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Training Grass Carp to Respond to Sound for Potential Lake Management Uses

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Abstract.—Future use of triploid grass carp *Ctenopharyngodon idella* as a control agent for aquatic macrophytes could be enhanced by efficient methods of removing the fish from stocked waters. In laboratory trials, we evaluated the ability to train triploid grass carp to move to a specific area for potential recapture by coupling low-frequency sounds (i.e., 1,000, 800, and 600 Hz) and grass carp feeding sounds with a food reward. Repeated-measures analysis of variance (ANOVA) indicated that grass carp response times to sound stimuli declined over training sessions for all low-frequency sounds tested. Percent return rates averaged 94, 94, 88, and 71% for low-frequency sounds of 600, 800, and 1,000 Hz and grass carp feeding sounds, respectively. Our results suggest that sound can be used to attract triploid grass carp to a central area where they potentially can be removed.

Grass carp *Ctenopharyngodon idella* and triploid grass carp have proven to be successful and cost effective control agents for aquatic macrophytes (Cassani 1985; Shireman 1985). A problem with using grass carp for aquatic macrophyte control is that when stocked at high enough densities (≥25 fish/ha of vegetation), they have the potential to remove all aquatic macrophytes from an aquatic system (Hanlon et al. 2000). Lake managers and citizens, however, often desire some aquatic macrophytes in their lakes because of esthetics and the associated benefits as fish and wildlife habitats. Consequently, if lake managers or the public use triploid grass carp for aquatic macrophyte control and achieve an undesired eradication of all aquatic macrophytes, development of a method to remove triploid grass carp from stocked waters is needed.

Several methods—such as herding, angling, attracting, use of lift nets, and toxic fish baits—have been investigated for use in the removal of grass carp from aquatic systems (Schramm and Jirka 1982; Bonar et al. 1993; Mallison et al. 1994). The techniques used in the removal studies were time consuming, labor intensive, and, in some cases, quite expensive. Each technique failed to remove a major portion of the carp populations, leaving a sufficient number of fish to maintain complete control of aquatic macrophytes.

The use of sound may be one viable method in attracting and removing grass carp from water bodies. Common carp *Cyprinus carpio* have been attracted and subsequently captured using a variety of sounds, including recordings of common carp swimming and eating (Hashimoto and Maniwa 1966). Richard (1968) showed that pulsed, low-frequency sound can attract many species of fish, including Nassau grouper *Epinephelus striatus*, mutton snapper *Lutjanus analis*, margate *Haemulon album*, yellowtail snapper *Ocyurus chrysurus*, yellowfin grouper *Mycteroperca venenosa*, and black grouper *M. bonaci.* Maniwa (1975) also researched sound attraction of marine fishes for harvesting purposes and discovered that buri or Japanese amberjack *Seriola quinqueradiata*, chub mackerel *Scomber japonicus*, Japanese scad *Trachurus japonicus*, and deep sea queen crabs *Chionoeceles japonicus* were attracted to the recordings of their own eating sounds.

This study was designed to determine if grass carp could be trained to respond to (1) low-frequency (600, 800, and 1,000 Hz) sound, or (2) their own feeding sounds. If grass carp can be trained to return to a designated area, they could potentially be captured before complete control of aquatic macrophytes occurred.

Methods

Adult triploid grass carp (20–40 cm total length [TL]) were trained using an operant conditioning protocol (Dudel 1986). Under operant conditioning, a desired response to a stimulus is rewarded. An intermittent reinforcement schedule was utilized to strengthen the association of the behavioral response (orientation to the sound) with a food reward. Prior to training, the grass carp were raised in ponds without supplemental feed.

Conditioning trials were conducted in an unheated steel building using three 950-L fiberglass

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TABLE 1.—Percent return rates of triploid grass carp to designated area (feeding square). Return rates are based on stages 4 and 5 of each sound for each replicate. Stage 4 represents a period in fish training when the sound was emitted and 10 s later the food was delivered; stage 5 represents a period when the sound was emitted and 20 s later the food was delivered.

Replicate number	Sound (Hz) or feeding	Number of training sessions, stage 4	Number of training sessions, stage 5	Number of training sessions carp returned	Return rate (%)
1	1,000	4	7	10	91
1	800	5	7	10	83
1	600	5	7	11	92
1	Feeding	5	25	21	70
2	1,000	5	28	25	76
2	800	5	20	25	100
2	600	2	21	26	100
2	Feeding	5	25	19	63
3	1,000	4	19	22	96
3	800	5	21	26	100
3	600	5	18	21	91
3	Feeding	5	25	24	80

tanks set up with a flow-through design. Water temperature (range, 17.5–27.0°C) and dissolved oxygen concentrations (range, 5.8–8.4 mg/L) stayed within the range necessary for continued feeding by grass carp (Shireman et al. 1983). One-meter-high black plastic sheeting was erected around each tank to prevent the fish from viewing the trainer during the trials. A 3-cm square hole was cut into the plastic sheeting at the trainer's eye level so the trainer could observe and monitor the behavior of the fish. Feeding tubes were placed through the plastic into the tanks so the fish would not relate the presence of the trainer to the floating fish food. A plastic floating 25-cm square was placed into a designated area in each tank to contain the floating catfish food. The plastic square was anchored by a rope to the side of the tank under the feeding tube.

Low-frequency sounds of 1,000, 800, and 600 Hz were chosen for this study because common carp can hear sounds in the 50 to 3,000 Hz range (Popper 1972). Popper (1972) determined the thresholds for common carp using avoidance conditioning and found 50 to 1,500 Hz to be the range of sound to which the fish is most sensitive and which elicits the best chance for a response. The study also suggested similar hearing capabilities among most species in the family *Cyprinidae*.

A Crass noise simulator (model S44) was used to produce the pure-tone, low-frequency sounds (1,000, 800, and 600 Hz) that were then recorded onto a cassette tape for use during the training. Feeding sounds of the triploid grass carp consuming hydrilla were recorded with an omnidirectional dynamic microphone (Radio Shack model 33-3008). The microphone was placed into a waterproof container and lowered into a tank near grass carp feeding on hydrilla.

The low-frequency and feeding sounds were played from a cassette recorder/player during the course of the study. The sounds were amplified by an 80-W amplifier (Realistic model 12-1870A). The amplified sounds were produced through a 16.5-cm speaker (Realistic model 40-1370) placed against the outside of the tank.

Once the tanks were operational, two 20–40-cm TL triploid grass carp were added to each tank. Two fish were added to each tank to ensure finishing a trial in case of a single mortality, and two new fish were added at the start of each new trial. The fish were fed pellet-size floating catfish food for approximately 2 weeks before each training trial began. This facilitated conditioning of the fish to eat the food and allowed them to acclimate to their new environment. Three replicate trials were conducted for each sound (1,000, 800, and 600 Hz, and the feeding sounds), for a total of 12 trials (Table 1).

One training session was conducted every successive day for each trial. During the first five training sessions (stage 1), the food was delivered into the plastic square; 20 s later, the sound was emitted for 5 s. During sessions 6–10 (stage 2), the food was delivered into the plastic square; 10 s later, the sound was emitted. During sessions 11–15 (stage 3), the food was delivered and the sound was emitted concurrently. During sessions 16–20 (stage 4), the sound was emitted and 10 s later the food was delivered. During session 20 and greater (stage 5), the sound was emitted and 20 s later the food was delivered. Stages 4 and 5 were used to determine whether the fish were or were not responding to the sound.

The response times for stages 1 and 2 are defined as the time (s) it takes the first fish to move to the designated area after the food (reward) has been given. The response time for stage 3 is defined as the time (s) it takes the first fish to move to the designated area after both the reward and sound have been given. The response times for stages 4 and 5 are defined as the time (s) it takes the first fish to move to the designated area after the sound has been emitted.

Repeated-measures analysis of variance (ANOVA) were used to determine if response time varied with the type of sound (1,000 Hz, 800 Hz, 600 Hz, and their own feeding sounds), time (i.e., feeding event), and the interaction between the type of sound and time (ANOVA; Procedure MIXED, SAS Institute 1997). Each replicate was used as a block factor, and the tanks within each replicate were used as the subjects in the analysis.

In the ANOVA data, a number of training sessions were removed due to unexpected circumstances, such a door slamming or a tank being bumped ($n = 25$). The data used for the ANOVA were not normally distributed and were therefore transformed to base 10 logarithms to accommodate for the lack of normality in the data. Statements of statistical significance for the repeated-measures analysis indicate $P \leq 0.05$.

The learning behavior based on the percent response rate of the fish in stages 4 and 5 of the training for each tank in each replicate was also evaluated. The combination of stages 4 and 5 was used because this is when the grass carp should be responding to the sound. Differences in the return rates (%) between sounds were tested by ANOVA (ANOVA; SAS Institute 1994). The percent return rate data were not normally distributed, so the data were transformed using arcsine transformation. Statements of statistical significance for the ANOVA analysis indicate $P \leq 0.05$.

Results and Discussion

Response times declined during training sessions 1–10 (stages 1 and 2) and leveled off after training session 20 for all low-frequency sounds (Figure 1). During this study fish were observed to be haphazardly distributed without obvious spatial patterns before each session. This decline and leveling off of the response times indicated the triploid grass carp probably learned to respond to the low-frequency sounds. Percent return rates averaged 94, 94, and 88% for low frequency sounds of 600, 800, and 1,000 Hz, respectively (Table 1). These data also indicate that the triploid grass carp were learning at all the low-frequency sounds.

Trends in response to feeding sounds did not follow the pattern of decreasing response time because response times were low from the onset of the training session (Figure 1). Results, however, do not support the premise that the triploid grass carp were not learning since they did have average return rates greater than 70% (Table 1). Perhaps the carp did not need to be trained to their own feeding sounds, and may have come regardless. For example, Hashimoto and Maniwa (1966) used recordings of common carp swimming and eating to attract them to a designated area for capture. Therefore, it may be entirely possible to just place the feeding sounds into a body of water to attract the fish to a capture location.

Repeated-measures ANOVA determined that the fish were learning. The interaction between all sounds and time was not significant ($P = 0.7840$). A significant difference in response time was not detected ($P = 0.0995$) among the sound types. The response times were significantly different across time (training sessions) ($P = 0.0001$). These data suggest that the triploid grass carp learned using all four sound types.

Because the measures of response time differ among stages, we also tested differences among stages 1–3 and stages 3–5. The results indicate no significant difference in response time between stages 1, 2, and 3 ($P = 0.2088$). There was, however, a significant decrease in response time between stages 3, 4, and 5 ($P = 0.007$) which corroborates the analysis through all the stages.

This study demonstrates that the triploid grass carp can be trained to respond to either low-frequency sound or to its own feeding sounds, but a question remains for the future training of triploid grass carp: which sound is optimal? There was a significant difference between the percent return rates for the different sounds. The feeding sound had the lowest percent return rate of all the sounds, suggesting a limited usefulness for future research. Based on data presented in this paper, it is plausible to say that any of the low-frequency sounds tested would work. However, we believe the 600 Hz level should be used for future training sessions. The 600 Hz sound had one of the highest average return rates (94%) and one of the fastest average response times (2.6 s) during stages 4 and 5 of the training sessions (Figure 1). Also, the 600 Hz level falls in the middle of the range of the low-frequency sounds that elicits a response for other fish in this

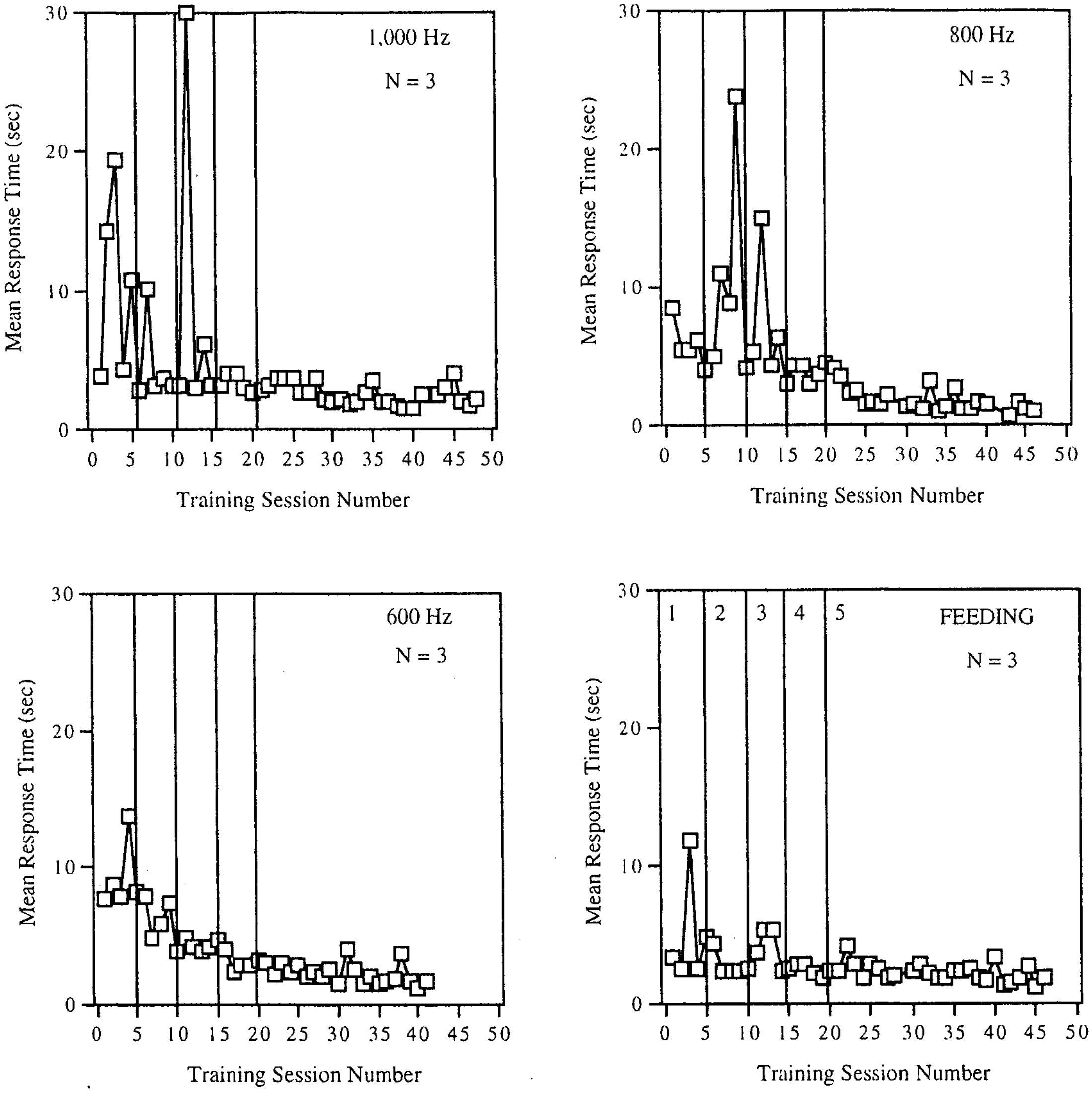

FIGURE 1.—The mean response times (s) in relation to the number of sessions for each sound in all the replicates. The vertical line on each plot separates the five stages of the conditioning. Each stage in the training represents a certain aspect of the training protocol. During the first five training sessions (stage 1), the food was delivered into the plastic square; 20 s later, the sound was emitted for 5 seconds. During sessions 6–10 (stage 2), the food was delivered into the plastic square; 10 s later, the sound was emitted. During sessions 11–15 (stage 3), the food was delivered and the sound was emitted concurrently. During sessions 16–20 (stage 4), the sound was emitted and 10 s later the food was delivered. During session 20 and greater (stage 5), the sound was emitted and 20 s later the food was delivered. The data used in the plots represents the values used in the statistical analysis with the outliers removed.

family (Popper 1972). Additionally, the lower the frequency the greater the distance sound will travel (Stewart and Lindsay 1930).

Triploid grass carp need to be trained and placed into a water body with aquatic macrophytes to determine if they will return, even in the presence of abundant food. The amount of time that the triploid grass carp retains the conditioned behavior is a major concern as extinction time of the conditioned behavior was not tested in this study. The retention of this conditioned behavior will determine how trained fish might be used to manage aquatic macrophytes. If the fish can only retain the behavior for a short time, high stocking densities will be needed to achieve desired control before losing the conditioned behavior, thus increasing the cost of this technique. If the fish will retain the conditioning for a long period, then less fish can be used and the removal time extended. Optimistically, it has been suggested that the intermittent reinforcement schedule used in this study shows a good resistance to extinction of a conditioned behavior (Tyler et al. 1953; Wodinsky and Bitterman 1960).

Triploid grass carp have been controlling aquatic macrophytes in Florida's water bodies for more than 20 years. Many of the lakes in Florida stocked in the 1970s still have grass carp controlling the aquatic macrophytes. Many removal techniques have been attempted, but all have had limited success due to their lack of effectiveness and/or the fact that the techniques were economically unfeasible. Until a practical, efficient, and economical method is found to remove the triploid grass carp, utilization of the fish for aquatic macrophyte removal should be viewed as a long-term management decision. This experiment has possibly opened the door for more options when using triploid grass carp to remove aquatic macrophytes.

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