Assessing the potential movement of invasive fishes through the Welland Canal

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Abstract

Aquatic invasive species have become one of the most serious threats to freshwater biodiversity due to the severe negative impacts they can have on native ecosystems. Examining the potential pathways that aquatic invasive species may use to invade and spread throughout the Great Lakes basin is a critical step in preventing their spread. This study focused on a major shipping canal, the Welland Canal, as a possible dispersal corridor for invasive species within the Great Lakes basin, specifically evaluating the ability of fishes to utilize canals and locks as a dispersal corridor between waterbodies. To determine the extent to which fishes were moving within the canal and through the eight locks, we captured, tagged, and released 179 fish of 10 species within the canal with acoustic tags and tracked their movement using 34 acoustic receivers placed in strategic locations within the system. Seven tagged fish (3.9%) moved from the canal into lakes Ontario or Erie. Within the canal, only one fish (0.6%) moved through the flight locks (locks 4, 5, and 6). These results indicate that fishes can move through the Welland Canal and out of it into lakes Ontario or Erie, but that the locks, particularly the flight locks, limit such dispersal.

Keywords; movement; telemetry; basin connectivity; Welland Canal; freshwater fishes

Introduction

In North America, extinction rates for freshwater fauna are five times higher than those for terrestrial faunal groups and rival those that are currently occurring in tropical forests due to wide spread habitat alteration, pollution, overexploitation, and the introduction of invasive species (Dextrase and Mandrak 2006; Jelks et al. 2008; Ricciardi and Rasmussen 1999). In the Great Lakes basin, these changes have resulted in the global extinction of three taxa and the extirpation of 18 species, lowering the number of currently extant native species from 169 to 149 species (Mandrak and Cudmore 2010). An additional 82 species have declined to the point of endangerment in at least one jurisdiction in the basin (Mandrak and Cudmore 2010). Globally, the Great Lakes region is one of the most severely invaded areas with an estimated 182 established invasive species (Ricciardi 2006). The establishment of aquatic invasive species have played a key role in the endangerment of 26 of 41 Canadian freshwater fish species and six of 11 freshwater molluscs, including many in the Great Lakes basin, assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Dextrase and Mandrak 2006).

In recent years, bighead carp (*Hypophthalmichthys nobilis*), silver carp (*H. molitrix*), grass carp (*Ctenopharyngodon idella*), and black carp (*Mylopharyngodon piceus*), collectively known as Asian carps, have become established in the Mississippi River basin and have had significant ecological and socio-economic impacts on its ecosystem (Chapman and Hoff 2011; Kolar et al. 2007). Asian carps have a very high likelihood of successful establishment should they enter the Great Lakes system and their spread will negatively affect natural lake ecosystems in the long term (Cudmore and Mandrak 2011, Cudmore et al. 2012). Recently, there is confirmed evidence of grass carp recruitment in the Lake Erie basin (Chapman et al. 2013). In Ontario waters, four triploid adult Grass Carp have been caught in Lake Erie and one triploid, six diploid, and one

unknown ploidy adults have been caught in Lake Ontario between 2013 and 2015 (DFO, unpubl. data; Marson et al. 2014). It is critical to assess potential pathways to fully understand how these and other aquatic invasive species could spread in the Great Lakes, and what can be done to prevent spread and establishment (DeGrandchamp et al. 2008).

Prevention is viewed as the most effective action at keeping aquatic invasive species from further damaging aquatic ecosystems (Keller et al. 2008; Kerr et al. 2005; Wittmann et al. 2014a), especially given that eradication of aquatic invasive species is often impossible and costs of active management are generally extremely high (Keller et al. 2008; Leung et al. 2002). Examining the pathways in which these aquatic invasive species enter novel aquatic systems has become a key focus for preventing their spread (Mandrak and Cudmore 2004; Wittmann et al. 2014a; Wittmann et al. 2014b), as spread is heavily dependent on human facilitation (Drake et al. 2015; Kerr et al. 2005). Canals and shipping channels have been identified as a potential vector because these artificial waterways can be used by invasive species to reach ecologically suitable areas that were not historically accessible to them (Kerr et al. 2005; Pagnucco et al. 2015).

The Welland Canal has been identified as a pathway for direct (dispersal) and indirect (shipping) bi-directional movement of aquatic invasive species, between Lake Ontario and Lake Erie (Griffiths et al. 1991; Mills et al. 1993; Rothlisberger and Lodge 2013). For example, sea lamprey (*Petromyzon marinus*) in 1921, alewife (*Alosa pseudoharengus*) in 1931, American eel (*Anguilla rostrata*) in 1850, and white perch (*Morone americana*) in 1950, are thought to have dispersed through the Welland Canal from Lake Ontario to Lake Erie (Daniels 2001; Mills et al. 1993; Pearce et al. 1980; Sullivan et al. 2003). rainbow smelt (*Osmerus mordax*), initially released into Crystal Lake, MI in 1912, is thought to invaded Lake Ontario by 1931 from Lake Erie via the Welland Canal (Daniels 2001; Mills et al. 1993). In contrast, threespine stickleback

(*Gasterosteus aculeatus*), ruffe (*Gymnocephalus cernua*), and tubenose goby (*Proterorhinus marmoratus*) likely have dispersed through the canal in ballast water (Crossman 1991; Grigorovich et al. 2003). Round goby (*Neogobius melanostomus*) likely used both pathways: originally transported in ballast water to the St. Clair River by 1990 then spreading throughout Lake Erie and dispersing into Lake Ontario by 1998 through the Welland Canal (Grigorovich et al. 2003; Jude et al. 1992). However, there has been no direct evaluation of fish movement using the Welland Canal system (Daniels 2001; Cudmore et al. 2012). Nonetheless, this route could be a future pathway for the spread of Asian carps and other aquatic invasive species into lakes Erie or Ontario, depending on their origin. Given the urgent need to assess potential fish dispersal between lakes, we conducted a three-year telemetry study to examine how fishes moved within the Welland Canal through locks.

Material and methods

Study site

The Welland Canal is an active shipping canal that extends 43.4 km from Port Weller on Lake Ontario to Port Colborne on Lake Erie (Fig. 1). The canal has a total lift of 99.5 m through a series of eight locks that enable ships to ascend and descend the Niagara Escarpment to bypass Niagara Falls (SLSMC 2003). The locks are 233.5 m long by 24.4 m wide, with an average lift of 14.2 m. They can accommodate vessels up to a maximum of 225.5 m in length and 23.8 m in width (SLSMC 2003). Seven locks are located closer to Lake Ontario and one lock is near Lake Erie. The flight locks (locks 4, 5, and 6) have a combined lift of about 50 m in height and operate adjacently with no open canal between each lock (Fig. 1; SLSMC 2003).

Annually, over 30 million tonnes of cargo and over 3000 vessels travel through the Welland Canal (USACE 2009). From 2012 to 2015, individual locks were opened and closed a total of 113,835 times (St. Lawrence Seaway Management Corporation (SLSMC), unpubl. data). Each lock, on average, opens and closes about 10 times per day. On average for 2012-2014, 61.1% of lock operations were for commercial vessel traffic, 5.4% were for pleasure craft traffic, and the remaining 33.5% were for turnback, also referred to as dummy lock (i.e. lock operation without a vessel, generally associated with preparation of lock for the next approaching vessels) (SLSMC, unpubl. data). The Welland Canal is closed annually, January – March, and partially drained to allow for maintenance.

Acoustic telemetry receiver array

To assess the movement of fishes in the Welland Canal, acoustic receivers were deployed in strategic locations to track tagged fish movements within the canal and between lakes Erie and Ontario. Receiver sites were selected to cover the entrances and exits to all locks in the canal, including reaches between locks (numbered based on the lower numbered lock of adjacent pairs), a major side channel that leads to Port Dalhousie, and where the canal meets lakes Erie and Ontario in Port Colborne and Port Weller, respectively (Fig. 1). Acoustic receivers (VR2W 69 kHz, Vemco, Halifax, NS) were deployed in the Welland Canal from 2012 to 2015. The receivers were moored by attaching each to a steel cable with a buoy on one end and cinderblock on the other end, which fixed them to the bottom of the canal. To place the receivers, a steel mooring cable connected the receiver to a point at the surface. This cable was used to deploy and retrieve the receivers by hand. In 2012, 21 acoustic receivers were deployed throughout the year.

Based on the 2012 data, an additional 13 acoustic receivers were deployed (total of 34 receivers) in 2013 and 2014 to provide more complete coverage, particularly in a side channel, Lake Gibson and Twelve Mile Creek to Port Dalhousie, with two Ontario Power Generation dams (Decew I, II) and Heywood Generating Station. All 34 receivers were removed from the study site by June 2015. Receivers that went missing and/or were damaged (6 in 2012, 4 in 2013, 0 in 2014) were replaced with new receivers.

Tagging and release of fishes

In December 2011, range testing was conducted using four stationary acoustic receivers deployed at fixed distances (90 – 410 m) in a line in the Welland Canal with series of transmitter tags (Vemco V7, V9, V13 tags). We tested the transmitters by moving them across seven fixed distances for 24 h, accounting for boat traffic (12 vessels/day; SLSMC, unpubl. data), lock operations, and weather conditions for seven days (Kessel et al. 2014). The V9 tag performed best and had 80% detection rate (i.e. detection rate = number of observed detections / number of expected detections * 100, where number of expected detections is calculated from the known delay between tag transmission and the time interval selected; Vemco 2015) at 409.9 m from the acoustic receiver (VR2W 69 kHz, Vemco). Fishes were collected in the Welland Canal using gill netting (2012) and boat electrofishing (2013), and tagged with acoustic transmitters (V9-2L, Vemco) through surgical implantation. A range of species were tagged including (in order of total number used): common carp (*Cyprinus carpio*) and other large-bodied fishes with varying swimming abilities such as freshwater drum (*Aplodinotus grunniens*), smallmouth bass (*Micropterus dolomieu*), northern pike (*Esox lucius*), brown bullhead (*Ameiurus nebulosus*), largemouth bass (*Micropterus salmoides*), white sucker (*Catostomus commersonii*), channel catfish (*Ictalurus punctatus*), goldfish (*Carassius auratus*), and shorthead redhorse (*Moxostoma*

macrolepidotum) (mean weight = 2.07kg, n = 179; Table 1). There is no one species that would best represent Asian carps; these 10 species were selected based on their availability in the canal, body size, and varying swimming abilities. gizzard shad (*Dorosoma cepedianum*) and bigmouth buffalo (*Ictiobus cyprinellus*) would be good surrogate species based on their feeding ecology (Cudmore et al. 2012), but their sensitivity to tagging procedures and limited availability in the canal, respectively, excluded them from this study. Upon capture, fishes were anesthetized using clove oil (mixed into a stock solution (10:1) with 99 % ethanol as solvent). Surgeries were performed using a small incision (~10 mm) to the fish between the pelvic and anal fin. This incision allowed for the placement of a 29 mm acoustic telemetry tag into the body cavity of the fish, using a minimum fish weight of 30 grams to ensure the tag weight to be less than 2% of the fish weight. The incision was closed with 2-3 absorbable monofilament sutures (PDS-II, 4-0, Ethicon, Inc., Somerville, NJ). The V9-2L transmitters were cylindrical (9 X 29 mm), weighed 3.3 g in water, and had an estimated transmission life of 2 years (~559 days: 267 days on, 90 days off (i.e. January to March), then on). Each transmitter emitted a unique code on random intervals ranging from 60 to 180 seconds. After the surgery, all fishes were held in live wells for a minimum of 30 min before release.

From June 29 to July 13, 2012, a total of 79 fish of seven species were tagged and released (Table 1). All fishes were collected using gill netting, with 30 m gill nets with 0.64 - 3.8 cm mesh set for approximately an hour in water temperatures ranging 20 – 25 °C. Of the 79 fish, 51 were released downstream of the flight locks in the lower side pond found between locks 3 and 4; upstream of the flight locks, 16 fishes were released in the upper side pond found between locks 6 and 7; and 12 fishes were released in the canal between locks 7 and 8 (Fig. 1). In 2013, a total of 100 fish of 10 species were tagged and released, July 2 – July 4. All fishes were collected

by boat electrofishing. To improve detection by receivers in 2013, 50 tagged fish were released directly in the canal between locks 2 and 3 downstream of the flight locks, and 50 tagged fish were released directly in the canal between locks 7 and 8 upstream of the flight locks (Fig. 1). No additional fish were tagged in 2014.

All detections observed by all receivers were used by using the specific tag codes with the assumption that receivers detected all fish that passed them. For data analysis, all fish detections were pooled monthly and spatially by receivers positioned in close proximity to represent particular locations (Port Weller, Port Dalhousie, Port Colborne, Lake Gibson) or reaches (note that reaches 4-5 were within the flight locks and excluded from analysis due to lack of channel between them). A fish was considered passing a lock if it was detected in one reach and then subsequently detected in either an adjacent upstream or downstream reach separated by a lock. The proportion of fish passing a lock was calculated by dividing the number of fish passing a lock by the total number of fish detected (i.e. 148 fish).

RESULTS

Throughout the three-year study, 148 (82.7%) of the 179 tagged fish were detected at least once. Seven (4.7%) fish, only freshwater drum and common carp, moved out of the Welland Canal to either Lake Ontario or Lake Erie in 2012, 2013, and 2014. Twenty-one (14.2%) fish moved through the locks at least once, most commonly through lock 3 and, least commonly, only one fish (0.6%) through the flight locks.

In 2012, two fish (one common carp, one freshwater drum) were detected leaving the Welland Canal towards Lake Erie, where they passed through 1 or 2 locks and moved about 20 km upstream towards Lake Erie (Fig. 2). In addition, one freshwater drum moved through the

flight locks from the upper pond (above the flight locks) to Reach 3 between locks 3 and 4 (Table 2).

In 2013, five fish (four freshwater drum, one common carp) were detected leaving the Welland Canal and three fish (two freshwater drum, one common carp) were detected moving 7 km downstream towards Lake Ontario through two locks (Fig. 2). In addition, two freshwater drum were detected moving towards Lake Erie through one lock and travelling about 25 km upstream (Fig. 2). No fish were recorded passing through the flight locks (Table 2).

In 2014, five fish were detected re-entering the Welland Canal and four fish were detected leaving the Welland Canal (Fig. 2). From Lake Ontario, one common carp and two freshwater drum were detected re-entering, moving upstream about 10 km through two to three locks. Subsequently, two freshwater drum were detected leaving the canal towards Lake Ontario, one fish travelling downstream about 7 km through two locks. From Lake Erie, two freshwater drum were detected re-entering, travelling downstream about 28 km through one lock and, subsequently, turning around and leaving the canal towards Lake Erie, travelling upstream about 28 km through one lock. No fish were recorded passing through the flight locks.

Of the tagged fishes detected at least once by the acoustic receivers (148 fish), 29 (20 %), 121 (82 %), and 66 (45 %) never passed a lock, respectively in 2012, 2013, and 2014 (Fig. 3). In 2012, 6 fish (4 %) passed through a lock once, 1 (1%) passed through a lock twice, and 1 (1%) passed through a lock more than twice. In 2013, 17 (11 %) passed through a lock only once, and 3 (2 %) passed through a lock twice. In 2014, 7 fish (5 %) passed through a lock once, 1 (1 %) passed through a lock twice and 1 (1 %) passed through a lock more than twice (Fig. 3). The number of fishes that passed through locks was not significantly different between years (one-way ANOVA: $F_{2,6} = 0.43$, $P = 0.67$; Fig. 3). Fish passed through lock 3 the most, followed by

lock 2, lock 8, locks 1 and 7, and the flight locks (4-6) (Table 2). Of the tagged common carp, 12 (9 %) moved through lock 3, followed by 2 (66 %) channel catfish, 1 (14 %) northern pike, and 1 (14 %) brown bullhead. For lock 2, 5 (4 %) common carp passed, followed by 3 (33 %) freshwater drum, and 1 (14 %) northern pike. For lock 8, 5 (56%) freshwater drum and 1 (1%) common carp passed. For lock 1, 3 (33%) freshwater drum and 2 (2%) common carp passed. For lock 7, 3 (2%) common carp, 1 (14%) northern pike, and 1 (11%) freshwater drum passed (Table 2).

Discussion

Our results demonstrate that fishes are able to pass through locks in the Welland Canal. Assuming detection was perfect for all receivers, four fish moved from the canal into Lake Erie and three fish into Lake Ontario. Considering the low number of fishes observed leaving the canal, such movement appears to be a rare event but likely to occur given the very large number of fishes present in the canal. Only one tagged fish, a freshwater drum, moved through the flight locks, which appear to be a major barrier within the Welland Canal. More than 30 individuals of five species were detected passing through one or more locks within the system multiple times (Fig. 3, Table 2). In addition, a tagged common carp released in Toronto Harbour was detected in Lake Erie in 2014 through Great Lakes Telemetry Acoustic Observation System (GLATOS) (C. Vandergoot, Ohio Department of Natural Resources, pers. comm.).

Although our results show that movement through locks in the Welland Canal is relatively low (4%), only a small number of individuals (< 20) is required for a high probability (75-100%) of establishment of Asian carps in the Great Lakes basin (Cuddington et al. 2014).

The likelihood of Asian carp arrival and establishment in the Great Lakes is high (Cudmore et al. 2012) or, in the case of grass carp, may have already occurred (Chapman et al. 2013). Spread is likely to occur relatively quickly among the freely connected Erie, Huron, and Michigan basins, but the ability to disperse through the locks in the Welland Canal into, or out of, the Ontario basin has been identified as a knowledge gap (Cudmore et al. 2012).

Our study informs several key management options that could be readily applied to control direct movement of aquatic invasive species. There is limited movement completely through the Welland Canal, and the flight locks act as a major barrier within the system. Therefore, the flight locks may be the most plausible control point to decrease the probability of fish movement directly through the Welland Canal. Various non-permanent barriers to fish movement using electricity, sound, bubble, light, CO₂, modified lock operation (e.g. flushing, anoxia) are being developed, tested, and deployed (DFO, unpubl. data; Noatch and Suski 2012; USACE 2015). By deploying one or more barriers at control points, such as the flight locks, the spread of aquatic invasive species through the Welland Canal may be preventable. However, further research is needed to address some knowledge gaps. The winter draining in the Welland Canal should be examined to determine if it facilitates movement of fishes, including aquatic invasive species into either lakes Erie or Ontario. It appears from our study that fishes are not bypassing the canal through hydroelectric dams (e.g. Decew I, II; Heywood Generating Station); however, determining if fishes are able to pass through the hydroelectric dams is important. While Niagara Falls is considered a major geographic barrier, relatively little is known about direct movement and survival of fishes over the falls, a potential pathway for spread from Lake Erie to Lake Ontario. Additional research would help refine the management options for aquatic invasive species, especially for artificial structures such as canals, locks, and hydroelectric dams.

Our study evaluated how fishes move within the canal and did not directly evaluate the extent of fish movement between lakes Erie and Ontario through the canal. The fish tagged in our study may have been resident to the canal, may carry out their entire life cycle in the canal, and may not move to either lake during their lives. As a result, our results may be an underestimate of the extent to which fish move between the lakes through the canal. Such movement could be more directly measured by tagging fishes in both lakes adjacent to the canal entrances; however, as many of the tagged fish may not actually enter the canal, many more fish would need to be used than were tagged in our study. Reciprocal transplants of tagged fishes might increase the number of fish attempting to move through the canal to the lake of their capture; however, such studies would be subjected to restrictions regulating the human movement of fish.

As with any telemetry study, there are potential limitations to the use of acoustic telemetry for fish movement studies (Donaldson et al. 2014; Hayden et al. 2014; Holbrook et al. 2011; Heupel and Webber 2012). By using acoustic telemetry, there is the potential for unpredictable technical issues. It is possible that the acoustic receivers did not detect all of the tagged fishes due to defective tags and receivers, sub-optimal placement of the receivers, missing and lost receivers, damage from being deployed throughout all seasons, and the possibility of theft or tampering. Although we conducted several range tests in the system prior to our study, uncontrollable influences, such as ambient noise, shipping traffic, and regular lock operations, may have interfered with the telemetry system. Lastly, as with all tagging studies, there is always the chance for mortalities or unanticipated expulsion of tags.

In conclusion, it is clear that fishes can move directly through the canal and lock system in the Welland Canal. Potential aquatic invasive species, such as Asian carps, may exploit this

pathway to spread to other basins within the Great Lakes system if they arrive in lakes Erie or Ontario. Monitoring and implementing mitigation measures to prevent movement through this potential dispersal corridor are vital steps in preventing the spread of future aquatic invasive species through the Great Lakes region.

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Figure captions.

Figure 1. Study site in the Welland Canal with locks, receivers, release locations, and dams (top inset shows general location of study site in the Great Lakes basin)

^a receivers (4) did not have data for July – November, 2012

^b receivers (2) did not have data for September – October, 2012

^c receivers (3) did not have data for December, 2013 – April, 2014

^d receiver (1) did not have data for October, 2013 - April, 2014

Figure 2. Number of fishes detected monthly in 2012 (□), 2013 (■), and 2014 (▒) at six locations: Port Weller; Port Dalhousie; Port Colborne; Reaches 1-3, between locks 1 and 4; Reaches 6-7, between locks 6 and 8; and, Lake Gibson

Figure 3. Number of fishes detected passing the locks of the Welland Canal in 2012 (□), 2013 (■), and 2014 (▒)

Table 1. Summary of fishes tagged and detected in the Welland Canal.

Common Name	Scientific Name	2012						2013					
		Tagged			Detected			Tagged			Detected		
		N	Mean Fork Length (mm)	Mean Weight (kg)	2012	2013	2014	N	Mean Fork Length (mm)	Mean Weight (kg)	2013	2014	2015
Common Carp	<i>Cyprinus carpio</i>	68	495 (66)	1.39 (55)	27	42	11	63	612	3.37	56	42	17
Freshwater Drum	<i>Aplodinotus grunniens</i>	2	429	0.89	2	1		7	559	2.24	7	5	
Smallmouth Bass	<i>Micropterus dolomieu</i>	5	407	0.99	5	2		4	309	1.11	4	1	
Largemouth Bass	<i>Micropterus salmoides</i>	1	440	1.24	1	1		5	378	0.82	4	1	
Northern Pike	<i>Esox lucius</i>	1	NA	NA	1	1	1	6	611	1.52	6	5	2
White Sucker	<i>Catostomus commersonii</i>	1	454	0.95	-	-		3	420	0.96	3	2	1
Brown Bullhead	<i>Ameiurus nebulosus</i>	1	475	1.05	1	1	1	6	323	0.46	6	2	1
Channel Catfish	<i>Ictalurus punctatus</i>							3	462	0.99	2	2	2

Goldfish	<i>Carassius auratus</i>							2	397	1.02	2	1	
Shorthead Redhorse	<i>Moxostoma macrolepidotum</i>							1	424	0.76	1	1	1
TOTAL		79	486 (76)	1.33 (65)	37	48	13	100	551	2.55	91	62	24

Table 2. Summary of fishes passing through locks in the Welland Canal.

Species	Lock 1			Lock 2			Lock 3			Flight locks (4-6)			Lock 7			Lock 8		
(Tagged N)																		
	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
Common	1	1		3	2	5	6	1					2	1	1			
Carp (131)																		
Freshwater	2	1		2	1					1			1			1	2	2
Drum (9)																		
Northern						1		1						1				
Pike (7)																		
Brown								1										
Bullhead (7)																		
Channel								2	2									
Catfish (3)																		
Subtotal	0	3	2	0	5	4	5	10	3	1	0	0	1	3	1	2	2	2
Total	5			9				18			1		5			6		