U.S. Fish & Wildlife Service - Midwest Region

Fisheries Program

Barge Fish Interaction Study 2016

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Executive Summary

2015 barge entrainment studies

Large Electric Dispersal Barriers were constructed in the Chicago Sanitary and Ship Canal (CSSC) to prevent the transfer of invasive fish species between the Mississippi River Basin and the Great Lakes Basin while simultaneously allowing the passage of commercial barge traffic. During 2015 an interdisciplinary team from the U.S. Fish and Wildlife Service, the U.S. Geological Survey, and the U.S. Army Corps of Engineers investigated the potential for entrainment, retention, and transport of freely swimming fish within large gaps (50 m^3) created at junction points between barges. Modified mark and capture trials were employed to assess fish entrainment, retention, and transport by barge tows. A multi-beam sonar system enabled estimation of fish abundance within barge junction gaps. Barges were also instrumented with acoustic Doppler velocity meters to map the velocity distribution in the water surrounding the barge and in the gap formed at the junction of two barges. Results indicate that the water inside the gap can move upstream with a barge tow at speeds near the barge tow travel speed. Water within 1.0 m to the side of the barge junction gaps was observed to move upstream with the barge tow. Observed transverse and vertical water velocities suggest pathways by which fish may potentially be entrained into barge junction gaps. Results of mark and capture trials provide direct evidence that small fish can become entrained by barges, retained within junction gaps, and transported over distances of at least 15.5 km. Fish entrained within the barge junction gap were retained in that space as the barge tow transited through locks and the Electric Dispersal Barrier System (EDBS), which would be expected to impede fish movement upstream (Davis et al. 2016).

Adapted from:
Davis, J. J., Jackson, P. R., Engel, F. L., LeRoy, J. Z., Neeley, R. N., Finney, S. T., & Murphy, E. A. (2016). Entrainment, retention, and transport of freely swimming fish in junction gaps between commercial barges operating on the Illinois Waterway. *Journal of Great Lakes Research*, *42*(4), 837-848.

More information on 2015 barge entrainment studies can be found at:
https://www.fws.gov/midwest/fisheries/carterville/documents/2015-barge.pdf

https://doi.org/10.1016/j.jglr.2016.05.005

2016 Barge entrainment studies

During 2016, additional fish entrainment studies were conducted at the EDBS with different tow configurations that are commonly used by commercial carriers on this reach of the Illinois Waterway (6 rake style barges; 2 wide by 3 long in two different configurations). Experimental methods utilized for this study were identical to methods employed during 2015

barge entrainment studies with the exception of the altered tow configurations. Results were very similar to those observed in 2015. Small (<100 mm) Golden Shiners were entrained in rake-box junction gaps and transported upstream across the EDBS at substantial rates. A mean of 24.7 % (SD=16.3%, n= 19) of fish entrained within junction gaps were transported across the entire barrier system during 2016 trials.

2016 Efficacy studies at the Electric Dispersal Barrier during tow transit: Non-entrainment pathways

In August 2016, the U.S. Fish and Wildlife Service, U.S. Geological Survey, and U.S. Army Corps of Engineers undertook another field study at the EDBS to examine the potential for transiting tows to create non-entrainment related pathways for fish passage of the barrier system. This novel study examined the influence of tow transit on the efficacy of the EDBS in preventing the passage of wild juvenile fish (total length < 100 mm). Dual-frequency identification sonar observations showed that large schools of wild juvenile fish (mean school size of 120 fish; n = 19) moved *upstream* and crossed the electric field of an array in the EDBS concurrent with downstream-bound (downbound) loaded tows in 89.5% of trials. Smaller schools of wild juvenile fish (mean school size of 98 fish; n = 15) moved *downstream* and crossed the electric field of an array in the EDBS concurrent with upstream-bound (upbound) loaded tows in 73.3% of trials. Observed wild fish passages through the barrier system were always opposite to the direction of tow movement, and not associated with propeller wash. These schools were not observed to breach the barrier system in the absence of a tow and showed no signs of incapacitation in the barrier during tow passage. Loaded tows transiting the barrier create a return current of water flowing between the tow and the canal wall that typically travels opposite the direction of tow movement, and concurrently cause a decrease in the voltage gradient of the barrier of up to 88%. Return currents and decreases in voltage gradients induced by tow passage likely contributed to the observed fish passage through the barrier. The efficacy of the EDBS in preventing the passage of small, wild fish is compromised while tows are moving across the barrier system. In particular, downbound tows moving through the barrier create a pathway for the upstream movement of small fish, and therefore may increase the risk of transfer of invasive fishes from the Mississippi River Basin to the Great Lakes Basin (Davis et al. 2017).

Adapted from:

Davis, J. J., LeRoy, J. Z., Shanks, M. R., Jackson, P. R., Engel, F. L., Murphy, E. A., Baxter, C.L., Trovillion, J.C., McInerney, M.K. & Barkowski, N. A. (2017). Effects of tow transit on the efficacy of the Chicago Sanitary and Ship Canal Electric Dispersal Barrier System. *Journal of Great Lakes Research*. In press.

More information on 2016 Efficacy studies at the Electric Dispersal Barrier during tow transit: Non-entrainment pathways can be found at:
http://www.asiancarp.us/documents/BargeTrafficStudy-InPress.pdf

2016 Barge Entrainment studies

Introduction

In August of 2015, the U.S. Fish and Wildlife Service (FWS), U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers (USACE) conducted a series of experimental trials to characterize the potential risk of upstream fish passage at the EDBS associated with entrainment of fish within barge junction gap spaces. Those studies investigated the potential for entrainment, retention, and transport of freely swimming fish within rake-box junction gaps. Modified mark and recapture trials were employed to assess fish entrainment, retention, and transport by barge tows. A multi-beam sonar system enabled estimation of fish abundance within barge junction gaps. Results of mark and recapture trials provided direct evidence that small fish (< 123 mm) can become entrained by barges, retained within junction gaps, and transported over distances of at least 15.5 km. Fish entrained within the barge junction gap were also retained in that space as the barge tow transited through locks and across the Electric Dispersal Barrier System (Davis et al. 2016).

These findings raised additional questions from researchers and industry partners regarding entrainment dynamics associated with different tow configurations and other potential effects that tow transiting may have on the efficacy of the EDBS. A series of studies were designed to address these inquiries during the 2016 field season. Mark-recapture methods identical to those used in 2015 were employed to assess entrainment and transport dynamics associated with various tow configurations typically operated on the Illinois Waterway at the EDBS site. Additionally, a study was conducted at the Electric Dispersal Barrier that measured flow dynamics, electrical gradients, and wild fish behavioral responses to tow transiting to explore issues unrelated to barge entrainment that may also affect the efficacy of the barrier system.

Methods

Study sites

The studies presented here were conducted during August of 2016 in the Illinois Waterway at the U.S. Army Corps of Engineers EDBS at RM 296 near Romeoville, IL. Entrainment, retention, and transport trials occurred at the EDBS (n=19) and within the Lockport Pool (n=2) (RM 292-296). Trials conducted at the EDBS had a total travel distance of approximately 1.0 km. The two trials conducted within Lockport Pool evaluated fish retention and transport over a distance of 6.2 km.

Barge Configurations

A barge tow consisting of a towing vessel typical for use on the Illinois Waterway and six fully loaded barges was utilized during all trials (Fig. 1, panel B). These test configurations contrasted the 2015 trials which used four fully loaded barges (Fig. 1, panel A.). During both years the tow vessel was 32.0 m long, had a 9.1 m beam, and drafted 2.3 m. Each 59.4 m by 10.7 m barge held approximately 1,360 metric tons (MT) of non-hazardous material and drafted 2.7 m. The barges were lashed together in two different configurations during 2016; both configurations were

three barges long by two barges wide. The difference between the two configurations was the location of the rake to box junction gap (Fig. 1panel B.). The connections between barges in the middle of the tow represented typical rake-to-box junctions with the exception that the connection junction was modified by placing two 38.0 cm spacers between the barges, at the push knees, to allow access for installation of instrumentation and fishing gear. All sonar and fish capture data were collected from the rake-to-box junction gap. The barge tow was pushed upstream with the rake ends of the barges facing in an upstream direction at normal operating speeds (1.6–5.6 km/h) during all trials.

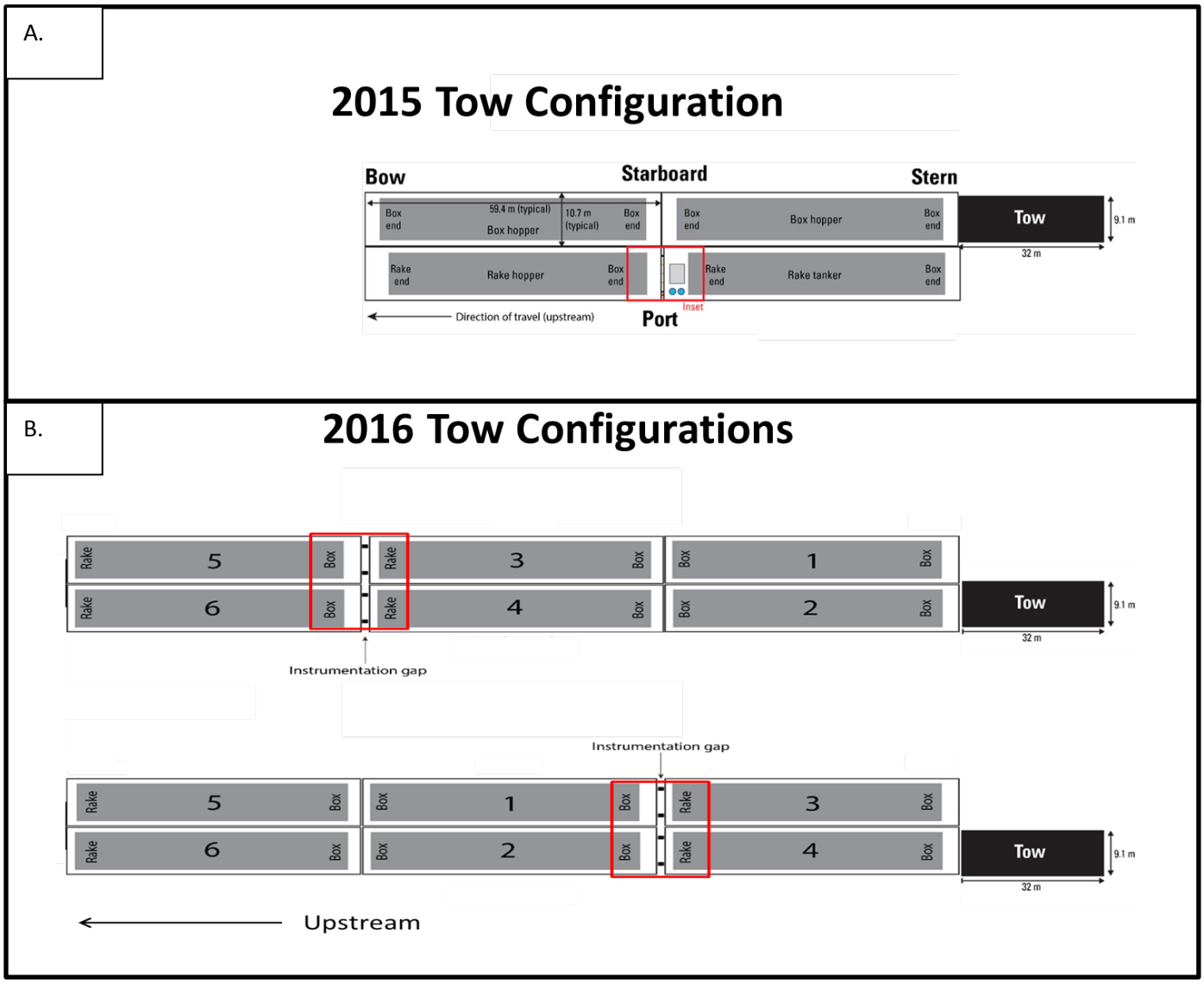

Figure 1. Conceptual model of 2015 and 2016 barge tow configurations used during upstream entrainment trials. Red square shows the location of the rake-to-box junctions used for instrumentation mounting and fish recapture events.

Mark and capture trials

Observations of fish entrainment and subsequent retention and transport were acquired through a series of mark and recapture trials. Hatchery-reared Golden Shiners (66 to 102 mm TL, subsample (n=125)) were marked by applying fin clips to anal, dorsal, upper caudal, and lower caudal fins in combination to provide positive identification of captured individuals. Unique combinations of fin clips were used for each trial during each week. These marked fish were subsequently stocked directly within the rake-box junction gap of the moving tow (n_S=300/trial). At the conclusion of each trial, the tow stopped and attempts to capture fish remaining inside the junction gap were accomplished by deploying a Betts Tyzac™ cast net; 1.2 m diameter with 0.95 cm monofilament mesh. The capture attempts were aided by the use of a multi-beam sonar system (Sound Metrics ARIS Explorer 3000™) which allowed personnel to determine the locations of fish within the junction gap. Attempts to capture fish were terminated once movement of the barge tow commenced or sonar observations suggested that no targets remained within the junction gap. Due to the limitation that capture attempts could not take place while the barge was moving, the number of capture attempts conducted during each trial was not standardized.

The multi-beam sonar system was mounted inside the rake-to-box junction gap on the port side of the tow facing in towards the center of the tow. The system was operated at low frequency setting (1.8 MHz), with wide pulse width, and data were collected at 6 frames per second. Receiver sensitivity was 22 dB and maximum range was 9.9 m. This system utilized 128 acoustic beams that provided a total field of coverage of 30° x 14° with 4.4 mm resolution. The unit was submerged 0.4 m below the water surface and rotated on its axis remotely using a Sound Metrics AR2™ rotator. Tilt and pan angle of the sonar unit was optimized during trials to track moving schools of fish. Typical tilt values ranged between -12.0 degrees and -3.0 degrees. This system enabled monitoring of schools and individual fish during trials and allowed targeted capture sampling to occur at the completion of each trial. The recording capability of the system was used to perform *post hoc* enumeration of fish that were present within the rake-to-box junction gap during different periods within each trial.

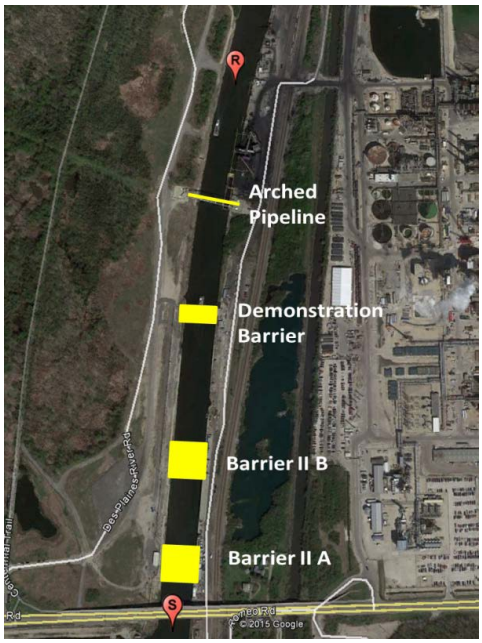

Figure 2. Map showing locations of fish stocking (S) and recapture (R) areas utilized for barge entrainment and retention trials at the Electric Dispersal Barrier during 2016 trials.

Data Analyses

Data were processed and analyzed using methods identical to those employed during the 2015 barge entrainment studies (Davis et al. 2016). Briefly, all fish that were captured at the conclusion of each trial were processed in the field by measurement and examination for the presence of fin clips. Sonar data were reviewed and analyzed in the laboratory to determine the number of fish remaining in the junction gap following capture attempts. Ten frames of sonar data were selected from the data collection period for each trial for further analysis. Three readers independently counted all fish identified via sonar. The grand mean of the three reader averages was then calculated to provide an estimate of the number of fish remaining in the barge junction gap after capture attempts were completed. The sonar data did not provide information that would allow the determination of species or whether or not individual fish possessed the mark that was applied before each stocking event. Because a small number of fish (wild juvenile Gizzard Shad and Golden Shiners with a different mark) which were not stocked during that trial were captured at the conclusion of some trials, a by-catch correction factor for each trial type was calculated (number of fish remaining in the gap minus the average percentage of non-target catches observed in each trial type). A total fish entrainment/retention estimate was calculated by adding the number of marked Golden Shiners that were physically captured at the conclusion of the trial to the by-catch corrected number of fish estimated to remain within the barge junction gap (Davis et al. 2016).

Results

Fish Retention and Transport through the Electric Dispersal Barrier System

Golden Shiners stocked directly into the rake-box junction gap downstream of the EDBS (n_S=300/trial) were retained within that junction gap as the tow traveled upstream through the barrier system. A mean of 24.7 % of fish entrained within junction gaps were transported across the entire EDBS (SD=16.3%, n= 19). Marked Golden Shiners captured at the completion of these trials ranged in size from 67-104 mm TL. No evidence of incapacitation of any fish by the electric field was observed.

Table 1. Table of results from Golden Shiner retention and transport trials at the Electric Dispersal Barrier System. Marked Golden Shiners were stocked into rake-box barge junctions below the barrier and recaptured from the junction upstream of the entire barrier system during 2016.

Date	No. Stocked	No. Recaptured	Recapture(%)	No. remaining (Sonar)	By-catch Correction	Corrected No. Remaining	Total Retention Estimate (%)
8/2/2016	300.0	22.0	7.3	10.4	0.2	10.2	10.7
8/2/2016	300.0	0.0	0.0	116.3	4.1	112.2	37.4
8/3/2016	300.0	37.0	12.3	No Sonar			12.3
8/3/2016	300.0	49.0	16.3	6.5	0.0	6.5	18.5
8/4/2016	300.0	24.0	8.0	8.0	0.0	8.0	10.7
8/4/2016	300.0	1.0	0.3	31.6	0.0	31.6	10.9
8/4/2016	300.0	8.0	2.7	32.8	0.0	32.8	13.6
8/4/2016	300.0	69.0	23.0	26.6	0.0	26.6	31.9
8/5/2016	260.0	83.0	31.9	38.2	0.0	38.2	46.6
8/8/2016	300.0	68.0	22.7	44.1	0.1	44.0	37.3
8/8/2016	300.0	41.0	13.7	30.4	0.3	30.0	23.7
8/8/2016	300.0	70.0	23.3	No Sonar			23.3
8/9/2016	300.0	6.0	2.0	1.2	0.0	1.2	2.4
8/9/2016	300.0	13.0	4.3	32.8	0.0	32.8	15.3
8/9/2016	289.0	26.0	9.0	20.0	0.1	19.9	15.9
8/10/2016	100.0	38.0	38.0	3.0	0.0	3.0	41.0
8/10/2016	300.0	49.0	16.3	0.9	0.0	0.9	16.6
8/10/2016	300.0	88.0	29.3	4.4	0.0	4.4	30.8
8/10/2016	300.0	205.0	68.3	3.4	0.0	3.4	69.5

Long Distance Fish Retention and Transport

Several trials were conducted which examined the transport of juvenile Golden Shiners over much longer distances. A mean of 37.80% (SD=8.7%; n=2) of stocked fish were retained after the tow traveled northwards from near the Lockport Lock and Dam, through the Lockport navigation pool, and traversed the entire EDBS (total distance traveled of 6.2 km). This is very similar to mean total retention estimates for similar distance trials conducted in the same location during 2015 with a different tow configuration. (35.11% (SD=5.78% n=2)).

Conclusions

The barge entrainment study conducted during 2015 showed that when loaded barges with a rake-box junction gap encounter juvenile fish, there is a possibility that they will become inadvertently entrained into the barge junction gap. Fish were also retained within the gap and transported upstream. Small fish that have been entrained into barge junction gaps may pass

navigational structures and breach the EDBS unhindered. This study expanded upon those findings by utilizing a variety of different tow configurations that are commonly encountered on this portion of the Illinois Waterway and comparing their entrainment dynamics with smaller tows such as the one utilized during the 2015 study. The results of the study presented here, suggest that fish entrainment and the implications for potential inter-basin transport of invasive fish species is ubiquitous among barge tows that are configured such that a rake to box junction gap exists. These findings establish the need for management actions to mitigate such risks.

2016 Efficacy studies at the Electric Dispersal Barrier during tow transit: Non-entrainment pathways

In conjunction with the study described previously in this document, the FWS, USGS and USACE undertook another large-scale field study to examine the influence of commercial barge vessels on the efficacy of the EDBS in preventing fish passage due to causes unrelated to direct entrainment and transport of fish across the barrier system. This study included sonar-based observations of wild fish behavior as a tow consisting of a tug vessel and six fully-loaded barges traversed the EDBS (Fig. 4 & 5). Additionally, as the tow passed through the barriers, its effect on flow velocities and voltage gradients were measured (Fig. 6). These observations and data collections provide a holistic understanding of the physical changes that take place at the EDBS while a tow transits and document behavioral responses of wild fish to these changes.

Methods

A mobile telescopic boom lift was used to deploy two Sound Metrics™ Dual-frequency identification sonar (DIDSON) 300 multi-beam systems into the canal from the western canal bank directly over the high-field array of Barrier IIB. The two DIDSON multi-beam sonar systems, were aimed so that the top 1.0 m of the water column between the boom arm and the wall could be observed to monitor wild fish behavior (Fig. 4). Recordings from the sonar system provided video-like data showing fish behavior directly downstream and directly over the electric barrier's high field array from the canal wall out approximately 7.0 m into the canal. Flow velocities were also measured using hydroacoustic instruments mounted on the canal wall and the tow. This instrumentation allowed the water velocity to be quantified across the width of the channel between the tow and shore while tows moved through the barrier system (Davis et al. 2017). Additionally, a 3-D electrical probe was placed on the boom lift arm directly beneath the DIDSON sonar system to measure the electrical current in the water during tow passage concurrent with sonar data recordings.

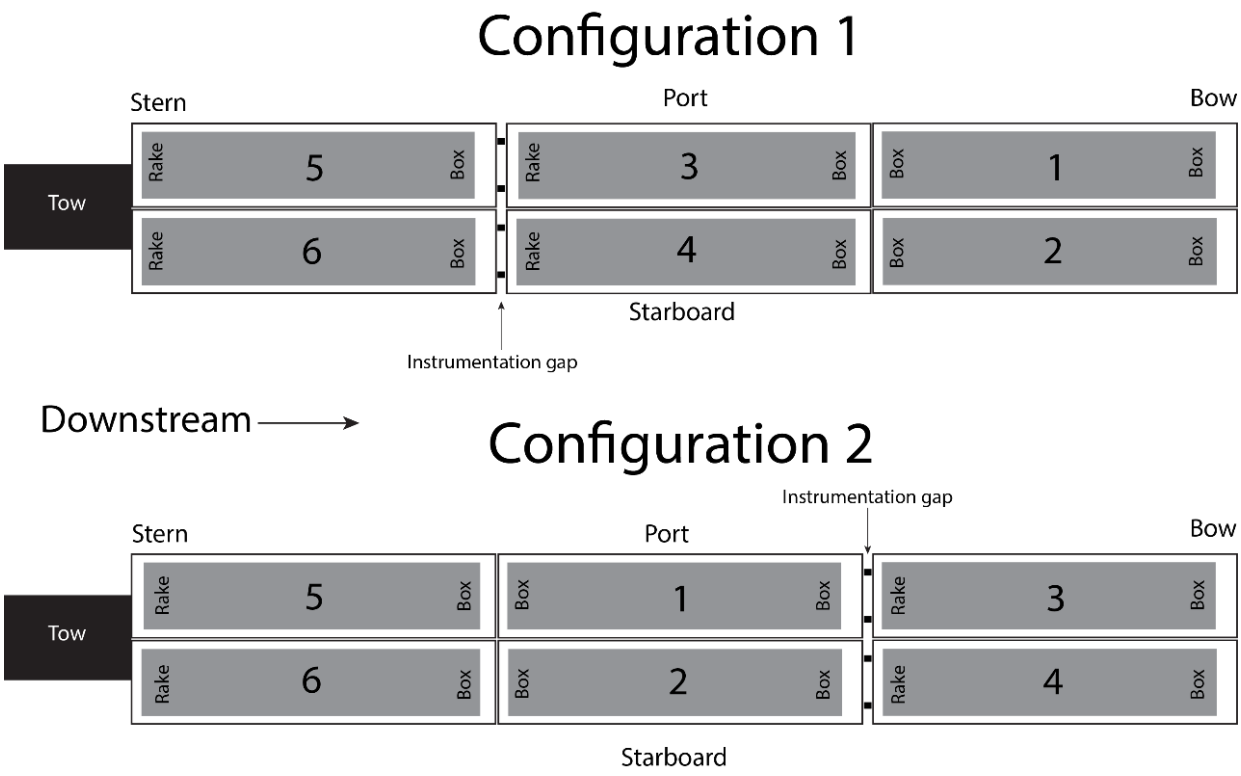

Figure 3.Tow configurations utilized during 2016 downstream transit trials at the Chicago Sanitary and Ship Canal Electric Dispersal Barrier System.

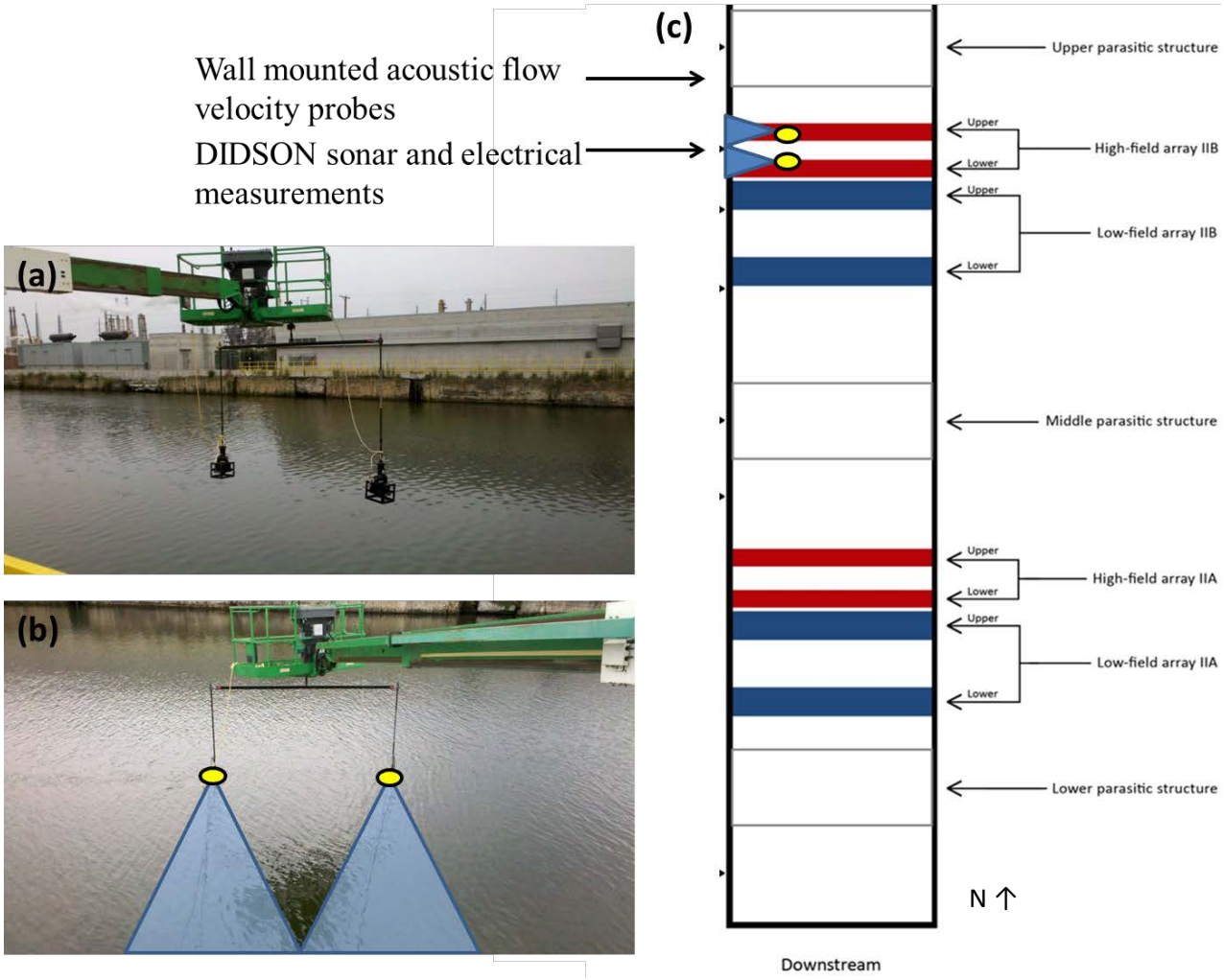

Figure 4. Telescopic boom lift that was utilized to deploy two DIDSON multi-beam sonar units in parallel at the Chicago Sanitary and Ship Canal Electric Dispersal Barrier System (panels a and b). Blue shading indicates approximate field of view obtained from the sonar system (panel b). The sonar units and electrical field measurement probe were positioned directly over the Barrier IIB narrow array, as shown in panel (c). Wall mounted acoustic flow velocity probes were positioned just upstream of the Barrier IIB narrow array (panel c).

Results

Electrical measurements collected during tow passage suggest that the passage of a tow causes a distinct decrease in voltage gradient within the canal (Fig. 5, bottom panel). The magnitude of the observed decrease varied due to the tows proximity to the probe. The minimum voltage gradient observed during each run ranged from 0.3 to 2.3 V/in corresponding to an 88% to 12% (mean = 25.88%; S.D. = 14.10; median = 20.42%) reduction from the baseline voltage gradient for each run (Davis et al. 2017).

Flow velocity measurements indicate that loaded tows transiting the barrier system in the downstream direction create a return current between the tow and the canal wall that travels in the upstream direction opposite tow travel direction at an average velocity of 0.18 m/s (n = 21) (Fig. 5, top panel) (Davis et al. 2017).

Concurrent with electrical voltage gradient decreases and return currents caused by downstream tow passage, schools of wild juvenile fish moved upstream and completely crossed the peak electrical field of Barrier IIB. Wild fish passed through the high field array of the barrier during 89.5% (n = 19) of trials. These schools were not observed to breach the EDBS under ambient conditions and showed no signs of incapacitation in the barrier's electric field during downstream tow passage. The number of fish passages observed during each downstream tow transit ranged from 0 to 822 (Mean = 120 fish, S.D. = 199). Sonar based size estimates of a sub-sample of fish that achieved passage of the barrier ranged from 37.7 mm to 92.3 mm (Mean = 61.4 mm, S.D. = 7.4 mm, n = 170). Fish that were physically captured in the area immediately downstream of the EDBS concurrent with tow transit trials were Gizzard Shad (*Dorosoma cepedianum*) (n = 304) and Threadfin Shad (*Dorosoma petenense*) (n = 6). The mean size of physically captured Gizzard Shad was 54.0 mm TL (S.D. = 8.95 mm) with sizes ranging from 33.0 to 94.0 mm (Davis et al. 2017).

Conclusions

Based on these study results, the efficacy of the EDBS in preventing upstream passage of small fish is compromised while tows are moving across the barrier system. This observation of upstream fish passage identifies a potential pathway for the movement of invasive fishes through the EDBS and into the Great Lakes. The identification of this pathway does not elevate the risk of invasive fish passage from current levels. Rather, it improves functional understanding of the efficacy of the EDBS, thereby enhancing the ability of invasive species managers to assess risk and implement appropriate actions.

Adapted from:

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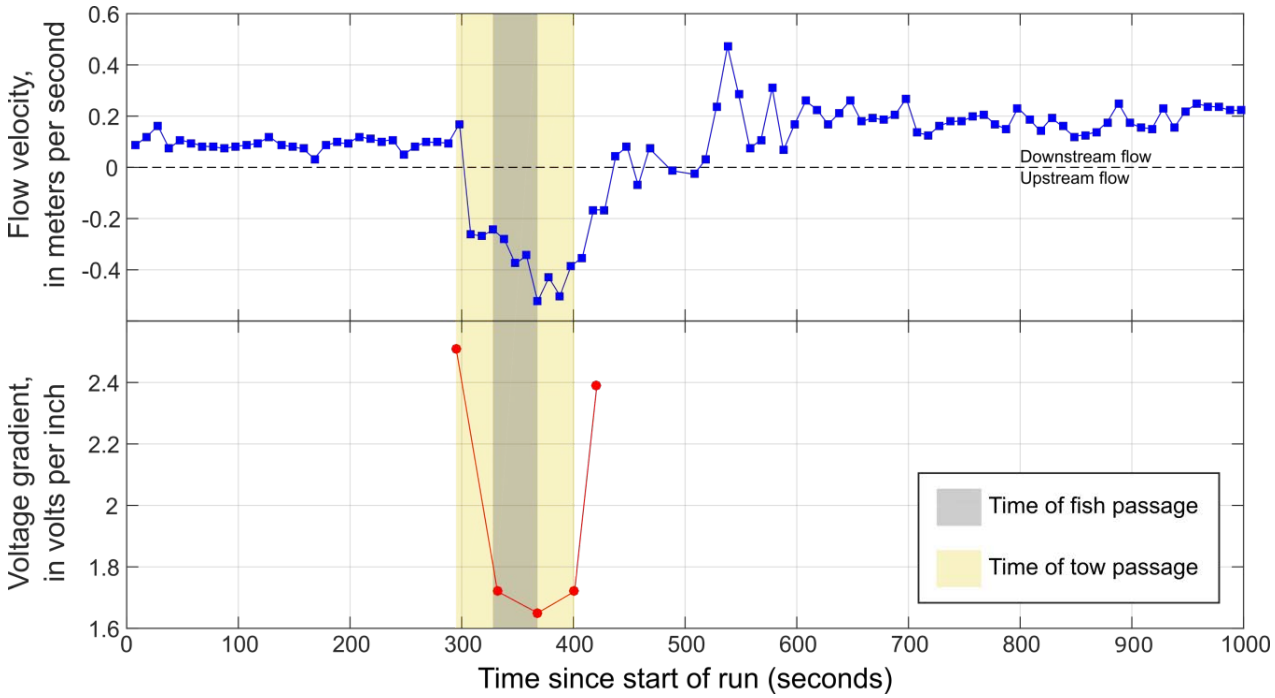

Figure 5. This figure shows velocity and voltage gradient data from a downbound tow transit of the Electric Dispersal Barrier System (EDBS) on August 8th, 2016. As the tow transited EDBS Barrier IIB, reverse flows (negative flow velocity, top panel) were initiated concurrent with substantial reductions in voltage gradient (bottom panel). **Top panel:** the streamwise component of velocity was measured 5.3 meters from the west wall of the canal. Positive flow velocity indicates downstream flow and negative flow velocity indicates upstream flow. **Bottom panel:** the voltage gradient during tow passage. The yellow shading indicates the time during which six loaded barges passed the DIDSON multi-beam sonar units. The grey shading indicates the time during which wild fish were observed fully traversing the EDBS Barrier IIB in the upstream direction.

Acknowledgments

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References

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