VULNERABILITY OF *TILAPIA ZILLII* FRY TO BLUEGILL PREDATION

by

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ABSTRACT

Tilapia zillii have been suggested as a biological control for profuse growths of aquatic plants occurring in recreational waters. The vulnerability of *T. zillii* fry, with and without biparental protection, to bluegill predation was tested in experimental ponds with either a high, medium or low density of cover. Results within each treatment were highly variable. The presence of bluegill predators significantly reduced fry survival, even at a high cover density. There were no differences in fry survival at the two relatively high bluegill densities tested. Fry survival with parental protection was significantly greater at the medium cover density (mean 68.17%) compared to the low density (mean 40.00%). Fry survival at the medium and high cover (mean 72.50%) densities were not significantly different. Survival of unprotected *T. zillii* fry after one day in the presence of a single bluegill was very low (mean 18.80%). With a predictive model, it is estimated that insufficient numbers of the first filial generation of *T. zillii* fry would survive to adequately control aquatic weeds, if sportfish are also present.

INTRODUCTION

Profuse growths of aquatic plants inhibit access for boating, fishing, and other aquatic recreation in shoreline areas of lakes and reservoirs. *Tilapia zillii*, an herbivorous fish, have been used as a biological control for *Chara vulgaris*, *Najas marina*, and *Potamogeton* spp. in some California and Arizona waters that are devoid of other fish species (Hauser and Legner, 1974, 1975, 1976; Rickel, 1975; Fitzpatrick, 1978; Saeed, 1979). However, no studies have been done to quantify the efficacy of *T. zillii* to control these aquatic plants in waters containing sportfish.

A sportfish of nearly ubiquitous distribution within North America is the bluegill sunfish (*Lepomis macrochirus*). They have been introduced in many of Arizona's reservoirs. Bluegill are lake margin dwellers and concentrate in waters 2.5 m or less in lightly weeded or open mixed vegetation types (Ziebell and McClain, 1977; Keast, 1978). When *T. zillii* and bluegill occur in the same body of water, they will both occupy the shallow areas of a reservoir near submerged vegetation.

Overpopulation and stunting of bluegill populations in closed systems are well known management problems. Stunted populations are usually predominated by large numbers of 7 to 10 cm bluegill (Applegate, Mullan, and Morais, 1966; Hackney, 1974). Bluegill are predacious on fish eggs and fry, and in the large numbers common in stunted populations, this predation has been shown to limit largemouth bass (Micropterus salmoides) reproduction (Swingle and Smith, 1943; Swingle, 1946; Applegate et al., 1966). Due to habitat overlap and numerical abundance, bluegill, more than any other species present, are likely to exert a high predation rate on T. zillii fry.

Flooded terrestrial vegetation and submerged aquatic plants have been shown to reduce predation on prey species by providing escape cover and cryptic retreats (Ball and Tait, 1952; Jackson, 1957; Bennett, 1962; Bross, 1967; Aggus and Elliott, 1975). Such cover could permit T. zillii to escape from predators. In addition, T. zillii exhibit a high degree of biparental care, protecting eggs and young from potential predators.

Attainment of T. zillii populations sufficient to control the nuisance aquatic vegetation in the presence of sportfish is dependent upon the survival of early life stages because the first filial (F_1) generation is primarily responsible for plant control. Therefore, fishery biologists need to predict the proper stocking density of adults, and the survival rate of the F_1 generation under different environmental conditions. Conditions under which predation by sportfish on T. zillii fry may occur can drastically alter the survival of the F_1 generation. This study sought to determine how the vulnerability of _T_. _zillii_ fry to predation is influenced by changes in predator and cover densities. The following hypotheses were tested:

1. Vulnerability of _T_. _zillii_ fry to predation by bluegills (7-10 cm) is inversely related to the density of cover.
2. Under the same cover density, the vulnerability of _T_. _zillii_ fry to predation by bluegills (7-10 cm) is proportional to the density of the bluegills.

MATERIALS AND METHODS

All experiments were conducted at the Arizona Cooperative Fishery Research Unit off-campus research facility between May and September, 1980. Tilapia zillii and bluegill were used in each test. The duration of all experiments was 72 h.

Circular ponds, 5.5 m in diameter, filled to a depth of 21 to 36 cm were used for predation experiments. In addition to T. zillii fry as potential food, the bluegill were fed pelleted catfish food, dispersed over the pond one time daily. Terrestrial insects landing in the ponds also contributed heavily at times to the diet of both the bluegill and T. zillii parents.

Cover was provided by artificial plants consisting of bundles of plastic strips, 1.5 cm wide and ranging between 45 and 90 cm in length. Percentage of cover was defined as the fraction of the total surface area of the pond containing artificial plants. Cover percentages of 25, 50, and 75 (75, 150, 225 individual plants per pond, respectively) were selected for replicate experiments (Figure 1).

Mature T. zillii were allowed to spawn in circular ponds, 1.8 m in diameter. In the morning, three days after the eggs hatched, a portion of the brood was siphoned from

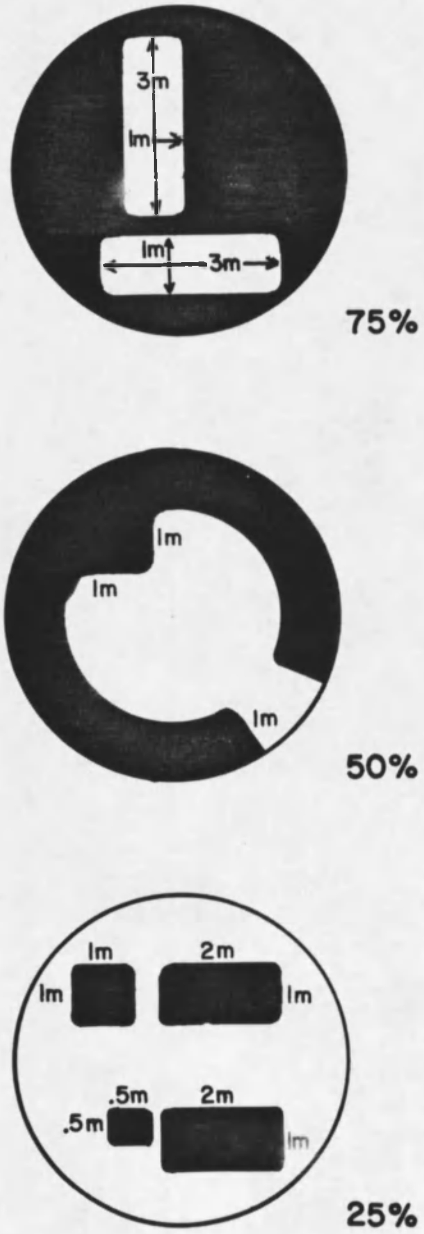

Figure 1. Configuration of cover (shaded area) at three densities (as percent of surface area) used in predation experiments

the pond and exactly 800 of these fry, and the T. zillii parents were transferred immediately to the experimental ponds.

To test the affect of bluegill density on the survival of T. zillii fry, bluegill were stocked at two densities, 15 and 20 per pond. Bluegill ranged from 6 to 11 cm in total length. Bluegill were introduced into the test ponds 0.5 to 1.5 h after sunset on the same day that T. zillii were introduced. Six replicates were run at each of the three cover densities, with half of the tests run at 15 and half at 20 bluegill per pond.

Three replicate tests were conducted to determine the mortality of T. zillii in a 3-d period (control). Tilapia zillii parents were transferred with 800 of their fry to an experimental pond containing no artificial cover or bluegill predators.

Visual observations were made during each experiment with regard to: (1) encounters between bluegill and T. zillii parents or fry, (2) mode of interaction between bluegill and T. zillii parents, and (3) distribution of fish within the pond. Observations were made for 10-min periods at least three times daily. At the termination of an experiment, the remaining fry were removed using a fine-meshed aquarium net and counted.

To determine the vulnerability of T. zillii fry after the termination of parental protection, experiments were conducted with fry at least two weeks old exposed to bluegill predators. These tests were performed over a 24-h period in a circular pond, 1.8 m in diameter, with cover set at 75% of the surface area. One hundred T. zillii fry were introduced into the pond and allowed to acclimate for 1 h prior to the introduction of a single bluegill. To rapidly terminate the experiments, the fish were killed with chlorine, insuring no further predation. The cover was removed, and all remaining fry were counted. Preliminary experiments under identical conditions but without bluegill were conducted to determine the efficiency of fry recovery.

The influence of cover and predator density on survival of T. zillii fry was tested statistically using a two-way ANOVA. Comparisons of mean survival rates were made with a Least Significant Range test. To test for a significant difference between the survival of the fry at 75% cover and when no cover or predators were present (control) a chi-square test of the data arranged in a 2 x 2 contingency table was computed. All statistical analyses were from Sokal and Rohlf (1969).

RESULTS

Fry survival was high (mean 92.00%) in the control experiments (Figure 2; Appendix A). The assumption was made that survival of *T. zillii* fry would remain constant at all cover densities in the absence of predators. No correction factor for "handling mortality" was applied to individual test results, even though it is realized that some unknown (but small) percentage of the observed mortality was not due to bluegill predation. All *T. zillii* fry not recovered were assumed to have been ingested by the bluegill.

The survival data were highly variable for all treatment combinations (Figure 2; Appendix A). Survival of *T. zillii* fry was higher at 20 bluegill per pond than at 15 per pond, but the difference was not statistically significant ($p > .10$) (Figure 2; Appendix B). Consequently, to estimate a mean survival rate for the fry all six replicates were used at each cover density. Fry survival was significantly different ($p < .05$) across cover density (Appendix B).

Fry survival was highest at 75% cover (mean 72.50%) and lowest at 25% cover (mean 40.00%) (Table 1). The survival rates of the fry between 50 (mean 68.17%) and 25% (mean 40.00%) cover densities were significantly different ($p < .05$). Similar analysis indicated no significant

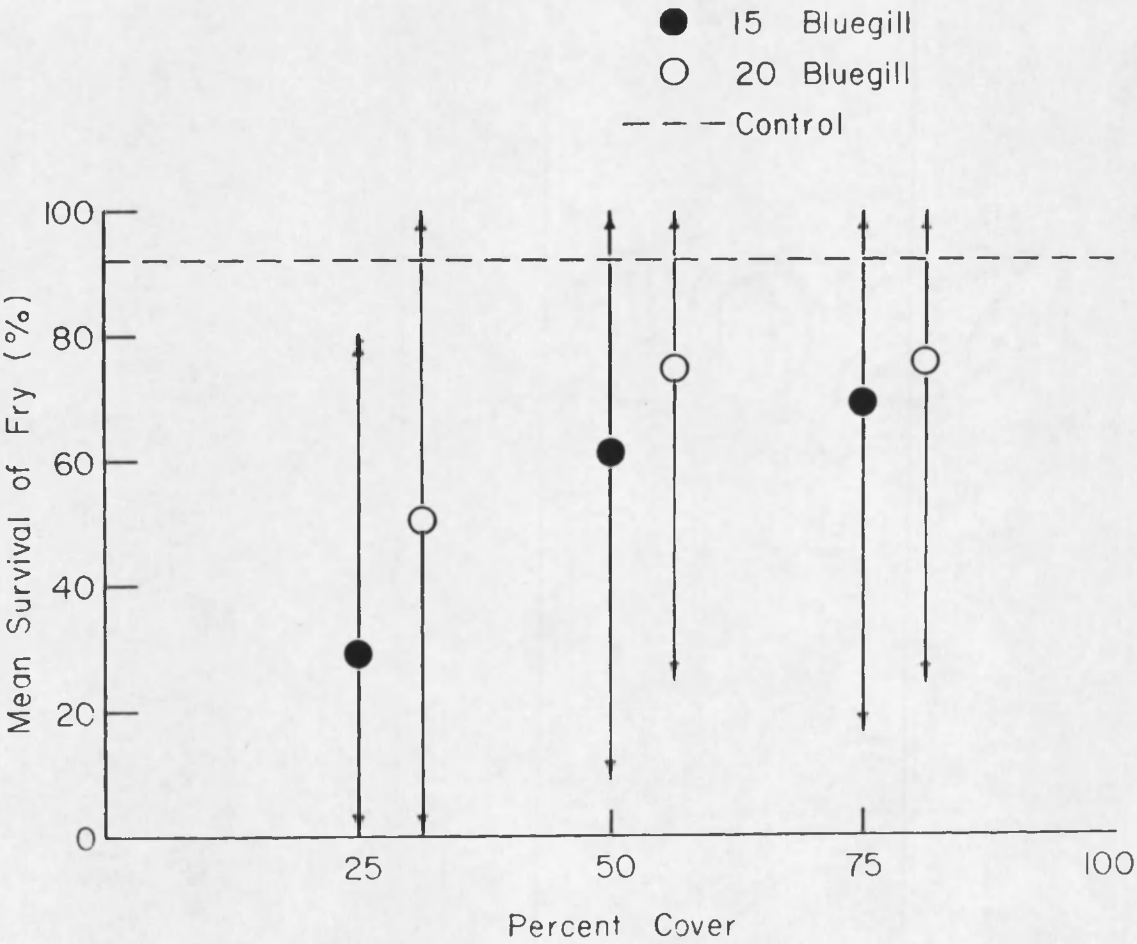

Figure 2. Mean survival (%) of T. zillii fry under two bluegill and three cover densities with 95% confidence intervals truncated at 0 and 100%. -- Variance is MSE from ANOVA.

Table 1. Mean survival (%) of T. zillii at two bluegill and three cover densities

Bluegill Density	Percent Cover 25	50	75
15			
$\bar{X}$	29.33	61.00	69.00
20			
$\bar{X}$	50.67	75.33	76.00
Grand Mean ($\bar{X}$)	40.00	68.17	72.50

difference ($p > .05$) between the survival rates at 50 and 75% (mean 72.50%) cover. Survival of T. zillii fry in the control was significantly greater than in 75% cover ($p < .001$).

Preliminary recovery experiments using 100 unprotected fry produced a mean recovery rate of 100% for three control replicates (no bluegill). Fry survival after one day in the presence of a single bluegill were 6, 8, 16, 30, and 34%. Apparently, individual bluegill consumed fry at different rates.

DISCUSSION

The vulnerability of T. *zillii* fry to bluegill predation was dependent on the amount of cover available, but was not appreciably different at the two densities of bluegill tested. Interspecific interactions between bluegill and T. *zillii* which may impact the potential for weed control can be identified from my experiments.

Affect of Bluegill Density

Test conditions of 15 and 20 bluegill per pond represent population densities of 2,568 and 3,424 per acre, respectively. Bennett (1962) stated that small bluegill severely limited population growth of largemouth bass through predation on eggs and young, after bluegill populations reached 1,000 per acre. The bluegill populations I tested were sufficiently high to produce this same effect, and do approximate population estimates made in closed systems (Applegate et al., 1966; Hackney, 1978). I predicted the vulnerability of T. *zillii* fry to bluegill predation would be proportional to the predator density; however, this was not shown by the two densities tested. The inability to identify a significant difference in survival of the fry at the two predator densities may have been the result of the degree of variability in the data and the small number of replicate experiments. However, the difference in density between the two bluegill populations tested may not be very different biologically. For example, it may be possible that predation does increase with increasing bluegill density, but at some population density intraspecific and interspecific interactions occur which limit the predatory effect. The amount of terrestrial insect input, an uncontrolled food source, may also have buffered predation on fry in some tests. Different thresholds of hunger for individual bluegill may also have contributed to the high variability in the data (Figure 2). Any of the variables discussed above probably influenced the predation rate in individual replicates. In a biological system, such as the one I tested, where individual differences in behavior are difficult to control, large variability in the data could be expected. Further tests need to be conducted before the importance of any of these variables may be determined.

Affect of Cover

Plant density may vary from 0-100% in different areas of a natural pond at any given time. My data indicate that as cover density increased, fry survival increased (Table 1; Figure 2). Bluegill preferred the areas of the pond containing cover, spending little time in the open areas. The *T. zillii* preferred the open areas of the experimental ponds. *Tilapia zillii* fry feed on zooplankton (Pelzman, 1973) which is most abundant in open water. Thus, the *T. zillii* parents take their fry to an open area to search for zooplankton.

Fitzpatrick (1978) observed that bluegill and bass attacked schools of *T. zillii* fry. While the parents were distracted by some of the predators, other predators were successful in attacking the school of fry. Visual observations during my experiments do not agree with those of Fitzpatrick (1978). I observed only one successful attack on a fry school by a bluegill at each of the three plant densities. Bluegill were generally successful in feeding on single *T. zillii* fry, when the attack followed a chance encounter with the fry, and when the encounter was a complete surprise to the parents. Observations of successful bluegill encounters revealed a regular pattern of events. A bluegill would move from the cover into the open area occupied by the *T. zillii*. If the bluegill was within its reactive distance to the fry, while both *T. zillii* parents were turned at the wrong angle to see the bluegill, then a successful attack was likely. A bluegill would only ingest a few fry before the parents chased it back into the cover. Considering the high degree of parental care *T. zillii* provide, only such surprise encounters of bluegill with the fry could be successful.

The reactive distance of T. zillii parents to a bluegill approaching from across an open area has to be greater than the bluegill's reactive distance to a potential prey. I observed many encounters between parental T. zillii and up to eight bluegill which approached from across an open area. These groups of bluegill were always repulsed by the parents with no mortality to the fry. These observations substantiate that only a surprise encounter with fry rather than a systematic group approach would be successful for the bluegill.

With this understanding of predatory encounters, the survival data under different cover densities can be explained. The significant difference in survival rates between low and high cover densities was a product of the (1) configuration of the plant cover in the test ponds (Figure 1), (2) proximity of bluegill to the edge of the cover, (3) movement of T. zillii in the open areas, and (4) probability of a chance encounter between bluegill and T. zillii fry.

With 25% cover, the preferred habitat of bluegill was limited when compared to the other two test conditions. Those bluegill which remained in open water were not successful in preying on fry, and virtually all bluegill within cover areas were relatively close to the cover/open water interface. Tilapia zillii frequently moved about the pond often passing close to cover patches in the low cover tests.

Thus, the probability of a chance encounter between those bluegill remaining in the cover and T. zillii fry at the cover/open water interface becomes very high.

The amount of open water area available for T. zillii to search for zooplankton is much less at 50 and 75% cover than at 25%. Therefore, the T. zillii remained almost stationary within the restricted open water areas under both of the higher cover densities. The probability of a successful predatory attack depends on the bluegill encountering the open area in a search for food, and on the fry being present within the reactive distance of the bluegill at the edge of the cover. At 50 and 75% cover, there were fewer bluegill close to the cover/open water interface because the bluegill had the potential to be farther from open areas. Tilapia zillii movements past these areas were reduced and, therefore, random encounters with bluegill at the cover/open water interface were lower than at 25% cover.

A significant difference was demonstrated in the survival rate of the fry between 25 and 50, but not between 50 and 75% cover. This suggests that the greatest increases in survival associated with increased cover occurred at cover densities between 0 and 50% (Figure 2). Little or no increase in survival occurred with additional cover beyond the 50% level. The probability of predation occurring was still quite high, even under abundant cover (75%) compared to the significantly greater survival achieved in the control experiments.

Management Implications

A concern of many fishery biologists is that *T. zillii* will eliminate too much of the protective cover of young gamefish and compete with sportfish for the same food resources (Legner and Medved, 1973; Pelzman, 1973). Also, *T. zillii* may compete for the same nesting sites used by centrarchids and even inhibit their reproduction (Buntz and Manooch, 1968; Noble, Germany, and Hall, 1975).

In the spring when mature *T. zillii* are usually stocked, the submerged aquatic plants are just starting to grow. Plant control is dependent on the high rates of plant consumption by the F_1 generation produced by the mature *T. zillii*. This generation must survive for *T. zillii* to be an effective biological control agent under the present stocking program. All of these concerns can be addressed with my data.

Using the mean survival rate at 75% cover (optimal survival conditions) as a predictive model and extending it to nine days, only 44% (Figure 3, line A) of the *T. zillii* fry would survive. This model assumes that the parents are not more efficient in protecting their young as fry mortality occurs and that no predatory loss occurs from egg to three days post hatch. After approximately 10 days,

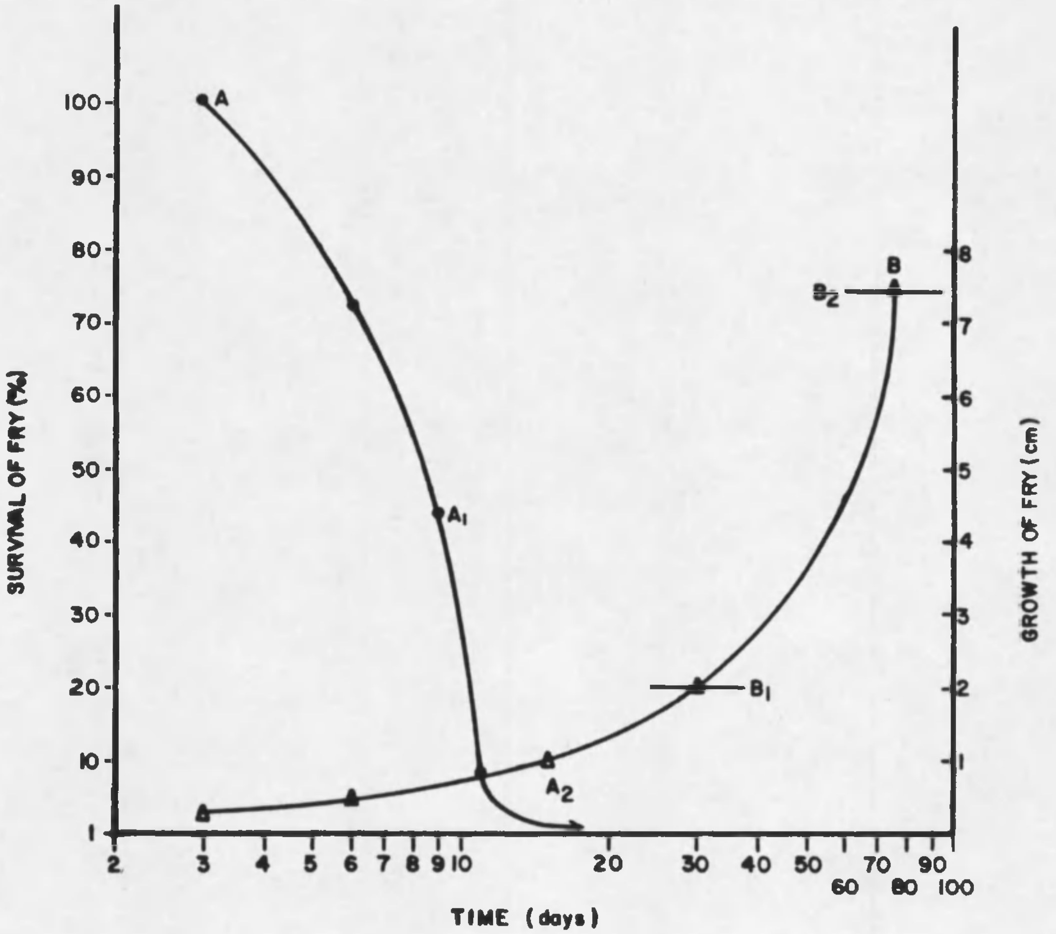

Figure 3. Predictive model for survival under optimal treatment conditions and growth of _T. zillii_ fry. -- A. survival curve; A_1. _T. zillii_ parents leave; A_2. near 100% mortality of fry; B. growth curve; B_1. "invulnerable" size of fry; B_2. effective size of _T. zillii_ for consuming plants.

the *T. zillii* parents leave their young (Figure 3, point A_1). The fry survival decreases to only 8% within one day after losing parental protection according to my tests. A growth curve was approximated from Rickel's (1975) data for *T. zillii*. The growth curve is plotted (Figure 3, line B) with the survival curve. Assuming that bluegill may consume *T. zillii* fry up to 2 cm in size (Figure 2, point B_1), the fry require about 30 days to reach an "invulnerable" size. *Tilapia zillii* do not reach the size at which they consume plants most efficiently (7.5 cm) until about 75 days old (Figure 3, point B_2). According to the survival curve I have projected, nearly 100% mortality of *T. zillii* fry would occur before they are 15 days old (Figure 3, point A_2). Little or no plant control could result since sufficient numbers of the F_1 generation never reach an appropriate size.

Tilapia zillii have controlled aquatic weeds in ponds where their density can become very high because no other fish species occur there. If *T. zillii* are introduced in ponds containing predatory fish, they are in a more natural situation to that which occurs in their native habitat, and predation on young will limit population growth. Larger numbers of *T. zillii* adults could be stocked to compensate for predation. Also, *T. zillii* 7.5 cm in length (large enough to eat plants) could be stocked and not depend on the F_1 generation. However, either of these stocking programs probably would not be economically feasible. Should it become feasible, then the adults and fry may potentially compete with sportfish for food resources or spawning habitat.

Only bluegill predators were used in my tests, but if other centrarchids such as the largemouth bass were also present, the survival of the *T. zillii* fry may be even lower. From stomach analyses, Hauser and Legner (1975) reported that largemouth bass over 15 cm preyed heavily on *T. zillii*. They were vulnerable to bass predation even at 7.5 cm, the size recommended at which to stock mature *T. zillii*. Therefore, no plant control is likely to be realized by stocking the exotic *T. zillii* in ponds, lakes, or reservoirs where sportfish are present.

APPENDIX A

PERCENT SURVIVAL OF *T. ZILLII* FRY AT TWO BLUEGILL AND THREE COVER DENSITIES

Bluegill Density	Percent Cover			
	25	50	75	Control[a]
	25	43	50	80
15	29	57	73	98
	34	83	84	98
	29	51	51	
20	39	87	84	
	84	88	93	

a. Test condition - no cover, no bluegill

APPENDIX B

RESULTS OF TWO-WAY ANALYSIS OF VARIANCE FOR *T. ZILLII* FRY AT TWO BLUEGILL AND THREE COVER DENSITIES

Source	df	MS	p value
Bluegill Density	1	910.22	$p > .10$
Cover Density	2	1,869.39	$p < .05$
Interaction	2	77.06	$p > .50$
Error	12	420.83	

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