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Contribution of manipulable and non-manipulable environmental factors to trapping efficiency of invasive sea lamprey

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ABSTRACT

We identified aspects of the trapping process that afforded opportunities for improving trap efficiency of invasive sea lamprey (*Petromyzon marinus*) in a Great Lake's tributary. Capturing a sea lamprey requires it to encounter the trap, enter, and be retained until removed. Probabilities of these events depend on the interplay between sea lamprey behavior, environmental conditions, and trap design. We first tested how strongly seasonal patterns in daily trap catches (a measure of trapping success) were related to nightly rates of trap encounter, entry, and retention (outcomes of sea lamprey behavior). We then tested the degree to which variation in rates of trap encounter, entry, and retention were related to environmental features that control agents can manipulate (attractant pheromone addition, discharge) and features agents cannot manipulate (water temperature, season), but could be used as indicators for when to increase trapping effort. Daily trap catch was most strongly associated with rate of encounter. Relative and absolute measures of predictive strength for environmental factors that managers could potentially manipulate were low, suggesting that opportunities to improve trapping success by manipulating factors that affect rates of encounter, entry, and retention are limited. According to results at this trap, more sea lamprey would be captured by increasing trapping effort early in the season when sea lamprey encounter rates with traps are high. The approach used in this study could be applied to trapping of other invasive or valued species.

Introduction

Manipulating behavior as an approach to improve pest management requires understanding the behavioral ecology of the pest (Foster and Harris, 1997). When traps are used for control, trapping effectiveness can be increased by adopting a systematic approach whereby pest behavior is closely observed in response to manipulations of attractant use, trap design, and trap positioning. Trapping of insect pests has been improved by manipulating behaviors related to encountering, entering, and exiting traps (Rodriguez-Saona and Stelinski, 2009). Phillips and Wyatt (1992) determined that differences in the efficiency of traps in capturing German cockroaches (*Blatella germanica*) were explained by differences in individual behavior when contacting and entering traps. Vale (1982) created a quantitative approach to tsetse fly (*Glossina* spp.) trap development that provided a rationale for understanding specific design features and linking trap design to behavior of the target species. In ensuing years, many different designs of tsetse fly traps and targets were developed based on this approach, which played a significant role in the control of tsetse and human African trypanosomiasis (Kuzoe and Schofield, 2005).

The behavior of organisms approaching and entering, or not entering, fishing gear can be complex and not amenable to ad hoc approaches for seeking improvements (Phillips and Wyatt, 1992). Systematic studies of an animal's behavior are expected to be more effective for determining important variables and trapping components affecting trap capture. The process by which fish enter and are retained involves a complex sequence of behaviors in response to the fishing gear (Winger et al., 2010). Observing and understanding these behavior patterns represent a critical step in effective gear design (Winger et al., 2010). For example, recognition of the elaborate relationship between trawl design and fish behavior was first articulated in the 1960s (Okonski, 1969). Consequently, there have been significant improvements in the way trawls are designed

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and tested, not only to improve fish capture, but also reduce fuel costs, bycatch, and impact on the environment (Winger et al., 2010).

Improving methods for trapping invasive sea lamprey (*Petromyzon marinus*) is a strategic goal of the sea lamprey control program in the Laurentian Great Lakes (GLFC, 2011). A better understanding of the trapping process and factors affecting trapping efficiency could help improve trapping tactics, removal rate of adults prior to reproduction, and overall sea lamprey control (McLaughlin et al., 2007; GLFC, 2011). The Great Lakes Fishery Commission and its control agents, Fisheries and Oceans Canada and U.S. Fish and Wildlife Service (USFWS), control sea lamprey in the Laurentian Great Lakes using barriers that deny adults access to spawning habitat in tributaries and periodic applications of semi-selective pesticides (lampricides) to tributaries where larvae occur (Christie and Goddard, 2003). Trapping of adults migrating into tributaries to spawn could be a third control option if the proportion of population of sea lamprey trapped (trapping efficiency) was high enough to suppress recruitment. Current trapping operations conducted throughout the Great Lakes remove approximately 40% of the adult population prior to spawning (Adair and Sullivan, 2015), which is too low to suppress recruitment. Sea lamprey populations exhibit density-dependent survival (compensation) and high variability in density-independent recruitment (Dawson and Jones, 2009). A simulation model of the sea lamprey control program in Lake Huron suggested that trapping coupled with an ongoing lampricide control program could reduce sea lamprey spawning abundances by upwards of 100,000 individuals if 50–60% of adult sea lamprey were removed prior to spawning (Young, 2005). This would require increasing trapping effort to include the 10 largest sea lamprey producing tributaries not currently trapped and a 48% average trap efficiency across all streams (Young, 2005).

Trapping efficiency involves a complex interplay between sea lamprey behavior, environmental conditions, and trap design. Bravener and McLaughlin (2013) summarized the trapping process by considering sea lamprey as belonging to one of four distinct states (unavailable, available, trapped, and removed) separated by five probabilistic events (encounter, departure, entry, retention, or escape; Fig. 1). A sea lamprey is "unavailable" while migrating upstream when it is not in close proximity to a trap. A sea lamprey becomes "available" to be trapped when coming into close proximity to a trap (encounter). Upon encounter, a sea lamprey either does not enter the trap (departs) or moves through the funnel into the trap (entrance). Upon entrance, a sea lamprey either remains in the trap until being removed by trap operators (retention) or leaves the trap prior to being removed by trap operators (escape). Sea lamprey behavior affects both the duration within each state as well as the transitions between states (Bravener and McLaughlin, 2013). Sea lamprey which are not captured may never encounter a trap, never enter a trap upon encounter, or escape after entrance (Bravener and McLaughlin, 2013). Trapping efficiencies within a tributary ultimately depend on the rates of encounter, entrance, and retention with traps (Bravener and McLaughlin, 2013).

Understanding the interplay between sea lamprey behavior and environmental conditions would help identify aspects of the trapping process where improvements in trapping efficiency seem most promising. For example, the St. Marys River connecting Lakes Superior and Huron is one of the largest producers of sea lamprey in the Great Lakes, and through the use of passive integrated transponder tags and underwater video at traps, sea lamprey in this river were found to have low rates of encounter and entry with traps (Bravener and McLaughlin, 2013). Suggestions for improving trap placement have resulted from recent research investigating migratory pathways of sea lamprey approaching traps (Rous, 2014; Holbrook et al., 2015). Behavioral responses of sea lamprey to increases in water discharge (and presumably attractive flows eliciting positive rheotaxis during spawning migration) at locations where traps are located indicate that improving trapping success will require manipulation of stimuli other than discharge (Barber et al., 2012; McLean et al., 2015). Responses of sea lamprey to a synthesized mating pheromone used as bait in traps has resulted in increased trap captures in some streams but not others, which warrants further investigation (Johnson et al., 2013).

Identifying environmental factors that can be manipulated by trap operators to increase rates of encounter, entrance, and/or retention offers a promising way of directing research to improve trapping efficiency and to assess possible gains. Some environmental factors that can influence sea lamprey behavior, such as pheromone concentrations or stream flow near a trap, can be manipulated. Other environmental factors, such as water temperature (or rate of change) and season, cannot be manipulated or are not practical to manipulate. The potential to improve trapping efficiency will depend on the relative importance of factors that can be manipulated by the trap operators versus those that cannot be manipulated, and the degree to which probabilities of sea lamprey encounter, entry, and retention change in response to environmental factors that can be manipulated. Understanding whether and how sea lamprey respond to the interaction between manipulable and non-manipulable factors can also help guide the determination of the conditions under which trapping is most likely to be effective. Lastly, if environmental factors that cannot be manipulated are strong determinants of trap efficiency, overall efficiency could still be improved by increasing trapping effort during times when those factors are expected to increase trap encounter and entrance rates.

We identified aspects of the sea lamprey trapping process that represent candidates for improving trap efficiency. Our first objective was to test how strongly seasonal patterns in daily trap catches (a measure of trapping success) were related to rates of trap encounter, entry, and retention (outcomes of sea lamprey behavior). Our second objective was to assess the relationships between rates of encounter, entry, and retention with environmental features that control agents can manipulate (pheromone addition, discharge) and features the agents cannot manipulate (change in water temperature, season). Pheromone application was considered because baiting traps with a synthesized mating pheromone component can increase trap capture of adults (Johnson et al., 2013). Tributary discharge was considered because stream flow is potentially manipulable at some trap sites, and higher tributary discharge could stimulate sea lamprey activity and/or attract sea lamprey upstream and increase the probability of encountering traps (McLaughlin et al., 2007; Binder et al., 2010; McLean et al., 2015). Tributary discharge also affects the hydraulic conditions around a trap,

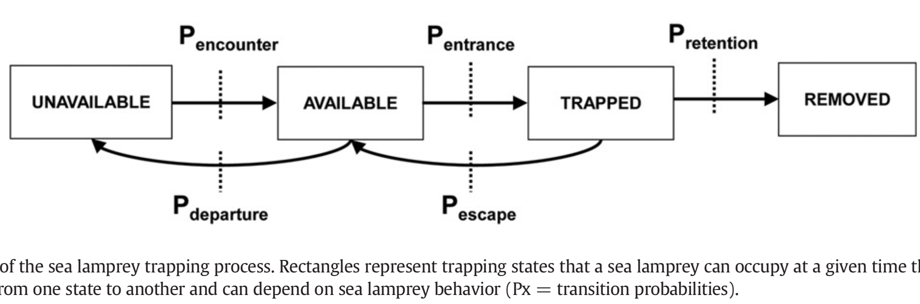

Fig. 1. Conceptual framework of the sea lamprey trapping process. Rectangles represent trapping states that a sea lamprey can occupy at a given time throughout the trapping season. Arrows represent transitions from one state to another and can depend on sea lamprey behavior (Px = transition probabilities).
Reproduced with permission from Bravener and McLaughlin (2013).