FISH PASSAGE FOR LAKE STURGEON: A LITERATURE REVIEW

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The health of aquatic ecosystems is dependent on healthy and diverse fish communities. Fragmentation of habitat, including the disruption of traditional migratory routes to spawning sites through barriers such as dams, adversely impacts the capacity of an ecosystem to support diverse fish communities. Fish passage may be used as a mitigation strategy of those impacts. Fish passage for Lake Sturgeon (*Acipenser fulvescens*) is of particular relevance as sturgeon species have been identified as endangered in several of north American jurisdictions. However, passage design criteria for effective up- and downstream migration for sturgeon are not well established. Consequently, we conducted a comprehensive literature review and evaluated the efficiency of existing sturgeon passage to establish baseline information on what has been tested, overall effectiveness, design limitations, and knowledge gaps. Our primary objective was to determine the most effective methods to provide passage for sturgeon at man-made barriers and dams; i.e., what design parameters allow safe up- and downstream passage at the site of either a proposed or an existing barrier. A systematic review and meta-analysis focused on combining and contrasting results from different studies in order to identify patterns among study results, sources of disagreement among those results, and to discover other interesting relationships that came to light in the context of analyzing multiple studies.

1 INTRODUCTION

Lake Sturgeon is a potamodromous fish, well known to undergo extensive movements for feeding, overwintering, and spawning in unimpeded river systems [1]. The species occurs in the North America's Great Lakes, the St. Lawrence River, the Detroit River, in the Mississippi River drainage basin south to Alabama and Mississippi, in the Winnipeg River, Lake Winnipeg, the North and South Saskatchewan rivers, and the Hudson Bay Lowland. Once abundant, the populations have seen a substantial decline across the distribution range with up to 1% of the historic level of density. Commercial harvesting and poaching were thought to be the primary cause for the population declines. However, other stressors such as habitat degradation and blockage of migration routes up to spawning grounds, due to the construction of dams and barriers, are found to be presently major causes for the population declines raising concerns for the effective and efficient recovery of Lake Sturgeon. The fragmentation of riverine ecosystem habitat due to barriers leads to the isolation of populations occurring above and below a given barrier by blocking movements that may take place during certain phases of the species life cycle.Most of the historic rivers within the Lake Sturgeon spatial distribution range have suffered from habitat fragmentation and degradation [2]. In general, the fragmentation of the river ecosystems due to dam constructions altered migration patterns of fish populations and also converted free-flowing rivers to reservoir habitat. Barriers are a critical issue in the river ecosystems, which needs to be addressed to assure successful recovery strategies for Lake Sturgeon. There are several methods to provide connectivity in a riverine ecosystem such as dam removal or establishing of fish passage (Fig. 1). If the removal of the dam is an option, it is likely the best method to re-establish a healthy riverine ecosystem. However, if removal is not an option, fishways may be used to provide connectivity in the river system. Several fishway types exist; however, their designs are conceived for strong swimming fish species such as salmonids and may not work effectively for Lake Sturgeon. Furthermore, temperature is a crucial environmental factor affecting metabolism and swimming performance. As swimming speed and fish swimming performance are main factors in fishway design, this study analyzed how the relationships between swimming speed and performance vary at different temperatures. Furthermore, the passage efficiencies from two case studies (spiral fishway and vertical slot fishway) are presented.

2 MATERIAL AND METHODS

2.1 Data acquisition

The study was carried out based on an extensive scientific literature review on fish passage for Lake Sturgeon. A literature search for articles using the search terms: 'fishway', 'fishpass', 'fish bypass', 'dam', 'passage', and 'sturgeon' was conducted via the ISI Web of Knowledge and the Aquatic Sciences and Fisheries. Furthermore, several principal investigators of projects and authors of papers related to the study were contacted to get the access of their data. More specifically, CanFishPass data, which is searchable database was provided by the author of Hatry *et al.* [3, 4]. Data was available in the Microsoft access data base system, so that required information such as location and type of the dams was transferred into GIS systems (shapefile) using spatial analysis and geo-processing techniques of the ArcGIS. Type of dams and its locations were also downloaded from many sources such as from Socioeconomic Data and Applications Center (SEDAC) of NASA (http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01/data-download).

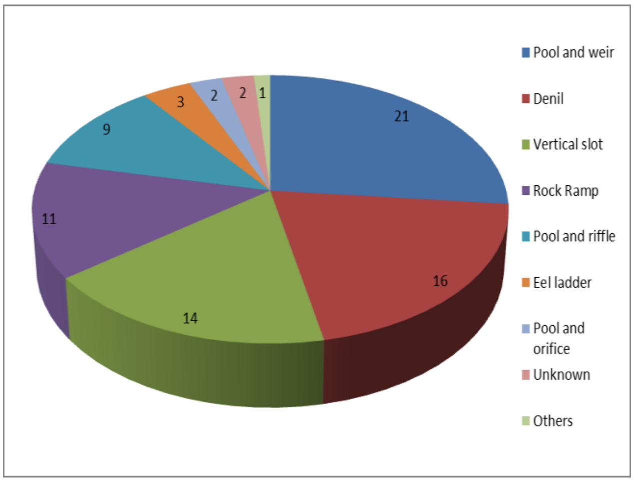

Figure 1. Percentage of different types of fish passage within the Canadian distribution range of Lake Sturgeon.

2.2 Swimming performance

A literature review on the swimming performance of sturgeon in both lab and field settings was conducted (Table 1). The data (n=232) related to temperature and swimming performances was first evaluated for normality using log transfer procedures. It was then determined whether Endurance (*ET*) depends on swimming speed (*SS*) at different temperature (at three treatments of temperature of 7 °C, 14 °C, and 21 °C). *ET* was defined as the amount of time a fish can swim at a particular velocity [5]. The relationship of *ET* and *SS* from the literature was determined using a linear model. Among the three temperature treatments, sample sizes varied (the smallest one was 55 sample sizes), which may introduce a bias in the comparison among the three treatments. Therefore, the linear relationship between *ET* and *SS* was run 1000 times by randomly selecting 50 samples out of 55 samples for each treatment. Consequently, a 1000 slopes (or coefficients) of the relationship between *ET* and *SS* for each treatment were obtained. The slopes represent the rate of change of one variable as a function of changing in other. The smaller and large slopes represent a weak and strong relationship between *ET* and *SS*, respectively. In order to find out whether the relationship of *ET* vs *SS* varied with temperature, an ANOVA was conducted using slopes of *ET* vs *SS* for each treatment (1000 slopes for each treatment).

3 RESULTS AND DISCUSSION

3.1 Swimming performance of Lake Sturgeon

The swimming performance of fish is often evaluated by determining the endurance time and the critical swimming speed (U_{crit}) of a species. The endurance (amount of fish swimming time) decreases as swimming speed increase. However, the relationship varies with water temperature (at 7 °C: $r^2 = 0.67$, slope = -13.22, p <

0.01; at 14 °C: $r^2 = 0.75$, slope = -14.18, $p < 0.01$; at 21 °C: $r^2 = 0.87$, slope = -20.93, $p < 0.01$). The relationship between *ET* and *SS* was stronger under higher water temperature than under lower water temperature (Fig. 2, $F_{2,2994} = 52646$, $p < 0.01$.), indicating that Lake Sturgeon fatigued faster under higher water temperature.

Table 1. Studies analyzing swimming performance of different sturgeon species.

Target species	**Temp (°C)**	**Critical swimming speed**	**Note**	**Literature**
Adult Shovelnose Sturgeon	16	65-116 $cm \cdot s^{-1}$		[6]
Lake Sturgeon (15.7 cm)	15	38 ± 4.2 $cm \cdot s^{-1}$	Lake Sturgeon has 3.5 times higher drag per unit area than other actinopterygian fish, probably because of the existence of scutes	[7]
Lake Sturgeon			Lake Sturgeon has inferior swimming capability than salmonids	[5]
Juvenile White Sturgeon			External transmitters reduced swimming performance of tagged juvenile sturgeon	[8]
Adult White Sturgeon			Swimming speed increase when tail beat frequency increases but as sturgeon total length increases the tail beat frequency decreases.	[9]
Lake Sturgeon (93.9-162.5 cm)	11- 20		Even though Lake Sturgeon's volitional entry into the vertical fishways was 82.2%, its overall efficiency was only 36.4%	[10]

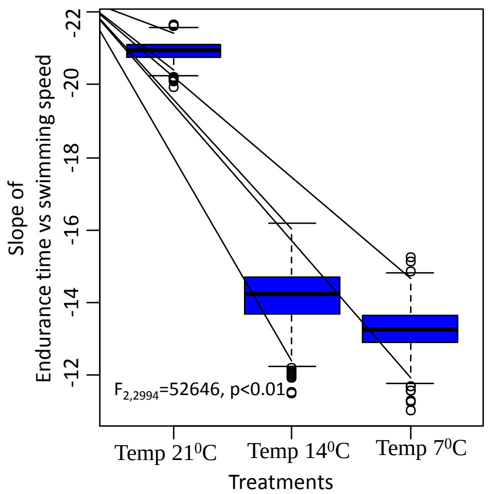

Figure 2. Analysis of variance of the slope of Endurance Time (*ET*) vs Swimming Speed (*SS*) for three temperature treatments (7 °C, 14 °C, and 21 °C).

3.1 Case study: Lake Sturgeon Passage in a Prototype Side-Baffle Fishway

Kynard and colleagues [10] studied the passage of Lake Sturgeon in a side-baffle fishway (spiral fishway) at the USGS S.O. Conte Lab in Turner Falls, Massachusetts. The side-baffle fishway had a slope of 6.3% (30.5 cm rise over 487.7 cm length), and the channel was 1 m deep and 1 m high on a 6.1 m diameter circle. The side baffles, alternating along the in- and outside channel walls, created a sinusoidal water flow with a large eddy behind each outside baffle. Fish behavior of juvenile (mean total length, L_t = 87 cm) and adult Lake Sturgeon (L_t = 140 cm) were observed in this structure and results revealed that 46-73% of the juveniles ascended the fishway and 91% of the adults moved to the top of the fishway. Descending juveniles moved tail-first (86.3%) orientating their body with the help of their pectoral fins. Consequently, slot size and water velocities were the important factors for Lake Sturgeon passage.

3.2 Case study: Lake Sturgeon Passage in the Vianney-Legendre vertical-slot fishway, Quebec, Canada

The fishway has 17 pools in total with a length of 48.5 m and a width of 9.60 m, 13 regular pools (3.5 m x 3.0 m), 2 turning pools, plus entrance and exit pools. The elevation change is 2.55 m [see 11 for further details on the fishway design]. Although most sturgeon entered and attempted to pass the vertical slot fishway (82.2%), passage efficiency was only of 36.4% [12]. Passage failure mainly occurred in the downstream portion of the fishway, and the turning basins presented a potential obstacle to sturgeon passage. Of the 56 individuals that failed passage, 20 failed in the two large “turning” basins; also, fish spent disproportionately more time in the turning basins than in regular basins, particularly in the first turning basin. There was no effect of body size on passage efficiency. Sturgeon that failed to pass swam an additional 49 m farther compared with those that passed on their first attempt.

4 CONCLUSION

Most of the existing fishways in the distribution range of Lake Sturgeon are targeted for salmonid species. Due to the inferior swimming performance of Lake Sturgeon in comparison to salmonids in terms of burst swimming, these fishways may not adequately accommodate Lake Sturgeon for a successful fish passage. Consequently, future fishway designs should consider the swimming performance and leaping abilities of Lake Sturgeon and velocities in the fishway should be lower than the maximum sustained swimming speed of Lake Sturgeon.

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