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Direct observations of fish incapacitation rates at a large electrical fish barrier in the Chicago Sanitary and Ship Canal

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ABSTRACT

The electric barrier system in the Chicago Sanitary and Ship Canal was designed to eliminate interbasin transfer of aquatic nuisance species between the Mississippi River and Great Lakes Basins. Electrical output was recently increased in an effort to more effectively eliminate the upstream migration of bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*). Using gizzard shad (*Dorosoma cepedianum*) as a surrogate species, we examined the effectiveness of the barrier at incapacitating fish by placing them in a non-conductive cage and transporting the fish through the barrier. This experiment was conducted before and after changes in operating parameters. Higher electrical output increased barrier effectiveness by decreasing the distance required to incapacitation. Overall, 97% and 100% of fish became incapacitated at the lower and higher electrical operating parameters, respectively. Fish were incapacitated the soonest during the winter and spring, which was likely influenced by the reduced movement activity in the cooler months and the larger fish available for testing later in the spring. Moreover, effectiveness was influenced by type of boat hull material used during testing. Fish that were transported through the barrier along an aluminum-hull boat were able to swim nearly twice the distance into the barrier as those transported with a fiberglass-hull boat during the summer. The delayed incapacitations along the aluminum boat were presumably due to distortion of the electrical field caused by the conductive hull. These results raise concerns regarding the effect that metal-hull barges might have on the effectiveness of the barrier during navigation.

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Introduction

The Laurentian Great Lakes Basin has a long history of exotic species introductions (Mills et al., 1966; Holeck et al., 2004). Additional, potential invaders of concern, namely bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*), are well established in the nearby Mississippi River Basin. These two species are of particular concern to fisheries managers because of their rapid population growth and planktivorous feeding, which may compete with native larval fishes and adult filter-feeding fishes (Chick and Pegg, 2001; Schrank et al., 2003; Irons et al., 2007; Cooke and Hill, 2010). These fish also have the potential to negatively affect a $7 billion per year fishing industry in the Great Lakes (Buck et al., 2010).

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The Chicago Area Waterway System (CAWS; Fig. 1) is a network of canals and heavily-modified rivers that artificially link the Great Lakes and Mississippi River Basins that can serve as a conduit for interbasin, invasive species exchange (Jerde et al., 2011). In 1990, the U.S. Congress authorized the U.S. Army Corps of Engineers (USACE) to study non-physical barriers in the CAWS in an effort to prevent the invasion of the non-native round goby (*Neogobius melanostomus*) into the Mississippi River Basin (Sparks et al., 2010). Based on factors such as cost, success likelihood, environmental impact, commercial availability, permit requirements, and effects on existing uses of the CAWS, an electrical barrier was recommended as the best option as a non-physical fish barrier (Moy et al., 2010).

In April 2002, an electric Demonstration Barrier was activated in the Chicago Sanitary and Ship Canal (CSSC), yet, downstream dispersal of round goby had occurred six years prior to its construction (Steingraeber and Thiel, 2000; Sparks et al., 2010). This electrical barrier system, the largest in the world, is much different than any other past or present electrical barriers in several respects, and it has been expanded greatly since its original construction (described below). The section of

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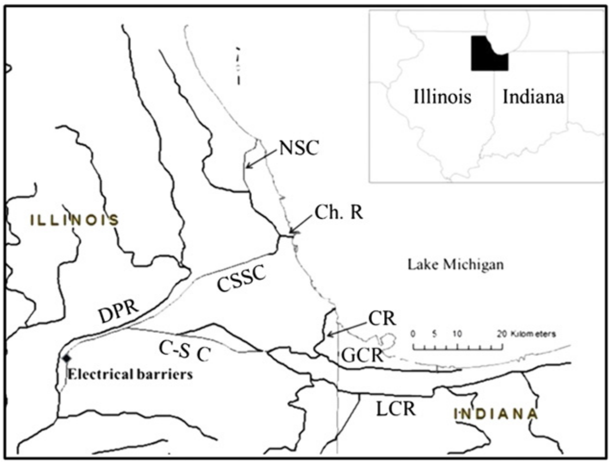

Fig. 1. Chicago Area Waterway System, important tributaries and canals, as well as the location of electrical barriers indicated by the black diamond. CR = Calumet River, C-S C = Cal.-Sag Canal, Ch. R = Chicago River, CSSC = Chicago Sanitary and Ship Canal, DPR = Des Plaines River, GCR = Grand Calumet River, LCR = Little Calumet River, NSC = North Shore Canal.

the CSSC where the barriers are located, near Romeoville, Illinois, is 57-m wide and 7.7-m deep; flow and conductivity fluctuate greatly throughout the year, and the canal is actively used for commercial and recreational vessel navigation (Moy et al., 2010; Sparks et al., 2010).

Despite being constructed post-invasion of round goby, the electric barrier system is still being used as a primary barrier to interbasin transfer of aquatic nuisance species in general. The effectiveness of electrical fish barriers has been evaluated in controlled laboratory and field settings (Barwick and Miller, 1996; Savino et al., 2001; Dawson et al, 2006; Holliman, 2011) and at smaller permanent barrier locations in small streams and canals that do not facilitate navigation (Swink, 1999; Verrill and Berry, 1995; Maceina et al., 1999; Clarkson, 2004). Effectiveness of electrical barriers in controlled laboratory settings were evaluated via direct observation. Studies in field settings relied on indirect assessment methods such as mark–recapture, and telemetry, as well as sampling above the barrier for the targeted species. Although the barriers in the abovementioned studies were largely effective, only Maceina et al. (1999) found their electric barrier to be 100% effective at inhibiting the movement of the targeted fish. Causes of barrier breach in other studies included persistent challenging of the barrier by the fish (Barwick and Miller, 1996; Savino et al., 2001; Dawson et al., 2006; Holliman, 2011), increased water flows (Verrill and Berry, 1995), or unknown causes (Swink, 1999). Clarkson (2004) extensively documented numerous problems that arose at a barrier in an Arizona canal, mainly power outages, that resulted in grass carp (*Ctenopharyngodon idella*) breach of the barrier.

The first studies to directly test the effectiveness of the Demonstration Barrier in the CSSC were by Dettmers et al. (2005) and Sparks et al. (2010). Dettmers et al. (2005) passed encaged fish (Catostomidae spp., *Morone* spp., and common carp [*Cyprinus carpio*]) through the Demonstration Barrier alongside metal-hull barges and fiberglass boats, finding that some fish that were towed along the metal-hulled barges were never incapacitated as they swam through the barrier. Dettmers et al. (2005) attributed the delayed and non-incapacitations to a distortion of the electrical field by the barges. The fiberglass boats did not cause any electrical distortion and all fish that were moved alongside it were incapacitated (Dettmers et al., 2005). Sparks et al. (2010) released 130 common carp with surgically-implanted, combined radio-and-acoustic transmitters downstream of the barrier. One fish was able to breach the barrier, which was later determined to have coincided with the passage of a barge through the barrier. This gave rise to the hypothesis that either (a) the fish was involuntarily entrained by the barge or (b) the barge distorted the electrical field, allowing the fish to swim alongside the barge in an electrical void (Sparks et al., 2010).

Shortly after the fish breach was recorded by Sparks et al. (2010), the operating parameters of the Demonstration Barrier was increased from 2 ms, 2 Hz, < 0.39 V/cm to 4 ms, 5 Hz, and 0.39 V/cm (0.39 V/cm). Following the Dettmers et al. (2005) study, design modifications were implemented to account for the barge-induced electrical distortion to two additional electrical barriers slated for construction. These barriers, Barriers IIA and IIB, began operating in 2009 and 2011 respectively. The newer barriers cover a much larger area than the Demonstration Barrier and are capable of generating electrical fields of much higher intensity. The two barriers consist of two downstream, wide arrays that emit a weak electrical field and two upstream, narrow arrays that emit the maximum target voltage. Parasitic structures are in place above and below the main barrier arrays to contain all “stray” electricity within the barrier system (Table 1; Holliman, 2011). The purpose of this gradual increase in voltage, moving from downstream to upstream, is for fish to slowly encounter increasing electricity. This allows them to alter their behavior before encountering a narrow, high voltage field meant to incapacitate them. Having only a narrow, high voltage field could induce a panic response in which the fish could continue to swim farther into the barrier until it breaches the barrier under its own momentum (Hartley and Simpson, 1967).

After the completion of Barrier IIA in 2009, additional field testing was performed by Sass and Ruebush (2010). Sass and Ruebush (2010) placed a wide variety of fish directly in the strongest part of the barrier and found that all fish were incapacitated when operating parameters were increased to 6.5 ms, 15 Hz, and 0.79 V/cm. The operating parameters of Barrier IIA were increased to 0.79 V/cm in August 2009 and later increased to 2.5 ms, 30 Hz, and 0.91 V/cm as a result of laboratory work with silver and bighead carps (Holliman, 2011). Holliman (2011) found that 0.91 V/cm incapacitated 100% of small bighead carp that were exposed to gradual increases in voltage in a swim tunnel. However, those parameters were only about 90% effective at preventing fish from swimming through an electrical barrier in a flowing raceway that small bighead carp were allowed to challenge.

The behavior of fish that encounter electrical barriers has been described in both laboratory (McMillan, 1928; Hadderingh and Jansen, 1990; Savino et al., 2001; Dawson et al., 2006; Holliman, 2011) and controlled field settings (Stewart, 1981; Barwick and Miller, 1996). We are only aware of one other study (Sass and Ruebush, 2010) that directly observed fish behavior in the new, larger barriers within the CSSC. Sass and Ruebush (2010) evaluated whether fish would become incapacitated or not by immediately placing the fish into the strongest part of the barrier system. However, they did not investigate the distance in which fish could potentially penetrate the barrier, which could have strong implications for maintenance operations in which barriers are switched from one to the other such that fish could swim

Table 1
Description of caged-fish observation points. For visual representation refer to Fig. 2.

Site number	Description
Site 1	Area downstream of all electrical structures where water-borne electricity is typically minimal.
Site 2	Area immediately downstream of the downstream operating parasitic structure where water-borne electricity is typically minimal.
Site 3	Middle of downstream operating, downstream parasitic structure
Site 4	Area immediately downstream of the downstream operating wide-array, low-field structure
Site 5	Area immediately downstream of the second electrode bank of the wide-array structure
Site 6	Area between the two narrow, high-field arrays where voltage is typically highest.
Site 7	Middle of first operating, upstream parasitic structure
Site 8	Area upstream of all barrier structures where voltage is typically minimal.