Snail Control Project

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Executive Summary

Digenetic trematodes ("grubs") are a significant problem in aquaculture ponds; small fish infested with trematodes are subject to high mortality rates, while larger fish feed poorly and are often unmarketable due to the presence of encysted grubs. Two common aquaculture pond snails, *Helisoma triviolis* and *Physa* spp. are intermediate hosts for grubs; currently, the only control method for trematodes is to severely reduce or eliminate snails from aquaculture ponds. Chemical control of pond snails is expensive and subject to many additional limitations. Non-native black carp *Mylopharyngodon pisceus* have strong potential for biological control of snails; however, this species poses a significant ecological risk to native bivalves in the U.S. and has been listed as an injurious species under the Lacey Act. Thus, native molluscivorous fishes, such as redear sunfish *Lepomis microlophus* and redear x green sunfish hybrids, represent a more desirable alternative for controlling snails. Some native molluscivorous fishes, such as river redhorse *Moxostoma carinatum* and white sucker *Catostomus commersoni* remain unevaluated as potential snail control agents. Additionally, stocking density of native molluscivores is a potentially important variable influencing the effectiveness of biological control of aquaculture pond snails that has not been thoroughly assessed. The objectives of this study were to evaluate the effectiveness of two densities of redear sunfish and redear x green sunfish hybrids for reducing abundance of *Physa* and *Helisoma* in ponds and to perform a preliminary laboratory assessment of the potential for river redhorse and white sucker to consume and control *Physa* and *Helisoma*. Snail densities (number/m^2) in ponds stocked with either 250 or 500 redear sunfish/ha declined each month during the study; snail densities increased in control ponds and ponds stocked

with 500 redear x green sunfish hybrids/ha during the first three months of the pond trials before declining in the final month of the study. Mean size of snails was smaller in ponds stocked with redear sunfish than in control ponds or ponds stocked with redear x green sunfish hybrids, suggesting that redear sunfish were more effective at limiting snail recruitment to relatively large sizes (>8 mm shell length) than hybrid sunfish. Fish stocking rate did not significantly affect snail density in ponds, suggesting that stocking >250 fish/ha may provide little additional benefit. While the results of this study and prior studies indicate that redear sunfish can potentially reduce snail abundance in ponds, it is unclear to what extent snail densities must be reduced to significantly decrease or eliminate grub infestations in cultured fishes. An integrated pest management approach for controlling aquaculture pond snails (including chemical treatment and redear sunfish stocking) is being evaluated at SIUC and likely holds the most promise as an alternative to black carp for control of *Physa* and *Helisoma* abundance. White suckers and river redhorse consumed < 50% of snails offered in laboratory trials, suggesting that these species are insufficiently voracious as snail predators compared to redear sunfish and redear x green sunfish hybrids to be considered further as potential biological control agents for pond snails.

Introduction

Infestation of fish with digenetic trematodes, commonly referred to as grubs, is a common problem in aquaculture ponds in the U.S. Digenetic trematodes frequently found in aquaculture ponds include black grub (*Uvulifer ambloplitis*), yellow grub (*Clinostomum complanatum*), white grub (*Posthodiplostomum minimum*), and eye fluke (*Diplostomum spathaceum*) (Lane and Morris 2000; Venable et al 2000). Recent observations confirm that two exotic trematode species are expanding their distributions across North America and are having a serious impact on aquaculture production. The trematode *Bolbophorus confusus* has inflicted considerable economic damage on the Southern U.S. catfish industry (Avery et al 1999; Wui et al 2007). *C. complanatum* and *B. confusus* infestations have been shown to cause massive kidney tissue damage and liver tissue destruction in fish (Terhune et al. 2003). Small fish afflicted with severe trematode infestations are subject to high mortality rates. Larger fish are less subject to trematode-induced mortality, as *B. confusus* and yellow grub are generally limited to the fins and skin in larger fish. However, large, severely infested fish appear emaciated and feed poorly. Cultured food fish are also often rendered unmarketable due to presence of encysted grubs (Lane and Morris 2000).

Digenetic trematode life cycles include two intermediate hosts and a final host. Rams-horn snails, *Helisoma triviolis*, pouch snails *Physa* spp., and fish are common intermediate hosts for digenetic trematodes, while many bird species serve as the final host. Adult flukes live in the throat of a fish eating bird, releasing eggs into the digestive tract, which pass within the excrement. Eggs enter the water column and larval trematodes hatch. Larval trematodes then enter a free swimming stage called a mericidium. Mericidia must enter a host snail a few hours post hatch or they die. Once the mericidia penetrate the host snail, they enter into the digestive gland or gonadal tissue of the snail host and produce sporocysts. The sporocyst produces rediae that migrate about the digestive gland and develop into the cercarial stage of the grub. The cercaria exits the snail through the mantle cavity looking for a host fish. Ten to 100 cercaria can be released from one snail per day (Terhune et al. 2002; Tucker 2004). Cercariae then infest the skin or flesh of the fish, forming a thick walled cyst or "grub". The encysted grub is freed when a bird swallows an infested fish, thus completing the trematode's life cycle (Terhune 2003).

Currently, there is no FDA approved control treatment for severe trematode infestation in fish. In order to prevent trematode infestations, it is necessary to disrupt the trematode life cycle at one or more stages. This may be accomplished by denying birds access to ponds or by denying miracidia access to snails (Ledford and Kelly 2006; Lorio 1989). Many piscivorous birds are protected under the Migratory Bird Species Act and restricting bird access to aquaculture ponds has proven difficult. Therefore, the only viable approach to preventing trematode infestations in fish is reduction or elimination of snail populations in aquaculture ponds.

Currently, hydrated lime, copper sulfate, and Bayluscide^{TM} (Niclosamide), a commercial molluscicide, are used to rid ponds of gastropods. However, the U.S. Food and Drug Administration (FDA) has not approved the use of Bayluscide^{TM} in ponds containing fish destined for human consumption. Hydrated lime and copper sulfate reduce snail populations within the treated zone (typically around pond margins), but do not eradicate the entire population; consequently, repeated chemical treatments are needed (Terhune et. al 2003). The effectiveness of copper sulfate for reducing snail densities is temperature dependent and its toxicity to fish is a function of a complex combination of proper pH, total alkalinity, and total hardness of the water. Copper sulfate concentrations needed to facilitate elimination or severe reductions of a snail population would be lethal to fish when applied to treat the entire pond (Post 1987; Slootweg 1995; Francis-Floyd et al. 1997). When used correctly, some snails may avoid the treatment by burrowing into the pond bottom (Mitchell 2002). Copper sulfate is also currently classified as an algicide and is not approved by the FDA as a foodfish parasiticide. Hydrated lime slurry is similar in effectiveness to copper sulfate, but can alter the pH of pond water, especially if the water is poorly buffered. Like copper sulfate, snails can avoid hydrated lime treatments by burrowing into pond sediments (Mitchell and Snyder 2007). Chemical treatments are also expensive, costing as much as $200 to $750 to treat a six-hectare pond (Ledford and Kelly 2006). Subsequent to chemical treatments, one or more biological control agents must also be utilized for long-term control of gastropod abundance.

Another snail reduction strategy is the introduction of natural snail predators into aquaculture ponds. Many different molluscivorous fishes have been tested with varying degrees of success. These include black carp (*Mylopharyngodon piceus*; Ledford and Kelly 2006; Venable et al 2000), redear sunfish (*Lepomis microlophus*; Wang et al 2003; Ledford and Kelly 2006), blue catfish (*Ictalurus furcatus*; Ledford and Kelly 2006), African cichlids (*Serranochromis* spp.), sheepshead (*Aplodinotus grunniens*), East African catfish (*Clarias gariepinus*), and eastern mudminnow (*Umbra pygmaea*; Slootweg et al 1994). Recent studies and commercial use of black carp have found this species to have one of the highest potentials for biological control of snails (Ledford and Kelly 2006; Venable et al 2000; Wui and Engle 2007). However, black carp are not native to North America, and much concern has been raised about their use in aquaculture. Sterile triploid carp are normally recommended for snail control, but in 1999 fertile black carp were permitted for use in Mississippi to control a *Bolbophorus* outbreak. If fertile diploid black carp were to escape captivity, they could pose a serious ecological threat to the native mussels of the Mississippi River basin (Naylor et al 2001). Because of the high ecological risk associated with the commercial use of black carp, they have been listed as an injurious species under the Lacey Act. Thus, native molluscivorous fishes would represent a more desirable alternative for controlling aquaculture pond snails.

Several native fishes have been evaluated as alternatives to black carp for control of pond gastropod populations. The redear sunfish (*Lepomis microlophus*) is a native centrarchid with a well documented ability to consume snails (Carothers and Allison 1968). Ledford and Kelly (2006) found that redear sunfish are less effective than black carp at consuming a broad range of snail sizes under laboratory conditions, but more effective than blue catfish (*Ictalurus furcatus*). Wang et al. (2003) found that large redear sunfish (24-cm total length) do not consume the largest 30-40% of *Helisoma* commonly found in ponds. Snail size is an important consumption constraint for redear sunfish, as many adult *Helisoma* have shell diameters in excess of adult redear sunfish mouth gapes. Redear × green sunfish hybrids have also been assessed as potential biological control agents for pond snails given their larger mouth gape compared to redear sunfish. In laboratory studies, redear × green sunfish hybrids consumed similar sizes and numbers of snails as redear sunfish in *ad libitum* snail consumption trials (Bajer and Hayward 2005; Whitledge, unpublished data). Other native molluscivorous fish species, such as river redhorse *Moxostoma carinatum* and white sucker *Catostomus commersoni* have not been evaluated as potential biological control agents for snails in either laboratory or pond settings.

Stocking density of native molluscivorous fish is a potentially important variable influencing the effectiveness of biological control of aquaculture pond snails that has not been thoroughly evaluated. A stocking density of 10.1 redear sunfish/ha is recommended by the National Warmwater Aquaculture Center; however, stocking at this density has never been demonstrated to eradicate or nearly eliminate snails from aquaculture ponds. Koppelman (2007) stocked redear sunfish and redear x green sunfish hybrids into six, 0.2 ha ponds at a density of 133.5 fish/ha; fish stocked at this density significantly reduced snail abundance during June through October 2006 but did not completely eliminate snails from ponds. Whether higher stocking densities of redear sunfish or redear x green sunfish hybrids would more severely reduce or eradicate snails from ponds is unknown.

The objectives of this study were to: 1) Evaluate the effectiveness of two densities (250 fish/ha and 500 fish/ha) of redear sunfish and redear x green sunfish hybrids for reducing abundance of *Physa* and *Helisoma* in ponds and 2) Perform a preliminary assessment of the potential for river redhorse (*Moxostoma carinatum*) and white sucker (*Catostomus commersoni*) to control *Physa* and *Helisoma* in ponds by conducting laboratory trials to determine snail consumption rates, size and species preferences, and maximum handling sizes for both of these fish species; data for this objective were compared with results from similar laboratory studies involving other molluscivorous fishes (Wang et al. 2003; Ledford and Kelly 2006).

Methods

Pond Trials – Redear and Redear x Green Sunfish at Two Densities

Redear sunfish and redear x green sunfish hybrids were stocked into 0.04 ha ponds at two densities to assess their effectiveness for controlling *Physa* and *Helisoma*. Twelve ponds at SIUC's pond research facility were drained during early April 2008 to eliminate any pre-existing fish. Ponds were refilled with water within one week of draining; additional water was added to ponds as needed during 2008 to maintain water levels at or near full pool. Pond socks were used during pond filling to avoid biological contamination. All ponds were fertilized with partially ground fish food to initiate a phytoplankton bloom and provide nutrition for snail populations. Each pond initially received 11.34 kg of fertilizer and an additional 2.72-3.63 kg of fertilizer per week for a minimum of one month to stimulate snail production. Low snail densities were observed in ponds during spring 2008, so additional snails were obtained from commercial fish farm ponds in southern Illinois and stocked into experimental ponds at SIUC to supplement pre-existing snail populations. Each pond was stocked with two triploid grass carp (*Ctenopharyngodon idella*) to limit macrophyte abundance; aquatic vegetation was also periodically removed manually with pond rakes.

Immediately prior to stocking of sunfishes in mid-July, each pond was sampled to estimate snail density. Three locations were randomly chosen from the littoral zone (within 1 m of shore) of each pond and one square meter of pond bottom was sampled per location. A 1-m^2 frame constructed from PVC pipe was placed in the water at each sampling location to standardize the area of pond bottom that was sampled. A D-frame dip net (30.46 cm wide) was used to collect snails from the pond bottom and any aquatic vegetation within the sample area. Vegetation was visually examined for snails. A Ponar dredge (0.02 m^2) was used to collect benthic sediment samples in six offshore (> 1 m from the shoreline) locations in each pond. Pond sediments collected with dip net and dredge samples were sorted through sieves to obtain snails. All snails collected in each of the littoral and pelagic samples from each pond were counted, measured (shell length, mm) and weighed. Mean snail densities (number/m^2) for littoral and pelagic zones of each pond were calculated and used to estimate the mean overall density of snails in each pond based on a weighted average of the area encompassed by littoral and pelagic zones within ponds. Each pond was subsequently sampled once per month through October 2008 to estimate snail density using the methods described above.

Stocking of redear sunfish and redear x green sunfish hybrids was conducted in mid-July 2008. Fish were originally intended to have been stocked into ponds during mid-May, but snail densities were very low during spring and early summer, so stocking was intentionally delayed to allow more time for snail populations to expand and to collect snails from other ponds to supplement the existing populations. Three of the twelve ponds were randomly selected for stocking with hybrid sunfish (12.7-17.8 cm total length) at a rate of 500 fish/ha, three ponds were chosen for stocking with redear sunfish (15.2-22.9 cm total length) at a rate of 500 fish/ha, and three ponds were stocked with redear sunfish (15.0-22.5 cm total length) at a rate of 250 fish/ha. Three ponds contained no sunfish and served as controls.

Kruskal-Wallis nonparametric analysis of variance was used to assess differences in snail densities among the four treatments (control, 250 redear sunfish/ha, 500 redear sunfish/ha, and 500 redear x green sunfish/ha) during each month of the pond study (July, August, September, and October).

Laboratory Snail Consumption Trials – River Redhorse and White Sucker

Laboratory trials were conducted during late fall 2007 to evaluate the potential of river redhorse (*Moxostoma carinatum*) and white sucker (*Catostomus commersoni*) to serve as biological control agents for *Physa* and *Helisoma*. River redhorse (25-30 cm total length) were obtained from the lower Meramec River, MO by boat electrofishing. White suckers (15-20 cm total length) were obtained from Logan Hollow Fish Farm, Gorham, IL; these fish originated from a commercial fish farm in North Dakota and were transported to Logan Hollow Fish Farm during the week prior to their transfer to SIUC. Fish were transported to SIUC in a live haul truck equipped with oxygen cylinders and aerators to maintain dissolved oxygen concentrations of at least 6-7 ppm. Fish were acclimated to laboratory conditions (water temperature 22° C ± 1°C, 14 h light:12 h dark photoperiod) over a period of 3-4 weeks. Each species was held in groups in 1000-L tanks and fed earthworms to satiation once daily during acclimation to the laboratory environment. Laboratory snail consumption trials followed methods developed by Ledford and Kelly (2006) and Wang et al. (2003). Ten fish of each species were placed individually into 37.8-L aquaria, not fed for 24 h, and then exposed to known sizes and numbers of *Physa* and *Helisoma* for 48 h; snail sizes represented the full size range commonly found in aquaculture ponds (3-12 mm for *Physa* and 3-18 mm for *Helisoma*).

One *Physa* and one *Helisoma* per 1-mm length group was provided to each fish. Uneaten snails were counted and measured at the end of the trials to identify sizes and numbers of snails that were consumed by each fish. Fish species that consumed $\geq$ 50% of snails in the first set of laboratory trials were to have been used in a subsequent trial to determine maximum daily consumption rates when feeding on *Physa* and *Helisoma*. However, neither species consumed at least half of the snails presented in the initial laboratory trials.

A relationship between mouth gape (mm) and total length (mm) was developed for white suckers from SIUC's Ichthyology Collection to determine the maximum size of snails that could potentially be consumed by white suckers of a given length. Least-squares linear regression was used to characterize the relationship between mouth gape and total length for this species.

Results

Pond Trials

Snail densities (number/m^2) in ponds stocked with either 250 or 500 redear sunfish/ha declined each month from July through October 2008 (Figure 1); snail densities increased in control ponds and ponds stocked with 500 redear x green sunfish hybrids/ha from July through September before declining during October. However, no significant differences in mean snail densities were detected among the four treatments (control, 250 redear/ha, 500 redear/ha, 500 hybrids/ha) during any of the four months of the pond study ($p>0.05$). Snail densities were highly variable among individual ponds within treatments throughout the course of the pond trials.

Snails ranging from 2-16 mm shell length were present in ponds at the time of fish stocking (Figure 2). Most snails were between 3 and 7 mm shell length; mean snail shell lengths in the four treatments ranged from 4.9-6.1 mm during July. This distribution of snail sizes persisted in ponds representing all treatments during August 2008 (Figure 3); mean snail shell lengths in the four treatments ranged from 5.2-6.3 mm during August. However, very few snails > 7 mm shell length were present in ponds stocked with redear sunfish at either 250 or 500 fish/ha during September or October 2008, whereas a broad range of snail sizes, including individuals ≥ 8 mm shell length, were relatively abundant in control ponds and ponds stocked with redear x green sunfish hybrids during September and October (Figures 4 and 5). Mean snail shell lengths ranged from 4.0-5.9 mm in the two redear sunfish treatments during September and October, while mean snail shell lengths in the control ponds were 9.4 mm and 11.3 mm during September and October, respectively. Mean snail shell lengths in ponds stocked with redear x green sunfish hybrids were 8.2 mm during September and 11.6 mm during October.

Laboratory Snail Consumption Trials

River redhorse consumed an average of 51% of *Physa* offered (± 6% SE) but consumed only 7% of the *Helisoma* offered (± 1% SE) on average. Mean shell length of the largest snail consumed by individual river redhorse was 7.8 mm (± 0.5 mm SE). White suckers consumed < 5% of *Physa* offered and did not consume any *Helisoma*. Maximum shell length of *Physa* consumed by white suckers was 7 mm. Additional laboratory trials to determine maximum daily snail consumption rates for river redhorse and white sucker were not conducted due to the low consumption rates observed in these initial trials. A significant linear relationship was observed between white sucker mouth gape and fish total length ($p<0.0001$; Figure 6).

Discussion

Pond Trials

Redear sunfish appeared to provide better control of pond snails than hybrid sunfish, although no significant differences in mean snail densities were detected between ponds stocked with redear sunfish and those stocked with hybrid sunfish. Redear x green sunfish hybrids were ineffective at reducing mean snail densities in ponds over time even at a relatively high stocking density (500 fish/ha) despite the relatively low initial snail densities in ponds. Mean shell length of snails in control ponds and ponds stocked with hybrid sunfish increased during the study, indicating that hybrid sunfish were ineffective at sufficiently reducing snail abundance to limit snail recruitment to relatively large sizes (≥ 8 mm shell length). Limiting snail recruitment to relatively large sizes is important given that snail fecundity increases with body size. Consumption of alternative prey items by hybrid sunfish may partially explain why snail densities did not decrease in ponds stocked with hybrids, although fish stomach contents were not examined during this study. Koppelman (2007) found that redear x green sunfish hybrids consumed a variety of prey items in ponds, whereas redear sunfish fed exclusively on snails.

Fish stocking density did not significantly affect snail density in ponds at the two fish densities tested (250 fish/ha and 500 fish/ha). Stocking rates used in this study were higher than those used in prior research and most commercial aquaculture applications.

Koppelman (2007) stocked redear sunfish and redear x green sunfish hybrids at a rate of 133.5 fish/ha based on stocking rates for sunfish for sport fishing in northern Missouri ponds. A stocking density of 10.1 redear sunfish/ha is recommended by the National Warmwater Aquaculture Center; however, stocking at this density has never been demonstrated to eradicate or nearly eliminate snails from aquaculture ponds. Based on equations given in Wang et al. (2003), 19-cm redear sunfish stocked at a rate of 125 fish/ha would theoretically be capable of eliminating all snails from the ponds used in this study within one week if fish fed exclusively on snails at maximum daily rates observed in laboratory trials. Despite the relatively high fish stocking densities used in this study and the relatively low densities of snails initially present in ponds, redear sunfish did not eradicate snail populations. However, mean snail densities declined within redear sunfish treatment ponds over time and abundance of larger snails (>8 mm shell length) did not increase in redear sunfish ponds as it did in control or hybrid sunfish ponds. These results suggest that redear sunfish, unlike the redear x green sunfish hybrids, provided some control of pond snail populations and effectively limited recruitment of snails to larger sizes (≥ 8 mm shell length). Koppelman (2007) found that redear sunfish stocked at a rate of 133.5 fish/ha significantly reduced snail abundance during June through October 2006 compared to fishless ponds, but did not completely eliminate snails from ponds. Thus, stocking redear sunfish at the relatively high densities tested in the present study does not appear to provide any additional capacity for reduction of snail densities in ponds beyond those observed at stocking rates of 125-150 fish/ha.

While the results of this study and prior studies (e.g., Koppelman 2007) indicate that redear sunfish can potentially reduce snail abundance in ponds, it is unclear to what extent snail densities must be reduced to significantly decrease or eliminate grub infestations in cultured fishes. Further research should address this important question. To date, neither biological nor chemical control methods alone have proven sufficient to eradicate pond snail populations. An integrated pest management approach for controlling aquaculture pond snails (including chemical treatment and redear sunfish stocking) is being evaluated at SIUC as part of a NCRAC-funded study and likely holds the most promise as an alternative to black carp for control of *Physa* and *Helisoma* abundance.

The absence of statistically significant differences in mean snail densities among treatments (control, 250 redear sunfish/ha, 500 redear sunfish/ha, and 500 hybrid sunfish/ha) can be partially explained by the limited number of replicate ponds (n=3) available to be applied to each treatment and considerable variation in snail densities among individual ponds. Factors responsible for high variability in initial snail densities among ponds are unclear. Snail densities immediately prior to pond trials were generally low in comparison to densities of snails that have previously been observed in research ponds at SIUC. Relatively low snail densities occurred in many ponds despite the delayed fish stocking date to allow additional time for snail populations to expand and supplemental stocking of snails collected from commercial aquaculture ponds in southern Illinois. Relatively cool weather during spring 2008 may have been partially responsible for low snail densities; very few of the commercial aquaculture ponds visited for snail collections had high densities of *Physa* or *Helisoma*, suggesting that low snail densities in late spring and early summer 2008 were not unique to ponds at SIUC.

Laboratory Consumption Trials – River Redhorse and White Sucker

Results of the laboratory snail consumption trials for both river redhorse and white sucker suggested that neither species shows much promise as a potential biological control agent for *Physa* and *Helisoma* in aquaculture ponds. River redhorse were sufficiently large to consume most of the snails offered, but their consumption rates (particularly for *Helisoma*) were relatively low in comparison to those of redear sunfish and hybrid sunfishes (e.g., redear x green sunfish and redear x warmouth) in similar laboratory trials (Wang et al. 2003; Bajer and Hayward 2005; Ledford and Kelly 2006; Whitledge, unpublished data). Likewise, white suckers consumed very few snails in the laboratory trials. Low snail consumption rates by river redhorse and white suckers were not likely due to fish stress from being held in a laboratory environment, as both species readily consumed earthworms that were provided during the pre-trial acclimation period; fish held after the snail consumption trials also readily consumed earthworms. Additionally, white suckers used in this study were hatchery-reared and were likely accustomed to confinement in tanks. Another potential reason for the relatively low snail consumption rates by white suckers is that the fish available for these trials were relatively small. However, these fish consumed very few of smaller snails that they were capable of ingesting based on the relationship between mouth gape and fish total length. Thus, the small size of white suckers used in the trials does not fully account for their very low observed snail consumption rates. The mouth gape-total length relationship developed for white suckers indicates that relatively large (300-400 mm TL) individuals of this species would be required to consume most of the snails that were observed in our pond study; even larger fish would be required to consume the largest *Helisoma* (up to 18 mm) that are commonly found in aquaculture ponds. Raising white suckers to these relatively large sizes in a hatchery would be costly, and the effectiveness of white suckers > 300 mm total length for controlling snail populations is uncertain given the relatively low consumption rates exhibited by fish used in this study. To date, the redear sunfish, despite its shortcomings (most notably its relatively small mouth gape), appears to be the best available native biological control option for snail populations in aquaculture ponds in the Midwestern U.S.

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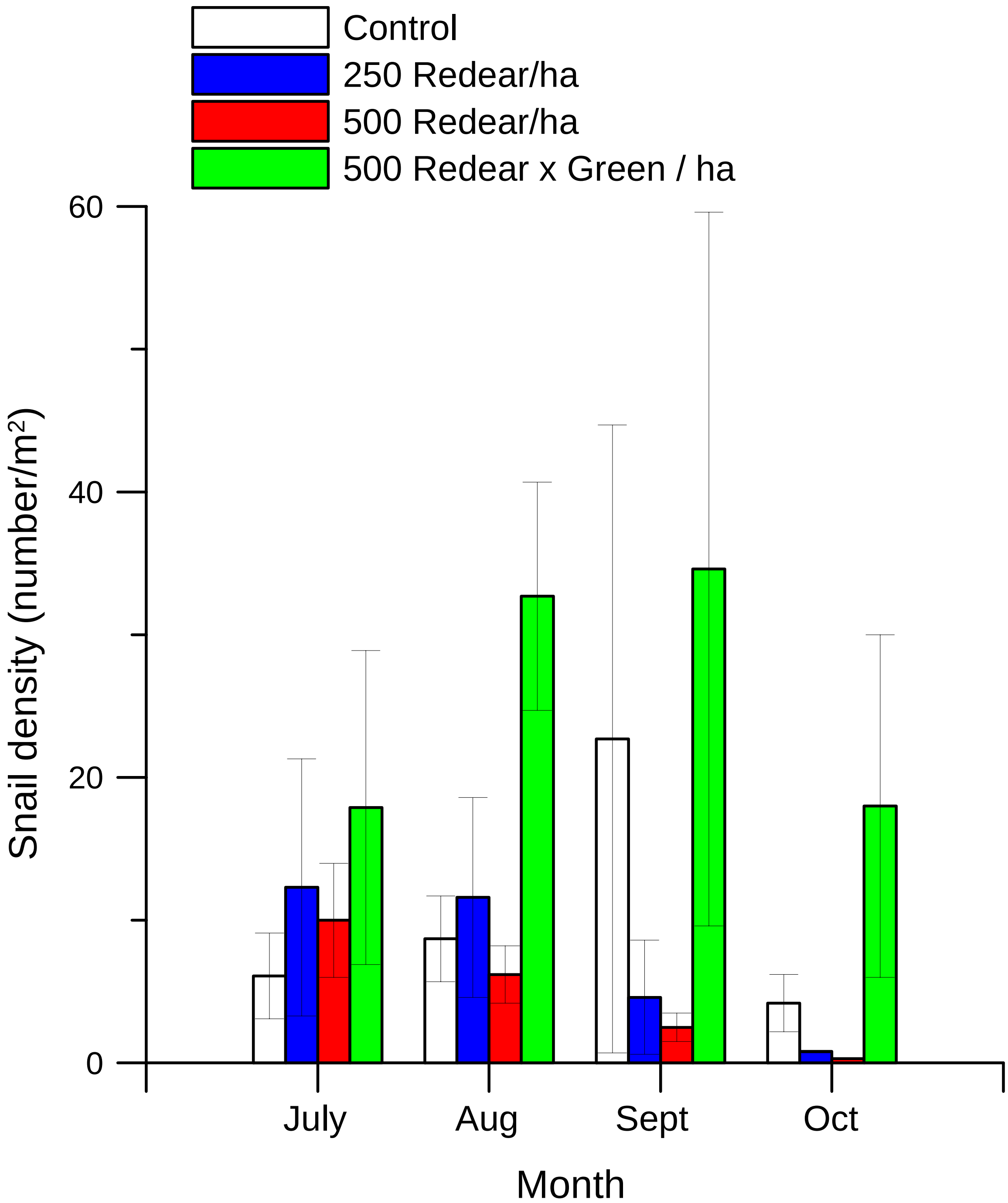

Figure 1. Mean densities (± SE) of snails (*Physa* and *Helisoma*) in control ponds (no fish present) and ponds stocked with either 250 or 500 redear sunfish/ha or 500 redear x green sunfish hybrids/ha during July-October 2008. Snail densities were measured once per month in each pond. N=3 ponds per treatment.

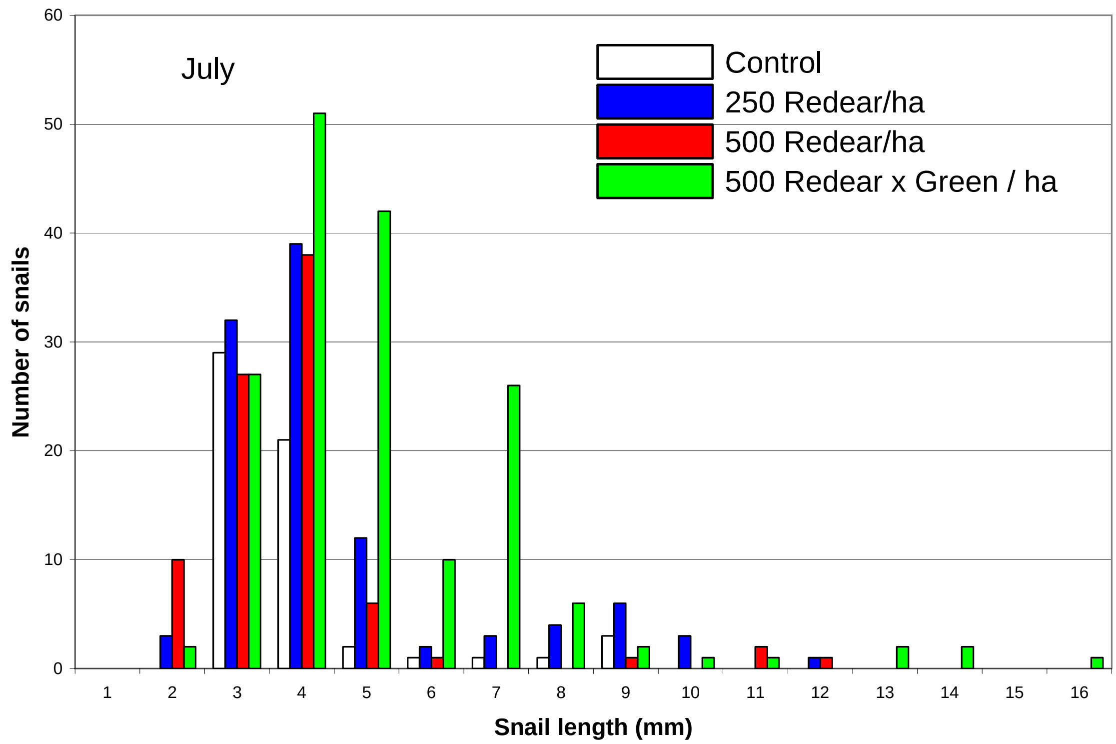

Figure 2. Size distributions of snails (*Physa* and *Helisoma*) in control ponds (no fish present) and ponds stocked with either 250 or 500 redear sunfish/ha or 500 redear x green sunfish hybrids/ha during July 2008 (immediately prior to fish stocking). N=3 ponds per treatment.

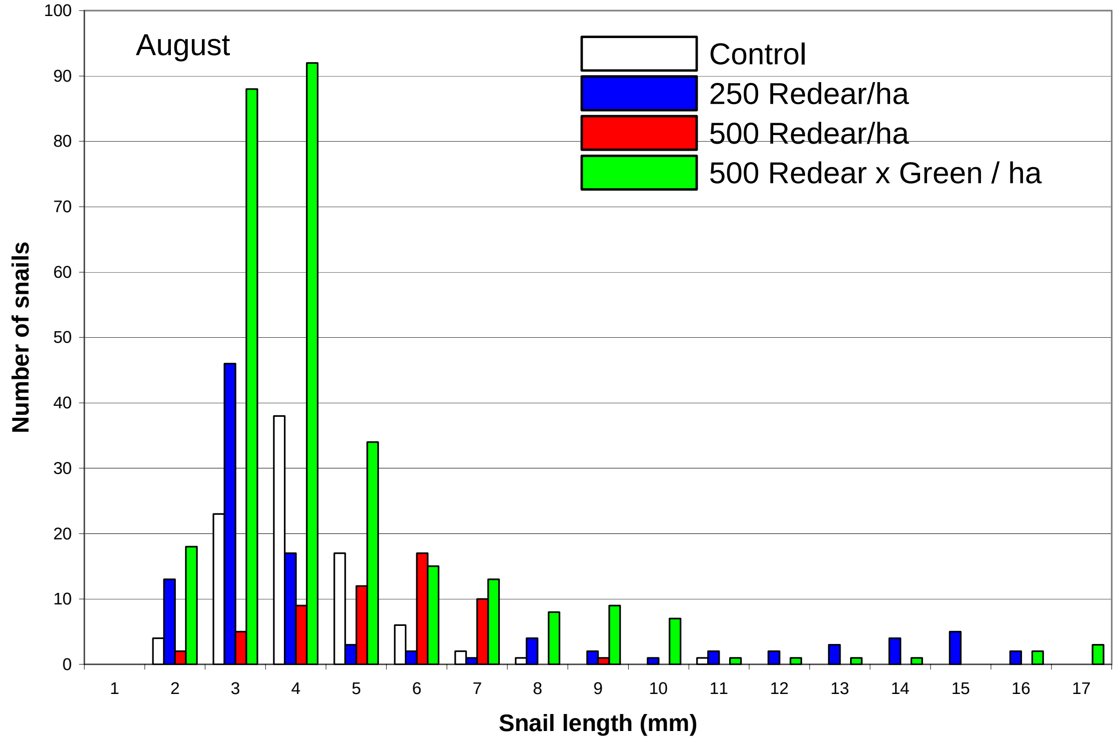

Figure 3. Size distributions of snails (*Physa* and *Helisoma*) in control ponds (no fish present) and ponds stocked with either 250 or 500 redear sunfish/ha or 500 redear x green sunfish hybrids/ha during August 2008. N=3 ponds per treatment.

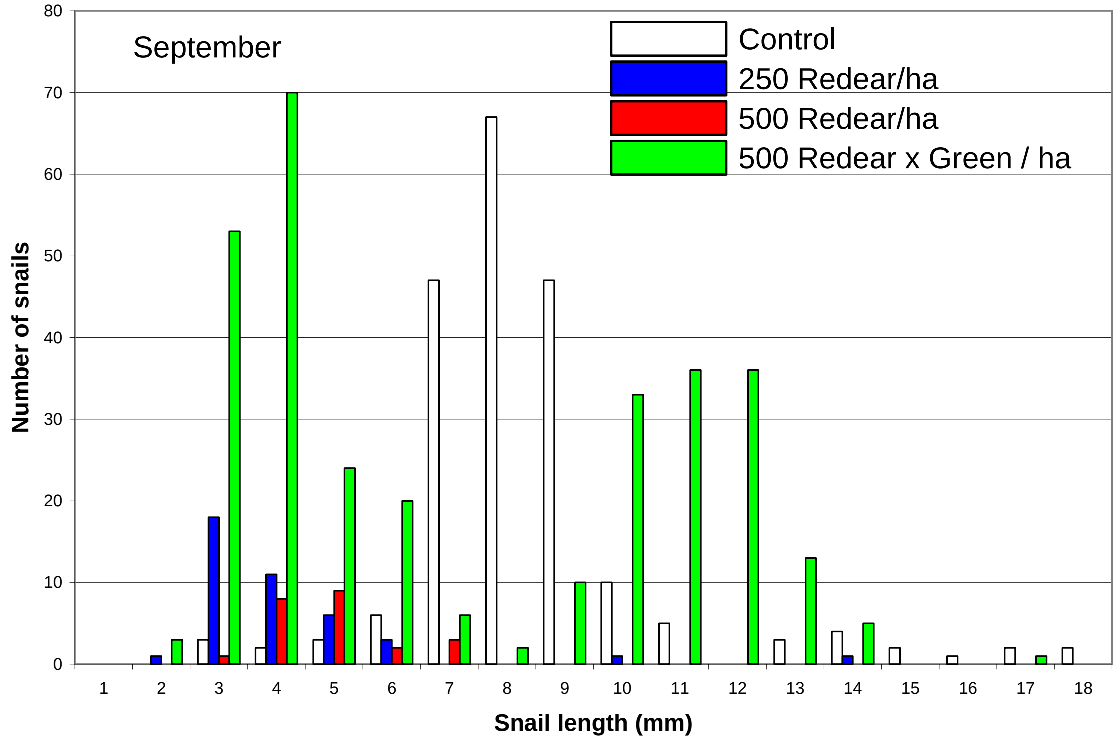

Figure 4. Size distributions of snails (*Physa* and *Helisoma*) in control ponds (no fish present) and ponds stocked with either 250 or 500 redear sunfish/ha or 500 redear x green sunfish hybrids/ha during September 2008. N=3 ponds per treatment.

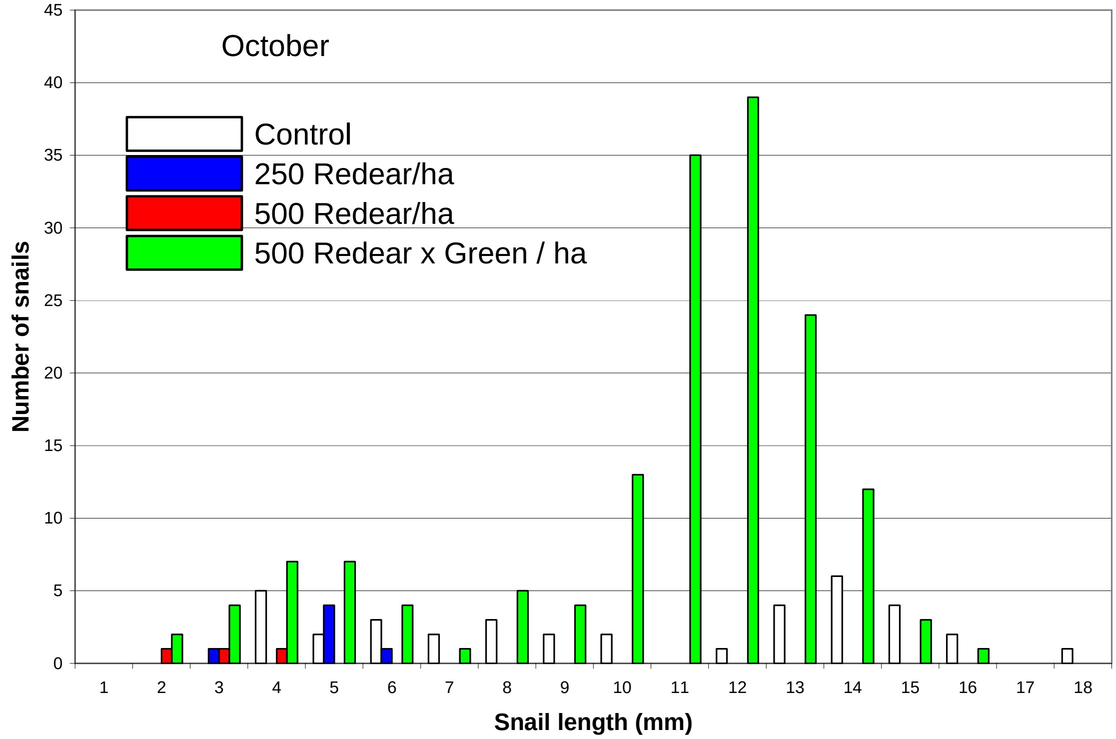

Figure 5. Size distributions of snails (*Physa* and *Helisoma*) in control ponds (no fish present) and ponds stocked with either 250 or 500 redear sunfish/ha or 500 redear x green sunfish hybrids/ha during October 2008. N=3 ponds per treatment.

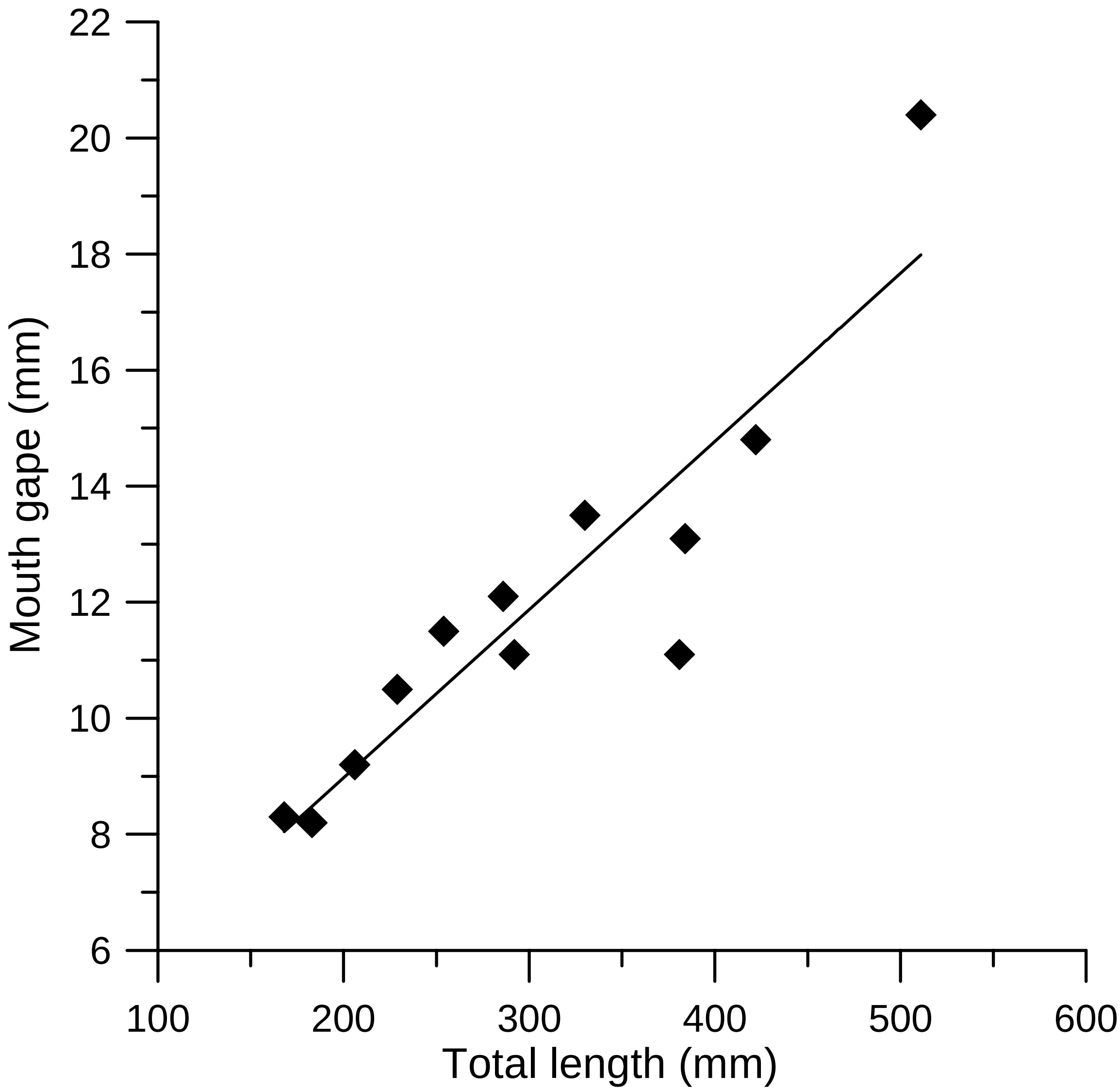

Figure 6. Relationship between mouth gape and total length for white sucker (*Catostomus commersoni*). Solid line is least-squares linear regression line fit to data ($y = 0.029 x + 3.1759$, $p<0.0001$, $r^2=0.83$).