Mitigation of tow-mediated fish passage at the Electric Dispersal Barrier System, Romeoville, IL - Preliminary Results, 2017 Field Trials

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Introduction

Interdisciplinary studies conducted by the U.S. Fish and Wildlife Service (USFWS), the U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers (USACE) indicated that small fish can be entrained into junction gaps between barges in commercial tows, transported upstream over long distances (at least 15.45 km), through lock chambers, and across the Electric Dispersal Barrier System (EDBS) in the Chicago Sanitary and Ship Canal (CSSC) (Davis et al., 2016). Additionally, small wild fish crossed the EDBS in the upstream direction concurrent with the passage of downstream-transiting commercial tows, which reduce the voltage gradient, and generate return flows (RFs) that can cause water to flow upstream through the EDBS as the tow passes (Davis et al. 2017).

In 2017 the USFWS, USGS, and USACE conducted two phases of preliminary field testing of techniques designed to mitigate tow-mediated fish passage at the EDBS. The Entrainment Mitigation (EM) phase tested a field-scale prototype water jet array that was placed on the bottom of the canal to direct high-velocity jets of water into tow junction gaps with the goal of hydraulically displacing entrained fish prior to passage through the EDBS. The RF mitigation phase of the study tested a range of canal discharges to determine the minimum ambient flow velocity required to prevent upstream RFs caused by downstream-transiting tows and maintain net downstream flow throughout the EDBS. In both study phases, the mitigation technique efficacy was evaluated with sonar observations of fish behavior *in situ*.

Entrainment Mitigation-Water Jet Array

Preliminary testing of a water jet array designed to displace entrained fish from junction gaps between barges before tows traverse the EDBS was conducted during the EM phase of this study. The water jet array, consisting of a 9.2 m long by 1.2 m diameter steel manifold equipped with three 0.3 m vertical jets, was positioned at the bottom of the canal approximately 500 m downstream of the EDBS. The tops of the vertical jets were approximately 3.0 m off the bottom of the canal and angled at 22 degrees off the vertical axis to provide a flow directed upstream. Each trial consisted of a single upstream tow crossing of the jet array, with the tow approximately centered over the jet array. Three Global Positioning System (GPS) receivers were used to monitor the position and orientation of the tow. Water velocities in the junction gap during jet array crossings were measured using two Nortek Vector™ acoustic Doppler velocimeters (ADVs). Golden Shiners (*Notemigonus crysoleucas*) (mean TL = 90.1 mm S.D. =7.6 mm) were stocked into the rake-box junction gap of the tow immediately before the tow passed over the jet array and were observed using an ARIS™ multi beam sonar system mounted within the gap.

A total of 74 trials were conducted using two typical tow configurations (in number of barges wide x barges long: 2x3 and 1x3), tow speeds ranging from 0.8 km/h to 6.6 km/h, and water jet exit velocities ranging from 2.4 m/s to 4.9 m/s. A single trial conducted with a 1x3 tow traveled upstream over the jet array at 3.2 km/h, centered over the jet array, with a jet exit velocity of 4.9 m/s (Fig. EM-1A), is presented as an example of anticipated data products derived from the testing. Data analysis for this study is not yet complete, but will include an assessment of the variability of the efficacy of the water jets in flushing fish from the junction gap. Flow velocities oriented parallel to the port-starboard axis of the tow (ejection velocities) exceeded 0.4 m/s as the jet array forced water out of the junction gap (Fig EM-1B). After the tow transited the jet array, an ejection velocity of 0.2 m/s was maintained for approximately 10 s and returned to near zero after 30 s. Two hundred marked Golden Shiners were stocked into the junction gap prior to the tow passing over the jet array. The number of fish visible within the sonar viewing cone in the 15 s period before jet passage and the 30 s period after jet passage

were determined. A 75% reduction in the number of fish visible within the sonar viewing cone was observed after jet passage during this trial. Preliminary results indicate that ejection velocities up to 1 m/s were observed, yet complete removal of all entrained fish was not observed during any trial. However, this preliminary field deployment used only three jets in comparison to the twelve required for complete flushing of junction gaps during laboratory testing (Bryant et al., 2018).

The data collected during this field study will be used to validate model systems at the USACE Coastal & Hydraulics Laboratory, evaluate waterway safety concerns associated with full scale water jet deployment, develop target ejection velocity thresholds for flushing fish of different sizes from junction gaps, and inform design characteristics and feasibility studies of larger scale models or full scale deployments.

Return Flow Mitigation

The RF mitigation phase of the study included measurements of water velocity, voltage gradient, and tow speed at Barrier IIB of the EDBS, and sonar-based observations of wild fish as a tow transited the barrier in both upstream (66 runs) and downstream directions (66 runs) (Fig. RF-1; Table RF-1). In an attempt to prevent upstream return flows, the canal discharge was varied over the course of the study, corresponding to a range in ambient flow velocities at Barrier IIB of 0 to 0.62 m/s. The analysis herein is limited to downstream-bound transits of tows in a 2x3 configuration, in which fish were present in the sonar observations, and includes observations from the Aug. 2017 study and from a similar study conducted in Aug. 2016 (Davis et al., 2017) (50 runs; Table RF-2).

Water velocities were measured using acoustic Doppler velocity meters (ADVMs) mounted on the canal's west wall at Barrier IIB (Fig. RF-1) for a range of canal discharges, tow speeds, and tow configurations to determine the minimum ambient flow velocity required to maintain downstream flow in the EDBS (Tables RF-1). Return flow velocities, defined as the water velocities measured between the tow and the wall during the time the tow passed the instruments, were positive (downstream-flowing water) during downstream tow transits when the ambient flow velocity was greater than 0.38 m/s for all tow configurations and speeds (LeRoy et al., 2016 & 2017) (Fig. RF-2). This ambient flow velocity corresponds to a canal discharge of approximately 152 m^3/s or 5,400 ft^3/s (USGS, 2017). The voltage gradient at the water surface was measured in the peak electric field of Barrier IIB at the location of the fish monitoring sonar system and at the canal wall. Measurements were taken in both the presence and absence of the tow for each run. A reduction in the component of voltage gradient that is parallel to the canal banks (the streamwise voltage gradient) was observed in the presence of the tow (Table RF-2). The percent reduction in streamwise voltage gradient was greater for runs in which the tow was closer to the probe (Fig. RF-3).

Two DIDSON multi-beam sonar systems, deployed using a boom lift located on the canal's west wall and aimed toward the wall (Fig. RF-1), were used to monitor wild fish behavior during both the 2016 and 2017 studies. Schools of juvenile fish moved upstream and completely crossed the peak electric field of the EDBS concurrent with downstream transiting tows in 32 of the 50 runs (64%) in which fish were present in the sonar videos (Table RF-2). These schools were not observed to breach the EDBS in the absence of a tow and showed no signs of incapacitation in the barrier field during downstream tow passage. The number of fish passages observed during each downstream tow transit ranged from 0 to 822 (Mean = 53 fish, S.D. = 133), and were highest for runs with strong negative return flow velocities (upstream-flowing water) (Fig. RF-4). The mean percent reduction in voltage gradient was similar for runs with fish passages (Mean = 26.6%, S.D. 7.4%) compared to runs in which fish were present but did not pass (mean reduction = 25.8%, S.D. = 5.3%). Several trials with entirely downstream

return flow did result in upstream fish passage (Fig. RF-4), suggesting fish passages cannot be entirely prevented by maintaining a minimum ambient flow in the canal.

Summary

The EM phase of the study indicated that the ejection velocities in the junction gap increase as the junction gap passes over the water jet array, which can cause small fish to be flushed out of the gap. However, complete removal of fish in the junction gap was not observed during any trial. The RF phase of the study showed that maintenance of downstream flow conditions is not sufficient to prevent fish passages at Barrier IIB during downstream transits of tows. Mitigation of the reduction in voltage gradient may help reduce small fish from passing the EDBS concurrent with the downstream transit of a tow.

There are several regulatory, policy, and budgetary constraints to consider in the decision process regarding implementation of mitigation techniques. The Lake Michigan water diversion budget and flood control practices must be balanced with any recommendation for flow control as a risk reduction measure. Any adverse effects to overall EDBS efficacy due to alteration of localized water movements, water quality, and fish habitat will also have to be considered. Finally, any risk reduction measure must also consider effects to native species, impacts to navigation and human safety, and the projected operation and maintenance costs of permanent implementation.

References

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loaded commercial tows in August 2017: U.S. Geological Survey data release, https://dx.doi.org/10.5066/F77D2TB3.

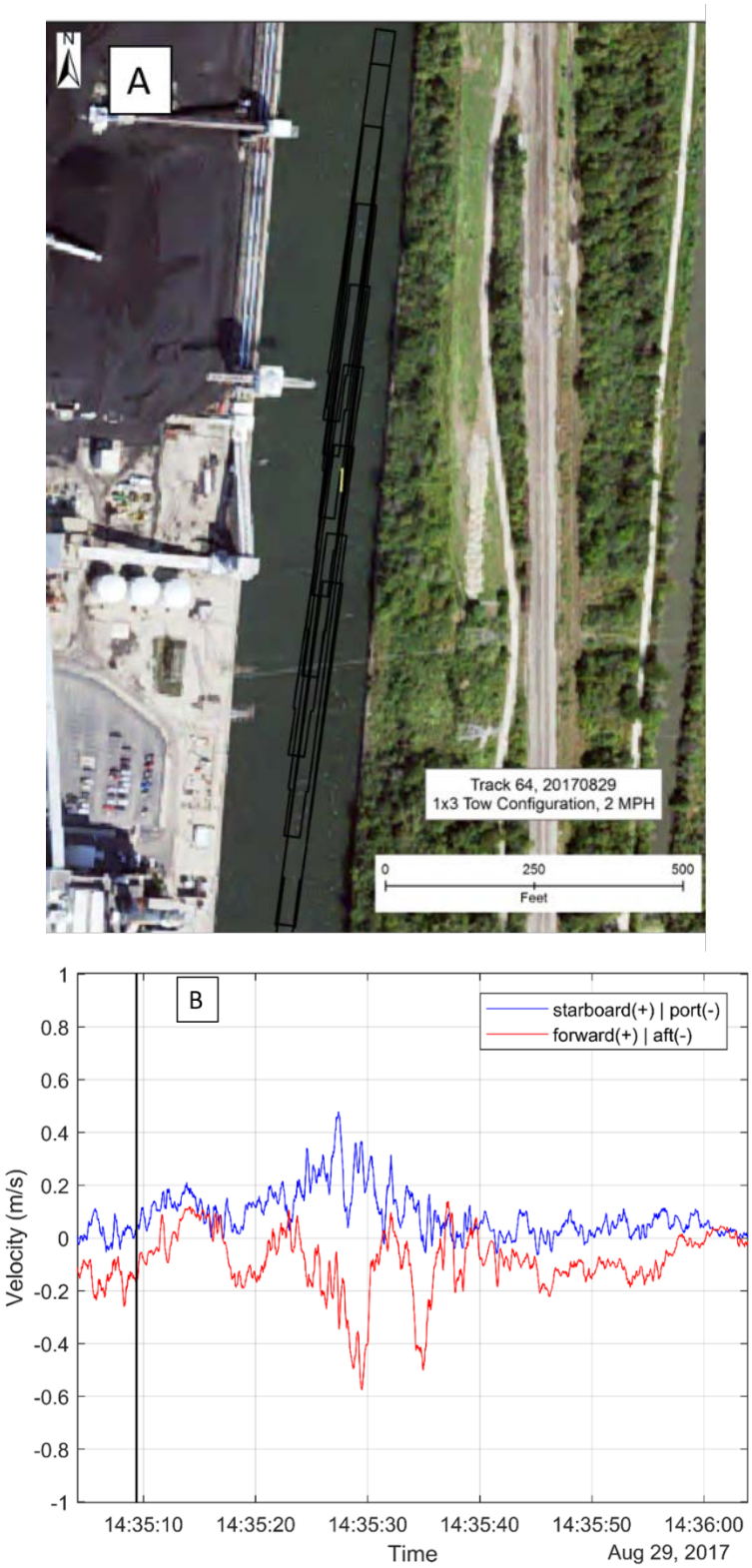

Figure EM-1. Tow path as it transited the water jet array (yellow line) on 8-29-2017 traveling at 2 mph (Panel A). Velocities observed within the junction gap as the tow passed over the jet array (Panel B).

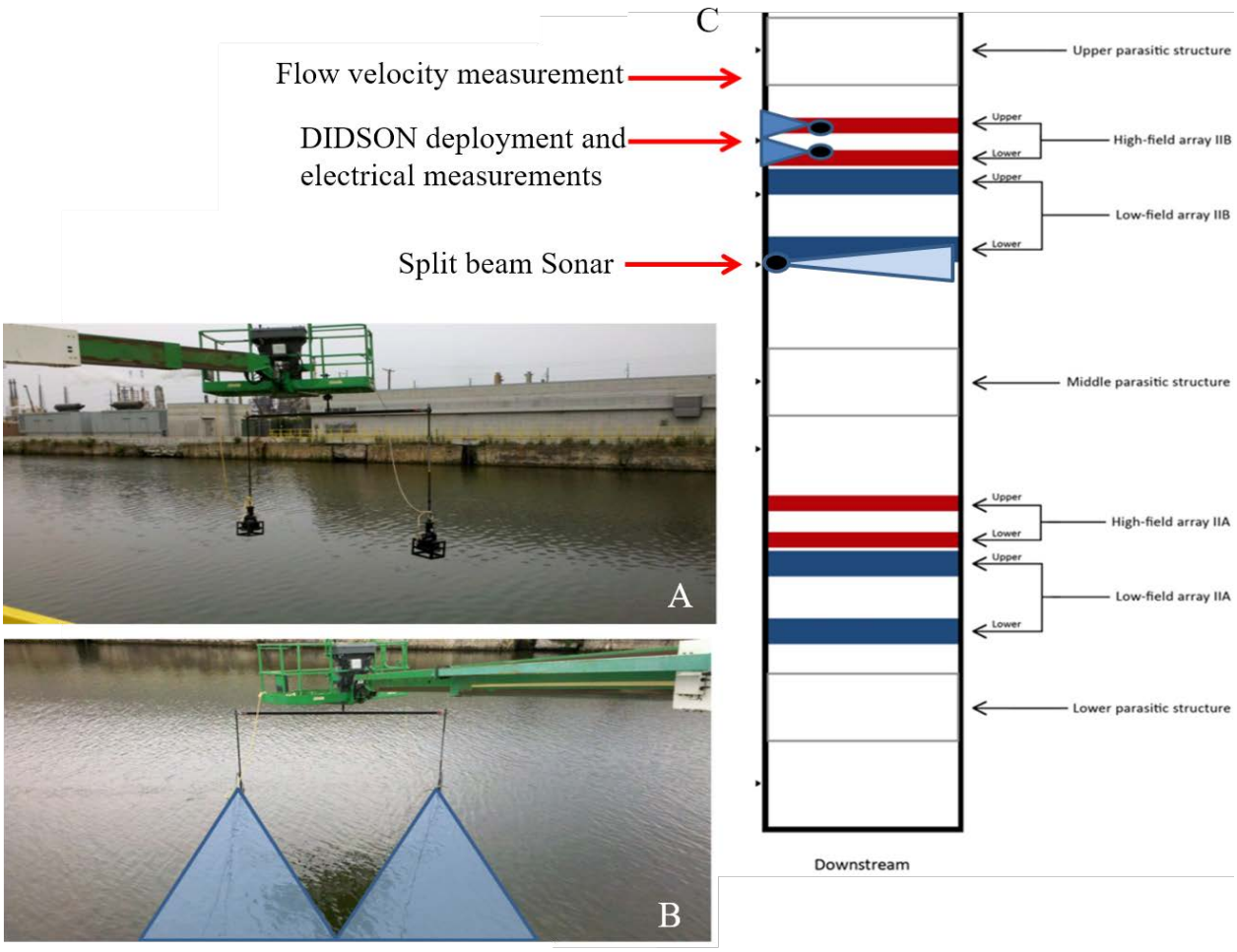

Figure RF-1: Telescopic boom lift that was utilized to deploy two DIDSON multi-beam sonar units in parallel at the Chicago Sanitary and Ship Canal Electric Dispersal Barrier System (Panels A and B). Blue shading indicates approximate field of view obtained from the sonar system (Panel b). The DIDSON sonar units and electrical field measurement probe were positioned directly over the Barrier IIB narrow array, as shown in panel C. Wall mounted acoustic Doppler velocity meters were positioned just upstream of the Barrier IIB narrow array (Panel C).

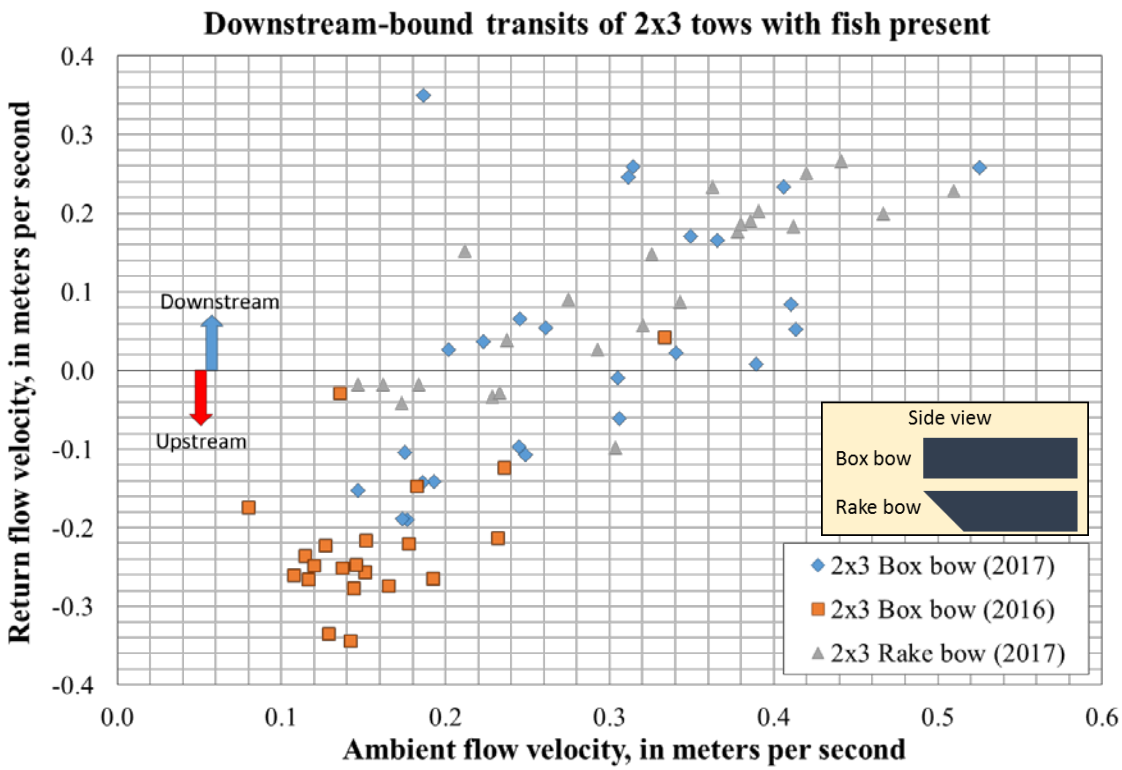

Figure RF-2. Return flow velocity (i.e. the measured flow velocity as the tow crosses Barrier IIB) as a function of the ambient flow velocity (i.e. the measured flow velocity averaged over the 5 minutes prior to the tow entering the study area) for downstream-bound transits in which fish were present in the sonar data. The tow speed varied from 0.40 to 1.99 meters per second for this dataset. Tow configurations are given as number of barges wide x number of barges long, followed by the bow type. Note that this figure includes data from the study completed in Aug. 2017 and data from a similar study completed in Aug. 2016 (Davis et al., 2017).

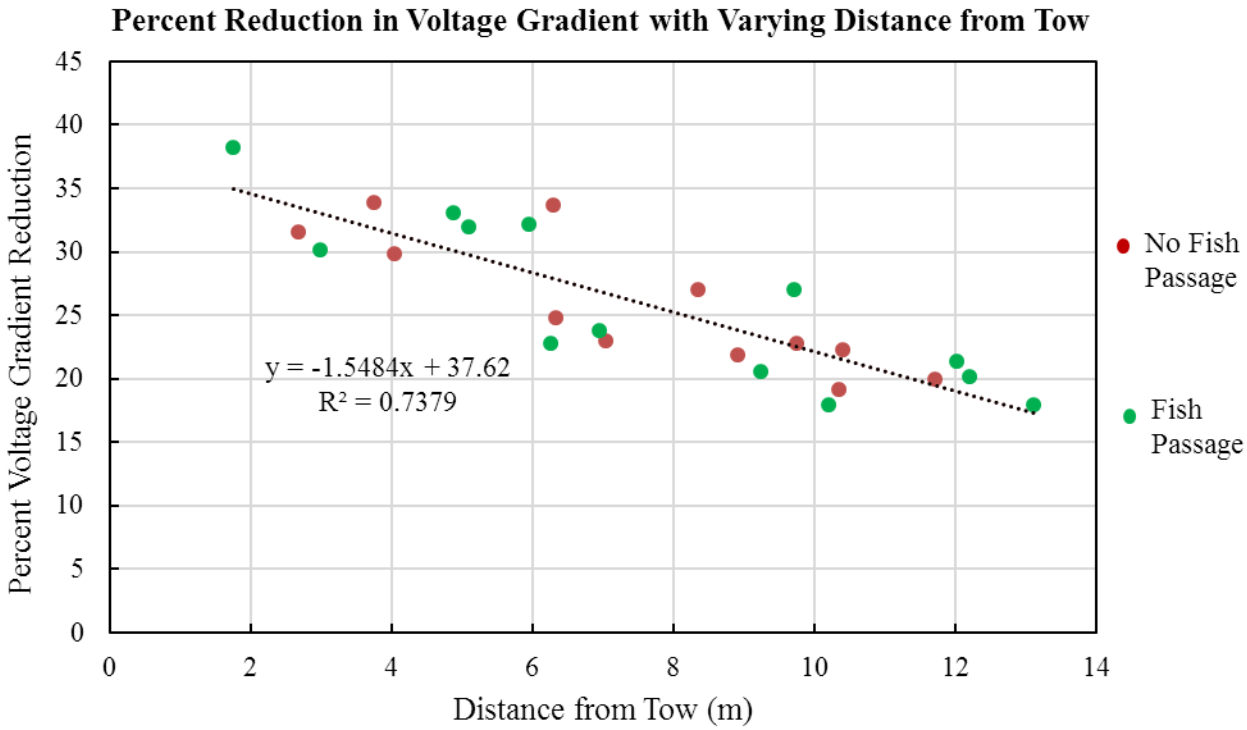

Figure RF-3. Percent change in voltage gradient[a] (VG) as a function of the distance between the voltage gradient probe. Distance to tow was measured at and the midpoint of the second barge as it passed over the narrow array of Barrier IIB (for runs completed by downstream-bound 2x3 tows with fish present in the sonar data).

[a] $\text{Percent change in VG} = \frac{\text{VG in absence of a tow} - \text{VG in presence of a tow}}{\text{VG in absence of a tow}} \times 100\%$

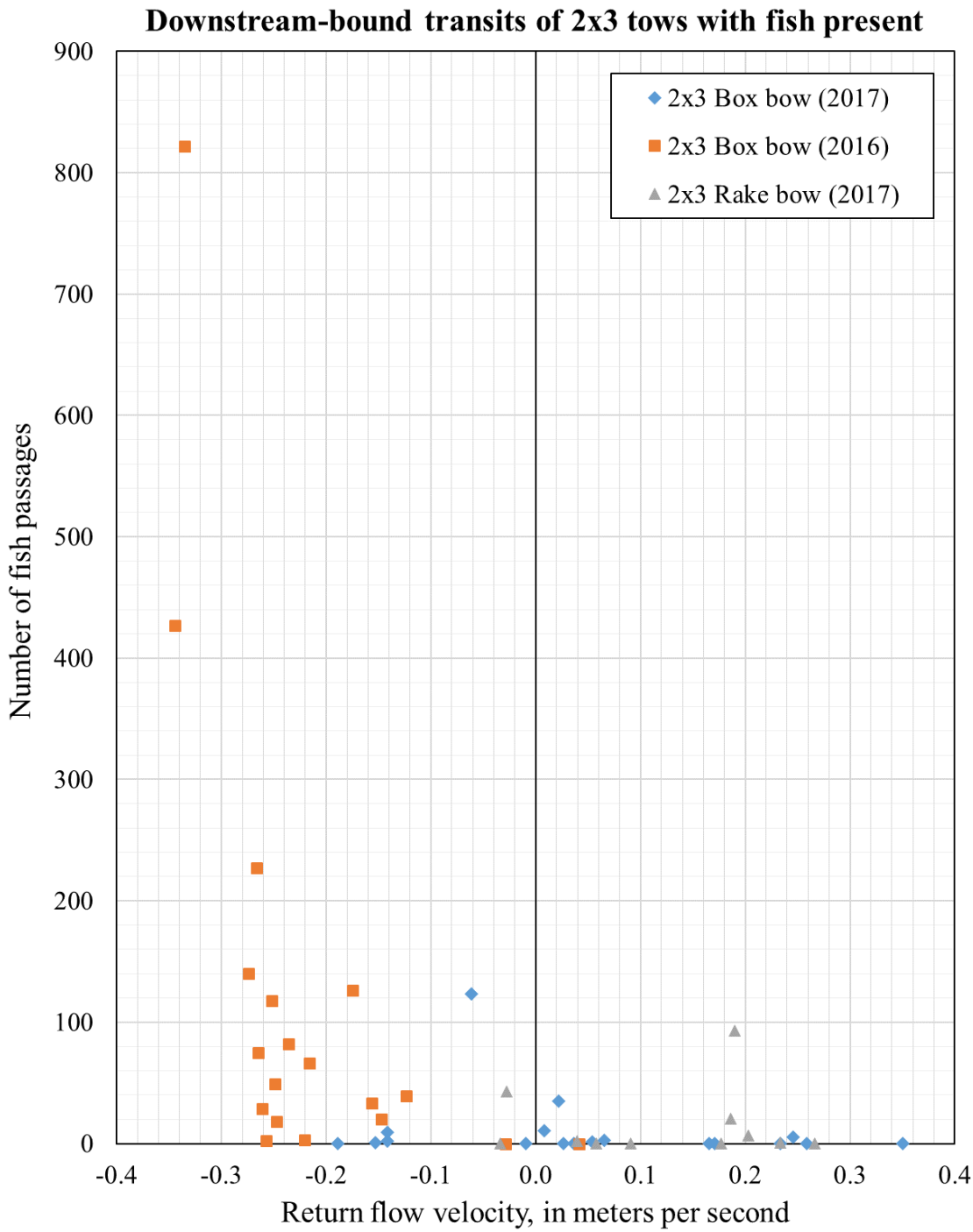

Figure RF-4. Number of fish passages as a function of Return flow velocity (i.e. the measured flow velocity as the tow crosses Barrier IIB) for downstream-bound transits by 2x3 tows in which fish were present in the sonar data. Tow configurations are given as number of barges wide x number of barges long, followed by the bow type. Note that this figure includes data from the study completed in Aug. 2017 and data from a similar study completed in Aug. 2016 (Davis et al., 2017).

Table RF-1: Return flow mitigation study: run conditions

Direction of tow movement	Tow configuration[a]	Bow type[b]	Range in ambient flow velocity (meters per second)[c]	Range in tow speed (meters per second)[d]	Range in tow distance from the west canal wall (meters)[e]	Number of runs
Downstream	2 X 3	Box	0.15 to 0.53	0.49 to 1.43	13.7 to 20.0	25
Downstream	2 X 3	Rake	0.15 to 0.51	0.89 to 1.70	11.9 to 16.6	24
Downstream	2 X 2	Box	0.12 to 0.45	0.94 to 1.39	16.5 to 21.6	8
Downstream	1 X 2	Box	0.0 to 0.39	0.96 to 1.90	11.7 to 23.6	9
Upstream	2 X 3	Rake	0.11 to 0.62	0.40 to 1.34	15.5 to 21.2	49
Upstream	2 X 2	Rake	0.12 to 0.34	0.98 to 1.39	16.5 to 20.0	8
Upstream	1 X 2	Rake	0.02 to 0.38	0.83 to 1.99	17.4 to 24.2	9

[a] Tow configuration is given as “number of barges wide X number of barges long”

[b] Bow type is given as “Box” or “Rake”, and indicates the type of barge located at the bow of the tow during each run.

[c] Measured using an acoustic Doppler velocity meter at Barrier IIB

[d] Measured using three Global Positioning System (GPS) receivers on the tow

[e] Measured using a laser rangefinder

Table RF-2: Downstream-bound transits of the EDBS for 2x3 tows in which fish were observed in the sonar data from field studies completed in 2016 and 2017 (continued on next page)

Year of study	Tow config.[a]	Bow type[b]	Tow distance from the west canal wall (meters)[c]	Tow speed (meters per second)[e]	Ambient flow velocity (meters per second)[d]	Return flow velocity (meters per second)[d]	Percent reduction in voltage gradient[f]	Number of fish passages[g]
2017	2x3	Box	17.8	1.28	0.17	-0.19	19.2	0
2017	2x3	Box	16.3	1.23	0.19	-0.14	22.7	2
2017	2x3	Box	19.7	1.23	0.15	-0.15	17.9	1
2017	2x3	Box	17.1	1.32	0.31	-0.06	21.3	123
2017	2x3	Box	19.4	1.28	0.19	-0.14	17.9	9
2017	2x3	Box	15.8	0.88	0.26	0.05	20.5	1.7
2017	2x3	Box	15.2	0.93	0.25	0.07	23.8	2.7
2017	2x3	Box	15.2	1.37	0.30	-0.01	21.9	0
2017	2x3	Box	16.0	1.41	0.34	0.02	No data	35
2017	2x3	Box	18.9	0.48	0.31	0.25	20.1	5
2017	2x3	Box	13.7	0.88	0.22	0.04	29.9	0
2017	2x3	Box	15.5	0.48	0.19	0.35	24.8	0
2017	2x3	Box	18.4	0.93	0.41	0.23	23.0	0
2017	2x3	Box	20.0	0.93	0.37	0.17	19.9	0
2017	2x3	Box	16.3	0.88	0.35	0.17	27.0	0
2017	2x3	Box	17.7	0.84	0.31	0.26	22.8	0
2017	2x3	Box	16.5	1.28	0.39	0.01	27.0	10.3
2017	2x3	Rake	13.7	0.93	0.38	0.18	33.9	0
2017	2x3	Rake	16.6	1.32	0.32	0.06	22.3	0
2017	2x3	Rake	13.1	0.97	0.44	0.27	33.7	0
2017	2x3	Rake	11.9	1.15	0.39	0.19	38.2	93
2017	2x3	Rake	13.6	0.88	0.36	0.23	31.9	1
2017	2x3	Rake	13.4	0.88	0.38	0.19	32.1	20.7
2017	2x3	Rake	13.7	0.88	0.39	0.20	No data	6.3
2017	2x3	Rake	14.0	0.88	0.24	0.04	30.1	2
2017	2x3	Rake	13.6	0.88	0.28	0.09	31.6	0
2017	2x3	Rake	14.5	1.32	0.23	-0.03	No data	0
2017	2x3	Rake	13.7	1.32	0.23	-0.03	33.0	43
2016	2x3	Box	16.6	1.30	0.15	-0.22	25.0	66
2016	2x3	Box	15.2	1.36	0.18	-0.15	27.3	20
2016	2x3	Box	16.8	1.55	0.08	-0.17	23.3	126
2016	2x3	Box	13.4	1.45	0.11	-0.26	35.1	29
2016	2x3	Box	16.8	1.42	0.15	-0.26	28.8	2
2016	2x3	Box	14.5	1.56	0.15	-0.25	35.7	18

Year of study	Tow config.[a]	Bow type[b]	Tow distance from the west canal wall (meters)[c]	Tow speed (meters per second)[e]	Ambient flow velocity (meters per second)[d]	Return flow velocity (meters per second)[d]	Percent reduction in voltage gradient[f]	Number of fish passages[g]
2016	2x3	Box	12.6	1.60	0.14	-0.34	39.8	427
2016	2x3	Box	15.2	1.45	0.19	-0.26	26.7	75
2016	2x3	Box	13.1	1.43	No data	-0.16	42.9	33
2016	2x3	Box	14.3	1.71	0.24	-0.12	19.4	39
2016	2x3	Box	15.2	1.69	0.17	-0.27	No data	14
2016	2x3	Box	14.9	1.73	0.12	-0.27	25.3	227
2016	2x3	Box	14.3	1.78	0.13	-0.34	27.4	822
2016	2x3	Box	14.9	1.57	0.11	-0.24	16.8	82
2016	2x3	Box	16.5	1.66	0.12	-0.25	No data	49
2016	2x3	Box	17.1	1.53	0.18	-0.22	18.9	3
2016	2x3	Box	17.1	1.68	0.14	-0.25	14.8	118

[a] Tow configuration is given as “number of barges wide X number of barges long”
[b] Bow type is given as “Box” or “Rake”, and indicates the type of barge located at the bow of the tow during each run.
[c] Measured using a laser rangefinder at the midpoint of the second barge
[d] Measured using a hydroacoustic velocity probe at Barrier IIB
[e] Measured using three Global Positioning System (GPS) units on the tow
[f] Percent reduction in voltage gradient measured near the DIDSON sonar for the time the midpoint of the second tow passed the sonar compared to in the absence of a tow
[g] Average of fish passage counts from three independent readers of the sonar data