications = 3.

* Estimated values were outside test parameter range.
-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Table 18. Probit analysis LC_{10} NH_3-N estimates utilizing freshwater shrimp survival means of each size class at each pH level and exposure period.

Post-larvae

Time (h)	pH 8.5	9.0	9.5	10.0
1	*	*	*	0.98
3	*	*	1.14	0.35
6	*	*	0.84	--
9	*	2.79	0.66	--
12	*	2.61	0.70	--
24	2.34	2.00	0.70	--
48	2.14	1.83	0.70	--
72	2.08	1.51	--	--

Replications = 3, except only 2 at 9 h.

Juveniles

Time (h)	pH 8.5	9.0	9.5	10.0
1	--	--	--	--
3	--	--	--	2.91
6	--	*	*	1.01
9	--	*	*	0.88
12	--	*	2.66	0.69
24	--	*	1.86	0.65
48	--	2.62	1.67	--
72	--	2.49	1.68	--

Replications = 3.

Sub-adults

Time (h)	pH 9.0	9.5	10.0	10.5
1	--	--	--	--
3	*	*	0.01	0.12
6	*	0.34	*	*
9	*	0.22	*	--
12	*	0.24	0.06	--
15	2.92	0.33	0.02	--
18	2.93	0.33	0.00	--
21	2.28	0.35	--	--
24	2.27	0.42	--	--

Replications = 3.

* Estimated values were outside test parameter range.
-- Values were not calculated due to insufficient data to meet the conditions of the trimmed Spearman-Karber method.

Estimates of LC_{50} for NH_3-N at each pH level for post-larvae ranged from 2.64 mg/L at 24 h and pH 8.5 to 0.02 mg/L at 48 h and pH 9.5. Juvenile freshwater shrimp exhibited a range of 2.48 mg/L NH_3-N at pH 9.0 and 48 h to 0.03 mg/L at pH 10.0 and 24 h, while sub-adult LC_{50} estimates for NH_3-N ranged from 3.00 mg/L at pH 9.5 and 6 h to 0.01 mg/L from 12-24 h at pH 9.5.

LC_{10} estimates for post-larvae, juveniles, and sub-adults were approximately 0.8, 0.9, and 0.8 mg/L NH_3-N lower than LC_{50} estimates, respectively. Post-larval NH_3-N LC_{10} estimates ranged from 2.82 mg/L to 0.01 mg/L NH_3-N, while juvenile values were found to range from 2.50 mg/L to 0.01 mg/L NH_3-N and sub-adult LC_{10}'s ranged from 3.00 mg/L NH_3-N to 1.78 mg/L.

Post-larval LC_{10} pH estimates ranged from pH 10.00 at 0 mg/L NH_3-N and 1 h to 9.01 at 72 h and 1 mg/L. Increased tolerance to the toxicants was exhibited by juveniles, ranging from pH 10.00 at 6 h and 0 mg/L NH_3-N to pH 8.52 at 72 h and 3 mg/L. Sensitivity increased in sub-adult bioassays, resulting in lower LC_{10} estimates as opposed to juveniles through 24 h. Sub-adult LC_{10} values ranged from 9.72 at 3 h and 0 mg/L NH_3-N to 9.02 at 12 h and 2 mg/L.

Figures 5-10 are graphs of LC_{50} and LC_{10} estimates for pH and NH_3-N calculated by the trimmed Spearman-Karber method for each size class. Sub-adult LC_{50} pH estimates (Table 9) were 0.2 to 0.5 unit lower than juvenile LC_{50} pH

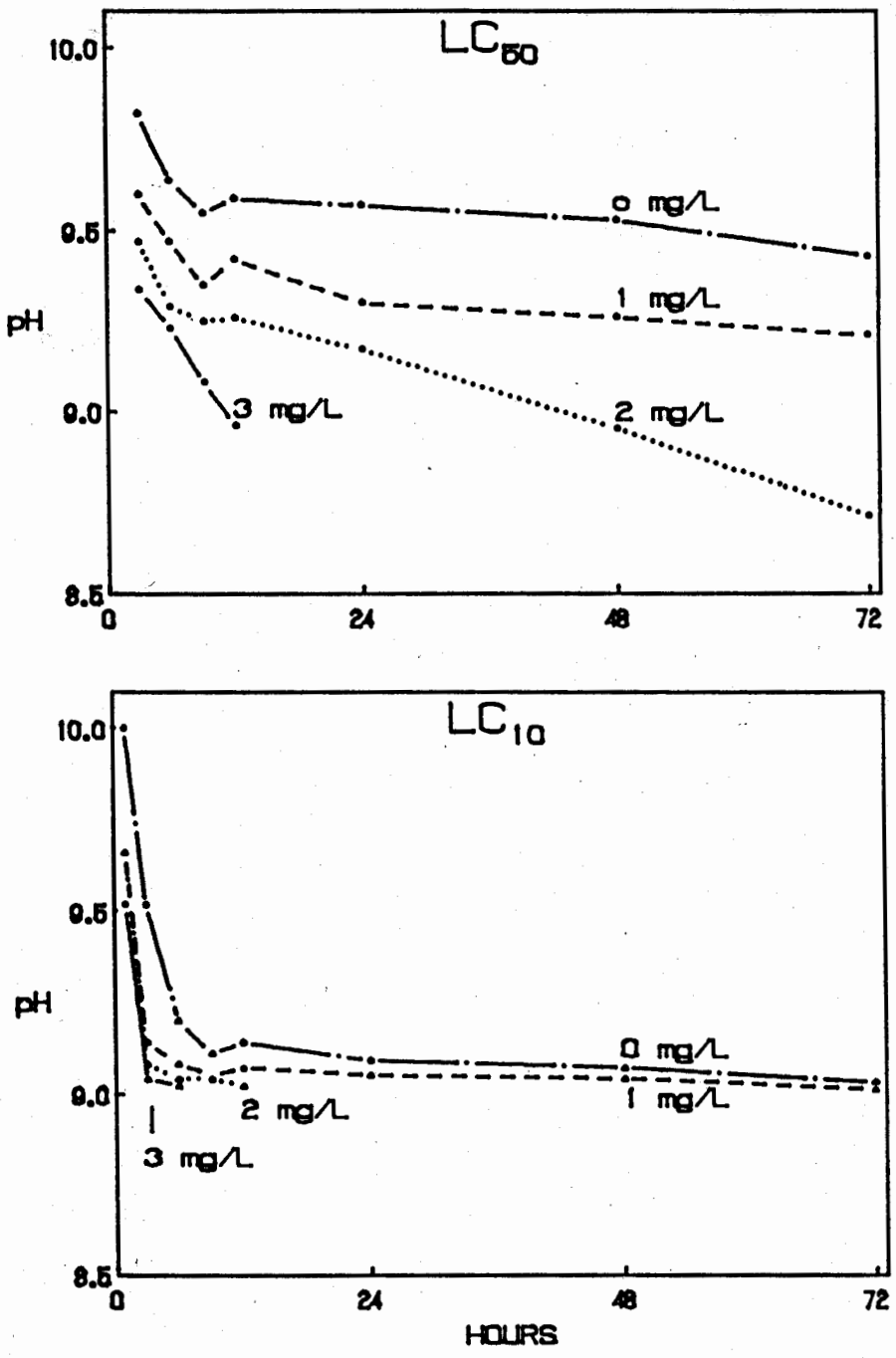

Figure 5. Graphical illustration of trimmed Spearman-Karber LC_{50} and LC_{10} for pH at 0, 1, 2, and 3 mg/L NH_3-N utilizing post-larval freshwater shrimp survival means from 1 to 72 h.

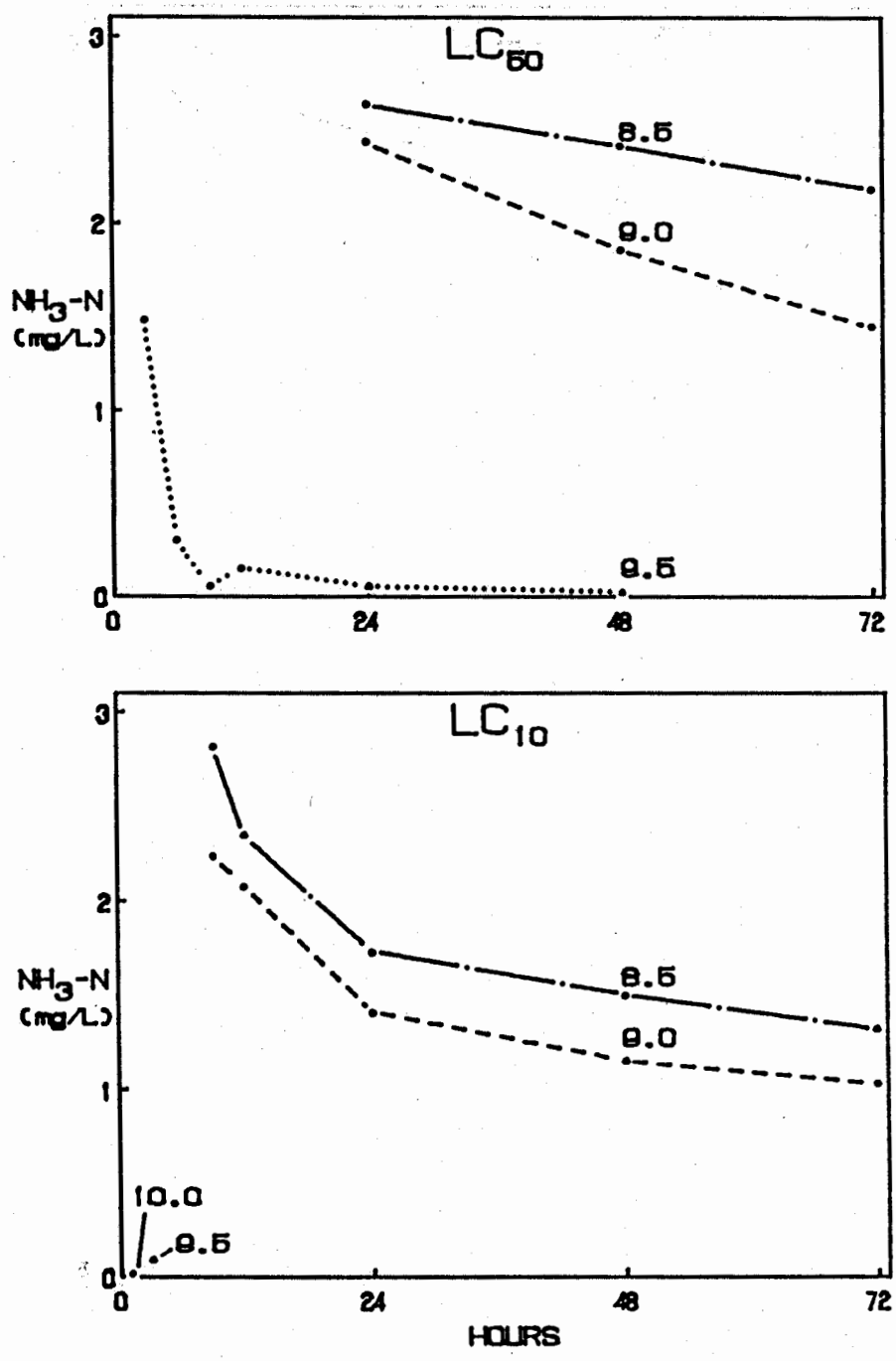

Figure 6. Graphical illustration of trimmed Spearman-Karber LC_{50} and LC_{10} for NH_3-N at pH levels of 8.5, 9.0, 9.5, and 10.0 utilizing post-larval freshwater shrimp survival means from 1 to 72 h.

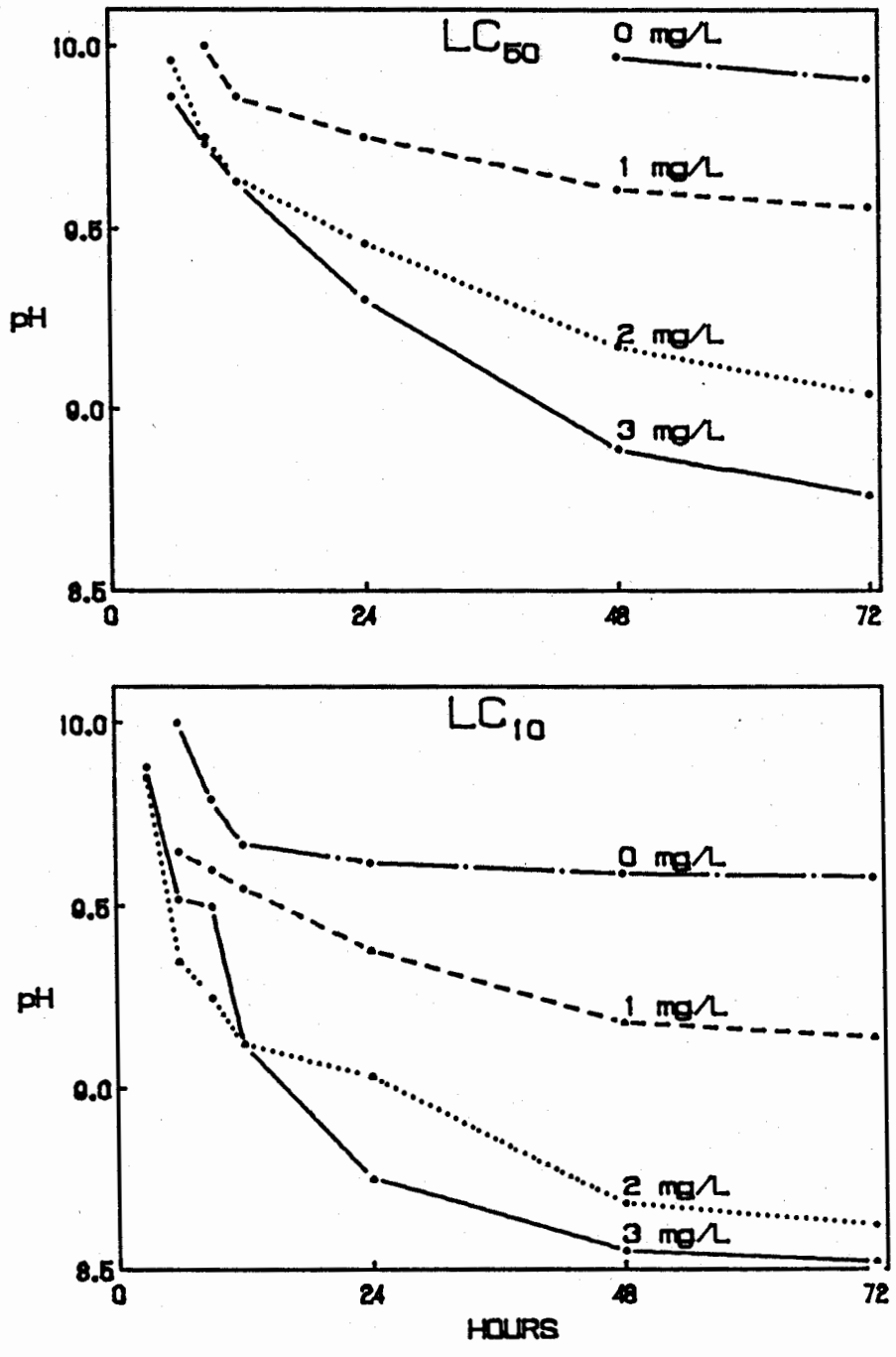

Figure 7. Graphical illustration of trimmed Spearman-Karber LC_{50} and LC_{10} for pH at 0, 1, 2, and 3 mg/L NH_3-N utilizing juvenile freshwater shrimp survival means from 1 to 72 h.

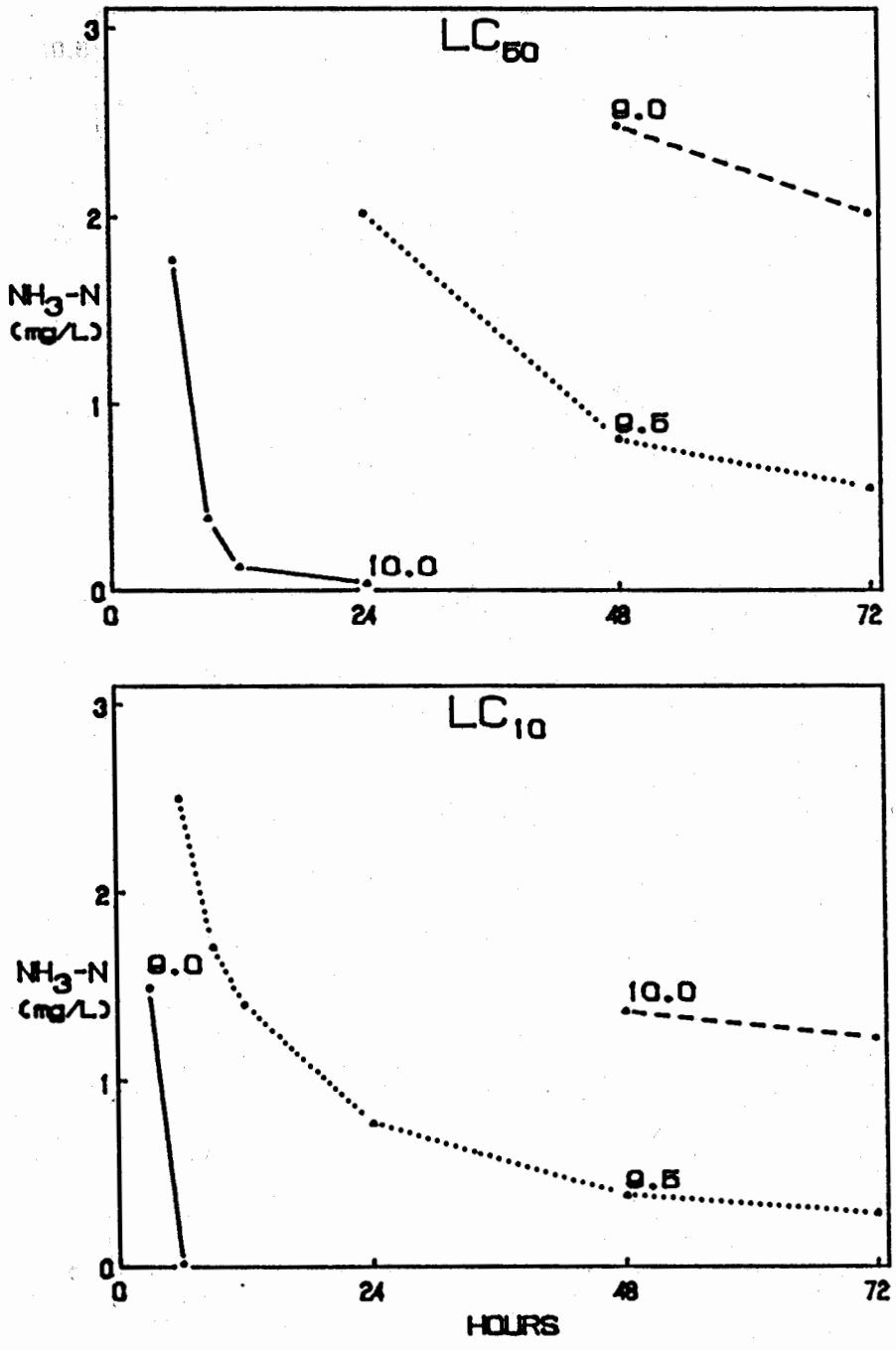

Figure 8. Graphical illustration of trimmed Spearman-Karber LC_{50} and LC_{10} for NH_3-N at pH levels of 8.5, 9.0, 9.5, and 10.0 utilizing juvenile freshwater shrimp survival means from 1 to 72 h.

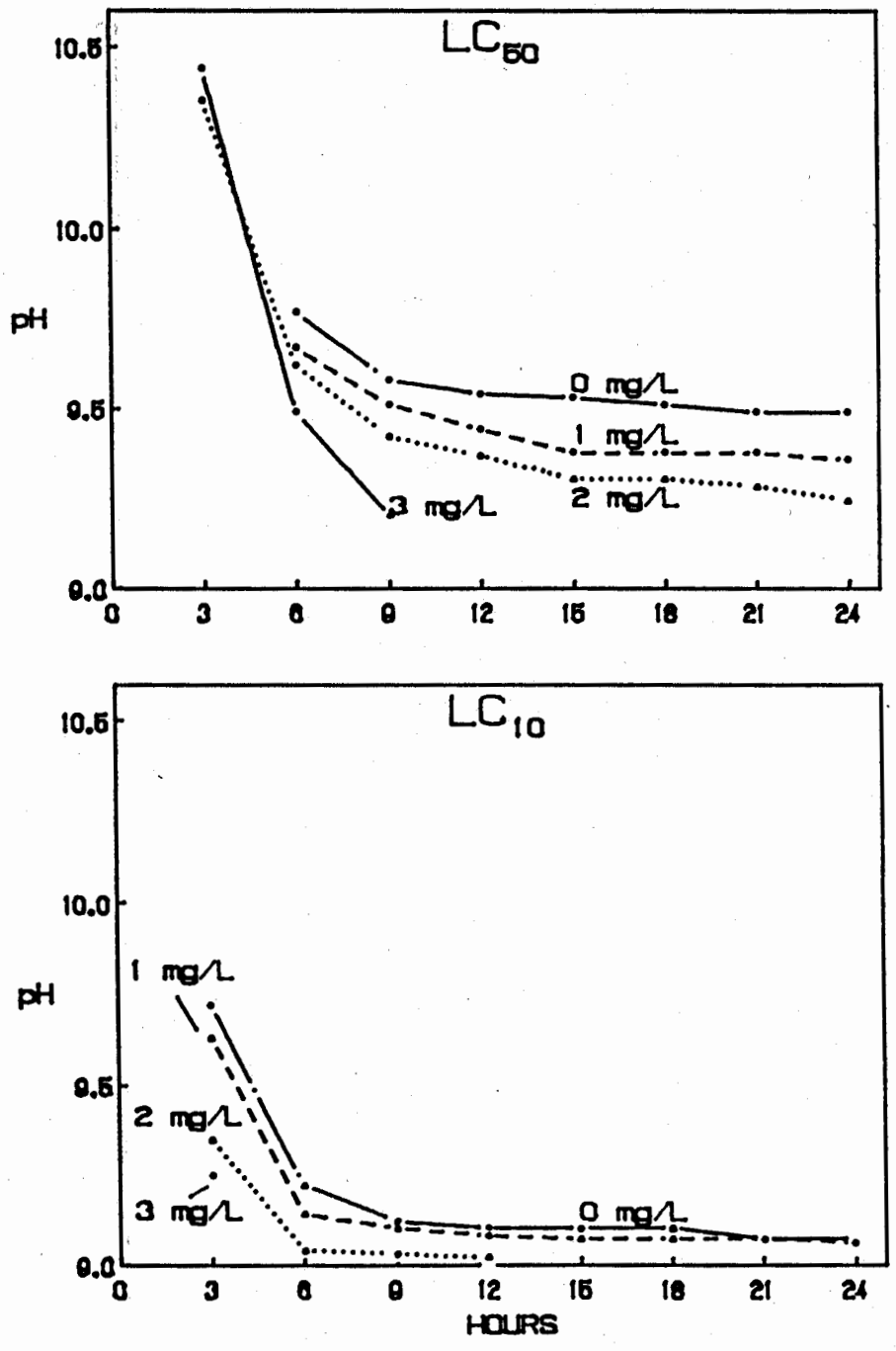

Figure 9. Graphical illustration of trimmed Spearman-Karber LC_{50} and LC_{10} for pH at 0, 1, 2, and 3 mg/L NH_3-N utilizing sub-adult freshwater shrimp survival means from 1 to 24 h.

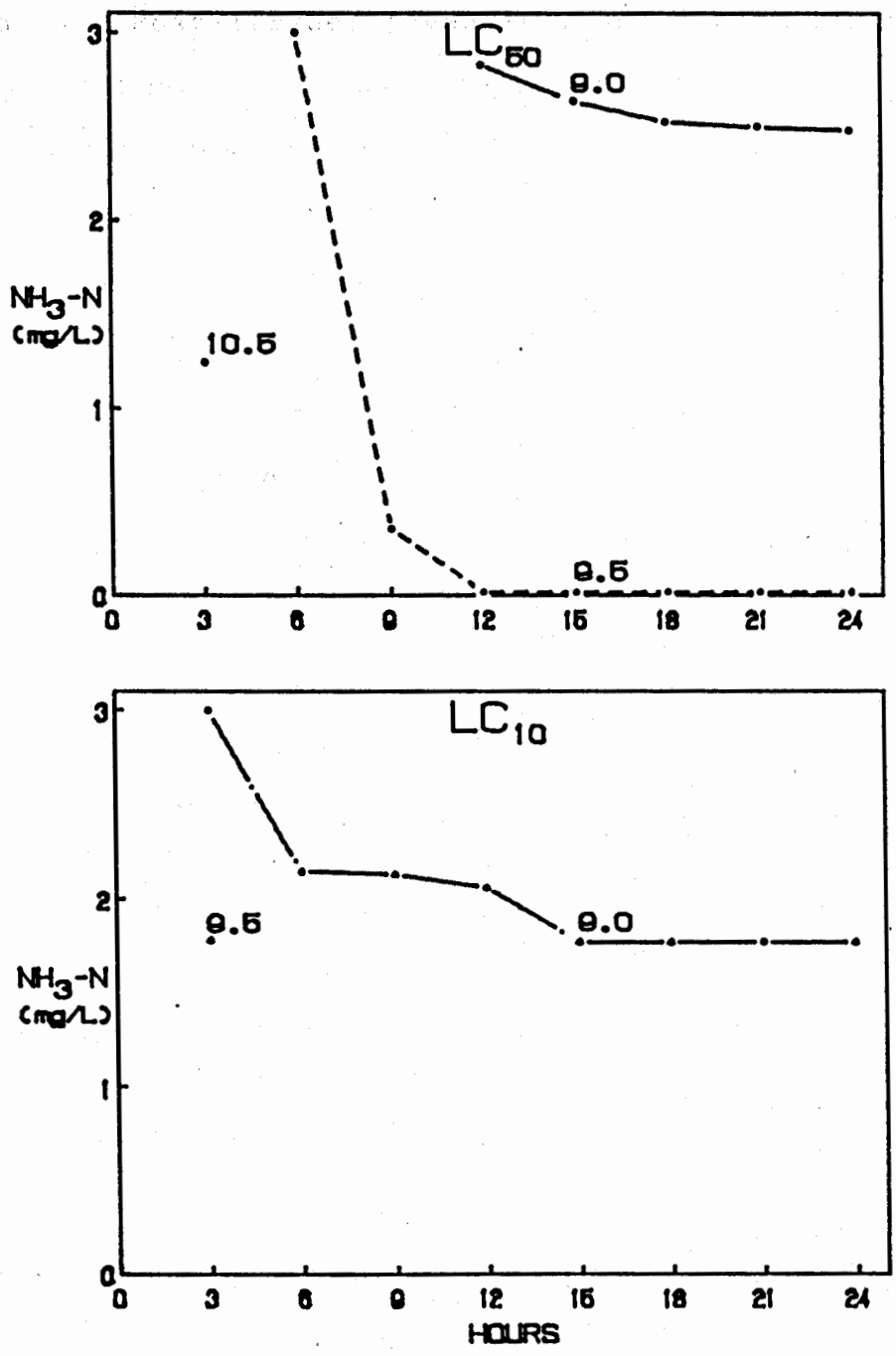

Figure 10. Graphical illustration of trimmed Spearman-Karber LC_{50} and LC_{10} for NH_3-N at pH levels of 9.0, 9.5, 10.0 and 10.5 utilizing sub-adult freshwater shrimp survival means from 1 to 24 h.

estimates (Table 8) for 24 h, while those for post-larvae (Table 7) were 0.2 to 0.7 unit lower than juvenile estimates. Post-larvae, juveniles, and sub-adults exhibited LC_{10} pH estimates that were approximately 0.3, 0.4, and 0.5 units lower, respectively, than LC_{50} estimates. Probit analysis results (Tables 15-18) were comparable to results obtained using the trimmed Spearman-Karber method; however, probit analysis results are presented only as a means of comparison to other studies using this analysis.

Data from the field study are found in Appendix F and are summarized in Table 19 along with survival and stocking density.

Table 19. Observed high pH levels (≥10.0) and associated parameters for freshwater shrimp culture ponds.

Pond	Date	pH	NH_3-N (mg/L)	Temp (°C)	Survival (%)
A34	6/27/87	11.0	0.18	30	22.7
	7/30/87	10.1	0.05	31	
A35	6/26/87	10.1	0.13	30	46.0
A37	9/03/87	10.1	0.10	26	16.5
B31	6/28/87	10.2	0.12	28	4.9
	6/29/87	10.3	0.12	30	
	6/30/87	10.3	0.12	29	
B33	9/02/87	10.0	0.12	27	1.0
B38	6/29/87	10.2	0.15	30	71.1

Stocking densities ranged from 29,652-49,420/ha.

Discussion

Generally, as animals mature, they become more tolerant to toxicants because of differences in degree of development of detoxification mechanisms between young and adult organisms. Rates of excretion of toxic chemicals may differ and are also involved in age dependent toxicity effects (Rand and Petrocelli 1985).

However, Sprague (1985) stated, "... there is no overall relation that can be applied across species, toxicant, and size ranges", and cited several studies of fish as supporting evidence. Dietary factors also influence sensitivity to toxicants by producing changes in body composition, physiological and biochemical functions, and nutritional status of the organism. External environmental factors which may influence toxicity include factors associated with the bioavailability of the chemical in the water medium, such as dissolved oxygen, pH, temperature, and dissolved solids (Rand and Petrocelli 1985).

Tables 3-5 and Figures 2-4 clearly indicate juveniles (mean weight = 0.836 g) were more tolerant to the toxicants than post-larvae (mean weight = 12.9 mg); however, results with sub-adults (mean weight = 10.18 g) did not support the idea that increased tolerance is associated with greater size. Sub-adult sensitivity may be attributed to the stressful situation of deteriorating water quality due to

placing approximately 1200% more biomass into the aquaria than was the case for juveniles.

As mentioned above, dietary differences and external environmental factors also may cause stress. In the present study, post-larvae grew to juveniles in an indoor flow-through environment while being fed a prepared diet; juveniles then grew to sub-adults in outdoor ponds while being fed a prepared diet supplemented with natural forage. The sub-adults were handled more (pond harvesting) and were much more crowded while in both acclimation and experimental tanks. This crowding greatly increased the number of agonistic encounters and was probably a key factor in the greater sensitivity of the sub-adults.

Probit analysis occasionally plotted estimates outside of the test parameter range or could not calculate estimates because data failed to satisfy the requirements for analysis. The trimmed Spearman-Karber method also could not calculate all estimates because some data failed to satisfy its requirements, but all estimates fell within the test parameter range.

LC_{50} and LC_{10} estimates from both methods decreased with increasing duration of exposure. In general, LC_{50} and LC_{10} pH estimates decreased approximately 0.5 unit from 6 to 72 h. At the conclusion of most tests, slopes of toxicity curves for pH and NH_3-N (Figures 5-10) were approaching asymptotes indicative of incipient LC_{50} values

(Sprague 1969).

Fewer than 40% of LC_{50} and LC_{10} estimates for NH_3-N were able to be calculated, because data were insufficient to meet the conditions of the trimmed Spearman-Karber method. Because of the lack of LC_{50} and LC_{10} NH_3-N estimates, trimmed Spearman-Karber pH estimates were typically used.

Results suggest that one possible advantage of nursing post-larval freshwater shrimp to juveniles before stocking into ponds is that juveniles have displayed a greater tolerances to the toxicants. Figures 11-13 show trimmed Spearman-Karber LC_{10} estimates of pH for each size class of freshwater shrimp at exposure periods of 9, 12, and 24 h, respectively. These bar charts show the increased tolerance of juveniles as compared to post-larvae and sub-adults. These exposure periods were selected because they exhibit the general trend of toxicity tolerances among size classes and because short exposure periods are relevant with respect to daily fluctuations of pH. Generally, LC_{10} estimates for pH decreased as NH_3-N concentration increased, indicating the synergistic effect between pH and NH_3-N.

High pH ($\geq$10.0) was often recorded in ponds during the field study, but these ponds contained negligible amounts of NH_3-N (<0.20 mg/L). This was attributed to phytoplankton blooms using ammonia as a nitrogen source, while creating high pH by utilizing CO_2 during photosynthesis. Conversely,

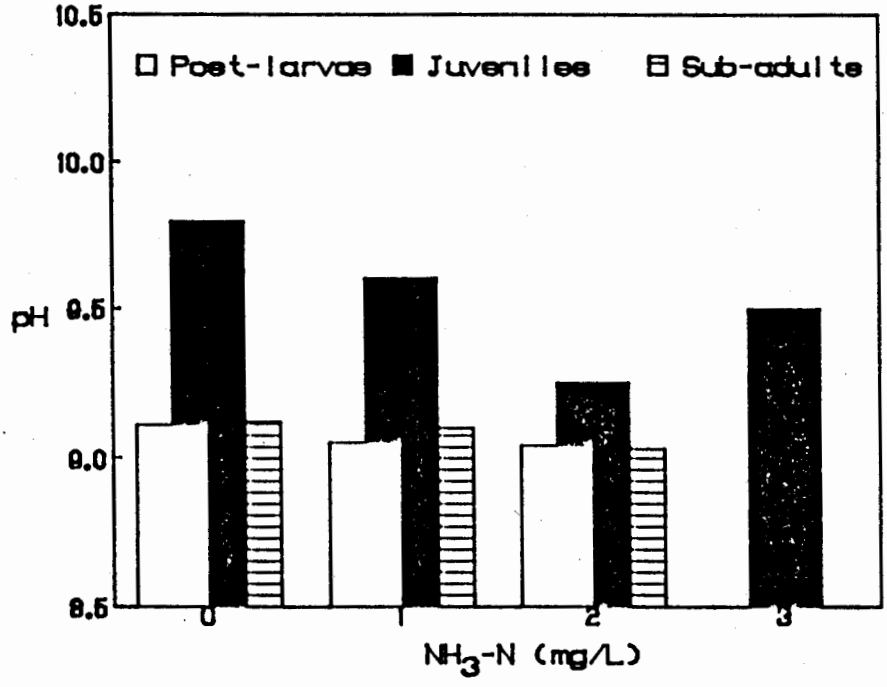

Figure 11. Trimmed Spearman-Karber LC_{10} estimates of pH at 0, 1, 2, and 3 mg/L NH_3-N for post-larval, juvenile, and sub-adult freshwater shrimp over 9 hours. Bars not displayed are omitted because of insufficient data to meet the conditions of the trimmed Spearman-Karber LC_{10} method.

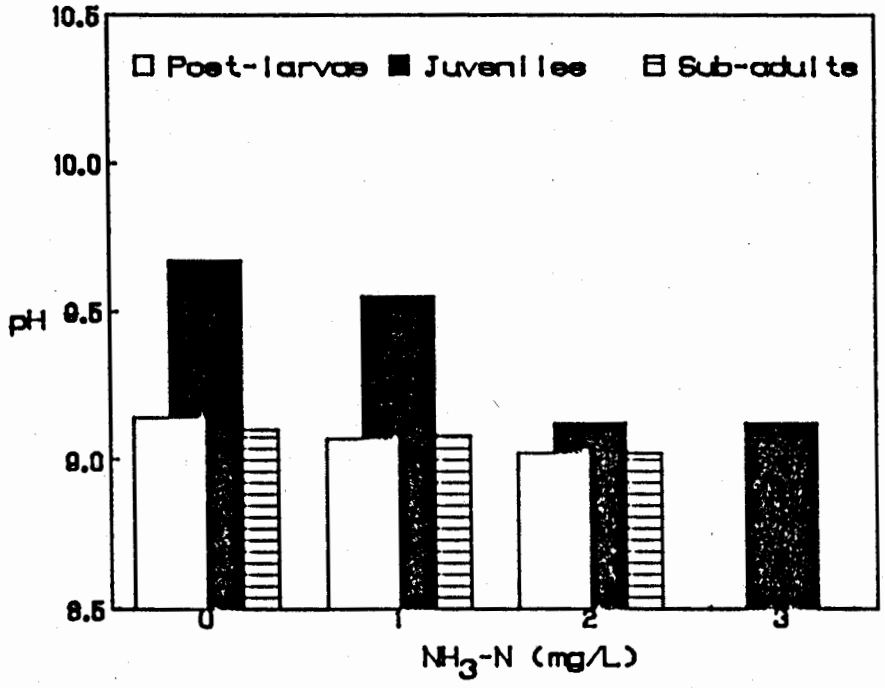

Figure 12. Trimmed Spearman-Karber LC_{10} estimates of pH at 0, 1, 2, and 3 mg/L NH_3-N for post-larval, juvenile, and sub-adult freshwater shrimp over 12 hours. Bars not displayed are omitted because of insufficient data to meet the conditions of the trimmed Spearman-Karber LC_{10} method.

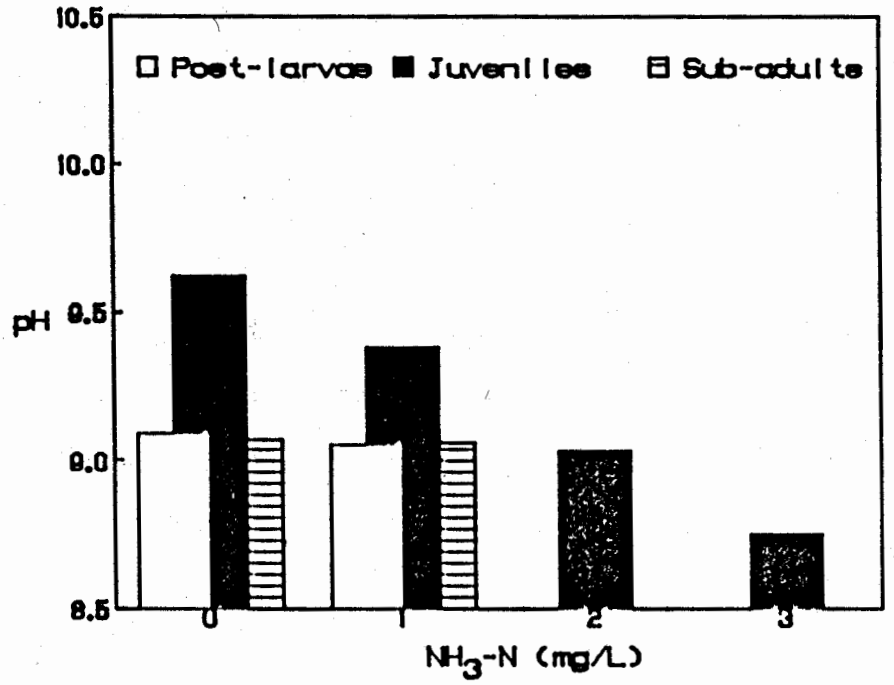

Figure 13. Trimmed Spearman-Karber LC_{10} estimates of pH at 0, 1, 2, and 3 mg/L NH_3-N for post-larval, juvenile, and sub-adult freshwater shrimp over 24 hours. Bars not displayed are omitted because of insufficient data to meet the conditions of the trimmed Spearman-Karber LC_{10} method.

if the bloom should die, nitrogen would be released by decomposition and the total ammonia concentration would increase. Decomposition would also increase CO_2 production and result in decreased pH, thus favoring non-toxic, ionized ammonia (Boyd 1979). Our pond pH levels tended to remain below 10 as the growing season progressed, presumably because increased biomass and feeding rates resulted in more production of carbon dioxide, which forms carbonic acid.

The data indicate that good survival ($\geq$ 70%) can occur in ponds with maximum recorded pH levels as high as 10.2 (Table 19). The concentration of NH_3-N associated with this 10.2 value was 0.15 mg/L. Survivals lower than about 70% were felt to be due to high pH which occurred on days on which pH was not monitored for the present study. (The pH levels were routinely measured by others throughout the total pond growth period, approximately early May to late September, so that high pH could be prevented by dilution of phytoplankton with new well water. However, mortalities due to high pH apparently occurred when the wells were not operable or when a faulty pH probe indicated lower pH levels than actually occurred).

Laboratory toxicity results are not necessarily directly applicable to pond situations. Pond pH levels were measured at about a 30 cm depth, where maximum photosynthesis by phytoplankton is likely to occur. However, benthic areas of the water column, particularly the

microhabitat immediately above the bottom, generally have lower pH levels because of the CO_2 released by respiration of benthic organisms. Shrimp, being benthic organisms, are generally found in this lower pH microhabitat and may therefore survive even though lethal levels are present in the upper water column. The degree of stratification in a pond is obviously important also.

Laboratory test results, which were determined using constant pH levels, will differ from results derived from field tests due to the natural diel fluctuation of pH in the ponds. However, if intensive culture in an enclosed environment is to be undertaken these results should prove valuable.

This study closely resembled the results attained by Sarver et al. (1979) with post-larvae, in that results from the studies showed similar survival at pH levels of 9.0, 9.5, and 10.0 for a 72 h exposure period. However, their study did not indicate ammonia monitoring. Comparison to our results suggests that little ammonia or nitrite was present in their bioassay tanks.

Hummel (1986) monitored ammonia at the conclusions of several experiments and found only trace amounts (<0.01 mg/L). The apparent discrepancy between his results and those of both Sarver et al. (1979) and the present study might be explained if NH_3-N levels were appreciably higher during his experiment, than at their terminations.

Increased concentrations of NO_2-N might be another explanation.

Results from this research are especially applicable to culture in enclosed, recirculating systems, but should be useful in production ponds as well. Bioassay results will be most beneficial when stocking shrimp into ponds. For example, when stocking juveniles, a pond exhibiting a pH level greater than 9.0 with an NH_3-N concentration of more than 1.0 mg/L should be avoided as well as a pond with a pH $\geq$9.5, regardless of the amount of NH_3-N present. Table 20 contains a summary of approximate maximum tolerable levels for shrimp of each size class; similarity between 24 and 72 h levels suggests that handling stress at stocking is very important. If high pH problems cannot be avoided, juveniles could be stocked rather than post-larvae, given the higher tolerances of juveniles to high pH.

Table 20. Summary of approximate maximum tolerable levels of pH and NH_3-N for freshwater shrimp of each size class at 9, 24, and 72 h, as determined from trimmed Spearman-Karber LC_{10} estimates.

	pH, mg/L NH_3-N		
Size class	9 h	24 h	72 h
Post-larvae	8.5,3	8.5,2	8.5,1
	9.0,2	9.0,1	9.0,1
Juveniles	9.5,2	9.5,1	9.5,0
Sub-adults	9.0,2	9.0,2	--

Literature Cited

APHA (American Public Health Association). 1985. Standard methods for the examination of water and wastewater. 15th ed. Washington, DC. 1268 pp.

AQUACOP. 1979. Macrobrachium rosenbergii culture in Polynesia: pH control in experimental pond waters by phytoplankton limitation with an algicide. Proc. World Maric. Soc. 10:392-402.

Boyd, C.E. 1979. Water quality in warmwater fish ponds. Auburn Univ. Agric. Exp. Sta., Auburn, AL. 359 pp.

Clardy, G.N., L.R. D'Abramo, M.J. Fuller, J.M. Heinen, M.J. Murphy, H.R. Robinette, J.H. Tidwell, and J.E. Waldrop. 1985. 1984 freshwater shrimp research: A preliminary report. Inform. Bull. 59, Miss. Agric. and For. Expt. Sta., Mississippi State, MS. 10 pp.

CMTTAO (Committee on Methods for Toxicity Tests with Aquatic Organisms). 1975. Methods for acute toxicity tests with fish, macroinvertebrates, and amphibians. Environmental Protection Agency, National Environmental Research Center, Corvallis, OR. EPA-660/3-75-009. 67 pp.

Emerson, K., R.C. Russo, R.E. Lund, and R.V. Thurston. 1975. Aqueous ammonia equilibrium calculations: Effect of pH and temperature. J. Fish. Res. Board Can. 32(12):2379-2383.

Finney, D.J. 1971. Probit analysis, 3rd ed., Cambridge Univ. Press, London, England. 333 pp.

Fisher Scientific Company. 1983. Instruction manual Fisher Accumet Model 805MP pH meter. Fisher Scientific Company, Pittsburg, PA. 37 pp.

Gelber, R.D., P.T. Lavin, C.R. Mehta, and D.A. Schoenfeld. 1985. Statistical analysis, p. 110-123. In G.M. Rand and S.R. Petrocelli [ed.] Fundamentals of Aquatic Toxicology. Hemisphere Publishing Co. Washington, DC.

Hamilton, M.A., R.C. Russo, and R.V. Thurston. 1977. Trimmed Spearman-Karber method for estimating median lethal concentrations in toxicity bioassays. Environ. Sci. Technol. 11(7):714-719; Correction 12(4):417 (1978).

Hummel, C.G. 1986. Effects of high pH on the mortality of Macrobrachium rosenbergii (de Man) postlarvae in green and clear water. M.S. Thesis. University of Puerto Rico, Mayaguez, PR. 37 pp.

Rand, G.M. and S.R. Petrocelli. 1985. Introduction, p. 1-28. In G.M. Rand and S.R. Petrocelli [ed.], Fundamentals of Aquatic Toxicology. Hemisphere Publishing Co., Washington, DC.

Sandifer, P.A., and T.I.J. Smith. 1985. Freshwater prawns, p. 63-125. In J.V. Huner and E.E. Brown [ed.], Crustacean and Mollusc Aquaculture in the United States. AVI Publishing Co., Westport, CT.

Sandifer, P.A., T.I.J. Smith, W.E. Jenkens, and A.D. Stokes. 1983. Seasonal culture of freshwater prawns in South Carolina, p. 189-204. In J.P. McVey and J.R. Moore [ed.], CRC Handbook of Mariculture. Vol. 1. Crustacean Aquaculture. CRC Press Inc., Boca Raton, FL.

Sarver, D., S. Malecha, and D. Onizuka. 1979. Development and characterization of genetic stocks and their hybrids in Macrobrachium rosenbergii: physiological responses and larval development notes. Proc. World Maric. Soc. 10:880-892.

Sprague, J.B. 1969. Measurement of pollutant toxicity to fish. Bioassay methods for acute toxicity. Water Res. 3:793-821.

Sprague, J.B. 1985. Factors that modify toxicity, p. 124-163. In G.M. Rand and S.R. Petrocelli [ed.], Fundamentals of Aquatic Toxicology. Hemisphere Publishing Co., Washington, DC.

Swingle, H.S. 1957. Relationship of pH of pond waters to their suitability for fish culture. Proc. 9th Pacific Sci. Congress 10(9):72-75.

Tabata, K. 1962. Toxicity of ammonia to aquatic animals with reference to the effect of pH and carbon dioxide. Bull. Tokai Reg. Fish. Res. Lab. 34:67-74. (Transl. from Japanese)

Thurston, R.V., R.C. Russo, and K. Emerson. 1979. Aqueous ammonia equilibrium - tabulation of percent un-ionized ammonia. Office of Research and Development. U.S. Environmental Protection Agency. Duluth, Minn. EPA-600/3-79-091. 428 pp.

Tucker, C.S. [ed.]. 1985. Channel Catfish Culture. Elsevier Science Publishers, Amsterdam. 657 pp.

Wickins, J.F. 1976. The tolerance of warm-water prawns to recirculated water. Aquaculture 9:19-37.

Yellow Springs Instrument Company Scientific Division. 1986. Instruction manual YSI Model 51B dissolved oxygen meter. Yellow Springs Instrument Company, Yellow Springs, OH. 5 pp.

Appendix A

Well water analyses performed during the toxicity study.

Table A-1. Summary of well water analyses performed on samples collected during the freshwater shrimp toxicity study.

	2/19/87	9/28/87
	mg/L	mg/L
Total Dissolved Solids	113.2	116.8
Loss on Ignition (Organic and Volatile Matter)	0.0	6.0
Carbonate	0.0	0.0
Bicarbonate (HCO_3^-)	102.5	108.6
Chloride (Cl^-)	10.0	10.0
Nitrite Nitrogen	0.3	0.0
Nitrate Nitrogen	0.1	0.9
Ammonia Nitrogen	---	0.0
Albuminoid Nitrogen	---	0.2
Total Acidity (as CO_2)	---	5.0
Total Iron, Fe	0.02	0.01
Calcium, Ca^{++}	12.0	8.2
Magnesium, Mg^{++}	6.0	1.9
Calculated Hardness (as $CaCO_3$)	54.7	28.5
Sodium	31.2	24.9
Potassium	3.1	3.1
Total Hardness	24.0	
pH	7.1	7.3

Analyses by: Mississippi State Chemical Laboratory, Mississippi State, Mississippi.

To calculate the fraction of NH_3-N in freshwater, values for temperature (°C) and pH must be known. Using the following equation, the pK_a value is calculated for the individual temperature.

Appendix B

Calculation of un-ionised ammonia-nitrogen.

To calculate the fraction of NH_3-N in freshwater, values for temperature (^0C) and pH must be known. Using the following equation, a pK_a value is calculated for each individual temperature.

$$pK_a = 0.09018 + 2729.92/(T + 273.15)$$

When the above value has been determined, the pH of the solution is then used in combination with the pK_a value to calculate the fraction (f) of NH_3-N using the following equation.

$$f = 1/(10^{pKa - pH} + 1)$$

The product of the f value and the TAN concentration will equal the concentration of NH_3-N in solution (Emerson et al. 1975).

For ease of use, tabulation of un-ionized ammonia at zero salinity has been previously reported by Thurston et al. (1979).

Table C-1

Appendix C

Water quality parameters during each replication of the toxicity study.

Table C-1. Water quality parameters for day 1 of post-larval freshwater shrimp toxicity study, replication #1, 7/31/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.6	0.00	0.001	29.0	7.0	8.5
8.5,1	8.5	0.97	0.005	28.9	7.1	8.6
8.5,2	8.5	1.97	0.007	29.0	7.0	8.5
8.5,3	8.4	2.83	0.004	29.1	7.0	8.4
9.0,0	8.9	0.00	0.001	28.9	7.0	8.9
9.0,1	9.0	1.00	0.005	29.0	7.1	9.0
9.0,2	9.0	2.08	0.004	28.9	7.0	9.0
9.0,3	8.9	2.86	0.004	28.8	7.1	8.9
9.5,0	9.5	0.00	0.001	28.9	7.0	9.4
9.5,1	9.6	1.02	0.005	28.9	7.1	9.5
9.5,2	9.5	1.92	0.004	29.2	7.1	9.4
9.5,3	9.4	3.07	0.003	28.8	7.1	--
10.0,0	10.0	0.01	0.001	29.0	7.0	--
10.0,1	10.1	0.88	0.005	29.0	7.1	--
10.0,2	10.0	1.84	0.004	28.7	7.1	--
10.0,3	10.0	2.88	0.004	29.0	7.0	--
Control 1	8.4	0.00	0.001	29.1	7.0	8.4
Control 2	8.5	0.00	0.001	29.2	7.0	8.5

* pH, mg/L NH_3-N.

-- Indicates parameters not measured, because of 100% mortality.

Table C-1 continued. Water quality parameters for day 2 of post-larval freshwater shrimp toxicity study, replication #1, 8/1/87.

Treatment combination*	am pH	NH_3-N (mg/L)	NO_2-N (mg/L)	Temp (°C)	DO (mg/L)	pm pH
8.5,0	8.6	0.00	0.002	28.9	7.0	8.5
8.5,1	8.6	0.92	0.043	29.0	7.0	8.5
8.5,2	8.5	1.91	0.034	29.0	7.1	8.5
8.5,3	8.5	2.82	0.030	29.0	7.0	8.5
9.0,0	9.1	0.00	0.000	29.0	7.1	9.0
9.0,1	9.1	0.89	0.025	29.1	7.1	9.0
9.0,2	9.0	1.88	0.021	28.8	7.1	9.0
9.0,3	9.0	2.90	0.019	28.8	7.2	9.0
9.5,0	9.4	0.01	0.002	29.1	7.2	9.5
9.5,1	9.6	0.87	0.027	29.2	7.0	9.5
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.002	28.8	7.1	8.4
Control 2	8.5	0.00	0.001	29.1	7.0	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-1 continued. Water quality parameters for day 3 of post-larval freshwater shrimp toxicity study, replication #1, 8/2/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.001	29.0	7.2	8.5
8.5,1	8.5	0.98	0.096	29.0	7.3	8.5
8.5,2	8.5	1.77	0.085	29.0	7.2	8.4
8.5,3	8.5	2.84	0.096	29.2	7.2	8.4
9.0,0	9.0	0.00	0.001	28.8	7.2	9.0
9.0,1	9.0	0.79	0.092	29.1	7.2	9.0
9.0,2	9.1	1.81	0.062	29.0	7.2	9.0
9.0,3	9.0	2.89	0.083	29.2	7.3	9.0
9.5,0	9.5	0.00	0.001	29.1	7.2	9.4
9.5,1	9.5	0.85	0.083	28.8	7.3	9.5
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.001	29.2	7.2	8.4
Control 2	8.5	0.00	0.001	28.9	7.2	8.5

* pH,mg/L NH_3-N.

-- Indicates parameters not measured, because of 100% mortality.

Table C-1 continued. Water quality parameters for day 4 of post-larval freshwater shrimp toxicity study, replication #1, 8/3/87.

	am					pm
Treatment combination*	pH	NH_3-N (mg/L)	NO_2-N (mg/L)	Temp (^{0}C)	DO (mg/L)	pH
8.5,0	8.6	0.00	0.001	29.0	7.2	--
8.5,1	8.5	0.95	0.700	29.2	6.9	--
8.5,2	8.5	1.75	0.542	28.9	7.0	--
8.5,3	8.4	2.84	0.597	29.2	6.9	--
9.0,0	9.0	0.03	0.001	29.0	7.2	--
9.0,1	9.1	0.87	0.722	28.8	7.0	--
9.0,2	9.1	1.83	0.328	29.1	7.1	--
9.0,3	--	--	--	--	--	--
9.5,0	9.5	0.02	0.002	29.1	7.2	--
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.004	28.9	7.1	--
Control 2	8.5	0.00	0.002	28.9	7.2	--

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-2. Water quality parameters for day 1 of post-larval freshwater shrimp toxicity study, replication #2, 11/24/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.001	29.0	7.2	8.4
8.5,1	8.4	1.09	0.013	29.2	7.2	8.5
8.5,2	8.4	1.98	0.002	28.9	7.1	8.5
8.5,3	8.4	2.97	0.013	29.0	7.1	8.5
9.0,0	9.0	0.00	0.001	28.9	7.0	8.9
9.0,1	8.9	1.04	0.004	29.1	7.2	8.9
9.0,2	8.9	2.12	0.004	29.1	7.1	8.9
9.0,3	8.9	3.08	0.002	29.0	7.2	9.0
9.5,0	9.5	0.00	0.004	28.9	7.2	9.4
9.5,1	9.5	1.00	0.002	29.0	7.1	9.4
9.5,2	9.4	2.07	0.001	29.3	7.1	--
9.5,3	9.4	3.07	0.001	29.0	7.1	--
10.0,0	9.9	0.00	0.005	28.9	7.2	--
10.0,1	9.9	0.98	0.002	29.1	7.1	--
10.0,2	9.9	1.98	0.004	29.0	7.2	--
10.0,3	9.9	3.10	0.003	28.7	7.2	--
Control 1	8.3	0.00	0.004	29.0	7.2	8.3
Control 2	8.3	0.00	0.004	29.1	7.2	8.3

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-2 continued. Water quality parameters for day 2 of post-larval freshwater shrimp toxicity study, replication #2, 11/25/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.002	29.0	6.7	8.5
8.5,1	8.5	0.96	0.059	29.0	6.9	8.5
8.5,2	8.6	1.79	0.059	29.0	6.9	8.5
8.5,3	8.5	2.87	0.070	29.0	6.8	8.5
9.0,0	8.9	0.01	0.002	28.9	6.8	9.0
9.0,1	9.0	0.90	0.144	29.2	6.8	9.0
9.0,2	9.0	1.85	0.064	29.1	6.8	9.0
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.01	0.002	29.0	6.8	9.5
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.00	0.000	29.1	6.7	8.3
Control 2	8.3	0.00	0.000	29.1	6.7	8.3

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-2 continued. Water quality parameters for day 3 of post-larval freshwater shrimp toxicity study, replication #2, 11/26/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (^{0}C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.001	29.0	7.1	8.4
8.5,1	8.4	0.94	0.295	29.2	7.1	8.4
8.5,2	8.4	2.04	0.280	28.8	7.1	8.4
8.5,3	--	--	--	--	--	--
9.0,0	8.9	0.00	0.001	28.9	7.1	9.0
9.0,1	8.9	0.79	0.500	29.1	7.0	9.0
9.0,2	8.9	1.98	0.240	29.0	7.2	9.0
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.001	28.9	7.2	9.5
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.00	0.002	29.0	7.1	8.3
Control 2	8.4	0.00	0.000	29.0	7.1	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-2 continued. Water quality parameters for day 4 of post-larval freshwater shrimp toxicity study, replication #2, 11/27/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.001	29.0	7.0	--
8.5,1	8.4	0.85	1.310	29.3	6.8	--
8.5,2	8.4	1.83	1.330	28.9	6.7	--
8.5,3	--	--	--	--	--	--
9.0,0	8.9	0.00	0.001	28.9	7.0	--
9.0,1	9.0	0.89	2.100	29.1	6.5	--
9.0,2	8.9	1.84	1.100	29.0	6.8	--
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.001	28.9	7.1	--
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.00	0.000	29.0	6.9	--
Control 2	8.4	0.00	0.001	29.0	6.9	--

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-3. Water quality parameters for day 1 of post-larval freshwater shrimp toxicity study, replication #3, 12/1/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.000	29.0	7.3	8.4
8.5,1	8.5	1.00	0.010	29.2	7.2	8.5
8.5,2	8.4	1.96	0.006	29.0	7.2	8.5
8.5,3	8.4	2.96	0.014	29.0	7.2	8.5
9.0,0	8.9	0.00	0.000	28.9	7.3	8.9
9.0,1	8.9	0.97	0.007	28.9	7.3	8.9
9.0,2	9.0	2.04	0.008	29.0	7.2	8.9
9.0,3	9.0	2.98	0.015	29.0	7.2	8.9
9.5,0	9.4	0.01	0.000	28.8	7.3	9.4
9.5,1	9.5	1.01	0.007	29.1	7.3	9.4
9.5,2	9.4	2.02	0.010	29.1	7.2	9.4
9.5,3	9.4	3.06	0.005	29.0	7.2	--
10.0,0	9.9	0.02	0.000	29.0	7.2	--
10.0,1	9.9	0.96	0.005	29.0	7.1	--
10.0,2	9.9	2.06	0.007	29.1	7.2	--
10.0,3	9.9	3.13	0.005	29.2	7.3	--
Control 1	8.4	0.00	0.000	28.9	7.3	8.3
Control 2	8.4	0.00	0.000	29.1	7.3	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-3 continued. Water quality parameters for day 2 of post-larval freshwater shrimp toxicity study, replication #3, 12/2/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.000	29.1	7.2	8.5
8.5,1	8.5	1.03	0.065	28.8	7.2	8.5
8.5,2	8.5	2.05	0.049	29.0	7.1	8.5
8.5,3	8.5	3.07	0.095	29.0	7.2	8.5
9.0,0	8.9	0.00	0.000	28.9	7.2	8.9
9.0,1	9.0	1.01	0.044	28.9	7.3	8.9
9.0,2	8.9	2.09	0.060	28.9	7.2	9.0
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.000	28.9	7.2	9.4
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.000	28.9	7.3	8.3
Control 2	8.4	0.00	0.000	29.1	7.3	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-3 continued. Water quality parameters for day 2 of post-larval freshwater shrimp toxicity study, replication #3, 12/2/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.000	29.1	7.2	8.5
8.5,1	8.5	1.03	0.065	28.8	7.2	8.5
8.5,2	8.5	2.05	0.049	29.0	7.1	8.5
8.5,3	8.5	3.07	0.095	29.0	7.2	8.5
9.0,0	8.9	0.00	0.000	28.9	7.2	8.9
9.0,1	9.0	1.01	0.044	28.9	7.3	8.9
9.0,2	8.9	2.09	0.060	28.9	7.2	9.0
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.000	28.9	7.2	9.4
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.000	28.9	7.3	8.3
Control 2	8.4	0.00	0.000	29.1	7.3	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-3 continued. Water quality parameters for day 3 of post-larval freshwater shrimp toxicity study, replication #3, 12/3/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (^{0}C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.002	29.0	7.1	8.4
8.5,1	8.4	0.98	0.306	28.8	7.2	8.4
8.5,2	8.5	2.14	0.232	29.3	7.2	8.4
8.5,3	--	--	--	--	--	--
9.0,0	8.9	0.00	0.001	28.9	7.2	9.0
9.0,1	8.9	0.90	0.201	29.0	7.2	8.9
9.0,2	8.9	1.98	0.268	29.1	7.1	9.0
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.000	28.8	7.2	9.4
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.000	28.9	7.1	8.3
Control 2	8.4	0.00	0.001	29.2	7.2	8.3

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-3 continued. Water quality parameters for day 4 of post-larval freshwater shrimp toxicity study, replication #3, 12/4/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (^{0}C)	am DO (mg/L)	pm pH
8.5,0	8.6	0.00	0.000	29.0	6.9	--
8.5,1	8.4	0.82	1.386	28.8	6.8	--
8.5,2	8.4	1.95	1.155	29.2	6.8	--
8.5,3	--	--	--	--	--	--
9.0,0	9.0	0.00	0.000	28.9	7.0	--
9.0,1	8.9	0.80	0.943	29.2	6.9	--
9.0,2	--	--	--	--	--	--
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.000	28.8	7.0	--
9.5,1	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.000	28.9	6.9	--
Control 2	8.4	0.00	0.000	29.1	6.9	--

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-4. Water quality parameters for day 1 of juvenile freshwater shrimp toxicity study, replication #1, 8/26/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.005	29.0	7.1	8.5
8.5,1	8.4	0.98	0.007	28.9	7.1	8.6
8.5,2	8.4	1.96	0.007	29.1	7.1	8.4
8.5,3	8.5	3.20	0.007	29.1	7.0	8.4
9.0,0	8.9	0.00	0.007	28.9	7.1	8.9
9.0,1	9.0	0.89	0.006	28.9	7.1	8.9
9.0,2	9.0	1.90	0.007	29.1	7.1	8.9
9.0,3	8.9	3.07	0.006	28.8	7.1	8.9
9.5,0	9.5	0.00	0.004	29.1	7.1	9.4
9.5,1	9.5	0.79	0.006	29.0	7.2	9.4
9.5,2	9.4	2.08	0.004	29.2	7.2	9.4
9.5,3	9.4	2.86	0.005	29.0	7.2	9.4
10.0,0	9.9	0.00	0.004	28.9	7.1	9.9
10.0,1	9.9	0.81	0.004	29.0	7.2	9.9
10.0,2	9.9	2.07	0.009	29.0	7.2	9.9
10.0,3	9.9	2.78	0.004	29.0	7.2	--
Control 1	8.3	0.00	0.004	29.1	7.1	8.3
Control 2	8.3	0.00	0.006	29.0	7.1	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-4 continued. Water quality parameters for day 2 of juvenile freshwater shrimp toxicity study, replication #1, 8/27/87.

Treatment combination*	am pH	NH_3-N (mg/L)	NO_2-N (mg/L)	Temp (°C)	DO (mg/L)	pm pH
8.5,0	8.5	0.01	0.039	28.9	7.1	8.6
8.5,1	8.4	0.98	0.035	28.9	6.8	8.6
8.5,2	8.4	1.75	0.036	29.2	7.0	8.6
8.5,3	8.4	3.14	0.033	29.1	7.0	8.6
9.0,0	8.9	0.01	0.031	29.0	7.0	9.1
9.0,1	8.9	0.93	0.024	29.0	7.0	9.1
9.0,2	9.0	2.01	0.023	29.0	6.9	9.1
9.0,3	8.9	2.96	0.021	28.9	7.0	--
9.5,0	9.4	0.02	0.034	28.9	7.0	9.4
9.5,1	9.4	0.96	0.021	29.1	6.9	9.6
9.5,2	9.4	2.11	0.013	29.2	7.0	9.6
9.5,3	9.4	2.83	0.014	29.0	6.8	9.6
10.0,0	9.9	0.06	0.038	29.0	7.1	10.0
10.0,1	9.9	0.94	0.014	29.0	7.0	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.01	0.024	29.1	7.1	8.3
Control 2	8.4	0.00	0.031	29.0	7.0	8.3

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-4 continued. Water quality parameters for day 3 of juvenile freshwater shrimp toxicity study, replication #1, 8/28/87.

Treatment combination*	am pH	NH_3-N (mg/L)	NO_2-N (mg/L)	Temp (°C)	DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.046	29.1	7.1	8.5
8.5,1	8.4	0.96	0.164	29.1	6.4	8.4
8.5,2	8.4	1.81	0.170	28.9	6.3	8.4
8.5,3	8.4	2.88	0.150	29.0	6.7	8.4
9.0,0	8.9	0.01	0.029	28.9	7.1	8.9
9.0,1	9.0	0.87	0.103	29.1	6.7	9.0
9.0,2	9.0	2.04	0.098	28.9	6.8	9.0
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.01	0.035	29.0	7.2	9.4
9.5,1	9.4	0.96	0.079	29.0	6.9	9.4
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	9.9	0.05	0.055	28.9	6.9	9.9
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.01	0.053	29.0	7.1	8.3
Control 2	8.4	0.00	0.017	28.9	7.1	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-4 continued. Water quality parameters for day 4 of juvenile freshwater shrimp toxicity study, replication #1, 8/29/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.013	28.9	7.1	--
8.5,1	8.4	0.88	0.930	29.1	6.0	--
8.5,2	8.4	1.92	0.898	29.1	6.0	--
8.5,3	8.4	2.96	0.674	29.0	6.2	--
9.0,0	8.9	0.00	0.009	28.9	6.9	--
9.0,1	9.0	0.82	0.490	29.0	6.8	--
9.0,2	--	--	--	--	--	--
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.01	0.011	28.9	7.0	--
9.5,1	9.4	0.77	0.317	29.1	6.8	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	9.9	0.02	0.039	28.8	7.1	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.00	0.058	29.1	7.0	--
Control 2	8.4	0.00	0.014	28.9	7.1	--

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-5. Water quality parameters for day 1 of juvenile freshwater shrimp toxicity study, replication #2, 9/1/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (^{0}C)	am DO (mg/L)	pm pH
8.5,0	8.6	0.00	0.001	29.0	7.2	8.5
8.5,1	8.4	1.01	0.005	29.0	7.1	8.5
8.5,2	8.4	1.83	0.007	29.1	7.0	8.4
8.5,3	8.5	3.11	0.007	28.9	6.9	8.4
9.0,0	9.0	0.01	0.001	28.8	7.3	8.9
9.0,1	9.1	0.94	0.016	29.1	7.0	9.0
9.0,2	8.9	1.88	0.005	29.1	7.1	8.9
9.0,3	8.9	2.82	0.005	29.0	6.7	8.9
9.5,0	9.5	0.01	0.000	28.8	7.2	9.4
9.5,1	9.6	0.88	0.014	28.8	6.9	9.5
9.5,2	9.4	2.00	0.004	28.9	7.2	9.4
9.5,3	9.4	2.95	0.006	28.9	7.2	9.4
10.0,0	10.0	0.01	0.000	28.9	7.2	9.9
10.0,1	10.0	0.91	0.006	29.0	6.7	10.0
10.0,2	10.0	1.85	0.005	29.1	6.8	9.9
10.0,3	9.9	2.94	0.008	28.9	7.2	--
Control 1	8.3	0.00	0.002	29.0	7.2	8.3
Control 2	8.4	0.00	0.001	29.1	7.2	8.4

* pH,mg/L NH_3-N.

-- Indicates parameters not measured, because of 100% mortality.

Table C-5 continued. Water quality parameters for day 2 of juvenile freshwater shrimp toxicity study, replication #2, 9/2/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.003	29.1	7.1	8.5
8.5,1	8.5	1.01	0.050	29.0	7.1	8.5
8.5,2	8.5	2.02	0.074	29.2	7.0	8.5
8.5,3	8.5	2.85	0.047	28.9	7.1	8.5
9.0,0	9.1	0.00	0.002	29.2	7.1	9.0
9.0,1	9.0	0.92	0.159	28.7	6.8	9.0
9.0,2	8.9	1.97	0.040	29.1	7.0	9.0
9.0,3	8.9	2.86	0.040	29.0	7.0	9.0
9.5,0	9.4	0.00	0.003	29.2	7.1	9.4
9.5,1	9.4	0.80	0.125	29.1	7.0	9.5
9.5,2	9.5	1.86	0.022	29.1	7.0	9.5
9.5,3	9.4	2.80	0.032	29.0	7.1	9.4
10.0,0	9.9	0.01	0.005	29.2	7.2	9.9
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.002	29.0	7.1	8.4
Control 2	8.4	0.00	0.003	28.9	7.0	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-5 continued. Water quality parameters for day 3 of juvenile freshwater shrimp toxicity study, replication #2, 9/3/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.001	29.2	7.0	8.6
8.5,1	8.5	1.02	0.261	28.8	6.9	8.5
8.5,2	8.5	1.79	0.360	29.1	6.9	8.4
8.5,3	8.5	3.08	0.215	29.1	6.9	8.5
9.0,0	8.9	0.00	0.001	29.0	7.1	9.0
9.0,1	8.9	0.75	0.691	28.9	6.5	8.9
9.0,2	9.0	1.82	0.199	29.0	6.9	9.1
9.0,3	9.1	2.79	0.163	28.9	6.7	9.1
9.5,0	9.4	0.00	0.002	29.0	6.9	9.4
9.5,1	9.4	0.86	0.496	28.9	6.8	9.4
9.5,2	9.5	1.96	0.080	29.0	7.0	9.5
9.5,3	9.5	2.99	0.107	29.0	7.2	9.5
10.0,0	9.9	0.01	0.004	29.0	6.9	9.9
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.001	28.8	7.0	8.3
Control 2	8.4	0.00	0.001	28.9	6.9	8.4

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-5 continued. Water quality parameters for day 4 of juvenile freshwater shrimp toxicity study, replication #2, 9/4/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.5	0.00	0.002	29.0	6.9	--
8.5,1	8.4	0.79	1.640	28.8	6.3	--
8.5,2	8.4	1.78	2.160	29.0	6.3	--
8.5,3	8.4	2.84	1.160	29.0	6.4	--
9.0,0	9.0	0.00	0.002	29.0	7.0	--
9.0,1	8.9	0.94	2.670	29.0	6.1	--
9.0,2	9.0	1.80	1.180	28.9	6.6	--
9.0,3	9.0	2.79	0.704	28.9	6.7	--
9.5,0	9.4	0.01	0.002	29.0	6.9	--
9.5,1	9.4	1.03	1.990	29.1	6.0	--
9.5,2	--	----	-----	----	---	--
9.5,3	--	----	-----	----	---	--
10.0,0	9.9	0.01	0.003	29.0	6.9	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.001	28.9	7.0	--
Control 2	8.4	0.00	0.001	29.0	6.9	--

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-6. Water quality parameters for day 1 of juvenile freshwater shrimp toxicity study, replication #3, 9/19/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.012	28.9	7.1	8.5
8.5,1	8.4	0.85	0.014	29.1	7.1	8.6
8.5,2	8.4	2.01	0.008	28.8	7.1	8.5
8.5,3	8.5	3.09	0.014	29.1	7.2	8.4
9.0,0	8.9	0.01	0.012	29.1	7.1	9.0
9.0,1	9.0	1.01	0.008	28.9	7.1	9.1
9.0,2	8.9	1.86	0.008	29.1	7.1	9.0
9.0,3	8.9	3.07	0.010	28.9	7.1	9.0
9.5,0	9.4	0.02	0.053	29.0	7.0	9.4
9.5,1	9.5	0.96	0.019	28.8	7.2	9.6
9.5,2	9.4	1.96	0.009	28.7	7.1	9.5
9.5,3	9.4	2.86	0.007	28.9	7.1	9.5
10.0,0	9.9	0.02	0.009	28.9	7.1	9.9
10.0,1	9.9	1.00	0.011	29.2	7.1	10.0
10.0,2	9.9	2.07	0.009	29.0	7.2	10.0
10.0,3	9.9	3.11	0.026	28.9	7.1	9.9
Control 1	8.3	0.00	0.004	29.0	7.1	8.3
Control 2	8.4	0.00	0.004	29.0	7.1	8.4

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-6 continued. Water quality parameters for day 2 of juvenile freshwater shrimp toxicity study, replication #3, 9/20/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.005	29.0	7.2	8.5
8.5,1	8.6	1.14	0.005	29.1	6.8	8.6
8.5,2	8.6	1.87	0.006	29.0	6.3	8.6
8.5,3	8.5	3.12	0.032	28.9	6.2	8.5
9.0,0	8.9	0.01	0.040	29.1	7.1	8.9
9.0,1	9.1	1.04	0.037	28.8	6.7	9.1
9.0,2	9.1	2.04	0.029	28.7	7.1	9.1
9.0,3	9.1	3.08	0.029	29.0	6.9	9.1
9.5,0	9.4	0.01	0.005	28.9	7.1	9.4
9.5,1	9.6	1.05	0.038	29.2	6.8	9.6
9.5,2	9.6	2.05	0.016	29.0	7.0	9.6
9.5,3	---	----	-----	----	---	---
10.0,0	9.9	0.01	0.044	29.1	7.2	9.9
10.0,1	10.0	0.94	0.025	28.9	7.1	----
10.0,2	----	----	-----	----	---	----
10.0,3	----	----	-----	----	---	----
Control 1	8.3	0.00	0.004	28.9	7.1	8.3
Control 2	8.3	0.00	0.001	28.9	7.1	8.3

* pH,mg/L NH_3-N.

-- Indicates parameters not measured, because of 100% mortality.

Table C-6 continued. Water quality parameters for day 3 of juvenile freshwater shrimp toxicity study, replication #3, 9/21/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.002	29.1	7.2	8.5
8.5,1	8.5	1.20	0.209	28.8	7.1	8.4
8.5,2	8.5	1.96	0.226	29.0	6.9	8.4
8.5,3	8.5	3.18	0.158	28.8	7.1	8.5
9.0,0	8.9	0.00	0.004	29.0	7.1	9.0
9.0,1	9.0	1.06	0.199	29.0	6.8	8.9
9.0,2	9.0	2.22	0.152	29.1	7.2	8.9
9.0,3	9.1	3.14	0.141	28.9	7.0	--
9.5,0	9.4	0.00	0.003	28.9	7.0	9.4
9.5,1	9.6	1.01	0.150	29.0	7.0	9.5
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	9.9	0.00	0.002	29.1	7.1	9.9
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.4	0.00	0.003	28.8	7.2	8.3
Control 2	8.3	0.00	0.002	28.9	7.1	8.3

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-6 continued. Water quality parameters for day 4 of juvenile freshwater shrimp toxicity study, replication #3, 9/22/87.

Treatment combination*	am pH	am NH_3-N (mg/L)	am NO_2-N (mg/L)	am Temp (°C)	am DO (mg/L)	pm pH
8.5,0	8.4	0.00	0.001	28.9	7.2	--
8.5,1	8.4	0.95	1.050	28.9	7.3	--
8.5,2	8.4	1.80	1.140	29.0	6.7	--
8.5,3	8.4	2.81	0.780	28.9	7.2	--
9.0,0	8.9	0.00	0.002	29.1	7.2	--
9.0,1	8.9	0.75	1.000	29.0	6.6	--
9.0,2	8.9	1.75	0.780	28.8	7.3	--
9.0,3	--	--	--	--	--	--
9.5,0	9.4	0.00	0.001	29.0	7.2	--
9.5,1	9.5	0.82	0.560	28.9	7.0	--
9.5,2	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--
10.0,0	9.9	0.00	0.001	29.1	7.2	--
10.0,1	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--
Control 1	8.3	0.00	0.002	28.9	7.2	--
Control 2	8.3	0.00	0.001	29.0	7.2	--

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-7. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #1, 10/11/87.

Treatment combination*	6am pH	6am NH_3-N (mg/L)	6am NO_2-N (mg/L)	6am Temp (°C)	6am DO (mg/L)	8am pH	10am pH
9.0,0	9.0	0.00	0.004	28.9	7.1	8.9	9.0
9.0,1	9.0	1.00	0.004	28.9	7.1	8.9	9.0
9.0,2	8.9	1.86	0.001	28.8	7.1	8.9	9.0
9.0,3	8.9	2.92	0.001	28.7	7.2	8.9	9.0
9.5,0	9.5	0.01	0.001	28.9	7.2	9.4	9.6
9.5,1	9.5	1.02	0.002	29.3	7.1	9.5	9.6
9.5,2	9.5	1.97	0.001	28.7	7.1	9.4	9.4
9.5,3	9.4	2.87	0.002	29.1	7.2	9.4	9.6
10.0,0	9.9	0.01	0.003	28.7	7.1	9.9	10.0
10.0,1	10.0	0.89	0.001	29.1	7.1	10.0	10.0
10.0,2	10.0	1.95	0.003	28.8	7.1	9.9	10.0
10.0,3	9.9	2.88	0.001	29.3	7.2	9.9	10.0
10.5,0	10.4	0.01	0.001	29.0	7.1	10.4	10.4
10.5,1	10.4	0.97	0.001	29.1	7.1	10.4	10.5
10.5,2	10.4	1.83	0.003	29.1	7.2	10.4	10.5
10.5,3	10.4	2.84	0.001	29.0	7.2	10.4	10.5
Control 1	8.4	0.00	0.002	29.0	7.2	8.2	8.1
Control 2	8.4	0.00	0.002	29.3	7.1	8.1	8.1

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-7 continued. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #1, 10/11/87.

Treatment combination*	1pm pH	1pm NH_3-N (mg/L)	4pm pH	7pm pH	7pm NH_3-N (mg/L)	7pm NO_2-N (mg/L)	7pm Temp (^{0}C)	7pm DO (mg/L)
9.0,0	8.9	0.03	8.9	8.9	0.02	0.101	28.8	6.0
9.0,1	8.9	0.99	8.9	8.9	1.02	0.072	29.0	6.1
9.0,2	8.9	1.92	9.0	8.9	2.11	0.022	28.9	6.3
9.0,3	9.0	2.92	9.0	9.0	2.94	0.049	29.0	6.4
9.5,0	9.4	0.06	9.5	9.5	0.10	0.029	28.9	6.5
9.5,1	9.5	0.90	9.5	9.5	1.06	0.015	28.9	6.4
9.5,2	9.4	1.92	9.5	9.5	2.04	0.007	28.7	7.0
9.5,3	9.6	2.92	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--	--	--
10.0,1	9.9	0.99	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--	--	--
10.0,3	9.9	2.97	10.0	--	--	--	--	--
10.5,0	--	--	--	--	--	--	--	--
10.5,1	--	--	--	--	--	--	--	--
10.5,2	--	--	--	--	--	--	--	--
10.5,3	--	--	--	--	--	--	--	--
Control 1	7.9	0.01	7.9	7.9	0.00	0.052	29.0	5.9
Control 2	8.0	0.02	8.0	8.0	0.00	0.089	29.0	6.2

* pH,mg/L NH_3-N.

-- Indicates parameters not measured, because of 100% mortality.

Table C-7 continued. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #1, 10/11/87.

Treatment combination*	10pm pH	1am pH	4am NH_3-N (mg/L)	4am pH	7am pH	7am NH_3-N (mg/L)	7am NO_2-N (mg/L)	7am Temp (°C)	7am DO (mg/L)
9.0,0	9.0	8.9	0.01	8.9	9.0	0.01	0.069	28.9	5.9
9.0,1	8.9	8.9	0.92	9.0	9.0	0.89	0.136	29.3	6.7
9.0,2	9.0	8.9	1.92	8.9	9.0	1.99	0.037	29.0	6.6
9.0,3	9.0	9.0	3.05	9.0	9.0	3.13	0.095	29.2	7.0
9.5,0	9.5	9.5	0.01	9.5	9.5	0.02	0.013	29.3	6.8
9.5,1	--	--	--	--	--	--	--	--	--
9.5,2	9.5	9.4	1.80	9.4	9.5	1.98	0.014	28.7	7.2
9.5,3	--	--	--	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--	--	--	--
10.5,0	--	--	--	--	--	--	--	--	--
10.5,1	--	--	--	--	--	--	--	--	--
10.5,2	--	--	--	--	--	--	--	--	--
10.5,3	--	--	--	--	--	--	--	--	--
Control 1	7.9	7.9	0.00	7.9	7.9	0.00	0.086	29.0	5.6
Control 2	8.0	8.0	0.00	7.9	8.0	0.00	0.063	29.1	6.1

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-8. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #2, 10/13/87.

Treatment combination*	6am pH	6am NH_3-N (mg/L)	6am NO_2-N (mg/L)	6am Temp (^{0}C)	6am DO (mg/L)	8am pH	10am pH
9.0,0	9.1	0.01	0.001	28.9	6.9	8.9	9.1
9.0,1	9.0	1.03	0.002	28.7	7.1	8.9	9.1
9.0,2	8.9	1.94	0.003	28.9	6.9	8.9	9.0
9.0,3	8.9	2.82	0.003	28.9	7.1	8.9	9.1
9.5,0	9.6	0.01	0.001	29.0	7.1	9.4	9.6
9.5,1	9.6	0.99	0.009	28.9	7.1	9.4	9.6
9.5,2	9.4	1.87	0.003	28.9	7.0	9.4	9.6
9.5,3	9.4	2.97	0.003	29.1	7.1	9.4	9.6
10.0,0	10.1	0.01	0.002	28.8	7.1	9.9	10.0
10.0,1	10.0	1.00	0.001	29.0	7.1	9.9	10.0
10.0,2	10.0	1.96	0.004	29.0	6.9	9.9	10.0
10.0,3	9.9	2.87	0.005	28.9	7.1	9.9	10.0
10.5,0	10.5	0.02	0.002	28.9	7.0	10.4	10.5
10.5,1	10.4	0.96	0.002	28.9	7.1	10.4	10.5
10.5,2	10.4	1.94	0.002	28.9	6.9	10.4	10.5
10.5,3	10.4	2.94	0.002	29.4	7.0	10.4	10.5
Control 1	8.4	0.00	0.005	28.8	6.9	8.0	8.0
Control 2	8.4	0.00	0.006	29.0	6.9	7.9	8.0

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-8 continued. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #2, 10/13/87.

Treatment combination*	10pm	1am		4am	7am				
	pH	pH	NH_3-N (mg/L)	pH	pH	NH_3-N (mg/L)	NO_2-N (mg/L)	Temp (°C)	DO (mg/L)
9.0,0	8.9	8.9	0.06	8.9	9.0	0.11	0.255	29.2	6.6
9.0,1	8.9	8.9	0.93	8.9	9.0	0.89	0.337	29.0	6.7
9.0,2	8.9	8.9	1.89	8.9	8.9	1.98	0.034	29.3	7.0
9.0,3	9.0	9.0	2.87	9.0	8.9	2.96	0.084	28.9	6.9
9.5,0	9.4	9.4	0.05	9.5	9.5	0.04	0.051	28.6	6.9
9.5,1	--	--	--	--	--	--	--	--	--
9.5,2	--	--	--	--	--	--	--	--	--
9.5,3	--	--	--	--	--	--	--	--	--
10.0,0	--	--	--	--	--	--	--	--	--
10.0,1	--	--	--	--	--	--	--	--	--
10.0,2	--	--	--	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--	--	--	--
10.5,0	--	--	--	--	--	--	--	--	--
10.5,1	--	--	--	--	--	--	--	--	--
10.5,2	--	--	--	--	--	--	--	--	--
10.5,3	--	--	--	--	--	--	--	--	--
Control 1	8.0	8.0	0.00	8.1	8.0	0.00	0.016	29.1	6.6
Control 2	8.0	8.0	0.00	8.0	8.0	0.00	0.030	29.1	6.5

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-9. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #3, 11/12/87.

Treatment combination*	6am pH	6am NH_3-N (mg/L)	6am NO_2-N (mg/L)	6am Temp (°C)	6am DO (mg/L)	8am pH	10am pH
9.0,0	8.9	0.01	0.002	28.9	7.3	9.1	9.0
9.0,1	9.0	0.85	0.001	29.0	7.4	9.0	9.0
9.0,2	9.0	1.92	0.003	29.0	7.3	9.1	9.0
9.0,3	8.9	2.87	0.004	28.7	7.3	9.0	9.0
9.5,0	9.4	0.10	0.004	29.0	7.3	9.6	9.5
9.5,1	9.4	0.98	0.003	29.1	7.3	9.6	9.5
9.5,2	9.4	1.85	0.001	29.0	7.4	9.5	9.5
9.5,3	9.4	2.93	0.004	28.9	7.3	9.5	9.5
10.0,0	9.9	0.09	0.003	28.8	7.4	9.9	10.0
10.0,1	9.9	0.89	0.003	28.8	7.4	10.0	10.0
10.0,2	9.9	1.83	0.002	29.0	7.4	10.0	9.9
10.0,3	10.0	2.83	0.002	29.1	7.3	9.9	10.0
10.5,0	10.5	0.08	0.002	29.0	7.3	10.4	10.4
10.5,1	10.4	0.89	0.002	28.9	7.4	10.5	10.5
10.5,2	10.5	1.82	0.005	28.9	7.3	10.4	10.5
10.5,3	10.5	2.78	0.002	28.8	7.3	10.5	10.5
Control 1	8.3	0.01	0.004	29.1	7.3	8.2	8.1
Control 2	8.3	0.01	0.002	29.0	7.4	8.2	8.1

* pH,mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-9 continued. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #3, 11/12/87.

Treatment combination*	1pm pH	1pm NH_3-N (mg/L)	4pm pH	7pm pH	7pm NH_3-N (mg/L)	7pm NO_2-N (mg/L)	7pm Temp (°C)	7pm DO (mg/L)
9.0,0	8.9	0.05	8.9	9.0	0.05	0.062	29.0	6.5
9.0,1	8.9	1.08	9.0	9.0	1.22	0.019	29.4	7.1
9.0,2	8.9	2.01	8.9	9.0	2.19	0.019	28.8	6.4
9.0,3	9.0	2.96	8.9	9.0	3.06	0.018	28.7	6.6
9.5,0	9.4	0.05	9.5	9.5	0.09	0.084	28.9	6.7
9.5,1	9.4	1.01	9.5	9.6	1.17	0.015	29.2	6.9
9.5,2	9.5	2.02	9.4	9.5	2.21	0.015	28.9	6.8
9.5,3	9.4	2.96	9.5	9.5	3.11	0.013	29.0	7.0
10.0,0	9.9	0.08	9.9	9.9	0.09	0.044	28.8	6.8
10.0,1	9.9	0.97	10.0	--	--	--	--	--
10.0,2	10.0	2.02	9.9	10.0	1.93	0.011	29.0	7.2
10.0,3	9.9	2.98	10.0	--	--	--	--	--
10.5,0	10.4	0.10	--	--	--	--	--	--
10.5,1	10.5	1.00	--	--	--	--	--	--
10.5,2	10.4	2.00	--	--	--	--	--	--
10.5,3	10.4	3.00	--	--	--	--	--	--
Control 1	8.0	0.01	8.0	8.0	0.00	0.119	29.0	6.7
Control 2	8.0	0.01	8.1	8.1	0.02	0.086	29.0	6.8

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Table C-9 continued. Water quality parameters of sub-adult freshwater shrimp toxicity study, replication #3, 11/12/87.

Treatment combination*	10pm pH	1am pH	1am NH_3-N (mg/L)	4am pH	7am pH	7am NH_3-N (mg/L)	7am NO_2-N (mg/L)	7am Temp (°C)	7am DO (mg/L)
9.0,0	8.9	9.0	0.04	8.9	9.0	0.02	0.079	29.0	7.2
9.0,1	8.9	8.9	0.93	8.9	8.9	0.94	0.027	29.1	7.4
9.0,2	9.0	9.0	2.00	8.9	8.9	2.06	0.026	28.9	7.3
9.0,3	8.9	8.9	2.92	8.9	8.9	2.93	0.025	29.0	7.4
9.5,0	9.4	9.5	0.13	9.5	9.5	0.04	0.104	28.9	7.1
9.5,1	9.5	9.5	0.97	9.4	9.5	1.11	0.019	29.3	7.2
9.5,2	9.5	9.5	1.79	9.4	9.4	1.85	0.016	29.0	7.4
9.5,3	--	--	--	--	--	--	--	--	--
10.0,0	9.9	9.9	0.15	9.9	9.9	0.08	0.050	29.0	7.1
10.0,1	--	--	--	--	--	--	--	--	--
10.0,2	9.9	9.9	2.13	--	--	--	--	--	--
10.0,3	--	--	--	--	--	--	--	--	--
10.5,0	--	--	--	--	--	--	--	--	--
10.5,1	--	--	--	--	--	--	--	--	--
10.5,2	--	--	--	--	--	--	--	--	--
10.5,3	--	--	--	--	--	--	--	--	--
Control 1	8.0	8.0	0.00	8.1	8.1	0.00	0.093	29.0	6.9
Control 2	8.2	8.2	0.02	8.2	8.2	0.01	0.203	29.0	7.2

* pH, mg/L NH_3-N.
-- Indicates parameters not measured, because of 100% mortality.

Appendix D

Statistics obtained from samples of post-orbital length and wet weight for each replication of the toxicity study.

Table D-1. Summary of toxicity sample statistics for post-orbital length and wet weight of post-larval freshwater shrimp replications.

n	Replication #1		Replication #2		Replication #3	
	Length (mm)	Weight (mg)	Length (mm)	Weight (mg)	Length (mm)	Weight (mg)
1	9	11	9	12	11	20
2	9	11	10	15	10	14
3	8	7	10	19	10	15
4	10	14	9	10	10	12
5	8	7	11	15	11	21
6	9	11	10	14	10	16
7	9	12	11	16	10	17
8	9	11	8	9	10	14
9	8	8	10	17	10	13
10	9	12	10	12	11	18
11	10	14	9	12	10	13
12	10	12	9	11	10	14
13	9	10	10	15	10	14
14	8	6	11	16	10	13
15	9	12	10	12	9	10
16	10	11	11	18	10	17
17	8	7	9	14	10	16
18	8	7	10	14	9	10
19	8	8	11	17	10	16
20	7	7	9	10	10	16
21	7	6	10	13	9	10
22	8	10	9	9	9	10
23	9	10	10	11	10	13
24	9	9	10	16	11	18
25	9	11	10	15	11	18
26	9	9	9	13	11	18
27	10	13	10	14	11	16
28	9	10	10	13	10	15
29	10	14	10	13	9	12
30	9	12	11	17	11	20
Mean	8.8	10.1	9.9	13.7	10.1	15.0
SE	0.15	0.44	0.14	0.48	0.12	0.56
Range	7-10	6-14	8-11	9-19	9-11	10-21

Table D-2. Summary of toxicity sample statistics for post-orbital length and wet weight of juvenile freshwater shrimp replications.

n	Replication #1		Replication #2		Replication #3	
	Length (cm)	Weight (g)	Length (cm)	Weight (g)	Length (cm)	Weight (g)
1	4.0	1.27	3.3	0.66	3.4	0.78
2	3.4	0.79	2.8	0.41	3.6	0.95
3	3.8	1.13	3.2	0.66	3.6	0.93
4	3.6	0.92	2.9	0.48	3.5	0.83
5	3.6	0.96	3.2	0.74	3.7	1.07
6	3.6	0.94	3.5	0.86	3.8	1.05
7	3.2	0.63	3.5	0.90	3.6	0.91
8	3.4	0.76	2.9	0.41	3.7	1.05
9	3.9	1.21	3.1	0.52	3.8	1.11
10	3.8	1.11	3.2	0.63	3.6	0.92
11	3.8	1.10	3.1	0.58	3.4	0.79
12	3.5	0.94	3.5	0.76	3.6	0.91
13	3.7	1.07	3.2	0.65	3.8	1.14
14	3.5	0.81	3.5	0.92	3.5	0.94
15	3.4	0.75	3.1	0.55	3.4	0.83
16	3.6	0.99	3.5	0.76	3.8	1.12
17	3.9	1.28	2.9	0.51	4.0	1.25
18	3.5	0.85	3.3	0.73	3.7	1.02
19	3.5	0.83	3.0	0.49	3.7	0.99
20	3.4	0.78	3.3	0.69	3.7	0.96
21	3.9	1.25	2.8	0.43	3.5	0.90
22	3.1	0.60	3.3	0.66	3.7	0.94
23	3.4	0.73	3.2	0.67	3.4	0.77
24	3.4	0.77	3.1	0.57	3.6	0.92
25	3.8	1.13	3.1	0.56	3.4	0.81
26	3.7	0.99	2.9	0.58	3.6	0.98
27	3.6	0.95	3.0	0.54	3.7	1.04
28	3.5	0.83	3.0	0.54	3.7	1.02
29	3.4	0.82	3.1	0.52	3.8	1.13
30	3.2	0.63	2.9	0.49	3.6	0.93
Mean	3.57	0.927	3.15	0.616	3.63	0.966
SE	0.041	0.036	0.039	0.025	0.027	0.022
Range	3.1-4.0	0.63-1.28	2.8-3.5	0.41-0.92	3.4-3.8	0.77-1.25

Table D-3. Summary of toxicity sample statistics for post-orbital length and wet weight of sub-adult freshwater shrimp replications.

n	Replication #1		Replication #2		Replication #3	
	Length (cm)	Weight (g)	Length (cm)	Weight (g)	Length (cm)	Weight (g)
1	7.6	11.4	8.5	14.5	6.9	7.5
2	8.2	13.5	8.4	13.9	7.3	9.1
3	7.9	11.5	7.0	8.1	7.2	8.6
4	8.1	12.3	8.4	14.3	6.9	8.1
5	7.9	11.6	8.2	11.7	7.4	8.8
6	7.7	10.5	7.2	9.6	7.1	7.7
7	7.0	7.7	7.2	8.2	7.0	7.8
8	7.0	7.6	8.2	13.2	7.4	9.3
9	7.6	9.5	7.3	8.9	7.2	8.9
10	8.3	13.5	8.6	15.3	7.0	8.3
11	7.0	7.6	7.2	8.8	7.1	8.5
12	8.2	12.9	7.9	11.4	7.0	7.3
13	7.5	10.2	7.7	10.5	7.5	10.1
14	7.4	8.9	7.4	9.3	7.3	9.0
15	8.5	15.0	7.7	9.9	7.0	8.3
16	7.9	10.9	7.8	10.8	7.1	8.4
17	6.8	6.9	7.6	10.1	7.4	9.8
18	7.7	11.1	8.4	13.9	7.8	11.5
19	7.8	10.8	7.4	8.9	7.0	7.2
20	7.6	10.8	7.8	10.9	7.4	9.0
21	8.3	14.9	8.1	12.7	7.0	8.1
22	8.0	13.0	8.5	15.4	7.7	11.0
23	7.7	9.9	7.7	9.6	7.2	8.6
24	7.4	9.3	7.2	8.1	7.3	8.7
25	7.2	8.3	8.1	12.2	6.8	7.4
26	7.5	9.3	8.7	16.8	7.0	8.0
27	7.7	9.8	7.2	8.8	7.0	8.0
28	7.4	9.9	7.1	8.4	7.3	9.2
29	7.3	8.8	7.5	9.6	7.0	7.5
30	7.8	10.7	8.9	16.3	7.2	8.3
Mean	7.67	10.60	7.83	11.34	7.18	8.60
SE	0.078	0.386	0.101	0.488	0.043	0.186
Range	6.8-8.5	6.9-15.0	7.0-8.9	8.1-16.8	6.8-7.8	7.2-11.5

Appendix E

Percent survival for each replication of the toxicity study.

Table E-1. Percent survival for post-larval freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #1.

Treatment combination*	Time (h)							
	1	3	6	9	12	24	48	72
8.5,0	95	95	95	--	95	95	90	90
8.5,1	100	100	100	--	100	100	100	100
8.5,2	100	100	100	--	95	95	90	90
8.5,3	100	95	95	--	90	80	40	15
9.0,0	100	100	100	--	100	95	95	95
9.0,1	100	100	100	--	100	100	100	95
9.0,2	100	100	95	--	95	90	90	25
9.0,3	100	100	95	--	90	55	5	0
9.5,0	100	100	90	--	85	85	85	40
9.5,1	100	95	80	--	75	40	15	0
9.5,2	100	95	35	--	25	10	0	0
9.5,3	95	55	0	--	0	0	0	0
10.0,0	95	65	5	--	0	0	0	0
10.0,1	80	15	0	--	0	0	0	0
10.0,2	65	0	0	--	0	0	0	0
10.0,3	75	0	0	--	0	0	0	0
Control 1	100	100	95	--	95	90	90	90
Control 2	100	100	100	--	100	100	100	95

* pH,mg/L NH_3-N.
-- Results were not recorded for the 9-h exposure period.

Table E-2. Percent survival for post-larval freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #2.

Treatment combination*	Time(h)							
	1	3	6	9	12	24	48	72
8.5,0	100	100	100	100	100	100	100	100
8.5,1	95	95	95	95	95	95	95	95
8.5,2	100	100	100	100	95	80	80	70
8.5,3	100	95	95	95	80	15	0	0
9.0,0	100	100	95	95	95	95	95	95
9.0,1	100	100	100	100	100	100	100	95
9.0,2	100	100	100	100	95	80	40	25
9.0,3	95	95	95	70	45	0	0	0
9.5,0	100	95	95	95	95	95	80	75
9.5,1	100	75	35	30	25	0	0	0
9.5,2	90	25	0	0	0	0	0	0
9.5,3	85	15	0	0	0	0	0	0
10.0,0	95	10	0	0	0	0	0	0
10.0,1	50	0	0	0	0	0	0	0
10.0,2	95	0	0	0	0	0	0	0
10.0,3	25	0	0	0	0	0	0	0
Control 1	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100

* pH, mg/L NH_3-N.

Table E-3. Percent survival for post-larval freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #3.

Treatment combination*	Time(h) 1	3	6	9	12	24	48	72
8.5,0	100	100	100	100	100	100	100	100
8.5,1	100	100	100	100	100	100	95	95
8.5,2	100	100	100	100	100	85	80	65
8.5,3	95	95	90	80	60	5	0	0
9.0,0	100	100	100	100	100	95	95	90
9.0,1	100	100	100	100	100	100	100	85
9.0,2	95	95	95	95	90	70	20	0
9.0,3	100	95	90	65	25	0	0	0
9.5,0	95	80	50	35	30	25	15	15
9.5,1	100[a]	35	20	15	10	0	0	0
9.5,2	100	20	5	5	5	0	0	0
9.5,3	95	0	0	0	0	0	0	0
10.0,0	80	5	0	0	0	0	0	0
10.0,1	85	0	0	0	0	0	0	0
10.0,2	65	0	0	0	0	0	0	0
10.0,3	55	0	0	0	0	0	0	0
Control 1	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100

* pH,mg/L NH_3-N.
[a] Signifies one molt.

Table E-4. Percent survival for juvenile freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #1.

Treatment combination*	Time(h)							
	1	3	6	9	12	24	48	72
8.5,0	100	100	100	100	100	100	100	100
8.5,1	100	100	100	100	100	100	100	100
8.5,2	100	100	100	100	100	100	100[a]	100[a]
8.5,3	100	100	100	100	90	90	90	90
9.0,0	100	100	100	100	100	100	100	100
9.0,1	100	100	100	100	100	100	100	100
9.0,2	100	100	90	90	80	80	40	0
9.0,3	100	100	100	100	90	70	0	0
9.5,0	100	100	100	100	100	100	100	100[a]
9.5,1	100	100	100	100	100	90	80	70
9.5,2	100	90	70	60	60	60	0	0
9.5,3	100	100	90	80	70	10	0	0
10.0,0	100	100	100	90	80	70	60	60
10.0,1	100	80	50	50	40	30	0	0
10.0,2	100	90	60	30	0	0	0	0
10.0,3	100	70	10	0	0	0	0	0
Control 1	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100

* pH,mg/L NH_3-N.
[a] Signifies one molt.

Table E-5. Percent survival for juvenile freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #2.

Treatment combination*	Time(h)							
	1	3	6	9	12	24	48	72
8.5,0	100	100	100	100	100[a]	100	100	100
8.5,1	100	100	100	100	100	100	100	100
8.5,2	100	100	100	100	100	100	100	100
8.5,3	100	100	100	100	100	100	100	90
9.0,0	100[a]	100	100[a]	100	100	100	100	100
9.0,1	100	100	100	100	100	100	100	100
9.0,2	100	100	100	100	100	100	100	100
9.0,3	100	100	90[a]	90	90	90	80	30
9.5,0	100	100	100	100	100	100	100	100
9.5,1	100	100	100	100	90	90[a a]	90	90
9.5,2	100	100	90	90	90	80	40	10
9.5,3	100	100	100	100	90	80	10	0
10.0,0	100	100	100	100	100	90	70	50
10.0,1	100	100	50	20	20	0	0	0
10.0,2	100[a]	80	30	10	10[a]	0	0	0
10.0,3	100	90	60	0	0	0	0	0
Control 1	100	100	100[a]	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100

* pH.mg/L NH_3-N.
[a] Signifies one molt.

Table E-6. Percent survival for juvenile freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #3.

Treatment combination*	Time(h)							
	1	3	6	9	12	24	48	72
8.5,0	100	100	100	100	100	100	100	100
8.5,1	100	100	100	100	100	100	100[a]	100
8.5,2	100	100	100	100	100	100[a]	100	100
8.5,3	100	100	100	100	100	100	100	100
9.0,0	100	100	100	100	100	100	100	100
9.0,1	100	100	100	100	100	100	100[a]	100
9.0,2	100	100	100	100	100	100	80	70
9.0,3	100	100	100	100	100	90	10	0
9.5,0	100	100	100	100	100	100	100	100
9.5,1	100	100	100	100	100	80	50	30
9.5,2	100	100	100	100	90	10	0	0
9.5,3	100	100	90	90	80	0	0	0
10.0,0	100	100	70	60	30	20	10	10
10.0,1	100	100	100	80	40	10	0	0
10.0,2	100	90	50	10	0	0	0	0
10.0,3	100	100	30	20	10	0	0	0
Control 1	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100

* pH,mg/L NH_3-N.
[a] Signifies one molt.

Table E-7. Percent survival for sub-adult freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #1.

Treatment combination*	Time(h) 1	3	6	9	12	15	18	21	24
9.0,0	100	100	100	100	100	100	100	100	100
9.0,1	100	100	100	100	100	100	100	100	100
9.0,2	90	90	80	80	80	70	70	70	70
9.0,3	100	70	60	60	30	30	20	10	10
9.5,0	100	100	50	30	30	30	30	30	30
9.5,1	100	100	40	30	10	0	0	0	0
9.5,2	80	80	40	30	30	20	20	20	10
9.5,3	100	80	10	0	0	0	0	0	0
10.0,0	100	60	0	0	0	0	0	0	0
10.0,1	90	30	10	0	0	0	0	0	0
10.0,2	100	50	0	0	0	0	0	0	0
10.0,3	100	60	20	10	0	0	0	0	0
10.5,0	100	50	0	0	0	0	0	0	0
10.5,1	100	50	0	0	0	0	0	0	0
10.5,2	100	30	0	0	0	0	0	0	0
10.5,3	100	20	0	0	0	0	0	0	0
Control 1	100	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100	100

* pH,mg/L NH_3-N.

Table E-8. Percent survival for sub-adult freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #2.

Treatment combination*	Time(h) 1	3	6	9	12	15	18	21	24
9.0,0	100	100	100	100	100	100	100	90[a]	90
9.0,1	100	100	100	100	100	100	100	100	100
9.0,2	100	100	100	100	100	90	90	90	90
9.0,3	100	100	70	60	40	10	10	10	10
9.5,0	100	100	80	50	40	40	40	40	40
9.5,1	100	90	50	20	20	0	0	0	0
9.5,2	100	80	30	10	0	0	0	0	0
9.5,3	100	90	40	0	0	0	0	0	0
10.0,0	100	70	10	0	0	0	0	0	0
10.0,1	100	80	0	0	0	0	0	0	0
10.0,2	100	50	10	0	0	0	0	0	0
10.0,3	100	60	20	0	0	0	0	0	0
10.5,0	100	50	0	0	0	0	0	0	0
10.5,1	100	10	0	0	0	0	0	0	0
10.5,2	100	30	0	0	0	0	0	0	0
10.5,3	100	20	0	0	0	0	0	0	0
Control 1	100	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100	100

* pH,mg/L NH_3-N.
[a] Signifies one molt.

Table E-9. Percent survival for sub-adult freshwater shrimp at 4 combinations of pH and NH_3-N over 72 h, replication #3.

Treatment combination*	Time(h) 1	3	6	9	12	15	18	21	24
9.0,0	100	100	100	100	100	100	100	100	100
9.0,1	100	100	100	100	100	100	100	100	100
9.0,2	100	100	100	100	100	100	100	100	100
9.0,3	100	100	90	90	60	60	40	40	30
9.5,0	100	100	100	90	80	80	80	80	80
9.5,1	100	100	100	100[a]	90	80	80	80	70
9.5,2	100	100	100	70	60	50	50	40	20
9.5,3	100	100	100	60	20	0	0	0	0
10.0,0	100	100	70	30	30	20	10	10	10
10.0,1	100	100	60	10	0	0	0	0	0
10.0,2	100	100	60	20	10	10	10	0	0
10.0,3	100	100	40	20	0	0	0	0	0
10.5,0	100	100	10	0	0	0	0	0	0
10.5,1	100	100	50	0	0	0	0	0	0
10.5,2	100	70	20	0	0	0	0	0	0
10.5,3	100	100	20	0	0	0	0	0	0
Control 1	100	100	100	100	100	100	100	100	100
Control 2	100	100	100	100	100	100	100	100	100

* pH, mg/L NH_3-N.
[a] Signifies one molt.

Table F-1. Water quality parameters for pond A, [illegible] during [illegible] field [illegible]

Appendix F

Water quality parameters of field study ponds.

Table F-1. Water quality parameters for pond A27 of the freshwater shrimp toxicity field study, 6/25/87 to 7/26/87.

Date	Temp (°C)	pH	NH_3-N (mg/L)
6/25/87	31	9.2	0.12
6/26/87	30	9.3	0.07
6/27/87	29	9.3	0.10
6/28/87	30	9.1	0.09
6/29/87	31	9.6	0.11
6/30/87	29	9.2	0.08
7/01/87	29	9.2	0.07
7/02/87	30	9.5	0.10
7/03/87	30	9.7	0.10
7/04/87	29	9.6	0.11
7/05/87	29	9.2	0.06
7/06/87	31	9.3	0.07
7/07/87	30	9.5	0.08
7/08/87	30	8.6	0.06
7/09/87	31	9.3	0.07
7/10/87	31	9.5	0.05
7/11/87	30	9.7	0.03
7/12/87	32	9.6	0.04
7/13/87	29	9.0	0.02
7/14/87	28	9.1	0.02
7/15/87	28	9.3	0.02
7/16/87	30	9.4	0.02
7/17/87	31	9.4	0.02
7/18/87	31	9.6	0.04
7/19/87	30	8.6	0.01
7/20/87	28	9.0	0.02
7/21/87	28	9.5	0.03
7/22/87	28	9.1	0.02
7/23/87	28	9.2	0.02
7/24/87	31	9.1	0.03
7/25/87	31	9.6	0.04
7/26/87	30	9.2	0.02

Table F-2. Water quality parameters for pond A33 of the freshwater shrimp toxicity field study, 6/25/87 to 7/26/87.

Date	Temp (°C)	pH	NH_3-N (mg/L)
6/25/87	33	9.0	0.10
6/26/87	30	9.1	0.08
6/27/87	30	8.9	0.09
6/28/87	29	8.7	0.06
6/29/87	31	8.7	0.06
6/30/87	30	8.5	0.06
7/01/87	30	9.0	0.10
7/02/87	30	9.2	0.17
7/03/87	32	9.0	0.10
7/04/87	30	8.9	0.09
7/05/87	32	9.1	0.12
7/06/87	30	9.0	0.07
7/07/87	30	8.8	0.07
7/08/87	30	8.0	0.01
7/09/87	33	9.0	0.10
7/10/87	33	9.2	0.04
7/11/87	32	9.1	0.05
7/12/87	35	9.0	0.05
7/13/87	32	8.5	0.03**
7/14/87	30	8.5	0.03**
7/15/87	28	8.6	0.03**
7/16/87	29	8.2	0.02**
7/17/87	31	8.8	0.04*
7/18/87	31	8.6	0.03*
7/19/87	30	9.8	0.09*
7/20/87	29	8.5	0.02*
7/21/87	29	8.4	0.03**
7/22/87	27	8.4	0.02*
7/23/87	30	8.3	0.02*
7/24/87	31	8.8	0.03*
7/25/87	31	8.8	0.07*
7/26/87	30	8.8	0.04*

* Pond appeared slightly turbid resulting in slight cloudiness in the test.

** Pond appeared turbid resulting in cloudiness in the test.

Table F-3. Water quality parameters for pond A35 of the freshwater shrimp toxicity field study, 6/25/87 to 7/26/87.

Date	Temp (°C)	pH	NH_3-N (mg/L)
6/25/87	30	9.3	0.10
6/26/87	30	10.1	0.13
6/27/87	28	9.8	0.13
6/28/87	29	9.6	0.10
6/29/87	30	9.7	0.11
6/30/87	31	9.5	0.09
7/01/87	30	9.2	0.07
7/02/87	30	9.0	0.07
7/03/87	30	8.8	0.06
7/04/87	29	8.7	0.04
7/05/87	31	8.8	0.04
7/06/87	30	8.4	0.02
7/07/87	32	8.3	0.03
7/08/87	30	9.1	0.10
7/09/87	32	8.2	0.03
7/10/87	32	9.0	0.07
7/11/87	31	9.5	0.09
7/12/87	34	9.5	0.07
7/13/87	33	9.0	0.06
7/14/87	30	8.8	0.02
7/15/87	29	9.1	0.03
7/16/87	31	9.3	0.05
7/17/87	31	9.7	0.05
7/18/87	31	9.1	0.04*
7/19/87	30	9.3	0.04
7/20/87	30	9.0	0.03
7/21/87	29	8.7	0.02
7/22/87	28	8.6	0.02*
7/23/87	30	8.5	0.02*
7/24/87	32	8.9	0.06*
7/25/87	32	8.8	0.05*
7/26/87	30	9.0	0.04*

* Pond appeared slightly turbid resulting in some cloudiness in the test.

Table F-4. Water quality parameters for pond B31 of the freshwater shrimp toxicity field study, 6/25/87 to 7/26/87.

Date	Temp (°C)	pH	NH_3-N (mg/L)
6/25/87	30	9.8	0.16
6/26/87	30	9.9	0.09
6/27/87	27	9.9	0.13
6/28/87	28	10.2	0.12
6/29/87	30	10.3	0.12
6/30/87	29	10.3	0.12
7/01/87	30	9.7	0.10
7/02/87	28	9.8	0.01
7/03/87	28	9.7	0.10
7/04/87	28	9.8	0.11
7/05/87	29	9.5	0.07
7/06/87	30	8.9	0.04
7/07/87	30	8.6	0.02
7/08/87	31	8.2	0.03
7/09/87	32	7.6	0.00
7/10/87	31	7.8	0.00
7/11/87	31	7.9	0.00
7/12/87	32	8.7	0.01
7/13/87	32	9.3	0.02
7/14/87	31	9.6	0.06
7/15/87	27	9.6	0.04
7/16/87	28	9.4	0.02
7/17/87	28	9.3	0.02
7/18/87	28	9.5	0.02
7/19/87	29	9.9	0.03
7/20/87	29	9.9	0.04
7/21/87	27	9.8	0.02
7/22/87	28	9.4	0.06
7/23/87	28	9.4	0.04
7/24/87	29	9.4	0.03
7/25/87	29	9.6	0.03
7/26/87	30	9.4	0.02

Table F-5. Water quality parameters for pond B35 of the freshwater shrimp toxicity field study, 6/25/87 to 7/26/87.

Date	Temp (°C)	pH	NH_3-N (mg/L)
6/25/87	33	9.1	0.13
6/26/87	30	9.2	0.10
6/27/87	30	9.1	0.14
6/28/87	30	9.0	0.07
6/29/87	30	9.2	0.11
6/30/87	31	9.4	0.17
7/01/87	30	9.3	0.14
7/02/87	30	9.1	0.13
7/03/87	30	8.8	0.07
7/04/87	29	8.7	0.07
7/05/87	31	8.8	0.06
7/06/87	32	8.6	0.05
7/07/87	31	8.9	0.06
7/08/87	28	8.9	0.04
7/09/87	32	8.2	0.03
7/10/87	31	9.5	0.08*
7/11/87	30	8.5	0.02**
7/12/87	32	8.7	0.04**
7/13/87	33	8.4	0.02**
7/14/87	30	8.4	0.05**
7/15/87	28	8.7	0.06**
7/16/87	30	8.5	0.05**
7/17/87	31	8.5	0.06**
7/18/87	31	8.6	0.08**
7/19/87	29	8.5	0.06**
7/20/87	30	8.5	0.06**
7/21/87	28	8.4	0.05**
7/22/87	29	8.5	0.06**
7/23/87	29	8.3	0.04**
7/24/87	30	8.7	0.12**
7/25/87	30	8.7	0.12**
7/26/87	30	8.7	0.11**

* Pond appeared slightly turbid resulting in some cloudiness in the test.

** Pond appeared turbid resulting in cloudiness in the test.

Table F-6. Water quality parameters for pond B38 of the freshwater shrimp toxicity field study, 6/25/87 to 7/26/87.

Date	Temp (°C)	pH	NH_3-N (mg/L)
6/25/87	32	9.0	0.14
6/26/87	30	8.8	0.07
6/27/87	30	9.4	0.18
6/28/87	31	9.6	0.19
6/29/87	30	10.2	0.15
6/30/87	30	9.6	0.13
7/01/87	28	9.4	0.16
7/02/87	28	9.6	0.15
7/03/87	28	8.7	0.04
7/04/87	29	8.7	0.04
7/05/87	31	9.0	0.06
7/06/87	30	8.7	0.04
7/07/87	30	8.6	0.04
7/08/87	30	8.5	0.03
7/09/87	32	8.1	0.02
7/10/87	31	8.6	0.03
7/11/87	31	8.4	0.02
7/12/87	34	8.6	0.02
7/13/87	32	8.3	0.02
7/14/87	30	8.2	0.01
7/15/87	29	8.5	0.02
7/16/87	30	8.2	0.01
7/17/87	31	8.4	0.01
7/18/87	31	8.4	0.01
7/19/87	30	8.6	0.02
7/20/87	30	8.6	0.02
7/21/87	29	8.5	0.01
7/22/87	28	8.5	0.01
7/23/87	30	8.5	0.02
7/24/87	32	9.0	0.04
7/25/87	32	9.4	0.04
7/26/87	31	9.8	0.06