Biological Conservation 144 (2011) 1068–1080

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

# Demographic analysis of trade-offs with deliberate fragmentation of streams: Control of invasive species versus protection of native species

Luis A. Vélez-Espino [a,1], Robert L. McLaughlin [a,*], Michael L. Jones [b], Thomas C. Pratt [c]

[a] Department of Integrative Biology, University of Guelph, Guelph, ON, Canada N1G 2W1
[b] Quantitative Fisheries Center, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824-1222, USA
[c] Fisheries and Oceans Canada, 1219 Queen St. E, Sault Ste. Marie, ON, Canada P6A 2E5

ARTICLE INFO

*Article history:*
Received 17 June 2010
Received in revised form 25 November 2010
Accepted 26 December 2010
Available online 31 January 2011

*Keywords:*
Dams
Fragmentation
Fish passage
Invasive species
Matrix models
Sea lamprey

ABSTRACT

Tools restricting the movements of invasive species (e.g. barriers) and reducing habitat fragmentation for native species (e.g. corridors, fishways) provide examples where actions taken to address one environmental concern can hinder efforts to address another environmental concern. We used perturbation analysis of stage-structured projection matrices to evaluate the efficacy of seasonally operated barriers and fishways for controlling non-native sea lamprey (*Petromyzon marinus*) in the Laurentian Great Lakes while minimizing effects on non-target fishes. For non-jumping fishes migrating in spring, seasonally operated barriers without a fishway will not balance the management objectives satisfactorily. Migration phenologies of the seven common non-target fishes considered in our analyses overlapped considerably with the migration phenology of sea lamprey, with peaks in migration typically being 7–43 days (median 12) from the peak in the sea lamprey migration. Consequently, across species, years, and tributaries, 44–100% of the migratory runs of non-target fishes would be blocked under the 75-day operation period required to block 99% of the sea lamprey spawning run, on average. Reductions in the production of non-target fishes due to blocking were also projected to be similar in magnitude to reductions projected in the production of sea lamprey, unless density-dependent compensation was strong or overlap in migration phenologies between a non-target species and sea lamprey was low. Even under density-dependent compensation, providing a fishway is advisable and passage of non-target fishes may have to be highly effective to avoid population declines in non-jumping species that migrate between a Great Lake and its tributaries.



## 1. Introduction

Ecosystem-based management requires that decision makers weigh opposing environmental concerns. For example, barriers to movement can provide an effective, economical ecosystem tool restricting the movements and reproduction of invasive species and facilitating protection or restoration of native communities (Sharov and Liebhold, 1998). They can also restrict the movements and reproduction of non-target, native species (Benstead et al., 1999; Porto et al., 1999). Conversely, provisioning movement corridors or fishways, or removing barriers to movement (e.g. dams) can reduce habitat fragmentation (Levey et al., 2005; With, 2002), but facilitate the spread of invasive species and their unwanted effects on native ecosystems (Proches et al., 2005). The need to evaluate the effectiveness of management tools restricting or facilitating movement in light of both perspectives has been recognized for some time (Saunders and Hobbs, 1991; With, 2002), but overlooked in prominent studies (Proches et al., 2005). This need will likely to increase as concerns regarding invasive and sensitive native species heighten (e.g. Fausch et al., 2009).

This study examines tensions between control of invasive species and habitat fragmentation surrounding the use of in-stream barriers to control sea lamprey (*Petromyzon marinus*) in the Laurentian Great Lakes. The sea lamprey is a fish that feeds on the blood and tissue of host fishes. Its status in Lake Ontario remains the subject of debate (Bryan et al., 2005), however, its invasion of the upper lakes following modifications to the Welland Canal (Christie and Goddard, 2003) was arguably one of the largest ecological disasters in North America during the 20th century. Sea lamprey parasitism, combined with habitat alteration and overfishing, caused significant declines in populations of large native fishes, altering food webs within the lakes (Eshenroder and

* Corresponding author. Tel.: +1 519 824 4120x53620; fax: +1 519 767 1656.
*E-mail addresses:* Antonio.Velez-Espino@dfo-mpo.gc.ca (L.A. Vélez-Espino), rlmclaug@uoguelph.ca (R.L. McLaughlin), jonesm30@msu.edu (M.L. Jones), Thomas.Pratt@dfo-mpo.gc.ca (T.C. Pratt).
[1] Present address: Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Rd., Nanaimo, BC, Canada V9T 6N7. Tel.: +1 250 756 7119.

0006-3207/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2010.12.026

Burnham-Curtis, 1999). Sea lamprey control began in the 1950s and is overseen by the Great Lakes Fishery Commission (GLFC), with field operations contracted to Fisheries and Oceans Canada (DFO) and the United States Fish and Wildlife Service (USFWS).

Control efforts over the past 50 years relied heavily on periodic application of the selective lampricide 3-trifluormethyl-4-nitrophenol (TFM) to streams and rivers where larval sea lamprey rear for their first four or more years of life. Lampricides remain the key component of the sea lamprey management program (Great Lakes Fishery Commission, 2001). Physical and electrical barriers to movement provide an effective control alternative. They deny maturing sea lamprey access to spawning habitat. Barriers played a significant role in early efforts to control sea lamprey (Hunn and Youngs, 1980), but their use declined due to maintenance needs of early designs and the success of chemical control. In 2001, the GLFC pledged to reduce its reliance on TFM and increase its use of alternative control methods such as barriers (Great Lakes Fishery Commission, 2001). It operates 69 sea lamprey barriers. It also monitors several hundred *de facto* dams that function as sea lamprey barriers, but were constructed for other purposes, and are owned and operated by other agencies and corporations (Lavis et al., 2003). Until 2007, the GLFC was considering construction of up to 100 more barriers over 20 years. In 2007, these expectations were reduced to a smaller number of tributaries where other control options are not viable, a barrier would be more cost-effective than lampricide control, or a barrier would be compatible with local watershed management plans (Burkett et al., 2007). The change was made to direct resources to the restoration or replacement of deteriorating *de facto* dams and to address growing, basin-wide demand for dam removal or provisioning of fish passage, which can increase spawning habitat available to sea lamprey and add to chemical treatment costs (e.g. Furlong et al., 2006).

The barrier design used most extensively for sea lamprey control is a permanent, fixed-crest barrier where the crest is a constant height relative to the stream bottom providing a drop of ∼0.5–2 m. This design is effective at blocking sea lamprey, but can also restrict movements of common non-jumping fish species (Porto et al., 1999), and alter the composition of fish assemblages above the barrier (Dodd et al., 2003). To avoid these outcomes, newer seasonal barrier designs have been developed that block movements of sea lamprey and other non-jumping fishes during the period of sea lamprey migration, but allow passage of non-target fishes at other times of the year (McLaughlin et al., 2007). These seasonal barriers involve either elevating crest height or turning on an electrical field across the tributary during the period of sea lamprey migration and lowering crest height or turning off the electrical field at other times. Newer fixed crest and seasonal barriers may also be outfitted with a trap or fishway where sea lamprey and non-target fishes are captured, sorted, and the latter released. Optimal operation of these devices, and their effectiveness in terms of blocking sea lamprey while passing non-target fishes, have been key uncertainties. The uncertainties are significant. Across the basin over 100 non-target fishes co-occur with sea lamprey in streams (Mandrak et al., 2003) and migration phenologies of migratory, non-target fishes overlap with that of sea lamprey (Klinger et al., 2003).

This study modeled the effectiveness of seasonally operated sea lamprey barriers and fishways in terms of blocking sea lamprey and passing non-target fishes. We first quantified overlap in migration phenologies of sea lamprey and seven migratory non-target teleost fishes that co-occur with sea lamprey. We then used stage-structured matrix population models to project how blocking the reproductive migrations of sea lamprey was expected to affect the production of sea lamprey and the non-target fishes. Lastly, we projected how population sizes of non-target species change proportionally over time under different levels of fish passage.

## 2. Methods

### *2.1. Modeling migration phenologies of sea lamprey and non-target fishes*

Data quantifying the migration phenology of sea lamprey were obtained from the DFO and USFWS. These data sets consisted of daily catches from traps and trap-and-sort fishways used to remove sea lamprey from the spawning run. Data were obtained for 149 sample years from 13 tributaries (Table 1 and Fig. 1). Annual catches ranged from 7 to 21 107 individuals (median = 997). Our analysis is based on 145 sample years where 30 or more individuals were captured during a run.

For sea lamprey, a single migration phenology was constructed by standardizing daily captures ($C_{ijk}$) for day $i$ into proportions of the total run for year $j$ and tributary $k$, calculating mean daily proportions across years, and repeating these steps across tributaries to obtain the proportion of the run expected on a given Julian date. The resulting phenology did not differ significantly from a normal distribution (Kolmogorov–Smirnov test: $p > 0.05$). Mean date of the phenology was calculated as $\mu = \sum_{i=c_{first}}^{c_{last}} f_i x_i$, where ($f_i$) represents daily frequencies computed from standardized daily captures, $x$ represents the Julian day and $c_{first}$ and $c_{last}$ are the first and last capture days, respectively, across all sea lamprey runs. Standard deviation of the phenology was calculated as

$$\sigma_X = \left( \sum_{i=c_{first}}^{c_{last}} f_i (x_i - \mu)^2 \right)^{1/2}.$$

Mean and standard deviation of the fitted distribution were used in our model to estimate the proportions of the migration run blocked by barrier operations.

**Table 1**
Locations, periods of data collection, median annual catch (minimum–maximum), and years of data available to quantify the phenology of the sea lamprey spawning migration.

| Tributary | Lake | Period | Catch | Years of data |
|---|---|---|---|---|
| Big Carp River | Superior | 1997–2000 | 10 (8–301) | 2 |
| Betsy River | Superior | 1989–1997 | 123 (61–253) | 6 |
| Carp River | Superior | 1988–1997 | 117 (91–221) | 6 |
| Manistique River | Michigan | 1983–1998 | 14,323 (7668–21,107) | 15 |
| Peshtigo River | Michigan | 1978–1998 | 447 (247–2611) | 14 |
| Ausable River | Huron | 1988–1995 | 309 (51–983) | 8 |
| Bridgeland Creek | Huron | 1979–2001 | 1033 (178–5181) | 24 |
| Echo River | Huron | 1987–2001 | 2045 (105–5716) | 15 |
| Ocqueoc River | Huron | 1980–1998 | 2771 (473–9836) | 15 |
| Big Creek | Erie | 1996–2001 | 212 (7–997) | 5 |
| Cobourg Brook | Ontario | 1998–2001 | 219 (168–258) | 4 |
| Duffins Creek | Ontario | 1981–2001 | 1059 (149–2414) | 21 |
| Humber River | Ontario | 1987–1996 | 2117 (473–9836) | 10 |