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[Article]

Capture of Ovulating Female Sea Lampreys in Traps Baited with Spermiating Male Sea Lampreys

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Abstract.—This study was conducted as an initial step in the development of a trapping technique for sexually mature female sea lampreys *Petromyzon marinus*. Recent research has demonstrated that spermiating male sea lampreys release a sex pheromone that attracts ovulating females. This discovery prompted us to hypothesize that traps baited with spermiating males would capture more ovulating females than empty traps or traps baited with nonspermiating males. We found that traps baited with spermiating males captured nearly 74% of the ovulating females released, whereas empty traps and traps baited with nonspermiating males did not capture any ovulating females. We conclude that pheromone-baited traps may complement current sea lamprey management through direct removal of ripe females from spawning grounds.

The sea lamprey *Petromyzon marinus* invaded the Laurentian Great Lakes and caused the collapse of numerous economically valuable fish populations (Smith and Tibbles 1980). Integrated management of sea lampreys is essential to maintain and restore the Great Lakes ecosystem (Great Lakes Fishery Commission 2003). Lampricides, barriers, trapping, and sterile-male releases are used to control sea lamprey populations (Klar and Young 2002), yet sea lampreys continue to be a significant source of fish mortality in the Great Lakes (Bergstedt and Schneider 1988; Kitchell 1990). Further, these techniques can be costly and some have uncertain environmental consequences (Lamsa et al. 1980; Smith and Tibbles 1980). Additional control techniques will improve sea lamprey management in the Great Lakes (Hanson and Manion 1980; Smith and Tibbles 1980).

Trapping currently targets sexually immature sea lampreys as they migrate upstream to their spawning grounds (Great Lakes Fishery Commission 2003). Captured females are killed and captured males are used in the sterile-male release program. Trapping reduces the population of migratory sea lampreys in rivers by an average of 39% in the whole Great Lakes basin and up to 60–80% in some rivers (Klar and Young 2002). We reasoned that if a trapping technique could be developed to further reduce the abundance of ovulating females, the reproductive potential of sea lamprey populations would be further reduced. This may be logistically challenging because mature sea lampreys do not appear to move great distances within a stream when compared to immature sea lampreys en route to spawning grounds (N.S.J. and M.J.S., personal observations). Nevertheless, recent advances in our understanding of sea lamprey sex pheromone communication indicated that baited trapping might provide a solution to this technical difficulty (Li et al. 2002; Siefkes et al. 2003).

Pheromones play an important role in mate searching and courtship behavior in sea lampreys (Teeter 1980). Recent research indicates that spermiating males release at least one sex pheromone that induces a strong preference and searching behavior in ovulating females (Li et al. 2002; Siefkes et al. 2003). Insect traps baited with specific female pheromones have successfully captured sexually mature males of the same species (Beroza and Knipling 1972; Oehlschlager et al. 2003). In principle, sea lamprey traps baited with a male pheromone or spermiating males could also be used to capture ovulating females to reduce the reproductive potential of sea lamprey populations (Teeter 1980; Li et al. 2002). Our objectives were to determine whether baiting traps with spermiating males could significantly increase the capture rate of ovulating females and if trapping rates varied significantly between day and night.

Methods

Experimental animals.—Sea lampreys were captured by hand or in traps from Lake Michigan and Lake Huron tributaries from May to July 2003. Males and females were identified and separated according to the protocol established by Vladykov

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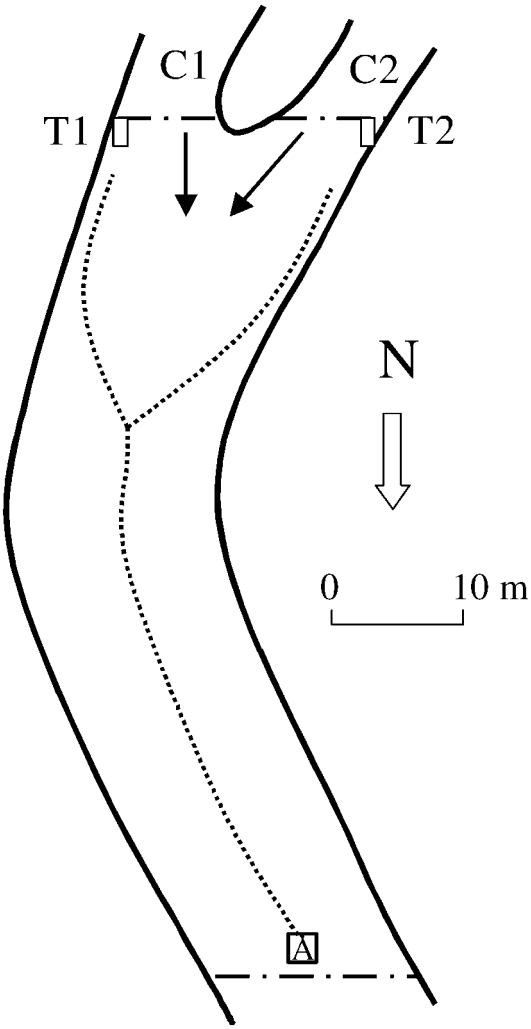

FIGURE 1.—The 65-m enclosed section of the Ocqueoc River, Presque Isle County, Michigan, used for trapping experiments between 27 June and 12 August 2003. At the upstream block net, an island naturally divides the river into two channels (C1 and C2). The arrows represent the flow of water coming from each channel. A sea lamprey trap was placed in each channel of the river approximately 0.2 m from the block net and 1.0 m from the shore (T1 and T2). Ovulating females were released from an acclimation cage (A) at the downstream block net and observed until they entered a trap or the end of the experiment (12 h from the time of release).

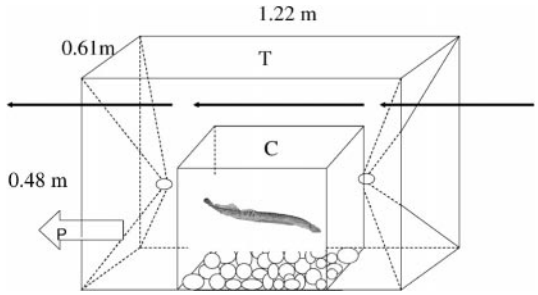

FIGURE 2.—The design and dimensions of sea lamprey traps used on the Ocqueoc River, Presque Isle County, Michigan, between 27 June and 12 August 2003. The dark arrows represent the current flowing through the trap. This flow created a pheromone plume (P) originating directly from the downstream funnel of the trap. A cage (C) with rocky substrate was placed inside the trap to hold spermiating male sea lampreys.

(1949). Each sex was further assigned to one of two maturity classes according to the protocol established by Siefkes et al. (2003). Males were classified as nonspermiating or spermiating. Females were classified as nonovulating or ovulating. Spermiating males and ovulating females were held in 150-L flow-through tanks at ambient temperatures ranging from 7°C to 20°C for immediate experimentation. Nonspermiating males and nonovulating females were held in 1,000-L flow-through tanks at temperatures ranging from 4°C to 8°C for future experimentation. Several nonspermiating males and nonovulating females were held together with spermiating males and ovulating females in an artificial spawning stream to induce maturation.

Experimental test site and equipment.—Trapping experiments were conducted above the lamprey barrier in a 65-m section of the Ocqueoc River (a Lake Huron tributary in Presque Isle County, Michigan; Figure 1). The Ocqueoc River is historically known for its large population of spawning sea lampreys (Applegate 1950; Heinrich et al. 1980; Coble et al. 1990; Houston and Kelso 1991). However, above the barrier, no adult sea lampreys were known to be present (N.S.J. and M.J.S., personal observations) and the stream contains suitable physical qualities and habitat for spawning (Applegate 1950). The 65-m section was enclosed using two block nets. At the upstream block net, an island naturally divides the river into two distinct channels with nearly equal discharge (1.6 m^3/s). The two channels converge and mix in the middle of the enclosed river section. Sea lampreys swimming upstream during an experiment must choose which channel to enter.

Two identical traps (0.359 m^3) were used to capture ovulating females in the enclosed section of the river (Figure 2). A trap was placed in each channel of the river along the upstream barrier. Each trap was approximately 1 m from the nearest shore and 0.2 m from the upstream block net. The

traps were set parallel to the current to create a pheromone plume originating from the downstream funnel of the trap (Figure 2). Water flow through each trap was approximately 0.30 m^3/s. Ovulating females were held in an acclimation cage along the downstream barrier (Figure 1). Males were held in cages placed inside the trap (Figure 2) to prevent them from escaping or physically interacting with ovulating females that entered the trap.

Experimental design and procedures.—The study was conducted between 27 June and 12 August 2003. Ovulating females were fitted with external radio tags (Advanced Telemetry Systems, Inc., Isanti, Minnesota) according to Siefkes et al. (2003) 24 h prior to experimentation. Five spermiating and five nonspermiating males were randomly assigned to a trap by flipping a coin. Males in traps and ovulating females were allowed to acclimate in the river for a minimum of 30 min before experimentation.

The study consisted of two experiments. In the first experiment, a single female was released in each trial to estimate the trapping rate of individual females. In the second experiment, five females were released in each trial to estimate the trapping rate of a group of females. Each experiment further consisted of treatment and control trials. Treatment trials were conducted by randomly placing five spermiating males in one trap and five nonspermiating males in the other. Control trials were conducted with no males in either trap and estimated the trapping rate of ovulating females using current trapping techniques. Treatment and control trials were conducted both day and night to investigate changes in trapping rates under specific lighting conditions (Teeter 1980). Day trials started at 0900 hours and ended at 2100 hours with ambient water temperatures of 15.2–29.2°C. Night trials and multiple-female releases started at 2100 hours and ended at 0900 hours with ambient water temperatures of 14.3–29.3°C.

Thirty-nine treatment trials (16 during the day and 23 during the night) and 24 control trials (11 during the day and 13 during the night) were conducted when individual females were released. Four treatment trials and one control trial were conducted during the night when groups of five females were released. In all trials, females were released at the downstream barrier and visually observed. If females were not visible, they were tracked with a directional radio antenna and receiver (Advanced Telemetry Systems, Inc. Isanti, Minnesota).

Ovulating females were allowed 12 h to enter a trap. Females that entered a trap before 12 h were removed and the trial was terminated. If a female escaped from the enclosed river section, the trial was counted because the female failed to respond to the pheromone cue. If a female died, the trial was not counted because we believed the female was physically unable to respond to the pheromone cue. Ovulating females were either captured in the trap containing spermiating males, captured in the trap containing nonspermiating males, captured in the empty trap, or not trapped. Finally, the behaviors of ovulating females around the traps were observed and described, but not quantified.

Capture rates of ovulating females were calculated by dividing the total number of females released by the number captured in each trap. Fisher's exact test was used to compare night and day trials and to compare single-female releases and five-female releases. If no significant differences were observed between day and night trials and single- and five-female releases, the data were combined.

Results

Six ovulating females died during treatment trials and one female died during control trials. These trials were not included in our data analyses. Eight ovulating females escaped the enclosed river section during treatment trials and three escaped during control trials. These trials were included in our data analyses.

Trapping rates did not differ significantly between day and night trials (Fisher's exact test, $P = 1.00$) or between single- and five-female releases (Fisher's exact test, $P = 0.86$; Table 1). Ovulating females were captured in traps containing spermiating males but not in those with nonspermiating males. During the 53 countable treatment trials, traps with spermiating males caught nearly 74% of ovulating females released, traps with nonspermiating males did not catch any ovulating females released, and approximately 26% of ovulating females were not captured in either trap (Table 1).

Furthermore, ovulating females were quickly captured in the spermiating male trap. Twenty-one of the 39 females captured entered the trap within 30 min after their release. The mean time a female was observed entering the trap was 27 min (range, 7–75 min). Observations of 17 of the 39 females captured revealed that 9 swam around the trap (swimming up and down one or both sides of the trap and often touching the trap) for up to several

TABLE 1.—Results of experiments using traps baited with spermiating male sea lampreys to attract ovulating females in the Ocqueoc River, Michigan, from June 27 to August 12, 2003. Three types of traps were used in the experiments: traps containing spermiating males, traps containing nonspermiating males, and traps containing no males (control). Trials involved groups of five females, single females released during the day, and single females released at night. The following abbreviations are used: N = the number of trials for each experiment, S = the number of females captured in traps with spermiating males, NS = the number of females captured in traps with nonspermiating males, NC = the number of females not captured in traps, and E = the number of females captured in empty traps.

	Experimental				Control		
Trial	N	S	NS	NC	N	E	NC
Group releases	19	14	0	5	4	0	4
Single; day	16	13	0	3	12	0	12
Single; night	18	12	0	6	11	0	11
Total	53	39	0	14	27	0	27

minutes before entering the trap; where as the other 8 swam directly into the trap.

During the 27 countable control trials, none of the ovulating females were captured in empty sea lamprey traps (Table 1). Additionally, most ovulating females did not move upstream when the traps were empty. Of 27 countable control trials, 21 females did not move upstream, 3 swam halfway up the enclosed river section, and 3 swam to the upstream block net.

Discussion

Our results imply that traps baited with spermiating male sea lampreys may be used to remove ovulating female sea lampreys from spawning grounds. In our experimental site, the capture rate of ovulating females was increased from zero to more than 70% by baiting the traps with spermiating males. These results are consistent with previous studies conducted in mazes and in the field. In a two-choice maze, male sex pheromones have been shown to induce a strong preference and searching response in ovulating females (Li et al. 2002; Siefkes et al. 2003). In field conditions, spermiating males have been shown to attract ovulating females upstream (Li et al. 2002; Siefkes et al. 2003); therefore, it is likely that sex pheromones released by spermiating males attracted ovulating females into the traps. Our study also confirms the ''infallible'' practice of French fishermen who used male lampreys to bait traps to capture females (Fontaine 1938).

An interesting observation in this study was that some females swam around the spermiating male trap before entering. This behavior may be due to some of the pheromone plume exiting through the side of the trap rather than through the funnel. Therefore, females may have followed the plume to the sides of the trap before finding the funnel and entering the trap. This pheromone-induced behavior could also be an important mechanism mediating the attraction of females to males and important to consider when designing a trapping strategy. More research is needed to find the exact cause of this behavior and to further quantify the behavior of ovulating females around pheromone-baited traps.

Our experiments were conducted under ideal conditions; large-scale studies in actual spawning situations are needed. First, male sex pheromones have been shown to attract ovulating females from up to 65 m away (Li et al. 2002; Siefkes et al. 2003; and data from this study). However, the maximum or effective distance ovulating females are attracted to pheromone-baited traps has yet to be determined. Second, resident spermiating males in the field may reduce the capture rate of ovulating females in pheromone-baited traps. Under the experimental conditions of this study, when no other spermiating males were present in the stream, traps with spermiating males yielded high capture rates of ovulating females. However, in actual spawning situations, background pheromones released by conspecific spermiating males may reduce the effectiveness of pheromone trapping.

Sex pheromone trapping techniques may be improved by additional research. First, specially designed traps may increase the capture rate of ovulating females (Teeter 1980). Traps designed to deflect the pheromone plume of spermiating males through the funnel(s) may result in higher capture rates. Second, if synthetic pheromones can be created that are as potent as spermiating males, they would eliminate the difficulties of using live spermiating males to bait traps and allow more males to be used in the sterile-male program. Currently, components of the pheromone mixture, 3-keto petromyzonol sulfate and 3-keto allocholic acid, are being chemically synthesized and tested in a two-choice maze to determine if they elicit a searching response similar to that of water conditioned with spermiating males (unpublished data).

Management Implications

Sex pheromones have appealing qualities that may benefit sea lamprey management in the Great Lakes. Although the behavior of ovulating females

appears to be difficult to exploit using current trapping practices (N.S.J. and M.J.S., personal observations), our results suggest that with the use of spermiating males, ovulating females might be efficiently trapped. In our study, the capture rate of ovulating females was high, pheromones were naturally released from spermiating males with no apparent environmental damage, and experiments were conducted at a low cost. Our study supports claims that sex pheromones are likely to be potent, environmentally benign, species-specific, easy to apply, and have a low cost of development (Teeter 1980; Li et al. 2002).

Our results indicate that pheromone-baited traps may complement integrated sea lamprey management in the Great Lakes (Smith and Tibbles 1980). Pheromone-baited traps may reduce the reproductive potential of sea lamprey populations through direct removal of females from spawning grounds. Additionally, by reducing female abundance, sterile-male releases may become more effective (Hanson and Manion 1980). Furthermore, in this study, females were commonly observed swimming upstream directly into the trap without interacting with the upstream barrier. Therefore, pheromone-trapping strategies may be conducted on streams that do not have barriers, while traditional trapping techniques are often conducted in streams with barriers. Finally, our initial results showed no significant differences between day and night trials; hence, pheromone trapping may be effective 24 h a day. This may be another advantage to pheromone-based trapping, because traditional trapping techniques are only effective at night.

Pheromone-baited traps may have broad applications in fisheries management (Young et al. 2003) because sex pheromones are used by a variety of fish species (Sveinsson and Hara 1995; Vermeirssen and Scott 2001; Young et al. 2003). Numerous undesirable fish species are present in North America (Courtenay et al. 1986). Therefore, sex pheromones may provide an inexpensive and environmentally benign method of fish control or population estimation (Young et al. 2003).

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