FISH PASS
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RESEARCH PUBLICATION 2023

FishPass baseline assessment of fish community assemblage and migratory patterns in the Boardman River, Traverse City, Michigan, USA

Reid G. Swanson, Daniel P. Zielinski, Theodore R. Castro-Santos, and Andrew M. Muir

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Cover image is a design rendering of the FishPass site.

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EXECUTIVE SUMMARY

This report on baseline assessment of fish community assemblage and migratory patterns of fishes in the lower Boardman River (LBR; Traverse City, MI (USA)) is one of four assessment projects conceived circa 2017 after the Boardman (Ottaway) River was selected by the Great Lakes Fishery Commission (GLFC) and collaborating agencies as the future site of the Selective Bi-directional Fish Passage (FishPass) project. This report describes the results from fisheries community sampling from 2017-2021 and the concurrent bio-telemetry project aimed at understanding phenological changes in the fish community and movement and space-use of a variety of large-bodied fishes in the LBR against which selective fish passage treatments will be developed and evaluated.

Fish migration in riverine environments is a growing area of concern as mounting anthropogenic influences, particularly fragmentation from dams and barriers, constitute a major threat to global river species diversity. Specifically, In the Laurentian Great Lakes basin, more than 250,000 dams, weirs, culverts, and other significant obstructions prevent the movement of species both between the Great Lakes and rivers, and within rivers. Barriers impede the movement of fishes between areas critical to the completion of their lifecycle, affecting both population and ecosystem viability. However, a conundrum arises in that the same barriers can also prevent the upstream invasion of non-native or undesirable species (most notably the sea lamprey *Petromyzon marinus* in the Great Lakes), prevent the transfer of contaminants and diseases, halt deleterious genes, provide recreational opportunities, or generate power. As a result, fish passage solutions with the capability of selectively passing desirable taxa while restricting the dispersal of undesirable taxa (selective connectivity) are sought to solve this connectivity conundrum. FishPass is a multi-agency initiative planned to replace the Union Street Dam on the Boardman River in Traverse City, MI (USA), aimed at developing and implementing automatic or semiautomatic selective bi-directional fish guidance, sorting, and passage techniques and technologies. Pivotal to both the successful development of selective connectivity and assessment of its effects is a more complete understanding of the Boardman River's fishery. Specifically, understanding the species and size composition of the fish community, fish movement phenology and the associated abiotic conditions.

Fish community sampling confirmed the presence of 28 unique species in the LBR (Boardman River reach below Union Street Dam). Passive Integrated Transponder (PIT) tag telemetry increased the resolution of phenological shifts in the fish community that could not have been captured from periodic fish sampling. This data demonstrates large variation within species and overlap between species presence. However, discrete periods of presence were identified across most species when considering the central tendencies in the distribution of their presence. Rainbow trout *Oncorhynchus mykiss* were found to be omni-present in the river while brown trout *Salmo trutta* and smallmouth bass *Micropterus dolomieu* also persisted throughout a majority of the year; all of which will require continually sorting at FishPass. PIT tag telemetry also provided the important understanding that individuals (3-64%) of all species return to the LBR across multiple years.

Radio telemetry (RT) proved useful in refining the entry and exit timing and in evaluating the proportion of individuals that encountered the current Union Street Dam and Kid's Creek (the only tributary confluence below the Union Street Dam) across six species (common white sucker *Catostomus commersonii*, rainbow trout, smallmouth bass, walleye *Sander vitreus*, brown trout, and common carp *Cyprinus carpio*). The RT results show that these species are present in

between April and August. Our analysis also demonstrated that not all fish that entered the river proceeded to the Union Street Dam, but those that did, did so prior to being detected encountering Kid's Creek. Common white sucker and rainbow trout were the only species to be detected encountering Kid's Creek.

Collectively, the results of this study provide a baseline understanding of the seasonal fish diversity and relative abundance of fishes in the LBR, and a basic description of observed movement patterns of a subset of species in the context of seasonal phenology, entry and exit behavior within the LBR, and the propensity at which telemetered individuals encounter the Union Street dam and/or Kid's Creek.

INTRODUCTION

Fish migration in riverine environments is a growing area of concern as mounting anthropogenic influences, particularly fragmentation from dams and other barriers, constitute a major threat to global river species diversity (Vörösmarty et al. 2010; Castro-Santos et al. 2022). Barriers impede the movement of fishes between areas critical to the completion of their lifecycle, affecting both population and ecosystem viability (Dudgeon 2011; Fuller et al. 2015). However, a conundrum arises in that the same impediment can also prevent the upstream invasion of non-native or undesirable species (Mclaughlin et al. 2013). As a result, restoring connectivity can have consequences for both desirable and undesirable species, resulting in a connectivity conundrum. Fish passage solutions capable of selectively passing desirable taxa while restricting the dispersal of undesirable taxa (selective connectivity) are sought to solve this connectivity conundrum (Zielinski et al. 2020).

The Selective Bi-directional Fish Passage (FishPass) project is a multi-agency initiative that will take place in the Boardman/Ottaway River (Traverse City, MI, USA; Figure 1) to develop and implement automatic or semiautomatic selective bi-directional fish guidance, sorting, and passage techniques and technologies (Zielinski et al. 2020). The Boardman River has been the subject of one of the most comprehensive dam removal and restoration projects in Michigan's history and one of the largest such projects in the Great Lakes Basin (U.S. Army Corps Engineers 2014). The Boardman River Ecosystem Restoration Project sought to improve habitat connectivity through the removal of three dams and modification of the last remaining dam, the Union Street Dam. The removal of the Union Street Dam was not recommended because it is the lone barrier preventing invasive sea lamprey *Petromyzon marinus* from gaining access to high quality spawning habitat in the newly connected 288 km of perennial streams (U.S. Army Corps Engineers 2014). Selective fish passage at Union Street Dam is necessary to maintain the barrier for invasive species management while simultaneously achieving the desired restoration goal to re-connect the Boardman River with Lake Michigan. FishPass will replace the ageing Union Street Dam with an improved dam and fish barrier with selective fish passage capabilities, providing the infrastructure and research capacity to develop approaches for selective fish passage that can be exported around the Great Lakes basin and beyond.

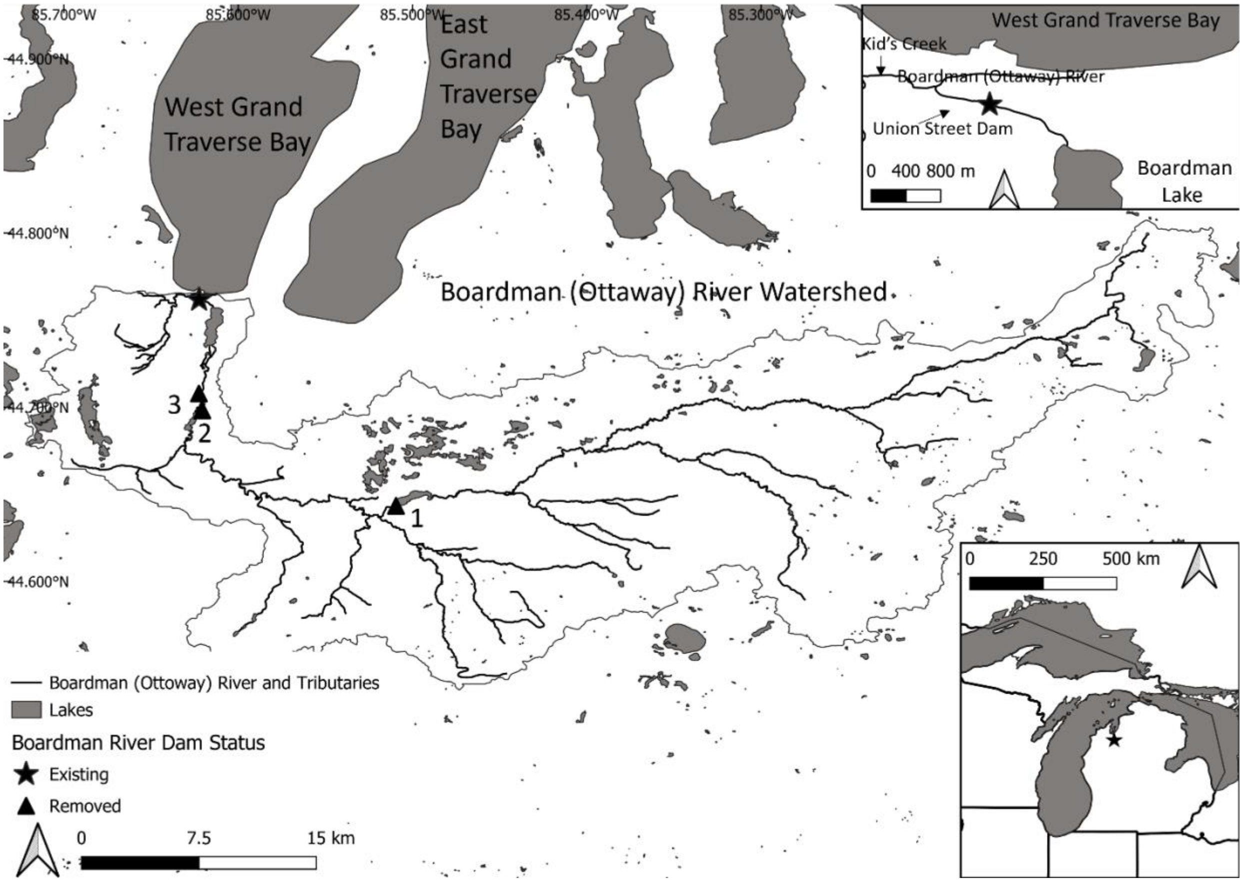

Figure 1. Map of the Boardman/Ottaway River Watershed (Traverse City, Michigan, USA) and location of the three former Boardman River dams (triangles: 1- Brown Bridge Dam, 2- Boardman Dam, 3- Sabin Dam) and future location of FishPass at the existing location of the Union Street Dam (star symbol in both main map and inset, upper right corner).

Understanding the composition of fish populations in the Boardman River and the phenological effects on their availability for passage at FishPass is fundamental to developing approaches for selective fish passage. Upwards of 56 species are known to currently or historically inhabit the watershed; although the connection between the Boardman River and Lake Michigan allows for the possibility of access by any species present in Lake Michigan (Kalish et al. 2018). The composition of the Boardman River fish community has changed across time as a result of a large number of factors including dam construction, intentional fish stocking, non-native organism introduction, road construction, road/stream crossings, and oil and gas extraction (Kalish et al. 2018). To our knowledge, no formal fisheries survey had ever been conducted downstream of Union Street Dam (hereafter termed the Lower Boardman River - LBR) prior to the onset of FishPass in 2017.

The movement phenology of the adult life stage of many species in the Boardman River is generally understood through the distillation of regional literature (Figure 2); however, site specific timing and movement cues from many species are unknown. The Union Street Dam acts as a barrier to nearly all upstream fish movement under normal flow regimes. However, sea lamprey larvae have been observed upstream of the Union Street Dam and periodic lampricide treatments have occurred since 1963. Following minor dam repairs and lampricide treatments upstream of the Union Street Dam in 2015, no sea lamprey larvae have been found upstream of Union Street Dam. Although the Union

Street Dam has a pool and weir type fishway, the challenging hydraulic conditions preclude passage by most fishes' native to the Great Lakes; only introduced Pacific salmonids and some brown trout *Salmo trutta* have been observed passing (Kalish et al. 2018). In 2019, the uppermost step of the fishway and auxiliary stoplog spillway was blocked to prevent passage of any fish, including salmon, during- and post-removal of Sabin Dam — the only remaining major impediment to fish movement upstream of Union Street Dam prior to removal in 2018 (Figure 1).

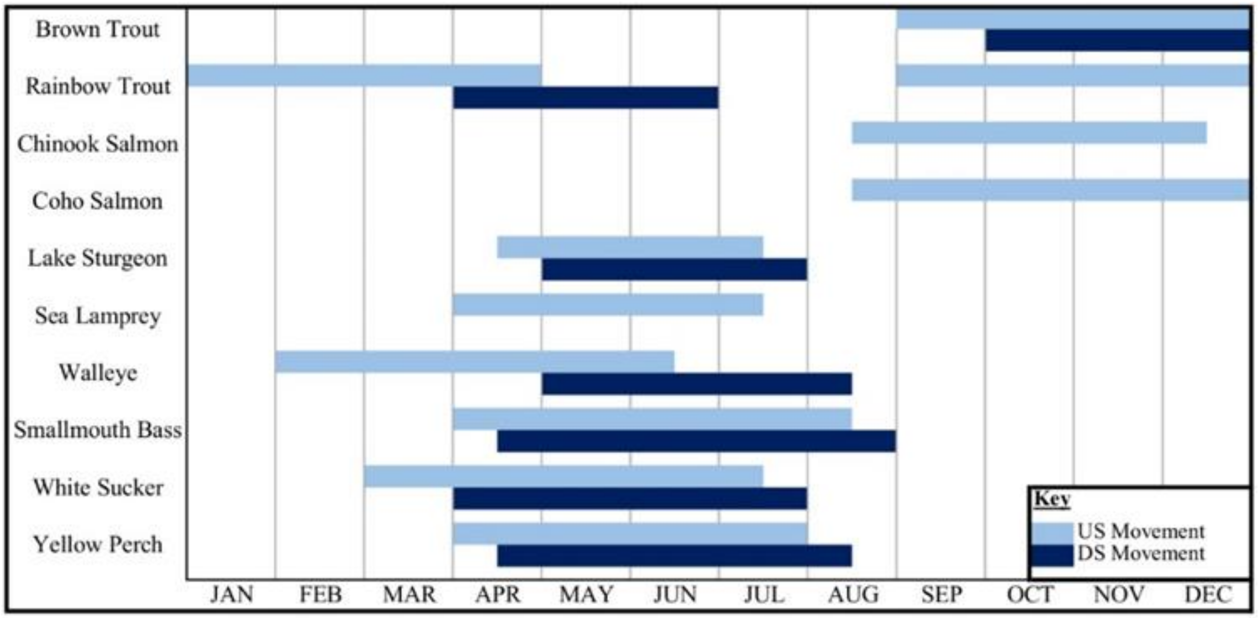

Figure 2. Upstream (US) and downstream (DS) migration timing of adults of brown trout Salmo trutta, rainbow trout Oncorhynchus mykiss, Chinook salmon Oncorhynchus tshawytscha, coho salmon Oncorhynchus kisutch, lake sturgeon Acipenser fulvescens, sea lamprey Petromyzon marinus, walleye Sander vitreus, smallmouth bass Micropterus dolomieu, white sucker Catostomus commersonii, and yellow perch Perca flavescens in the Boardman River (Traverse City, Michigan, USA). Timing data adapted from Goodyear et al. (1982), Biette et al. (1981) and Velez-Espino et al. (2011).

Considering the lack of current fisheries community data and site-specific understanding of fish movement phenology in the LBR, baseline assessment studies were started in 2017 in support of FishPass. As part of this assessment work a Dual-frequency Identification Sonar (DIDSON) was deployed in the river and river entry of three size classes of fish were analyzed with Cox regression to quantify the relation and magnitude of the effect that environmental covariates had on river entry (Swanson et al. 2021). Results indicated that medium size fish (>30 cm and <50 cm), primarily composed of white sucker and longnose sucker were positively influenced by increases in temperature and discharge, but negatively influenced by increases in Lake Michigan water levels. While the DIDSON provided a passive tool to acquire a first glimpse of fish movement in the LBR, this method was unable to distinguish fish species and was limited to a small portion of the LBR (Swanson et al. 2021). Thus, additional methodology including telemetry and seasonal fisheries surveys were required to evaluate the seasonal diversity of the fish assemblage and site-specific movement phenology in the Boardman River. In 2018, standardized fisheries surveys and a bio-telemetry study was initiated on a subset of fish species found in the LBR as part of this project.

The overarching objectives of this project were to establish a baseline understanding of 1) seasonal fish diversity and relative abundance in the LBR and; 2) movement and space-use of a variety of large-bodied fishes in the LBR against which selective fish passage treatments will be evaluated. For the second objective, we targeted six species (white sucker, rainbow trout, smallmouth bass, brown trout, and common carp) representing the typical assemblage of large-bodied fishes up- and down-stream of Union Street Dam and sea lamprey to determine the following sub-objectives:

(2a) longitudinal space use of individuals in the LBR, (2b) the proportion of individuals that encounter the features of interest (Boardman River, Kid's Creek and FishPass site), and (2c) evaluate if site encounter proportion, spatial distributions, differ among species, season, or environmental conditions.

METHODS

STUDY SITE

A tributary to Lake Michigan's Grand Traverse Bay, the Boardman/Ottaway River is located in Grand Traverse County of Michigan's Lower Peninsula, USA. The river is approximately 45.4 km long, with a watershed area of approximately 743 km^2 that encompasses 288 lineal kilometers of perennial streams and 74 natural lakes. The Union Street Dam (44.76172° N, 85.62245° W; Figure 1) is located approximately 1.85 km upstream of where the Boardman River drains into Grand Traverse Bay (44.76499 N, 85.61272° W; Figure 1). The LBR is entirely contained with the municipal boundaries of Traverse City and is characterized as an urban landscape.

ABIOTIC DATA

Collection of rudimentary environmental conditions was done in association with the monitoring of fish behavior. Hydrologic conditions (e.g., river discharge, water level) in the Boardman River and around FishPass are remotely monitored by gauges at five locations. Discharge in the Boardman River is continuously monitored by U.S. Geological Survey (USGS) gauges at Beitner Road (04127200) and Brown Bridge Road (04126970), which are used to derive continuous discharge data at Union Street Dam through direct drainage area ratio adjustment. River stage (centimeters relative to sea level) and water temperature data were collected from three sensors installed near the US-31 Highway Bridge over the Boardman River approximately 100 m from where it drains into Grand Traverse Bay, Union Street Bridge (downstream of Union Street Dam), and upstream side of Union Street Dam. Continuous water quality data were collected at the approximate mid-point of the LBR using a multiparameter water quality sonde (YSI, Xylem Inc.) installed at the Michigan Dept. of Natural Resources (MIDNR) salmon weir. Water quality parameters measured include temperature, specific conductivity, conductivity, turbidity, dissolved oxygen, and dissolved oxygen saturation

OBJECTIVE 1: SEASONAL FISH DIVERSITY AND RELATIVE ABUNDANCE IN THE LBR

To address our first objective of understanding the fish community diversity, relative abundance, and seasonal changes, the adult fish community was sampled using boat electrofishing and trap and backpack electrofishing were used to characterize small fish not readily represented in boat electrofishing surveys. Adult fish community samples were conducted seasonally but small fish community sampling was constrained within one year and season. Additionally, Passive Integrated Transponder (PIT) telemetry was used to show the seasonal changes in community diversity through a basic evaluation of the timing and location of fishes detected within the LBR. Protocols involving the handling of fishes were carried out in accordance with United States federal and American Fisheries Society guidelines for care and use of animals (Jenkins et al. 2014).

Adult fish community

In 2017, staff from the MIDNR and Grand Traverse Band of Ottawa and Chippewa Indians (GTB) conducted periodic electrofishing surveys of the LBR. These surveys utilized a boom shocker electrofishing boat and followed MIDNR electrofishing sampling protocols for non-wadeable rivers (Wills et al. 2011). Each survey was conducted during daylight hours and consisted of a single pass through the sample area with an electrofishing boat. Fish were collected using 4.77 mm size delta mesh dip nets and identified to species, measured for total length (TL), and sex was recorded when gametes could be expressed or species were sexually dimorphic. The mass of a subset of fish sampled throughout the study was also recorded when logistically feasible. In instances when more than 50 individuals of a species were sampled, only the length of the first 50 individuals of each species were measured. Chinook *Oncorhynchus tshawytscha* and coho salmon *O. kisutch* were intentionally not captured during surveys due to their semelparous spawning migration. Estimates of relative abundance for these species were provided by the MIDNR weir program. In some instances, Chinook and coho salmon were captured during electrofishing surveys for identification purposes or in groups of mixed fish species.

The Great Lakes Fishery Commission (GLFC) joined the effort in 2018 and the survey plan was modified prior to the 2019 season to occur at least 4 times a year on or near the 1st week of May, last week of July, 2nd week of September, and 1st week of November. These survey dates were selected based on staff availability and to account for seasonal variation in fish community diversity. The intention was to obtain annual samples of spring, summer, fall, and late fall period, respectively. Additional discretionary surveys have occurred in the LBR since the onset of this work for a variety of reasons but primarily to implant telemetry transmitters for the purpose of studying fish movement behavior. Accessing the entire LBR has been limited at times due to river closures during bridge construction, high water levels, and unsuitable bank conditions in the upper reach preventing crews from launching a boat, preventing survey of the full reach during some surveys. Between 2017 and 2021, 28 total and 16 index electrofishing surveys were conducted in the LBR accounting for approximately 36 and 19 hours of shock time, respectively (Table 1.)

Table 1. *The total effort and occurrence of index electrofishing surveys in which full (F), partial(P) or no (-) access was available in the Boardman River (Traverse City, Michigan, USA) below Union Street Dam (LBR) 2017-2021.*

Year	Total effort (minutes)	Spring	Summer	Fall	Late Fall
2017	105	F	-	-	-
2018	156.8	-	F	F	P
2019	387.1	F	F	F	F
2020	200	-	F	P	F
2021	278.2	F	F	F	-

PIT telemetry

During the adult fish community sampling, fish captured over 150 mm were implanted with individually coded 23 mm PIT tags (Oregon RFID, Portland, Oregon), and released. All species sampled were PIT tagged with the exception of semelparous salmonids. The PIT tag implantation target was initially set to 50/species/year at the onset of 2019 and increased to 100/species/year in 2020 to both bolster the sample sizes and also provide a potential community of tagged fish to facilitate future research at the FishPass Facility which plans to use PIT telemetry as a primary monitoring technology. PIT telemetry was used, in the context of the first objective, to describe seasonal presence across species by documenting a detection on any of the monitoring arrays within the system. A description of the PIT antenna array in the LBR is described along with other telemetry systems in a later section of this text (see Telemetry network).

An evaluation of all fish implanted with a PIT tag was conducted to understand basic presence/absence within the Boardman River and reflects the seasonal changes in fish community diversity and relative abundance (Objective 1). Rainbow trout are well known to exhibit both spring and fall migrations (Seelbach, 1993); therefore, the distribution of rainbow trout presence was described/depicted by bifurcating the year into a spring and fall migratory population (i.e., separating the detections from the January-June from July-December). While the course resolution of the PIT tag data set does not allow for the assignment of behavior, it does allow for a much greater number of individuals to be included. These data were refined by consolidating all detections on a given individual antenna within a five-minute time period to a single detection event. PIT data were then used to determine the proportion of fish that were present in a year post tagging as an approximate measure of return and/or residency between years.

Small fish community

To assess the small fish community, additional exploratory sampling was conducted using baited minnow traps and backpack electrofishing of the wadable banks in the LBR. Minnows trap surveys consisted of deploying four Gee (Memphis Net and Twine, Memphis, TN, USA; ¼” galvanized steel mesh, 17.5” L x 9” W, 1” openings on each side) and six large square minnow traps (Memphis Net and Twine, Memphis, TN, USA; ¼” galvanized steel mesh, 18” L x 16” W x 8” H, 1” openings on each side) on the river side for approximately 42-48 hours. Deployments occurred twice in 2021 on May 10-12 and June 8– 10 (Figure 3).

Backpack electrofishing consisted of two sampling events on May 12 and June 10, 2021 in which two people sampled approximately 387 linear meters of wadeable stream bank (<1 m depth) accounting for approximately 1200 m of distance traveled and a total shock time of 43:07 (Figure 3).

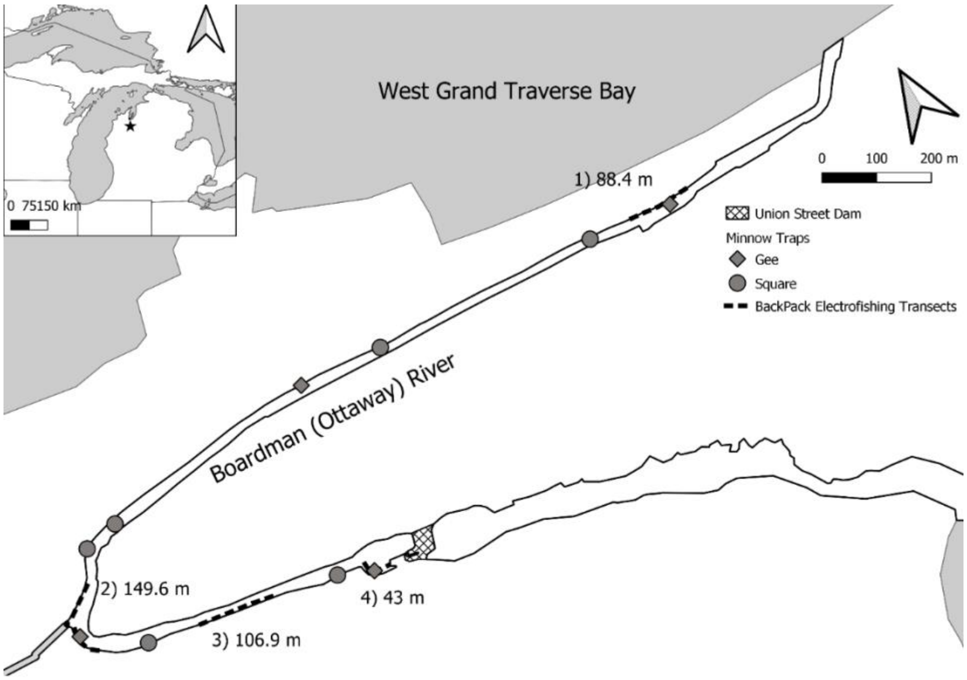

Figure 3. *The location of small bodied fish sampling methods including Gee and square minnow trap placement and the location of electrofishing transects in the Boardman River (Traverse City, Michigan, USA).*

OBJECTIVE 2: MOVEMENT AND SPACE-USE OF A VARIETY OF LARGE-BODIED FISHES IN THE LBR

Addressing the second objective for this project, of developing a baseline understanding of movement patterns of large-bodied fish included a combination of PIT and radio telemetry. There are implicit tradeoffs when studying movement behavior with both PIT and radio telemetry (RT) due to the properties of the technologies (Cooke et al. 2013). The integration of two different types of telemetry used in this study allowed coverage of the study system to be optimized in terms of spatial resolution and number of individuals.

In addition to the study of large bodied-fishes, sea lamprey were also included in the radio telemetry study. Sea lamprey were included in this study as they are a priority species for control and blockage at FishPass and there is a need to increase our understanding of their site-specific movement timing. The run size of sea lamprey in the LBR is relatively small with current estimates below one thousand individuals (Appendix A; Figure A1).

Radio telemetry

RT tags consisted of three different models of Pisces transmitters (Sigma Eight, Ontario, CAN; models TX-PSC-I-80, TX-PSC-I-160, and TX-PSC-I-1200). All three models produce a coded radio signal but differ in size and consequently battery life. The variety of sizes was initially selected to allow for an assortment of fish sizes to be monitored while still maintain a low tag mass to fish mass ratio (ideally < 2%). The model 80 tags were specifically selected for the sea lamprey. The model 160 tags were implanted in smaller fish (455-720g), while the large tags were reserved for fish > 800 g. The resulting tag implantation kept the tag mass below 2% of fish body mass for model 1200 tags while the small tags remained < 3.8% of fish body mass. Two transmission rates were used throughout the study, 15 and 30 pings per minute (ppm), the latter of which was initially selected to increase detection probability given the observed detection efficiency of the radio telemetry network. This high transmission rate was modified to 15 ppm to alleviate observed difficulty in manual tracking and facilitate post-hoc false positive detection filtering. Estimated battery life of the model 80 tag at 15 ppm is 135 days. Estimated battery life of the model 160 tag at 30 ppm is 218 days and at 15 ppm is 357 days. Estimated battery life of the model 1200 tag at 30 ppm is 1795 days (~4.9 years) and at 15 ppm is 3247 days (8.9 years).

Originally, a sample target of 10 RT tags of each target species (*n*=10 of each fish in Year 1, 60 total; *n*=40 in Year 2) was selected. This allocation was subsequently increased to achieve a sample size of > 10 individuals with the larger model 1200 RT tags (Table 1). An increase in tagging was desired to account for observed mortality, lack of return of some fish to the river, and to achieve a battery life > 1-year post tagging to document return behavior to the study area. The intermediate size 160 RT tags are not considered in the remainder of the analysis presented here due to the short battery life. All fish that received an RT tag were also tagged with PIT tags.

Sea lamprey were sampled differently than other study species. Individuals were obtained from GTB staff contracted by the U.S. Fish and Wildlife Service (USFWS) to operate the sea lamprey adult abundance index traps maintained at the Union Street Dam. Sea lamprey captured in these traps were transferred to a holding cage near the bottom of the LBR (Approximately 270 m upstream from the river mouth). They were clipped with a double dorsal fin clip, implanted with PIT and/or RT tags and released. The double dorsal clips were utilized to identify tagged animals from those marked with single dorsal clips for the purposes of population abundance estimation by the GTB and USFWS. Only the larger body size females were implanted with RT tags while PIT tagging was conducted on both males and females. In some instances, sea lamprey were recaptured in the index traps after which they were again transported downstream to the release location and released again. Due to confusion between index trapping mark-recapture population estimate goals and the goals of this project some animals that received a double dorsal fin clip, RT and/or PIT tags were removed from the study. The identity of those individuals was not recorded.

Table 2. The number of radio telemetry (RT) tags and Passive Integrated Transponder (PIT) tags implanted in the Boardman River (Traverse City, Michigan, USA) by species and the average total length of tag recipients across the study period 2018-2021.

Species	**PIT Tags**	**Ave. Total Length PIT (mm)**	**RT Tags**	**Ave. Total Length RT (mm)**
Northern pike (*Esox lucius*)	18	685.6	-	-
brown trout (*Salmo trutta*)	67	422.4	3	537.7
common carp (*Cyprinus carpio*)	37	700.9	15	714.8
common white sucker (*Catostomus commersonii*)	203	449.7	15	445.9
gizzard shad (*Dorosoma cepedianum*)	3	447.3	-	-
golden redhorse (*Moxostoma erythrurum*)	6	579.5	-	-
lake sturgeon (*Acipenser fulvescens*)	1	1727.0*	-	-
lake trout (*Salvelinus namaycush*)	54	703.7	-	-
largemouth bass (*Micropterus salmoides*)	1	281.0*	-	-
longnose sucker (*Catostomus catostomus*)	159	441.9	-	-
rainbow trout (*Oncorhynchus mykiss*)	193	578.8	13	572.1
rock bass (*Ambloplites rupestris*)	27	198.3	-	-
sea lamprey (*Petromyzon marinus*)	71	479.8	11^{Δ}	495.6
smallmouth bass (*Micropterus dolomieu*)	89	338.7	12	425.5
walleye (*Sander vitreus*)	48	576.0	15	652.6
All Species Total	**977**			

**Denotes a sample size of one, Δ denotes Pisces transmitters models TX-PSC-I-80 all others received TX-PSC-I-1200, - denotes no tags implanted.*

Fish implanted with RT tags were anesthetized with either eugenol (AQUI-S 20E per MIDNR INAD) prior to surgical implantation or with electroanesthesia using a Transcutaneous Electrical Nerve Stimulation (TENS) unit at the time of surgery. Briefly, fish were placed ventral-side up in a mesh cradle and their gills irrigated with river water using a small pump. While in the cradle, a small incision was made in the abdomen immediately posterior to the pelvic girdle. The RT tag was then inserted into the peritoneal cavity, and the incision was closed with 3-5 interrupted sutures (Ethicon PDS 45 cm, size 4-0 with 22 mm circle reverse cutting needle; monofilament absorbable). Surgical tools and tags were sterilized before each surgery with chlorohexidine or isopropyl alcohol.

Telemetry network

Movement behavior of radio tagged fish was monitored using a combination of stationary PIT and RT array stations and a standardized mobile tracking approach.

Stationary array

RT tag presence was monitored by four broadband receiver/datalogger systems (Orion; Sigma Eight, Ontario CAN). The systems operated at 164.290, 164.480, and 164.330 MHz bands. One array of receivers was installed at the river mouth confluence with West Grand Traverse Bay (WTB Array; Figure 4) to document movement in and out of the river. The WTB Array was initially deployed as a single radio receiver and switch board alternating between two directional Yagi antennas every second. This was modified on 9 April 2019 and maintained throughout the remainder of the study as two separate radio receivers with an individual directional Yagi antenna (one pointed upstream, one pointed downstream). This configuration was selected to maximize longitudinal detection range within the receiver and to gain directionality of movement through order of receiver detections in a given detection history. A second array was installed underneath the South Union St. Bridge (USB Array; Figure 4) to document presence at the future FishPass project area. The USB array consisted of two radio receivers with an array of whip style antenna submerged on the river bottom across the river with the goal of understanding the and cross-channel distribution (north vs. south bank) of fish as they encountered the future FishPass site. The antenna consisted of coaxial cable with 99 mm of shielding stripped from the distal end. At the onset of the study the whip style antenna arrays consisted of two antenna per receiver which was increased to four antenna per receiver array after a vandalization event removed the original array from the site.

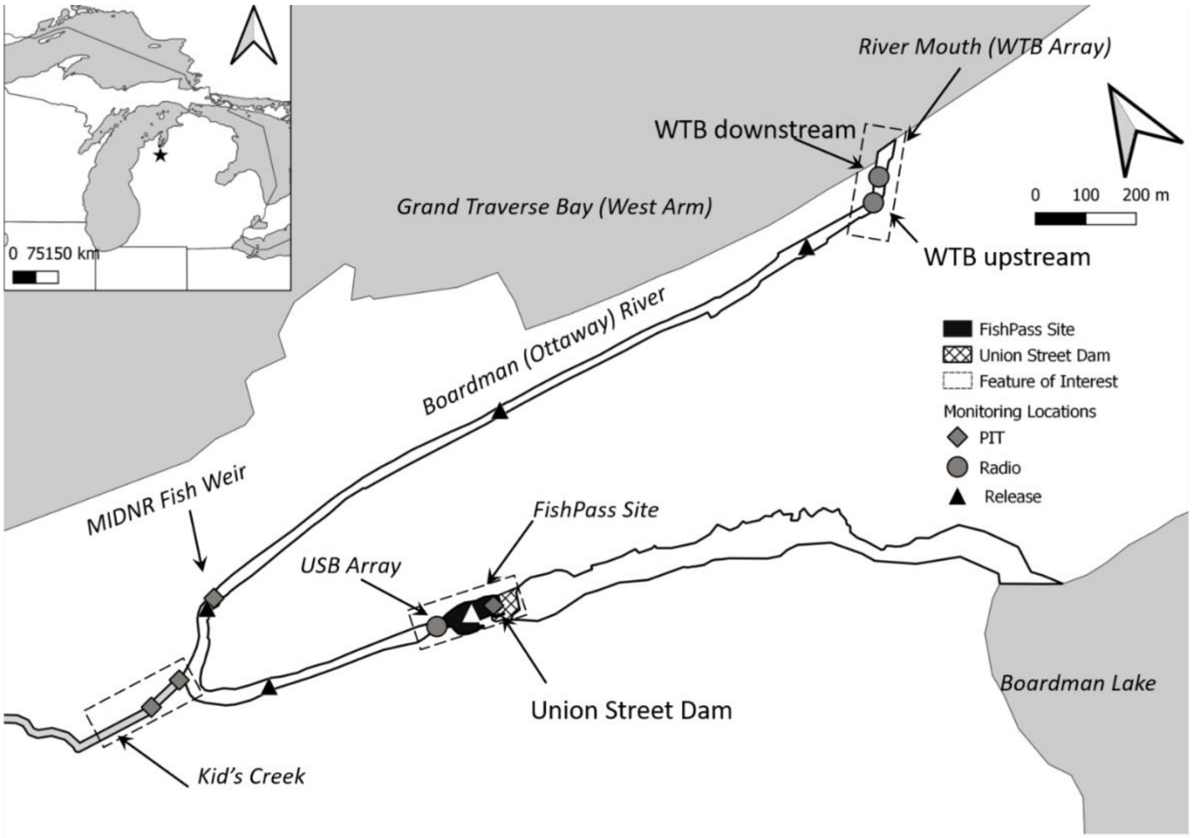

Figure 4. *The location of the Passive Integrated Transponder (PIT) tag antenna arrays, radio Telemetry monitoring arrays (radio), release location of tagged fish, future FishPass site, Union St. Dam, and the three main features of interest (Boardman River Mouth, Kid's Creek and FishPass site), related to fish movement in the Boardman River (Traverse City, Michigan, USA; 44.76172° N, 85.62245° W).*

PIT tag presence was monitored at three locations during the study period. The locations monitored included the MIDNR fish weir (20 July 2018-2021), in the fish ladder on the Union Street Dam (26 June 2018-26 March 2019), and Kid's Creek (18 April 2019-2021; Figure 4). The PIT antenna arrays varied by site but generally consisted of 2-4 antennas per site and a multi-Antenna half-duplex reader (Oregon RFID, Portland, Oregon, USA). Each antenna consisted of 2-3 loops of 12-gauge stranded wire tuned to an inductance of ~30-80 μH. All antennas were connected to tuning modules and connected to the PIT tag reader by twin axial cable. Each time a tagged fish passed through an antenna, the time of passage, PIT tag identification number, antenna number, and time between detections were logged. The weir PIT array consisted of four rectangular pass-through antennas (4-6 m L x 1.25 m W) spanning the entire width of the river channel and covering approximately 75-85% of the water column from substrate to surface dependent upon water level (i.e., at high water levels a large proportion of the top of the water column was outside the detection field). The Union Street Dam ladder array consisted of two pass-through antennas, one affixed to the face of the ladder entrance, and the second affixed approximately halfway between the entrance and first step of the ladder. Upon closure of the fish ladder in March 2018, the system was relocated downstream to the culvert at the confluence of Kid's Creek. The Kid's Creek antennas consisted of one pass through antenna affixed to the downstream face of the culvert and a second pass over antenna submerged on the bottom of the culvert approximately 10 m upstream from the confluence. The downstream antenna had a detection range less than 30 cm in the upstream and downstream direction. As a result, detections on this antenna were viewed a fish encountering the creek rather than swimming past it in the river. Kid's Creek was selected as a feature of interest because it is the only tributary to the river downstream of Union Street Dam and only alternative pathway upstream in the system.

Active tracking

The study area between E. Grandview Parkway and Union Street Dam was searched from shore approximately once every two weeks using a handheld radio receiver (model SRX 800, LOTEK, Newmarket Ontario, Canada) and Yagi antenna. Location (Universal Transverse Mercator zone 13N, NAD 83), signal strength (dB), and bearing (°) of each detection were recorded and approximate location of fish detected during each survey was estimated using bi-angulation. This data was then digitized to a shapefile using the LOAS (Location of A Signal, Ecological Software LLC, V. 4.0.3.8). The fish positions detected through manual tracking were then integrated into the static array data using the Nearest Neighbor Merge (NNM) tool in geographic information system software (QGIS version 3.14.15-Pi, QGIS.org, 2022. QGIS Geographic Information System (QGIS Association. http://www.qgis.org) to append the bi-angulated tracking location to the nearest midline river meter (meter 0 to 1830 m, in 10-meter increments). The combined static and active tracking data were visualized and analyzed together using longitudinal river distance upstream from confluence. The active tracking locations act as a sporadic detection array in the data format.

Data preparation and integration

Initial exploration of the RT detection files indicated the likely presence of false positive detections. Consequently, all radio telemetry data was filtered using a Naïve Bayes classifier (Biotelemetry Analysis Software, BIOTAS; Nebiolo and Castro-Santos 2022) prior to any further analysis or integration with other data sources. The classifier was used to remove over a million false positive detections while only potentially removing 48 likely true (false negative) detections as determined by the cross-validation procedure (Appendix B).

For the movement analysis, all available data were integrated into a common data set to include all capture data (first capture and release and all subsequent recaptures), PIT detections, and static and active RT detections. Capture data were integrated into the bio-telemetry derived data set using the same method described in the active tracking section but rather than using bi-angulated locations the known location at which a fish was released was used. The recreational angling, tribal, and commercial fishing community in the area (hereafter termed public) were also made aware of the project through proactive communication and signage. During the study period 18 tagged fish were captured by the public of which 13 were reportedly harvested. The approximate time and location of capture and harvest events were gathered through the reporting process and also integrated into the final movement data set.

Censoring and data sets

After integration of all data sources, a set of censoring rules were applied to derive the most meaningful data to address a given objective. First, all potential detections of a fish prior to release were removed from the data set (i.e., if a tag was detected during transport and/or survey activities prior to tag implantation). All detections of 160 model RT tags were removed from the RT analysis. All individuals that were not detected at the river mouth (WTB array) at least once were removed from further analysis. These individuals either remained resident in the river post tagging for the duration of their tag's life, were harvested and not reported, or experienced some type of mortality (natural or tag induced) within the river system. Due to the difficulty in decoupling these factors their fate remains unknown and thus they provided little information on entry/exit phenology. After this censoring, individuals that remained had sufficient tag battery life to document movement phenology when present in the monitoring network. Fish were removed from the number of available individuals when reported as harvested or in the occurrence of a mortality event. Mortality events were identified in the data set through visual inspection of static array and tracking data. If a fish remained stationary for > 6 months during manual tracking cycles without a detection on a stationary array site, or remained within a stationary array detection field beyond the same threshold of time, or only made slow prolonged downstream movements, the fish was classified as "dead". The detection history of dead fish was subset to end at the last static array point before these behaviors were observed.

STATISTICAL ANALYSIS

The process of fish moving through a fishway or other feature of interest is typically defined by four sequential stages: (1) approach; (2) entry; (3) passage/blockage; and (4) fate (Silva et al. 2017). The proportion of individuals is calculated as the number of individuals transitioning to a consecutive stage (in either direction) of those available in the previous stage. We adopt and adapt these terms to allow for comparison to anticipated future work which is intended to be developed at multiple spatial scales in the context of a given feature of interest such as the entire system (e.g., Boardman River, FishPass – project site), partial system (e.g., within the planned fish sorting channels, nature-like bypass channel), and even individual sorting mechanisms. The focus of this research considered three main features of interest: the Boardman River, the FishPass site and Kid's Creek. Union Street Dam currently blocks passage of all fish, and as a result, there are no passage events to monitor at the FishPass site and all fish are considered blocked. Because the LBR has no impediments to fish passage this work was constrained to evaluating entry/exit and fate.

Objective 2a - Longitudinal Space Use Of Individuals In The Lbr

Understanding the timing at which fish enter and exit the Boardman River is important to anticipate future sorting needs at FishPass. Site specific movement phenology was examined through the integrated movement data set by assigning a set of rules to delineate entrance and exit behavior at the river mouth (WTB Array). The rules used to define these behaviors were applied sequentially and ultimately resulted in five possible behaviors associated with a telemetered detection termed release, river resident, exit, entry, or harvest (Figure 5). The release information was added as the first spatial data point in the fish's detection history and the behavior defined as "Release". Public harvest information was assigned as" Harvest". Then the most downstream antenna of the entire array (WTB downstream) was used to document an exit behavior by assigning all detections on that antenna without another detection at any location from any source upstream within a 12-hour period as an "Exit". Entry behavior was then assigned to the detections subsequent to an exit that occurred at the WTB array and were not a harvest event outside the monitoring network (e.g., in Grand Traverse Bay). Entry was also assigned to any detection at the WTB downstream receiver if no detections were recorded within a three-week period prior. "River residence" was then assigned to all detections not yet classified within the data set. Previously assigned exit behaviors were changed to river resident if the subsequent detection did not occur at the WTB Array and the time between the detections was less than three weeks. This rule was assigned to account for behaviors observed in which fish remained in the river network at unknown locations between monitoring locations. The 3-week time period was used as a threshold as the river was actively searched with mobile radio gear approximately bi-weekly allowing for those behaviors to be accurately classified as resident rather than a potential miss-assignment of exit and re-entry. At the conclusion of the study time period, 31 December 2021, fish behaviors were assigned river resident if the last detection was not at the WTB array and exit if at the WTB array.

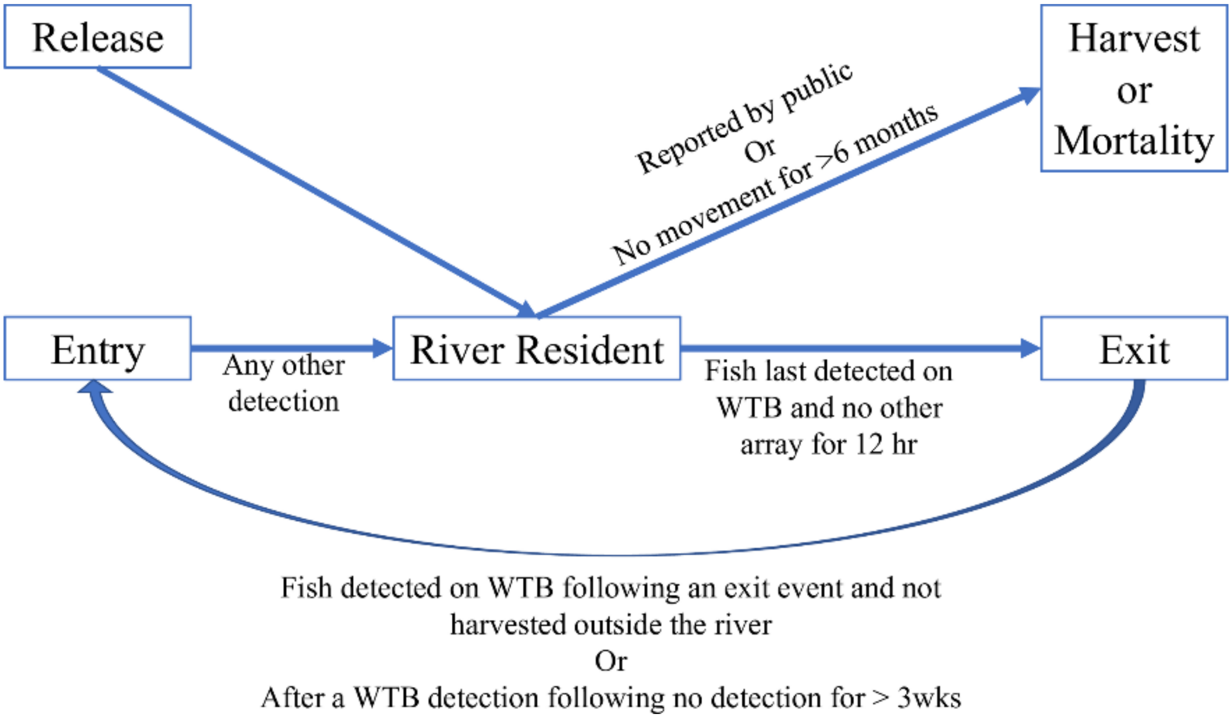

Figure 5. *Conceptual diagram of the rules used to define fish behaviors associated with a telemetered detection termed release, river resident, exit, entry, or harvest (WTB is the radio telemetry array at the river mouth near West Grand Traverse Bay).*

After the assignment of behaviors, the proportion of available individuals exiting and entering the river within a given year was calculated. Inherent to these assignments is the ability to examine the rate of return of tagged individuals across species and years. The timing of each individual entry and exit event across species and year was also characterized. The timing of entry and exit in the years post tagging were evaluated to reduce any possible tagging effects on the behavior. Fish were iterated through and their detection histories subset into bouts (the time between and entry and exit event). After this subset, the number and average length of a bouts (residence time between entry and exit events) were calculated. The overall fate of fish was categorized by those exiting the system, exiting and returning, and encounter with other features of interest (Kid's Creek, FishPass site) following a re-entry, and known mortalities.

Additionally, longitudinal space use of the study animals in areas located between the static array points was obtained from the active manual radio telemetry tracking protocol. Active tracking locations were visually examined to provide additional information as to the portion of the LBR individuals utilized across study species. Maps of active telemetry bi-angulated positions were censored to remove all locations obtained after an identified mortality event.

Sea lamprey were evaluated differently than the fusiform fishes due to differences in RT tag life span, animal acquisition, life stage at acquisition, presence of translocation within the observational period, and known accidental removal of study animals from the system without documentation of identity or tag presence. Sea lamprey were captured after already reaching the Union Street Dam at or near the end of their life cycle, so exit and entry behaviors were not assigned to their detection histories. Furthermore, sea lamprey movement behaviors were characterized within the same year of tagging due both to the life stage acquired and implantation of tags (model TX-PSC-I-80) which at the established programming only allowed monitoring for approximately 135 days. As a result, the detection histories of sea lamprey that received only a PIT tag were used to determine the proportion that attempted to return upstream. That is, the proportion of sea lamprey that received a PIT tag and were subsequently detected upstream at the Weir PIT array. Sea lamprey that received only a PIT tag and that were subsequently detected upstream at the Weir were further evaluated to understand the time and upstream travel rate (m/hr.) to reach the weir (approximately 930 river meters upstream from release site). Movement of sea lamprey that received both a RT tag and PIT tag were evaluated by examining the proportion of sea lamprey tagged and subsequently detected at both the Weir PIT array and the USB Radio Array. Radio tagged sea lamprey that were detected at these two upstream monitoring locations were also evaluated to understand the time it took them to reach the weir and FishPass site (approximately 1470 river meters upstream from release site) and the resulting rate at which they proceeded upstream (m/hr.) was also calculated. The known accidental removal of study animals from the system without documentation of identity or tag presence prevented us from evaluating the proportion of sea lamprey that eventually exited the system as the proportion available through time was impossible to know.

Objective 2b – proportion of individuals that encounter the features of interest (Kid's Creek and FishPass site)

To evaluate the proportion of tagged individuals that encountered the future FishPass site and/or Kid's Creek, the total number of individuals that entered the LBR in a given year and detected at the USB Array (FishPass encounter) and KID PIT array (Kid's Creek encounter) was quantified. The total number of individuals that entered during a given year was used as the denominator and the subsequent proportion encountering these two features of interest were calculated for the first entry of an individual within a year and for any/all entry events of an individual within a year. Further, the proportion of the cumulative entry events across species within years that consisted of an encounter for a feature of interest (encounter feature of interest / # of entry events) was calculated. When fishes were identified to encounter one of these given features of interest, the time it took them to do so was calculated as the difference between entry time and first arrival at a feature of interest.

Objective 2c - evaluate if site encounter proportions, spatial distributions, differ among species, season, or environmental conditions

The sample size of returning RT tagged fish in this study was not sufficient for a statistical comparison across species, season, or environmental condition owing to low sample sizes. As a result, a qualitative comparison between the phenological space use of each species and seasonal and environmental correlates is provided within the results for Objectives 2a and 2b.

RESULTS AND DISCUSSION

ABIOTIC DATA

River temperature below Union Street Dam ranged between 0.24 to 26.72°C across the study, with a peak temperature of 25.9°C, 25.3°C, 26.72°C, and 25.74°C in July 2018-2020, and 12 June 2021 respectively (Figure 6). Discharge ranged from 5.2 to 23.92 m^3/s across the study, with a peak discharge of 17.49 m^3/s, 23.03 m^3/s, 23.92 m^3/s, and 18.96 m^3/s in September 2018, July 2019, October 2020, and July 2021 respectively. River stage in the LBR was greatly impacted by rising water levels in Lake Michigan between 2018 and 2020, reaching a peak stage of 17831.14 cm above sea level in October 2020.

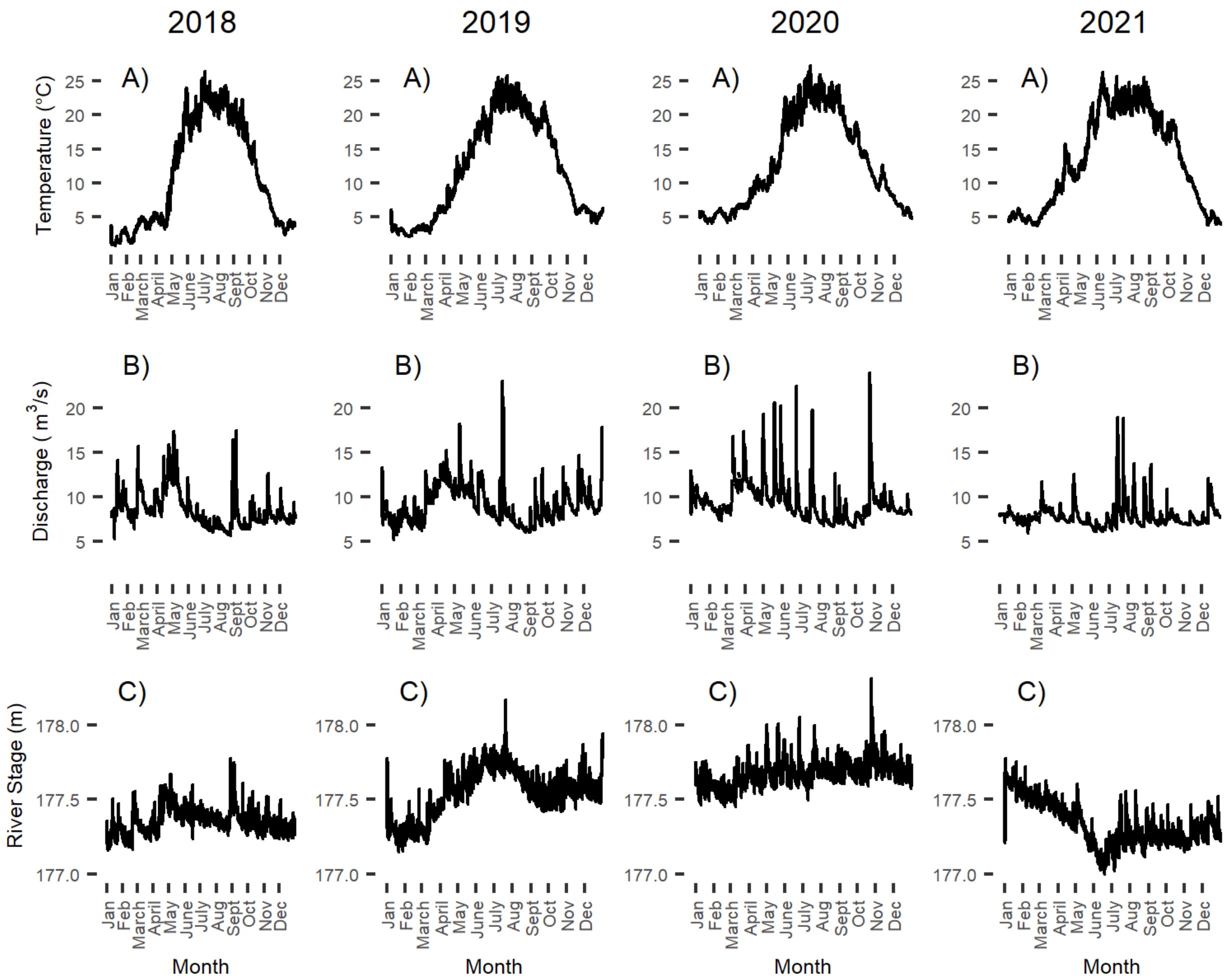

Figure 6. *Abiotic data including river temperature (A), discharge (B), and river stage (C) at the Union Street Dam (Traverse City, Michigan, USA) from 2018-2021.*

OBJECTIVE 1: SEASONAL FISH DIVERSITY AND RELATIVE ABUNDANCE IN THE LBR

Adult fish community

Twenty-six species of fish were sampled during all boat electrofishing work conducted in the LBR (Table 3). The diversity and relative abundance were variable across years and index periods ranging from six to fourteen unique species (Figure 7) and 21-356 total individuals captured across all index surveys (Figure 8). In general, both diversity and abundance were highest in the spring. However, the relative abundance is under represented during the fall index period using these methods as Chinook and coho salmon were intentionally not captured. More reliable estimates of relative abundance for these species are available through the MIDNR weir program (Appendix A; Figure A2). The addition of these individuals would likely result in fall sampling to have a relative abundance on a similar order to that observed in the spring. Further, no sea lamprey abundance was obtained from this work but their numbers are monitored via the GLFC's Sea Lamprey Spawners Assessment trapping (Appendix A; Figure A1; http://trapping.glfc.org/). Large variation was also observed in the average abundance in the summer index period resulting from large numbers of alewives *Alosa pseudoharengus* during the 2019 survey. Across all boat electrofishing surveys, 2723 fish (Table 3) were captured and 977 were implanted with PIT tags (Table 2).

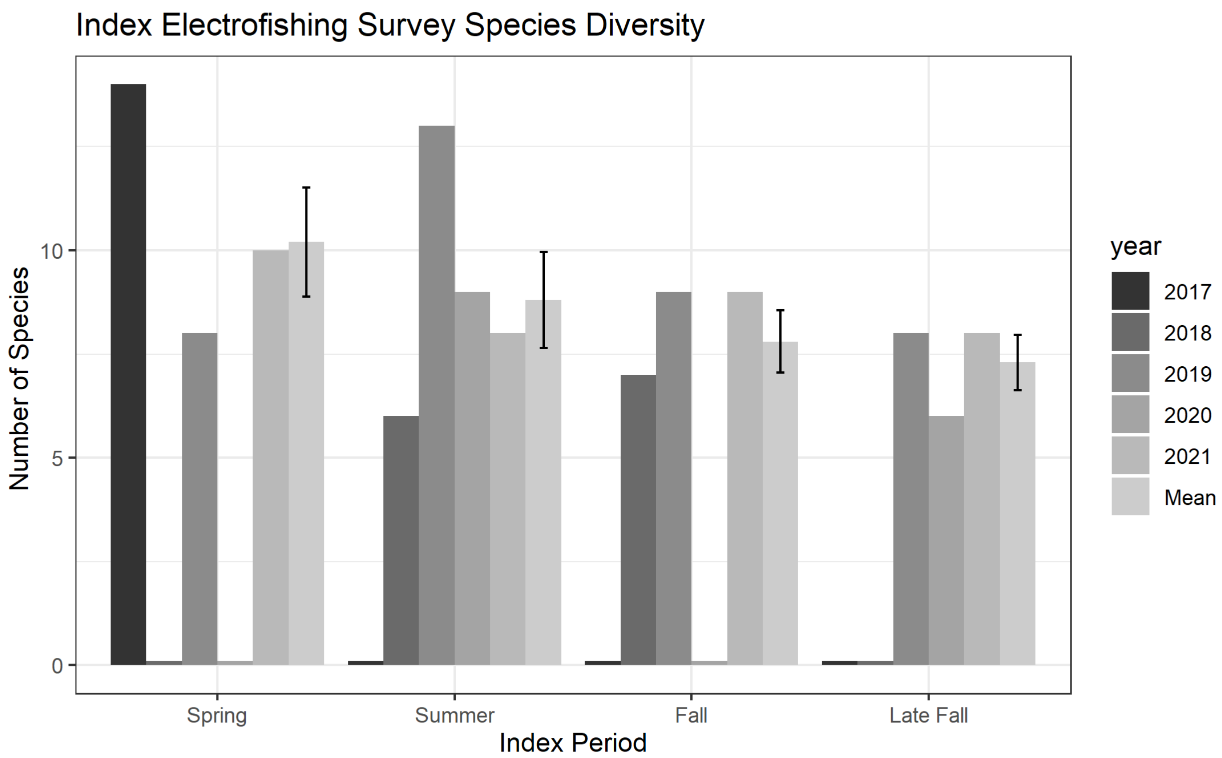

Figure 7. *The number and mean (±SE) number of fish species sampled during all index boat electrofishing surveys in the Boardman River (Traverse City, Michigan, USA) below Union Street Dam from 2017-2021.*

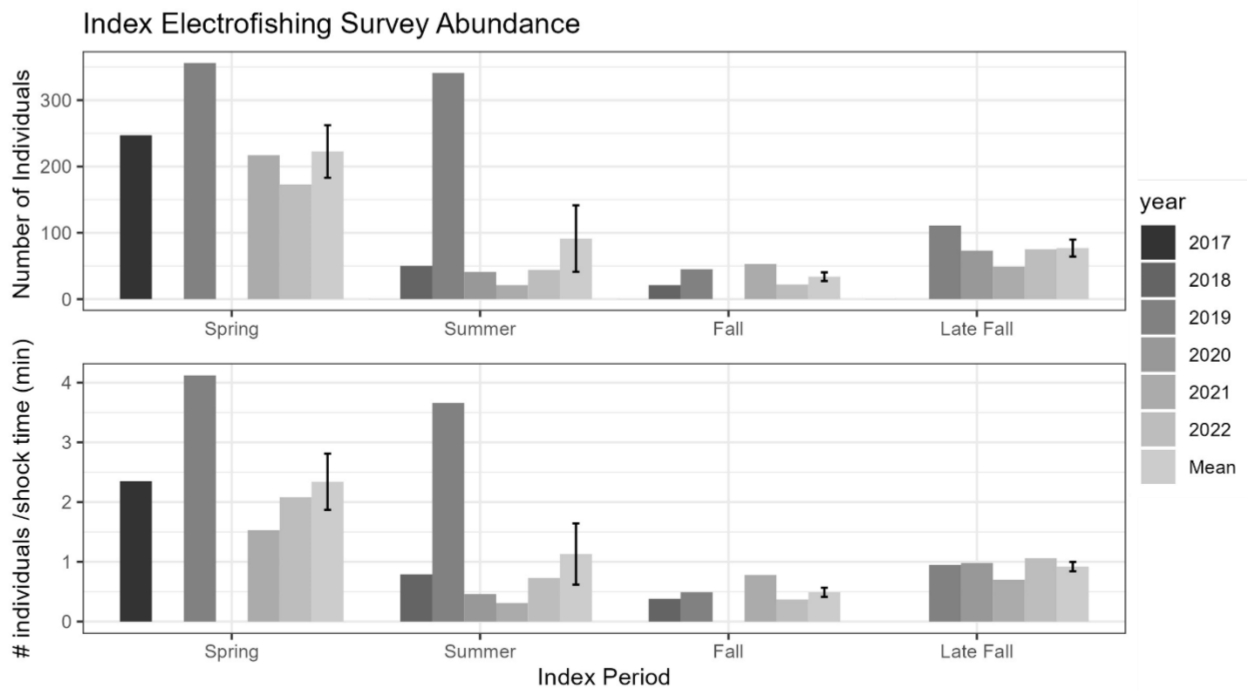

Figure 8. The number and mean (±SE) number of individual fish sampled (top) and number of fish caught per minute electrofishing time (bottom) during all index boat electrofishing surveys in the Boardman River (Traverse City, Michigan, USA) below Union Street Dam from 2017-2021

Table 3. The total number of fishes sampled (n) and recaptured and the average total length and mass of fish sampled during all boat electrofishing surveys in the Boardman River (Traverse City, Michigan, USA) below Union Street Dam from 2017-2021

Species	n	Recap	Ave. Total Length (SE) - mm	Ave. Mass (SE) - g
Atlantic salmon (*Salmo salar*)	3	0	612.7 (69.9)	-
Chinook salmon (*Oncorhynchus tshawytscha*)	7	0	807.6 (78.7)	7982.5 (2763.4)
Northern pike (*Esox lucius*)	21	1	674.5 (33.8)	2467.6 (405.4)
alewife (*Alosa pseudoharengus*)	276	0	154.6 (2.3)	-
black bullhead (*Ameiurus melas*)	3	0	237.3 (9)	-
bluegill sunfish (*Lepomis macrochirus*)	4	0	156 (13.3)	-
brown trout (*Salmo trutta*)	93	9	401.2 (10.8)	919.6 (102.3)
cisco (*Coregonus artedi*)	3	0	186.3 (3.2)	-
coho salmon (*Oncorhynchus kisutch*)	69	0	383.7 (24)	1975.8 (372.9)
common carp (*Cyprinus carpio*)	39	0	699.5 (9.3)	4655.7 (509.6)
common white sucker (*Catostomus commersonii*)	572	9	439.7 (2.8)	1119.1 (35.8)
gizzard shad (*Dorosoma cepedianum*)	7	0	449.7 (6.8)	1067.5 (72.5)
golden redhorse (*Moxostoma erythrurum*)	7	0	591 (18.9)	2881.8 (473.2)
golden shiner (*Notemigonus crysoleucas*)	5	0	109 (4.7)	-
green sunfish (*Lepomis cyanellus*)	3	0	91 (7.6)	-
lake sturgeon (*Acipenser fulvescens*)	1	0	1727*	-
lake trout (*Salvelinus namaycush*)	82	3	699 (8.3)	3296 (170.7)
largemouth bass (*Micropterus salmoides*)	2	0	236.5 (44.5)	-
longnose sucker (*Catostomus catostomus*)	485	0	440.8 (1.8)	1098.4 (30.5)
pumpkinseed sunfish (*Lepomis gibbosus*)	3	0	128.3 (13.3)	-
rainbow trout (*Oncorhynchus mykiss*)	591	8	431.2 (9)	2670.6 (148.7)
rock bass (*Ambloplites rupestris*)	113	0	160.5 (4)	225.2 (41.7)
round goby (*Neogobius melanostomus*)	7	0	90.7 (12.2)	-
smallmouth bass (*Micropterus dolomieu*)	248	5	216.4 (7.8)	885.2 (83.1)
walleye (*Sander vitreus*)	72	6	561.8 (13.8)	2122.9 (317.6)
yellow perch (*Perca flavescens*)	7	0	115.4 (12.2)	-

PIT Telemetry

An evaluation of the detection records from all PIT tagged fish demonstrated the general phenological shifts in the fish community of the LBR (Figure 9). An evaluation of the number of individuals detected in a year post tagging demonstrated variable results across years and species with 3-64% of tagged fish within a given year being detected in a subsequent year (Table 4). White and longnose suckers, walleye, and smallmouth bass had the highest percentage of individuals detected in years subsequent to PIT tag implantation, while common carp and lake trout had the lowest percentage. These results were observed to generally decrease across years. Rainbow trout, brown trout, and smallmouth bass demonstrated the largest temporal spread of presence whereas golden redhorse, gizzard shad, and lake sturgeon had the most abbreviated presence (Figure 9; Table 2).

PIT tag detection records indicate that 132 (of 193) rainbow trout were present within the community year-round while the other ten species demonstrate a more discrete range of phenological presence. When all rainbow trout are grouped, they have the largest interquartile range (IQR) and demonstrate a more continuous presence in the river in comparison to all other species evaluated. Evaluating rainbow trout in spring and fall migratory groups shows 17 and 19 of April as the median and mean values of spring rainbow trout presence and 09 November and 20 October as the median and mean values for fall rainbow trout presence. Evaluating presence across two parts of the year also demonstrates the presence of outliers in the spring migratory group. This is likely a result of rainbow trout remaining resident across the transition between years or through the winter. It's noted in the literature that they typically spawn in the spring (Seelbach, 1993; Scott and Crossman, 1973), which further suggests that some fish are coming into the river much earlier, even as early as late fall of the previous year. These data suggest rainbow trout will be present for significant periods of time and thus eligible for sorting and/or required to be sorted at FishPass.

Brown trout show the next largest range of phenological presence in the LBR. PIT tag detections on 39 (of 67) brown trout show they were only absent during the first 11 days of January across the three years of study. Half of brown trout detections occur between 23 June and 26 August (presence median:11 Jul.; mean 17 Jul.). Numerous detections of brown trout fall well outside 1.5 times IQR, suggesting that at least a few brown trout are present most of the year.

Smallmouth bass demonstrated the third largest range of phenological presence in the LBR. PIT tag detections on 49 (of 89) smallmouth bass showed they were only absent from the system over the winter months from 16 November to 02 February across the three years of study. Similar to brown trout, there are numerous outlying detections of smallmouth bass suggesting that fewer individuals are present outside the central tendencies for this species.

The three species with the lowest duration of presence within the LBR were golden redhorse, gizzard shad, and lake sturgeon. However, there were both a low number of individuals tagged (fewer than 10) of these species (Table 2) and few detection events recorded for those individuals relative to the other species in the data set. These factors resulted in extremely abbreviated time period in which these species were present.

Lake trout showed a truncated range of phenological presence. PIT tag detections on 26 (of 54) animals indicated lake trout were only present in the system from 26 October to 08 December across the three years of study. Half of lake trout detections occur across less than a weeks' time between 06 and 15 November (presence median: 07 Nov.; mean 12 Nov.). This truncated presence in the river aligns with the fact that 84% of lake trout are sampled in November. Note that during electrofishing, most lake trout (61%) appeared in spawning condition (i.e., gametes were observed) and a majority (90%) were observed with a variety of fin clips (indicating that these are hatchery fish planted across multiple years). Historical accounts of wild adfluvial lake trout populations have been documented in the Dog and

Montreal Rivers, Lake Superior (Loftus 1958), and recent work has documented their present-day presence in the Dog River, Lake Superior (Jones et al. 2018) and in the Niagara River, Lake Ontario (Gatch et al. 2021). Currently, there is no documented adfluvial spawning lake trout in Lake Michigan, and it is unclear whether these lake trout were actually spawning in the LBR. To ascertain whether lake trout are spawning in the LBR, future work is needed to confirm the presence of eggs and/or larvae.

Longnose sucker showed the next most truncated range of phenological presence of the fusiform fish. PIT tag detections of 93 (of 159) longnose suckers demonstrate presence in the system from 08 April to 11 June across the three years of study. Half of longnose sucker detections occur across a 30-day period between 24 April and 24 May (presence median: 02 May; mean: 08 May). This truncated presence in the river aligns with catch rates observed during electrofishing. During the spring index sampling a majority of longnose suckers captured are readily expressing gametes or appear to be spent. Further, a large mark-recapture study conducted in the Boardman River targeting suckers during the 2022 spring index period identified 95% of the 2543 longnose sucker captured as ripe or spent (Swanson et al. 2023). The presence of gamete expression in combination with the documented detection histories, supports longnose sucker only being present in the riverine environment for the purposes of spawning. Once spawning is complete, they quickly return back to lentic environments. Water temperatures in the LBR between 24 April and 24 May ranged between 6.1-18.6°C across the years of study and with a mean water temperature of 11.5°C. This temperature value aligns with those observed by Geen et al. (1966) who concluded that rising temperatures were an important cue for longnose sucker migration which began after a threshold of 5°C was reached.

Common carp, Northern pike, walleye, white sucker, and rock bass all demonstrate intermediate ranges of phenological presence relative to the other species. PIT detections of 23 (of 37) common carp were present in the system for over a third of the year (129 days) from 26 April to 02 September and half of their detections occur across almost two months (55 days) between 27 June and 21 August (presence median: 09 Aug.; mean: 28 Jul.). Carp are clearly absent from the river in the fall and spring time periods but are present in the river within the summer months. Northern Pike were present in the system for almost 75% of the year (257 days) from 09 April to 22 December and half of their detections occur across a single month (31 days) between 04 July to 04 August (presence median 12 Jul.; mean: 12 Jul.). PIT detection histories of 26 (of 48) walleye indicate their absence from the system was limited to the time between mid-winter and early spring. Walleye were present in the system for approximately 68% of the year (250 days) from 10 March to 15 November and half of their detections occur across 46 days between 23 May to 07 July (presence median 06 Jun.; mean: 10 Jun.). PIT detections of 153 (of 203) common white suckers indicate their absence from the river system from late-fall to early spring. Common white suckers were present in the system just under half of the year (165 days) from 25 March to 06 September and half of their detections occur across two months (65 days) between 10 May to 14 July (presence median: 28 May; mean: 08 Jun.). PIT detections of 13 (of 27) rock bass were present during the summer and fall time periods. Rock bass were present in the system just under half of the year (162 days) from 25 May to 03 November and half of their detections occur across only two weeks (16 days) between 03 and 19 August (presence median: 11 Aug.; mean: 06 Aug.).

The combination of the PIT telemetry and physical sampling of the adult fish community provide an increased understanding of the phenological shifts of the fish community assemblage within the Boardman River. The two datasets were complementary and help to clarify the observations contained within each data set. The fish community sampling is limited in that it is a snapshot of fish present in the river. The PIT detection histories provide increased resolution across the year and can provide information as to whether the same individuals are returning or remain resident year after year. However, the distributions of PIT detection data may not truly represent abundance as high movement rates (and thus over the PIT arrays) increase the number of detections which can introduce a potential bias as a disproportionate number of animals may be driving those detection histories.

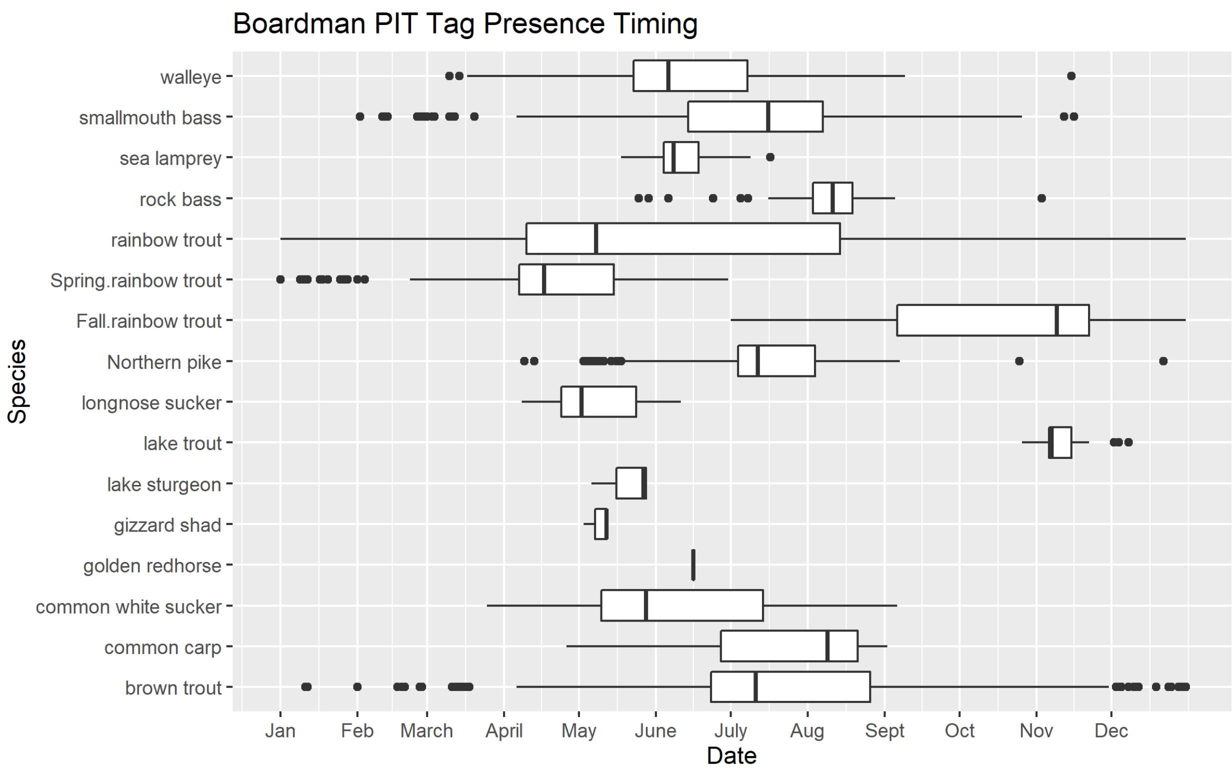

Figure 9*. The interquartile range (IQR) Box, Whisker (1.5 * IQR), and outlying data point (± whisker) plot of presence of only pit tag detection across all PIT systems and all years in the lower Boardman River across the species tagged (See Table 3 for scientific species names). Note that rainbow trout detections are also presented separately for the first (spring) and second (fall) half of the year.*

Table 4. The cumulative presence within the lower Boardman River in years post tagging of only PIT tag fish (no radio tag fish included) across species (See Table 3 for scientific species names).

Species	Detection Year	Return (n)	Tags Implanted in prior years (n)	Pct. (%) Present in years post-tagging
brown trout	2019	5	17	29%
brown trout	2020	5	32	16%
brown trout	2021	7	47	15%
common carp	2020	2	31	6%
common carp	2021	1	34	3%
common white sucker	2019	2	12	17%
common white sucker	2020	11	58	19%
common white sucker	2021	12	65	18%
lake trout	2020	3	28	11%
lake trout	2021	1	50	2%
longnose sucker	2020	21	55	38%
Northern pike	2020	3	10	30%
Northern pike	2021	3	15	20%
rainbow trout	2019	9	28	32%
rainbow trout	2020	12	82	15%
rainbow trout	2021	20	129	16%
rock bass	2019	3	10	30%
smallmouth bass	2019	9	14	64%
smallmouth bass	2020	14	37	38%
smallmouth bass	2021	12	46	26%
walleye	2020	8	25	32%
walleye	2021	8	27	30%

Small fish community

The small fish community sampling documented one additional species, common shiner *Luxilus cornutus*, not observed through the adult community sampling (Table 3; Figure 8). The diversity of the fish community targeted with these gears was low (Figure 10), suggesting additional methods should be considered in the future. Further evaluation of the small fish community is recommended to occur within the FishPass project footprint, once constructed. Understanding the composition of the small fish community will be important if small fish are to be passed or sorting is to occur on size due to the fact that this community can potentially be made up of juveniles from both desirable and undesirable taxa.

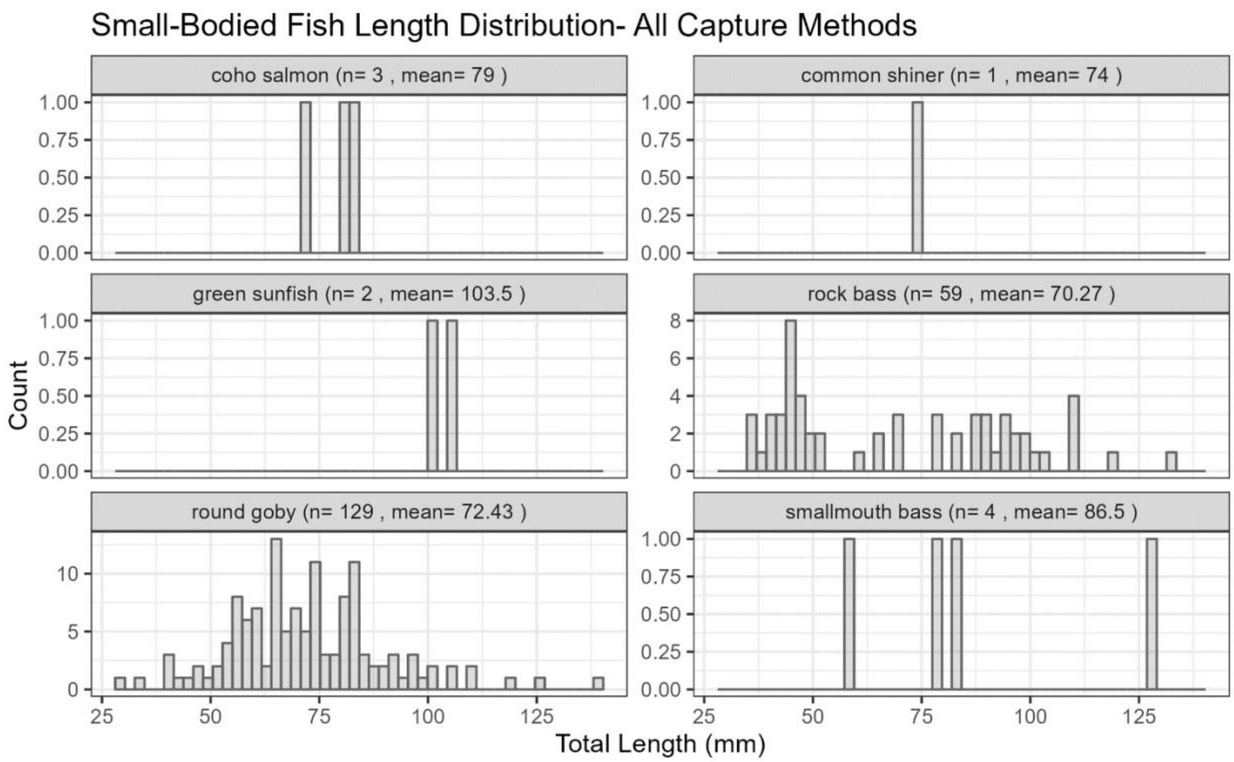

Figure 10. *The number of individuals captured in the Boardman River (Traverse City, Michigan, USA), total length (TL) distribution, and mean TL of fish sampled in targeted small bodied fish sampling including Gee and large square minnow traps and backpack electrofishing on 12 May 2021 and 10 June 2021 (See Table 3 for scientific species names; common shiner Luxilus cornutus).*

OBJECTIVE 2: MOVEMENT AND SPACE-USE OF A VARIETY OF LARGE-BODIED FISHES IN THE LBR

Objective 2a - longitudinal space use of individuals in the LBR

An evaluation of the proportion RT tagged fish returning (i.e., entry in years post tagging) was variable across species and across years within species (Table 5). However, 30/64 (46.9%) of RT tagged individuals that were not censored across all species returned to the Boardman River at least once and all species had more than 25% of individuals return at least once, with the exception of brown trout which never had a documented return in subsequent years. Of the returning individuals, a total 187 entry events occurred in years post tagging (Table 5). The results demonstrate both variation across species as well as inter- and intra- annual variation in both entry and exit timing within species. The mean and median dates of entry and exit varied within species across years. Residence time between entry and exit events was also variable across species ranging from 2.78 to 12.01 days (Table 6). Common carp demonstrated the lowest average residence time within the river of approximately three days, while smallmouth bass exhibited the largest residence time at approximately twelve days (Table 6). The IQR of all species entry behaviors fall between

April-August, suggesting that key times for passing these fish upstream occur in the spring and summer time periods (Figure 11). Visual inspection of active tracking locations also indicates that different species are utilizing discrete portions of the LBR during periods of residency (Figure 12).

Rainbow trout entered the LBR earlier than the other four fusiform species implanted with RT tags. Entry behavior was observed from 06 April to 15 May with median entry observed on 28 April. RT tagged rainbow trout also had the lowest variation in entry and exiting timing with behaviors ranging across 39 and 53 days respectively. However, rainbow trout demonstrated the lowest cumulative return rate out of any radio tag fish at 25% (only 3 out of 12 returned). The rainbow trout that did return to the LBR, entered in a fairly synchronized manor in the spring and stayed only for a short duration with a residence time of just over eight days (Table 6). One possible explanation for the low observed return rate is the potentially large spatial extent of movement undertaken by rainbow trout once they left the LBR. Anglers reported two tagged rainbow trout were captured on the Western shore of Lake Michigan, over 155 aerial kilometers away from the Boardman River near both Kewaunee and Two Rivers, Wisconsin, USA. Despite the recreational value of rainbow trout, there is an apparent lack of research on their movement patterns outside of riverine environments in the Great Lakes or lentic freshwater environments in general. One radio telemetry study conducted in Lake Ontario also documented a sizeable proportion of tagged animals “disappeared” or moved off-shore outside of monitoring capability suggesting that large spatial movements are perhaps common in this species (Haynes et al. 1986). Contrary to the synchronized entry and exit behavior observed in the RT tagged rainbow trout, the adult fish community data and PIT tag detection histories (Figure 9) demonstrates that rainbow trout are generally present in the LBR throughout the year. The apparent abbreviated entry and exit timing is likely due to a combination of low returning individuals, which appeared to be primarily composed of “spring run” individuals. Taken in combination with the PIT tag telemetry, the data suggest different individuals may be occupying the river at different time periods for a relatively short period of time, but as a species they are present in the fish community year-round. Further, it is well documented that rainbow trout show a panoply of life history and migratory patterns both in the Great Lakes and in its native range (Scott and Crossman, 1973; Biette et al. 1981; Goodyear et al. 1982). Goodyear et al. (1982) documents that rainbow trout in the Great Lakes spawn between November-July at 0.5-18°C with peak spawning usually occurring in April-May at 6-8°C. The RT tagged rainbow trout entered and exited during this time of peak spawning. Daily average temperatures in the LBR over the range of days entry was between 5.9-14.8°C, 9.2-13.1°C, and 10.1-15°C in 2019, 2020, and 2021 respectively. Entry behavior was observed at daily average water temperatures between 5.4-12.5°C. The ranges of migratory behavior demonstrated by the RT tagged rainbow trout occurred later than those documented in the St. Joseph River, a Southern Lake Michigan tributary, who entered the river between 04 March and 30 April (Workman et al. 2002). However, Workman et al. (2002) highlighted the importance of increasing flow and water temperature as a driver of migration timing of rainbow trout in the St. Joseph and Pere Marquette Rivers and water temperatures observed in the LBR during entry were similar to the 2-15 °C range at which a majority of individuals migrated in the St. Joseph River. Collectively, our results support the hypothesis that temperature values in the 2-15 °C range are important for entry of rainbow trout into Lake Michigan tributaries, although the RT tagged fish in the LBR had no documented entries below 5.9°C.

Evaluation of the central tendencies of river entry in the RT detection histories show common white suckers tended to enter the LBR second in comparison to the other RT tagged species with median entry occurring on 14 May. Common white sucker demonstrated the largest range of entry and exit phenology of any species, with ranges covering almost the whole year at 325 and 324 days respectively (Figure 11). These extreme ranges of values are highly influence by a single outlying individual (common white sucker (CWS) 59, See Appendix C) that appeared to move frequently in and out of the river for almost all 2021 with a lack of detections at upstream sites following entry events. The IQR of common white sucker entry occurred between 21 April to 21 July a range which mostly aligns with the presence observed on the PIT systems. Average residence time was approximately eleven days with a median residence time of less than a day. The large difference between the mean and median residence time is again biased by the same individual whom made numerous entries and exit behaviors, which skews the median time downward as this individual only made short forays into the lower river. When data from CWS 59 is removed, entry behavior is only observed between 28 March and 02 May, values that align more closely with that of the PIT data. Similarly, censoring this individual from the data set results in mean and median exit behaviors occurring on 26 and 08 April. These time periods align with the observed spring migratory period for common white suckers in the fish community sampling. An evaluation of the LBR water temperature profile on the day's entry behavior was observed ranged from 5.1-9.5°C with a mean water temperature of 7.0°C. The temperature threshold for white sucker spawning varies across the literature is between 7.2°C (Raney and Webster, 1942) and 10°C (Corbett and Powles 1983; Geen et al. 1966). There are important thermal considerations engrained in the physiology of these animals, as egg incubation time is negatively related to temperature in suckers, and cold temperatures extend the duration of incubation often increasing egg mortality (Hamel et al. 1997). Stream temperatures of 10-13°C were estimated to be a critical threshold at which spawning behavior (laying and fertilizing eggs) takes place for white suckers spawning in inland tributaries (Hamel et al. 1997). Entry behavior observed in our study aligns logically as suckers likely enter the river prior to optimal spawning temperature. Active tracking locations documented common white sucker throughout the upper two thirds of the river (Figure 11) in areas where observations of sucker spawning were common during the spring. However, common white suckers have been captured in the lower third of the river during electrofishing surveys.

Walleye were the next species to enter the LBR with median entry occurring in 21 May and demonstrated the highest return rate of 73.3% (11 out of 15), which is similar to the return rate (63%) documented in the Saginaw River, a tributary to Lake Huron (Hayden et al 2014). Mean daily water temperature across all entry behaviors for walleye was 15.4°C (range 6.6-25.2°C), which also coincided with decreases in river discharge indicated by a mean difference in average daily discharge from the day prior of -0.24 m/s^3. Walleye had a median and mean residence time of 0.34 and 5.26 days respectively (Table 6). Some individuals came into the LBR for only short durations, which lowers the residence time median value while others stayed for longer periods and bring up the mean. Unlike RT tagged common white suckers, multiple walleyes demonstrated short forays into the LBR (See Appendix C), suggesting these patterns are more common behavior in walleye. This observation raises additional questions as to what is driving the frequent entry and short residence period. An evaluation of walleye spawning movements in two large tributaries to Lake Huron documented an average out-migration timing of 21 days (Hayden et al. 2014), a much longer time period than the average residence timing observed in the LBR. Genetic analysis of walleye sampled in the LBR suggests that little to no successful reproduction of walleye is currently occurring as no individuals of genetically intermediate composition between any of the three strains identified in the Boardman River system have been observed (Gehri et al. 2020). Taken in combination, the RT results suggest that entry of walleye to the LBR is likely not strongly related to spawning behavior. Gehri et al. (2020) concluded that most of the walleye sampled for genetics in the LBR assign to two strains, “Bay De Noc” and “Muskegon”, stocked in West Grand Traverse Bay rather than the “New York” strain historically stocked and currently present in Boardman Lake, above Union Street Dam. The Bay De Noc strain of walleyes was annually stocked in West Grand Traverse Bay almost annually since 2008 with the exception of 2020; while the Muskegon strain hasn’t been stocked since 2010 (MIDNR 2022). This finding has implications to the observed movement data and suggests that walleye entering the Boardman are perhaps straying from stock source populations elsewhere in Lake Michigan rather than fish produced above the Union Street Dam that are attempting to return to natal habitats. Straying rates have been documented at 0-23% between spawning tributaries of Green Bay on the Western shore of Lake Michigan (Dembkowski et al. 2018). If the walleye migrating into Boardman River are straying from other systems, they appear to be doing this repeatedly as demonstrated by the high return rates. Collectively, the combination of high return rates and dissimilar ancestry between returning fish and upstream populations suggest that walleye entry may not be for the purposes of spawning or if walleyes are entering for spawning, their efforts are not resulting in substantial recruitment. An alternative explanation is that walleye entry may be driven by foraging behavior as the time period coincides with the end of sucker spawning and perceivably the emergence of their fry. Active tracking of walleye showed a notable absence of walleye in the intermediate reach between Union St Bridge North and South and walleye were most often located in areas characterized by deeper pools (Figure 11).

Common carp followed walleye in observed entry timing with median entry occurring on 31 May. Only 26.7% of common carp (4 out of 15) returned in any year after tagging. The returning carp displayed the second smallest range of entry and exit timing with behaviors ranging across 63 and 62 days respectively. Entry behavior was observed from 25 April to 27 June, while exit behavior was observed from 26 April to 27 June. The middle 50% of detections occurred between 23 May to 10 June and 29 May to 15 June for entry and exit behavior respectively. Mean daily water temperature across all entry behaviors for common carp was 18.5°C, and entry behavior was observed when the LBR water temperature was between 9.4-23.4°C. Only a single detection of common carp occurred during an active tracking cycle (Figure 11), likely due to the bi-weekly interval of active tracking as we observed a residence time of approximately three days for common carp. These results suggest that common carps are utilizing the LBR primarily in that late spring and early summer time period, during which individuals only remain for a sort duration. While the specific reason for common carp entering the LBR is unknown, their presence does overlap with the later portion of their known spawning period and the temperature profile of the LBR during their presence does overlap with documented optimal spawning temperature of 17-26°C (See and McCrimmon 1966; Auer 1982). However, common carp broadcast spawn in shallow habitats on submersed vegetation (Scott and Crossman 1973), which is in limited quantity in the Boardman River, suggesting that other drivers may be motivating the common carp entry into the LBR.

The last fusiform species implanted with an RT tag to arrive to the LBR was the smallmouth bass. Smallmouth bass demonstrated a high return rate of 63.6% (7 out of 11) and the second highest range of entry and exit across the study species entry and exit behaviors ranging across 153 and 160 days respectively. Entry behavior was observed from 04 April to 04 September and exit behavior was observed from 07 May to 14 October. These data suggest smallmouth bass are utilizing the LBR primarily in the summer months with an IQR of 28 May to 02 August and 04 July and 07 August for entry and exit behavior respectively. Smallmouth bass typically spawn in May and June in Northern Lake

Michigan (Kaemingk et al. 2010a, 2010b) and typically initiate spawning when mean daily temperatures exceed 15°C (Ridgway et al 1991b). Entry behavior was observed when the LBR water temperature was between 9.4-25°C, but water temperatures during the IQR of smallmouth entry was 14.2-24.6°C with an average of 19.5 °C. The underlying driver responsible for inciting these movements into the river is unclear. A comparison between the critical spawning temperature threshold and the observed entry events suggest that this behavior would be occurring in the spawn and post-spawn time periods. It has also been documented that two unique genetic groups of smallmouth bass exist in the Boardman River watershed that are hypothesized to differentiate based on multiple factors including, isolation by distance, connectivity to the Great Lakes, and differential use of habitats (Gehri et al. 2020). Lacustrine and riverine smallmouth bass populations have become genetically divergent in Lake Erie as a result of reproductive separation (Borden, 2008) and strong genetic structure has been documented in smallmouth bass populations in Lake Michigan across small spatial scales (10‑30 km), which often correlate to differences in habitat type rather than geographic distance (Euclide et al. 2020). Further, Euclide et al. (2020) found that gene flow between smallmouth bass collected at lake and river sites was low, even though individuals from the two habitat types likely mixed outside of the spawning season. However, Gehri et al. (2020) found that smallmouth bass above Union Street Dam were primarily a single homogonous "Boardman River (BR)" group while smallmouth bass sampled in the LBR were a mixture of the "BR", "Great Lakes (GL)", and one or two other intermediate genetic groups (or possibly hybrids). Additionally, Gehri et al. (2020) found that "GL" genetic type smallmouth made up a larger proportion of their samples collected in May compared to those collected in July or September. These finding may suggest that the RT tagged fish may have been composed of multiple genetic groups and perhaps some mixing and limited gene flow between groups is occurring in the LBR. A tissue sample from one of the RT tagged smallmouth bass (SMB 10) was genotyped as part of Gehri et al.'s (2020) study and was assigned to the BR group. This individual showed a high amount of site fidelity to the LBR, returning every year of the study and generally moving between Grand Traverse Bay and the LBR frequently across July-September (See Appendix C). Smallmouth bass are known to have a high degree of site fidelity particularly for spawning (Ridgeway et al. 1991a). This suggest that perhaps the smallmouth bass that spawn in Grand Traverse Bay (GL genetic group) may utilize the LBR earlier in the year while the BR genetic group may be potentially spawning in the LBR in June and July as demonstrated by the high fidelity and return phenology of SMB 1

__Table 5.__ The entry years, tags available, total entry events, percent of fish returning to the Boardman River (Traverse City, Michigan, USA) and exiting post return and the min, max, mean median of both the __first__ entry event of any individual and the __last__ exit event in each year (See Table 3 for scientific species names).

							First Entry				Last Exit			
Species	**Entry year**	**Tags**	**Return (n)**	**Events**	**Return (%)**	**Exit Post Return (%)**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**
brown trout	2019	1	0	0	0	-	-	-	-	-	-	-	-	-
brown trout	2020	2	0	0	0	-	-	-	-	-	-	-	-	-
brown trout	2021	2	0	0	0	-	-	-	-	-	-	-	-	-
common carp	2019	4	0	0	0	-	-	-	-	-	-	-	-	-
common carp	2020	15	4	15	26.67	100	4/24	5/29	5/17	5/23	5/11	6/26	6/3	6/2
common carp	2021	15	1	2	6.67	100	5/22	5/22	5/22	5/22	6/9	6/9	6/9	6/9
common white sucker	2019	2	0	0	0	-	-	-	-	-	-	-	-	-
common white sucker	2020	9	4	9	44.44	75	3/26	4/30	4/11	4/9	5/18	5/29	5/24	5/25
common white sucker	2021	11	2	41	18.18	100	2/2	5/2	3/18	3/18	5/19	12/24	9/6	9/6
rainbow trout	2019	6	2	4	33.33	100	4/15	4/28	4/21	4/21	5/5	5/15	5/10	5/10
rainbow trout	2020	11	1	3	9.09	100	4/5	4/5	4/5	4/5	5/27	5/27	5/27	5/27
rainbow trout	2021	9	1	2	11.11	100	4/24	4/24	4/24	4/24	5/26	5/26	5/26	5/26
smallmouth bass	2019	2	2	14	100	100	5/28	5/29	5/28	5/28	8/27	9/13	9/5	9/5
smallmouth bass	2020	8	4	35	50	100	5/3	5/27	5/14	5/13	5/28	10/13	7/19	7/2
smallmouth bass	2021	11	5	7	45.45	100	4/4	5/23	5/8	5/15	5/7	8/9	6/30	7/5
walleye	2019	0	0	0	-	-	-	-	-	-	-	-	-	-
walleye	2020	15	10	30	66.67	100	3/15	5/25	4/29	5/8	5/9	7/11	6/1	5/28
walleye	2021	14	7	25	50	100	3/21	5/28	4/27	5/4	4/10	6/20	5/22	5/28

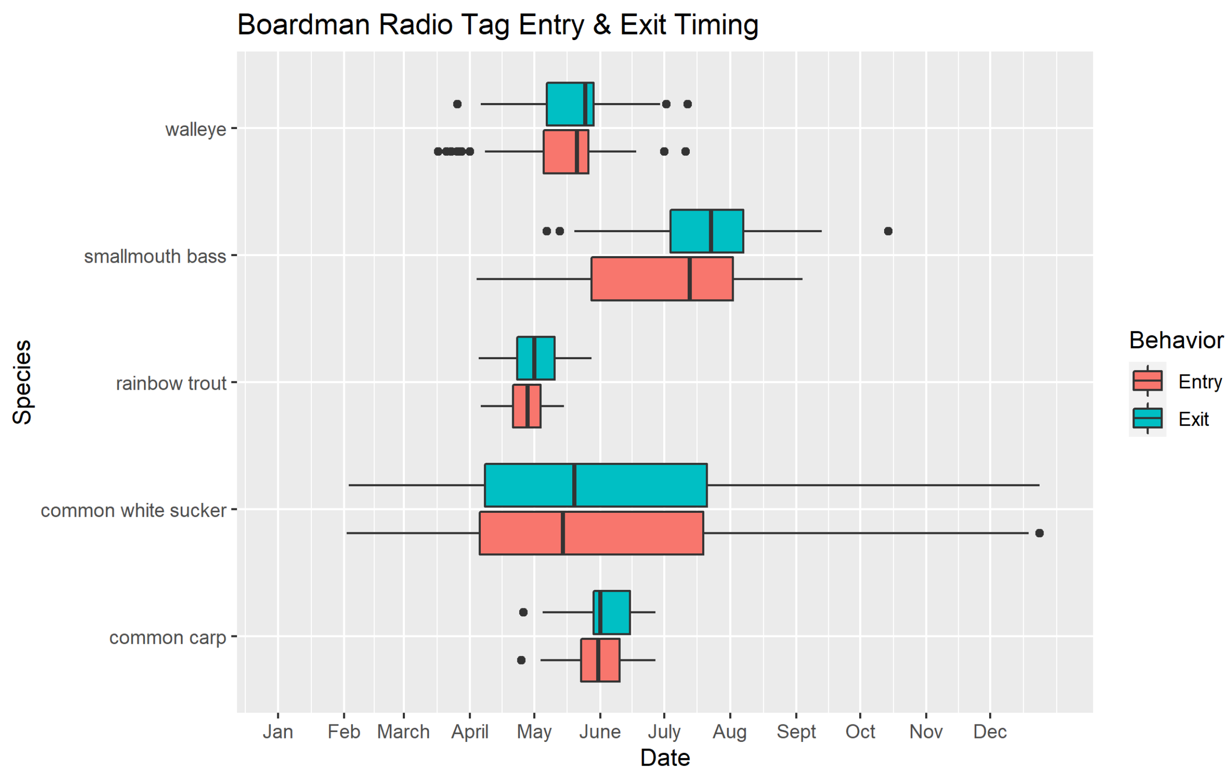

Figure 11. *The interquartile range (IQR) Box, Whisker (1.5 * IQR), and outlying data point (± whisker) plot of entry and exit behaviors of individuals with model 1200 radio tags that returned to the Boardman River (Traverse City, Michigan, USA) in subsequent years post tag implantation (See Table 3 for scientific species names).*

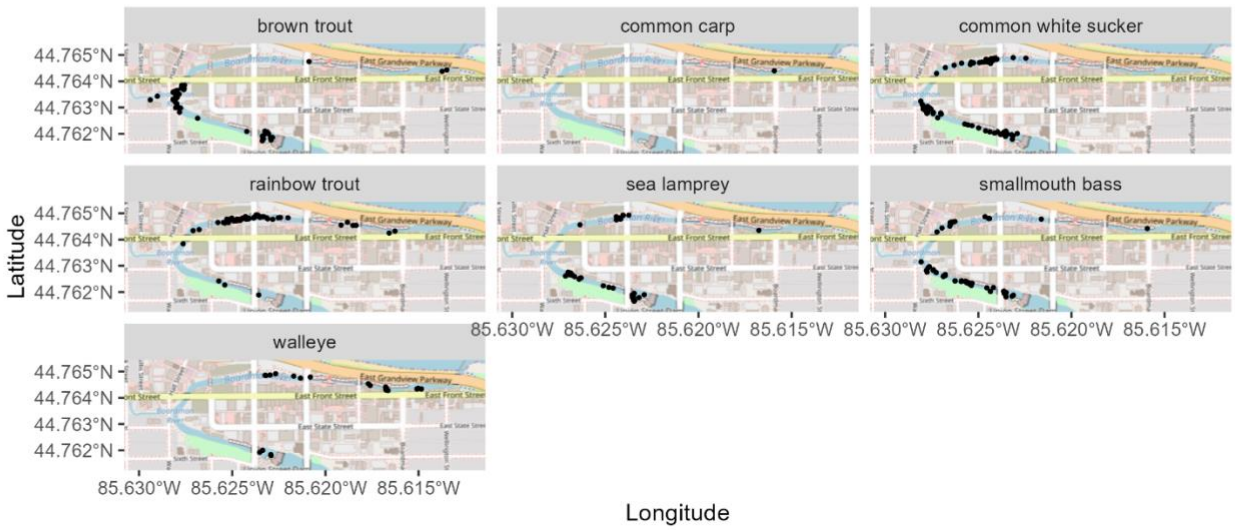

Figure 12. *Visual depiction of bi-angulated positions of fishes obtained from active radio telemetry tracking protocol in the Boardman River from July 2018 to November 2021 across species (See Table 3 for scientific species names).*

Table 6. *The mean and median residence time (i.e., the interval between entry and exit events) for radio tagged fish returning to the Boardman River (Traverse City, Michigan, USA) in years subsequent to tag implantation.*

Species	Mean Residence (Days)	Median Residence (Days)	SE (Days)
common carp (*Cyprinus carpi)*	2.78	1.21	0.80
common white sucker (*Catostomus commersonii*)	11.05	0.26	7.42
rainbow trout (*Oncorhynchus mykiss*)	8.62	6.10	2.94
smallmouth bass (*Micropterus dolomieu)*	12.01	0.41	3.69
Walleye (*Sander vitreus*)	5.26	0.34	1.43

Sea Lamprey

A large proportion of sea lamprey, 83% (50 out of 60) were detected at the Weir PIT array. It took 99.60 hours on average for PIT tag only fish to reach the weir, which represents a movement rate of 43.7 m/hr. (SE= 5.92, range = 1.86-131.85 m/hr.). All 11 RT tagged sea lamprey (100%) progressed upstream after release, taking 100.97 hours on average to reach the weir. This represents a movement rate of 33.2 m/hr. (SE= 11.41 m/hr., range = 2.35-118.42 m/hr.). Eight of the eleven (73%) RT tagged sea lamprey progressed back up to the Union Street Dam after release, taking on average 109.07 hours to reach the future FishPass site (USB Array) at a rate of 51.35 m/hr. (SE= 20.2, range = 3.54 – 175.83 m/hr.), suggesting that sea lamprey traverse the later third of the distance between the release site and future FishPass site faster relative to the first two thirds of the distance. Increased movement rates in the upstream reach is corroborated by an evaluation of the six RT tagged sea lamprey detected at both the weir and the FishPass site on a given upstream movement that demonstrated an average movement speed of 469 m/hr. (SE= 222.25, range = 1.41 - 1153.92 m/hr.). From visual inspection of detection histories, at least seven sea lamprey were detected exiting the Boardman River at the WTB array. Further visual examination also revealed repeated entry back into LBR for some individuals (see SL23, SL43) and repeated entry into the FishPass site after previous encounter (See SL 7, SL23, SL43, SL 48). The combination of these observations suggests that sea lamprey will challenge the Union Street Dam multiple times after both translocation and volitional downstream movement, but after repeated challenges, they eventually leave the LBR.

Objective 2b – proportion of individuals that enter the features of interest (Kid's Creek and FishPass site)

Encounter rates with the Union Street Dam and Kid's Creek are variable across entry event, species, and years (See Table 7). Most individuals proceed upstream to the Union Street Dam upon first entry, although it appeared that some individuals entered the river and returned downstream to Grand Traverse Bay prior to proceeding all the way to the Union Street Dam. This type of behavior could be indicative of staging behavior. There was a general decrease in encounter rates across all entry events, suggesting that while individuals of most species will enter the river across multiple discrete events, they do not always challenge the Union Street Dam. Failure to reach the Union Street Dam on subsequent challenges may indicate these fish ultimately selected habitat downstream of USB. Utilization of existing habitat in the LBR downstream of the Union Street Dam is further supported by the observation that not all individuals are encountering the Union Street Dam in all years. These individuals are making discrete, likely long scale, movements from Grand Traverse Bay and/or Lake Michigan but never proceeding all the way to the Union Street Dam suggesting that some level of suitable habitat is available to them in the LBR.

There was substantial variation across species in the time it took for an individual to reach a feature of interest. The common white sucker took the longest on average at approximately 11 days (Table 8), while common carp encountered the Union Street Dam faster on average than any other species with a mean interval of approximately 15 hours between entry event and encounter with the Union Street Dam. The long time it took on average for common white sucker to encounter the Union Street Dam suggests that they are holding in the lower portion of the LBR and demonstrating some level of staging behavior. An evaluation of the median time between entry and encounter with the Union Street Dam shows that walleye and smallmouth bass commonly made faster movements to the Union Street Dam at around five hours. However, the average value for these species and rainbow trout remains on the order of a few days demonstrating that some individuals took much longer to encounter the Union Street Dam.

Common white sucker and rainbow trout were the only species to encounter Kid's Creek, but all such events occurred after an encounter with the Union Street Dam. Rainbow trout encountered the Kid's Creek system within approximately four to five days after entry. The one common white sucker that encountered Kid's Creek did so over a month after entry. This individual remained in the river for a prolonged period and also contributed to the long mean residence time for this species (Table 6).

Table 7. The proportion of fish encountering the Union Street Dam (Dam) and Kid's Creek (Kid) features of interest after returning in a given year during their entry events summarized by years across an individual's entire detection history, an individual's first entry within a given year, and by individual entry events across species (See Table 3 for scientific species names).

			Individual		Individual First Entry		Entry Event		
Species	**Year**	**Return Fish**	**Dam**	**Kid**	**Dam**	**Kid**	**Entry Events**	**Dam**	**Kid**
common carp	2019	0	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%
common carp	2020	4	50.0%	0.0%	25.0%	0.0%	15	26.7%	0.0%
common carp	2021	1	0.0%	0.0%	0.0%	0.0%	2	0.0%	0.0%
common white sucker	2019	0	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%
common white sucker	2020	4	100.0%	25.0%	50.0%	0.0%	9	44.4%	11.1%
common white sucker	2021	3	33.3%	0.0%	33.3%	0.0%	42	2.4%	0.0%
rainbow trout	2019	2	50.0%	50.0%	50.0%	50.0%	4	25.0%	25.0%
rainbow trout	2020	1	100.0%	100.0%	100.0%	100.0%	3	100.0%	100.0%
rainbow trout	2021	1	0.0%	0.0%	0.0%	0.0%	2	0.0%	0.0%
smallmouth bass	2019	2	100.0%	0.0%	100.0%	0.0%	14	50.0%	0.0%
smallmouth bass	2020	4	75.0%	0.0%	50.0%	0.0%	35	40.0%	0.0%
smallmouth bass	2021	5	80.0%	0.0%	40.0%	0.0%	7	57.1%	0.0%
walleye	2019	0	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%
walleye	2020	10	40.0%	0.0%	30.0%	0.0%	30	16.7%	0.0%
walleye	2021	7	42.9%	0.0%	42.9%	0.0%	25	12.0%	0.0%

Table 8. The mean and median time (in days) between an entry event and an encounter with Union Street Dam and/or Kid's Creek by species

Species	Mean Time (Days)	Median Time (Days)	SE (Days)	Mean Time (Days)	Median Time (Days)	SE (Days)
	Dam			Kid's Creek		
common carp (*Cyprinus carpi)*	0.62	0.64	0.18	-	-	-
common white sucker (*Catostomus commersonii*)	10.62	10.20	5.00	44.45*	44.45*	-
rainbow trout (*Oncorhynchus mykiss*)	1.27	1.12	0.48	5.9	5.4	1.8
smallmouth bass (*Micropterus dolomieu)*	3.18	0.22	2.04	-	-	-
Walleye (*Sander vitreus*)	1.85	0.23	1.54	-	-	-

**Denotes a sample size of one, - denotes no available data*

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

The results of this study provide a baseline understanding of the seasonal fish diversity and relative abundance of fishes in the LBR, and also describe observed movement patterns of a subset of species in the context of seasonal phenology, entry and exit behavior to the LBR, and their encounter with multiple features of interest in the LBR. While additional information is desired, the results presented here provide a starting point for understanding the Boardman River system in support of the development of selective passage at FishPass. Prior to the onset of this work, little investigation into the LBR fishery had been conducted, further emphasizing a need to establish this baseline understanding.

In particular, the physical sampling of fish, implantation of relatively large numbers of PIT tags, and operation of static PIT arrays for over three years offers a refined understanding to the presence phenology of fishes in the LBR. This investigation has established that upwards of 28 species (26 in adult sampling, 1 additional in small fish sampling, sea lamprey) are currently present in the LBR (2 additional species identified after end of reporting period presented here; channel catfish *Ictalurus punctatus* and chestnut lamprey *Ichthyomyzon castaneus*) and, when taken in combination with harvest data from the MIDNR weir program, spring and fall time periods appear to have the highest relative abundance. Establishing a baseline level of diversity identifies a need for additional research on movement behavior of numerous species as the more detailed analysis presented was limited. The investigation also established that rainbow trout, common white sucker, longnose sucker, smallmouth bass, alewife, coho, and Chinook salmon occur in higher abundance relative to other species observed. Our preliminary investigation into the small fish community failed to add much detail, suggesting that additional sampling should be considered post-construction of FishPass to understand the influence of small-bodied fish on sorting approaches.

The PIT telemetry greatly increased the resolution of our understanding of phenological shifts that could not have been captured from periodic electrofishing surveys. These data demonstrate a high amount of variation within species, large overlap between species presence but discrete periods of presence across most species when considering the central tendencies around the distribution of their presence. These data also identified that rainbow trout are omni-present in the river while brown trout and smallmouth bass are also present throughout a majority of the year, which will require continual sorting of these species relative to passage goals. PIT telemetry also provides the important understanding that some individuals of all species return to the LBR across multiple years. Thus, animals tagged can likely be used as study organisms in subsequent years for additional research, although the number of tagged individuals returning clearly varies across species and will diminish though time if more individuals are not tagged as all return rates are below 100%.

The ability to use RT to refine phenology patterns of entrance and exit behaviors and to evaluate encounter proportion and timing with Union Street Dam and Kid's Creek provides additional detail on complex movement behaviors and further refines the time periods at which the six study species (white sucker, rainbow trout, smallmouth bass, walleye, brown trout, and common carp) will be eligible for sorting. Our RT results show that these six study species are primarily present in the April to August time period. Our analysis showed that not all fish that enter the river proceed to the Union Street Dam, but those that do appear to do so prior to encountering Kid's Creek. Additionally, of the six study species, only common white sucker and rainbow trout appeared to encounter Kid's Creek. Collectively, these results have improved our understanding of movement behavior of this subset of species. However, at conception, additional correlative study was envisioned to help understand the relationships between river entry and the environmental cues that incite entry behavior in the LBR. Initial small samples sizes coupled with relatively high dispersal of telemetered animals from the Boardman River prevented us from achieving or even attempting this goal in earnest. However, in lieu of more robust statistics we were able to characterize the movement patterns observed in concert with some of the environmental covariates collected.

Future correlative study should consider increased sample sizes within any species of interest. In this context, it is also important to recognize that with a given number of tags available, a trade off exists between the number of tags implanted per species and the number of species selected for study. Our study represents the first exploration into movement behavior of fish for the Boardman River, consequently we decided to stratify the available tags across a number of species. This decision provided a broader understanding of movement behavior across the fish community at the cost of greater inter-species resolution sufficient for further correlative investigation. In particular, it does not appear that our RT tag implantation strategy captured the full diversity of behaviors present for rainbow trout as return animals appeared as primarily spring run individuals, while PIT telemetry and physical sampling clearly documented the presence of rainbow trout year-round in the system.

An important next step for understanding fisheries dynamics in the Boardman River is to confirm spawning behavior by identifying additional evidence of eggs and/or larvae across all species. It appears from our data that a majority of the river entry across species relates to their respective spawning migration. However, we currently only have anecdotal data such as spawning observations and specimen reproductive condition to base these assertions on. The ability to seasonally describe egg and/or larvae density across time in the system offers the potential to connect movement phenology to underlying physiological and behavioral drivers. We assert confidence that both the white and longnose sucker migrations appear to be driven by spawning migration due to the number of observational records of these species engaging in spawning behavior (i.e., visually observed depositing eggs and milt on substrate). Spawning of the other RT tagged species is highly likely, but ambiguity remains as to which entry and exit patterns relate to reproduction in comparison to other parts of a species life cycle. In addition, genetic study in the river system raises question as to whether spawning within the LBR is occurring for both walleye and smallmouth bass. Further, we hypothesize here that a spawning population of lake trout exists in the Boardman River. If evidence to support our hypothesis of an existing spawning population of lake trout, it will have important implications to lake trout restoration and would suggest that further analysis of the fin clip patterns and/or genetic analysis should be considered to determine the stocking strain makeup of the potential spawning population. Notable differences in strain stocking performance have been observed in Lake Michigan (Larson et al. 2021; Lake Trout Working Group Report, 2021) and this additional analysis could contribute to the evolving understanding of strain performance. Further, additional acoustic telemetry work on lake trout could be useful to understand the contribution of this potential source population to spatial stocks and management units.

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This manuscript is contribution 10 of FishPass. FishPass is the capstone to the 20y restoration of the Boardman (Ottaway) River, Traverse City, Michigan. The mission of FishPass is to provide up- and down-stream passage of desirable fishes while simultaneously blocking or removing undesirable fishes, thereby addressing the connectivity conundrum. We are grateful to the primary project partners: Grand Traverse Band of Ottawa and Chippewa Indians (GTB), Michigan Department of Natural Resources (MIDNR); U.S. Army Corps of Engineers; U.S. Fish and Wildlife Service, and U.S. Geological Survey. We also extend sincerest thanks to the primary partner, the City of Traverse City. Without the city's support and the vision of the city commission, FishPass would not have been possible. Funding for this contribution came from the Great Lakes Restoration Initiative and the Great Lakes Fishery Commission. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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APPENDICES A-C

FishPass baseline assessment of fish community assemblage and migratory patterns in the Boardman River, Traverse City, Michigan, USA

Reid G. Swanson, Daniel P. Zielinski, Theodore R. Castro-Santos, and Andrew M. Muir

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APPENDIX A-
LONG TERM BOARDMAN RIVER FISH ABUNDANCE RECORDS

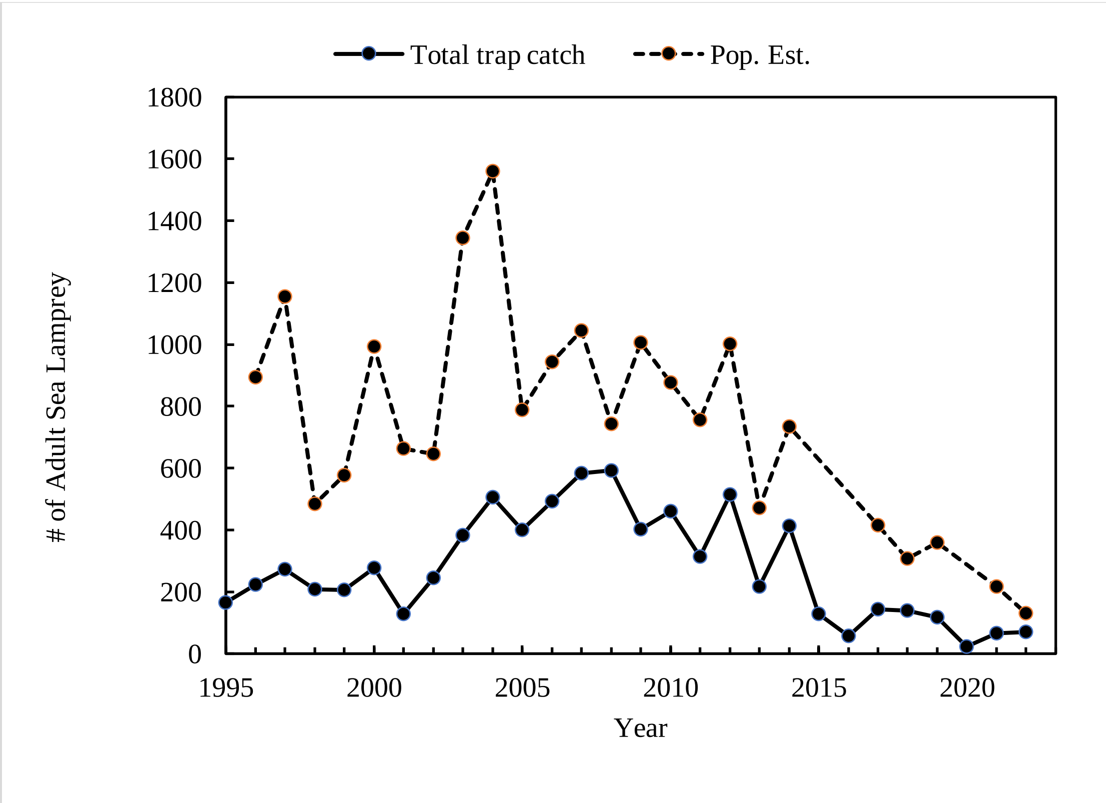

Figure A1. *Boardman River trap catch records and resulting population estimate of sea lamprey Petromyzon marinus from traps operated by the U.S. Fish and Wildlife Service and contractual agencies 1995-2022 (http://trapping.glfc.org/).*

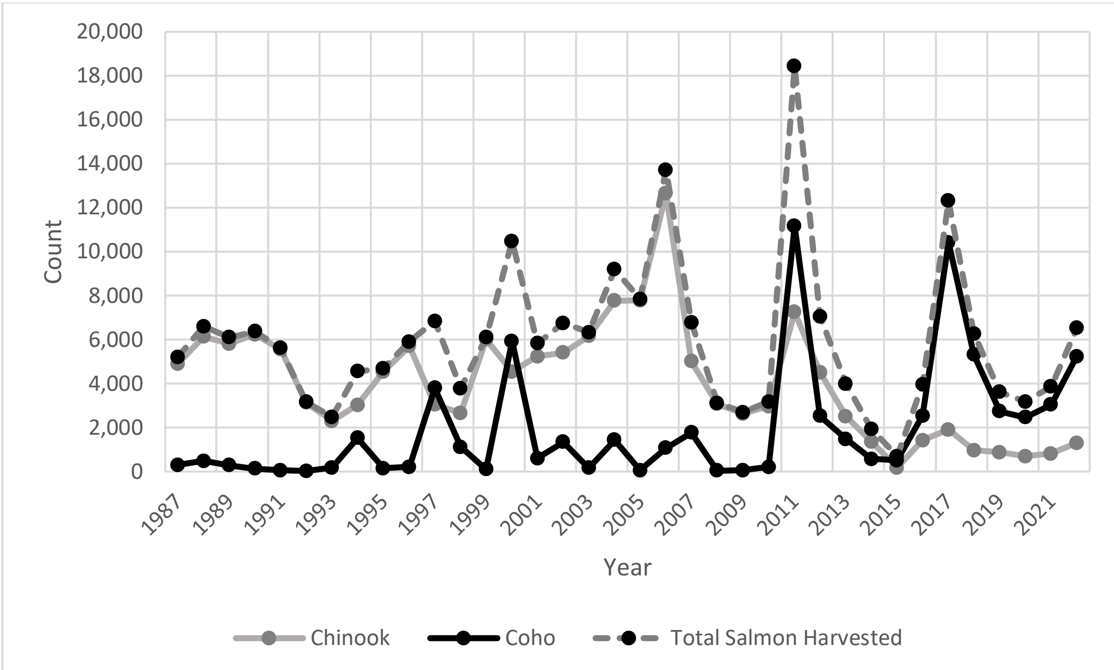

Figure A2. *Harvest records of Chinook Oncorhynchus tshawytscha and coho Oncorhynchus kisutch salmon from the Michigan Department of Natural Resources Traverse City Salmon Weir 1987-2021 (Personal communication; H. Hettinger, Fisheries Management Biologist, Central Lake Management Unit, Michigan Department of Natural Resources).*

APPENDIX B-
RADIO TELEMETRY DATA PROCESSING

Initial exploration of the radio tag detection files obtained in support of the FishPass baseline assessment of fish community assemblage and migratory patterns in in the Boardman River, Traverse City, Michigan, USA indicated the likely presence of false positive detections (when a noise or other factor produces a signal that is logged as a detection of an animal signal). Radio telemetry has been shown to be susceptible to both false positive detections and false negatives (when a transmission fails to be detected despite being present within the know range of a receiver) which effect the reliability of metrics derived from the use of radio telemetry (Montgomery et al. 2011). Consequently, all radio telemetry data was filtered using a Naïve Bayes classifier (in BIOTelemetry Analysis Software ;BIOTAS; Nebiolo and Castro-Santos 2022) prior to any further analysis or integration with other data sources. The classifier was used to remove over a million false positive detections while only potentially removing 48 likely true (false negative) detections as determined by the cross-validation procedure (Table B1.).

Table B1. The k-fold Cross-Validation results of BIOTAS Naïve Bayes Classifier using model parameters of consecutive record length (CRL), hit ratio (HR), noise ratio (NR), received signal strength (RSS), and difference in time between detections of radio telemetered fish in the Boardman River, Traverse City, Michigan, USA . Performance metrics include the total detections (td), true positive detections (tp), true negative detections (tn), false positive detection (fp), false negative detection (fn), sensitivity (sen; tp/(tp + fn)), specificity (spctn/(fp + tn),positive predictive values (ppv; tp/(tp + fp)), negative predictive value (npv; tn/(fn + tn)), false positive rate (fpr; fp/(fp + tn)), and the area under the curve (AUC) of the precision-recall curve(PRC) statistic.

Model	td	tp	tn	fp	fn	sen	spc	ppv	npv	fpr	PRC-AUC
CRL+HR+NR +RSS+δ2L	2197328	2089717	107438	125	48	1.0	0.9988	0.9999	0.9996	0.0012	0.845

APPENDIX C-
DETECTION HISTORY PLOTS

See box link https://glfc.box.com/s/py3kwg7al49e4xwkkblrz6fiidaqpy38

ABOUT FISHPASS

FishPass is the capstone of a ~20y restoration project on the Boardman (Ottaway) River, Traverse City, Michigan, re-connecting the river with Lake Michigan. FishPass will replace the deteriorating Union Street Dam with a new, complete barrier to all fish that will have the ability to sort and selectively pass desirable fishes while blocking harmful invaders like sea lamprey. While fully automated selective passage is the long-term goal of the project, passage of any fish during the initial 10-yrs will be coordinated with fishery management agencies, limited in number, and restricted to fishes native to the upper Great Lakes.