Study Report Phase II of the Diadromous Fish Behavior, Movement, and Project Interaction Study

Lawrence Project (FERC No. 2800)

Prepared For
Essex Company, LLC
A subsidiary of Patriot Hydro, LLC

PATRIOT HYDRO

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1 Introduction

Essex Company, LLC (Essex), a subsidiary of Patriot Hydro, LLC, is the Licensee, owner, and operator of the Lawrence Hydroelectric Project (Project or Lawrence Project), which is Federal Energy Regulatory Commission (FERC or Commission) Project No. 2800. The Project was licensed by the Commission on December 4, 1978 (with an effective date of December 1, 1978), and the license expires on November 30, 2028. The Lawrence Project is located on the Merrimack River in the City of Lawrence in Essex County, Massachusetts.

In accordance with 18 C.F.R. § 5.15, Essex has initiated studies and information gathering activities as provided in the study plan and schedule approved by the Commission. Among the studies initiated was the Diadromous Fish Behavior, Movement, and Project Interaction Study (Project Interaction Study), the methodologies of which were outlined in the Revised Study Plan (RSP) filed by Essex with the Commission on April 10, 2024, and approved with modifications by FERC in their May 10, 2024, Study Plan Determination (SPD). Essex successfully completed Phase 1 of the Project Interaction Study during the 2024 field season and findings from that effort were filed with the Commission as part of the Initial Study Report (ISR) on April 28, 2025. The Phase 1 study collected field data to inform a determination on an appropriate acoustic telemetry tool to address the overall study goal when considering the hydromorphological conditions of the Merrimack River and the downstream study area as influenced by the Project facilities and its operations. Included with the ISR was an updated study plan outlining the methodologies to address Phase 2 of the Project Interaction Study. This report describes the Licensee's implementation of the Phase 2 study plan and schedule, the data collected, and any variances from the study plan and schedule.

2 Goals and Objectives

The goal of the Project Interaction Study was to assess Project-related effects on the behavior of diadromous fish species in and around the Lawrence Project. As described in the RSP, the Project Interaction Study design is a two-phase approach whereby Phase 2 sought to:

- Assess tagged fish distribution and movement in the Project tailrace and proximal downstream reach (striped bass, alewife, blueback herring, and American shad).
- Evaluate the overall passage effectiveness of the existing fish lift for alewife and blueback herring given the extent of alosine behavioral modification due to predator presence and passage related delay.
- Evaluate alosine movement through the Project (i.e., through the Project forebay and into the impoundment) following alosine behavioral modification as it relates to predator presence downstream of the dam.

3 Project Description and Study Area

The Lawrence Project works consist of: (1) the 35-foot-high by 900-foot-long gravity Essex Dam of stone masonry construction (also known as the Great Stone Dam), with a five-foot-high pneumatic crest gate system mounted on the spillway crest; (2) a 9.8-mile-long impoundment having a surface area of 655 acres at a normal water elevation of 44.17 feet National Geodetic Vertical Datum of 1929 at the top of the crest gates, and gross storage capacity of approximately 19,900 acre-feet; (3) a powerhouse located at the end of a small forebay adjacent to the south abutment of the Essex Dam containing two 8.4 megawatt generating units and a tailrace channel extending into the Merrimack River channel; (4) fish passage facilities integral with the powerhouse, including a fish lift, downstream fish bypass, an eel lift at the left abutment of the dam, and an eel ladder at the right abutment of the dam; (5) the North Canal, approximately 5,300 feet long by 95 feet wide by 15 feet deep, originating at the north abutment of the dam and paralleling the Merrimack River downstream of the Essex Dam; (6) the South Canal, approximately 2,750 feet long by 35 feet wide by 10 feet deep, originating at the south abutment of the Essex Dam and generally paralleling the Merrimack River downstream of the Essex Dam; (7) a single-circuit, underground/underwater 23.0-kilovolt transmission line to the Massachusetts Electric Company’s Lawrence No. 1 substation; and (8) appurtenant facilities.

The study area for the Project Interaction Study included the reach of the mainstem Merrimack River from the lower extent of the Project impoundment upstream of Essex Dam and downstream of the powerhouse to the Lawrence I-495 bridge.

4 Study Methods

Phase 1 of the Project Interaction Study determined that the Juvenile Salmon Acoustic Telemetry System (JSATS) could be used to monitor tagged fish in the riverine environment downstream of the Lawrence Project. The JSATS technology was developed by the Pacific Northwest National Laboratory (PNNL) and National Oceanic and Atmospheric Administration to monitor the behavior, movement, habitat use, and survival of juvenile salmonids migrating out from freshwater in the Pacific Northwest. PNNL notes that JSATS has been previously used to (1) estimate route-specific dam passage, (2) observe predator–prey interactions, and (3) evaluate fish behavior in dam tailraces using high-accuracy, high-efficiency 3-D tracking.

The JSATS system is comprised of three major components: acoustic transmitters, receivers, and the associated management/processing software. Each transmitter produces a signal at a fixed interval by inducing high-frequency (416.7 kHz) vibrations (signals) in the water. Submerged hydrophones will receive the signals and convert to an electrical impulse which is relayed to the receiver. The receiver identifies the signal as a unique identification code and then logs them along with the ID of the receiving hydrophone, time and date of the detection, and any other information relayed by the transmitter (e.g., pressure).

When a tagged fish swims within the detection range of multiple JSATS receivers, each receiver will record the unique identifier of the tag and the time of detection. By analyzing the times it takes for the signal to travel from the transmitter to multiple receivers, a technique known as Time of Arrival (TOA), the system can, through trilateration, determine the position of a tagged fish. Data from multiple receivers can be collected and processed to reconstruct a fish's travel path over time. This data can then be used to inform on behavior, movement patterns, and response to environmental changes. This requires that multiple receivers within the study array can detect the same emitted pulse by the transmitter, while each receiver can have a variable detection capacity due to the background noise existing at its position.

4.1 Acoustic Telemetry Equipment

Movements of acoustically tagged river herring, American shad and striped bass were recorded using a set of stationary ATS SR3001 and SR3017 acoustic receivers installed at specific locations in the vicinity of the Essex Dam and Project powerhouse. All acoustic receivers operated on a frequency of 416.7 kHz. The ATS SR3001 receivers are autonomous and are designed to be deployed underwater in a fixed location. The ATS 3017 acoustic receivers allow for deployment of a cable-based hydrophone connected to the receiver unit which is positioned on the shore and allows for installation from Project infrastructure.

The Phase 2 assessment incorporated two acoustic transmitter models manufactured by ATS: model SS300 and model SS400. The SS300 transmitter weighs 300 mg and measures 10.7 x 5.0 x 2.8 mm and the SS400 transmitter weighs 200 mg and measures 15.0 x 3.3 mm. When incorporating the smallest battery available, these two tag models will last approximately 23 and 48 days, respectively, when set at a 3-second Ping Rate Interval (PRI). The two transmitter models differ in that the SS300 transmitter incorporates a pressure sensor which allows for a calculation of transmitter depth during the post-processing of field data.

4.2 Deployment Approach

A maximum of up to 30 ATS receivers were planned for installation during late April to evaluate the movement and behavior of tagged diadromous fish species during spring 2025. As outlined in the RSP, receivers were to be strategically placed throughout the Project area, with gate receivers (i.e., those used to determine if fish were entering/leaving the study area) covering points upstream and downstream of the dam, and a concentrated region with significant overlap intended to provide 2D positioning in the powerhouse tailrace. For the purposes of initial 2D receiver placement, a detection range of 50 m was assumed based on observations recorded during the Phase 1 assessment. To ensure receiver coverage in the 2D zone met the study needs (i.e., high probability of simultaneous detection of a tag transmission by three or more receivers), range testing was conducted prior to fish release.

Figures 4-1 and 4-2 present the preliminary receiver locations identified during the study planning process. Receivers comprising the 2D array (Figure 4-1) were installed in a manner intended to limit their ability to change position during the study and also provide overlap among units to maximize the likelihood of multiple detections of any single tag transmission.

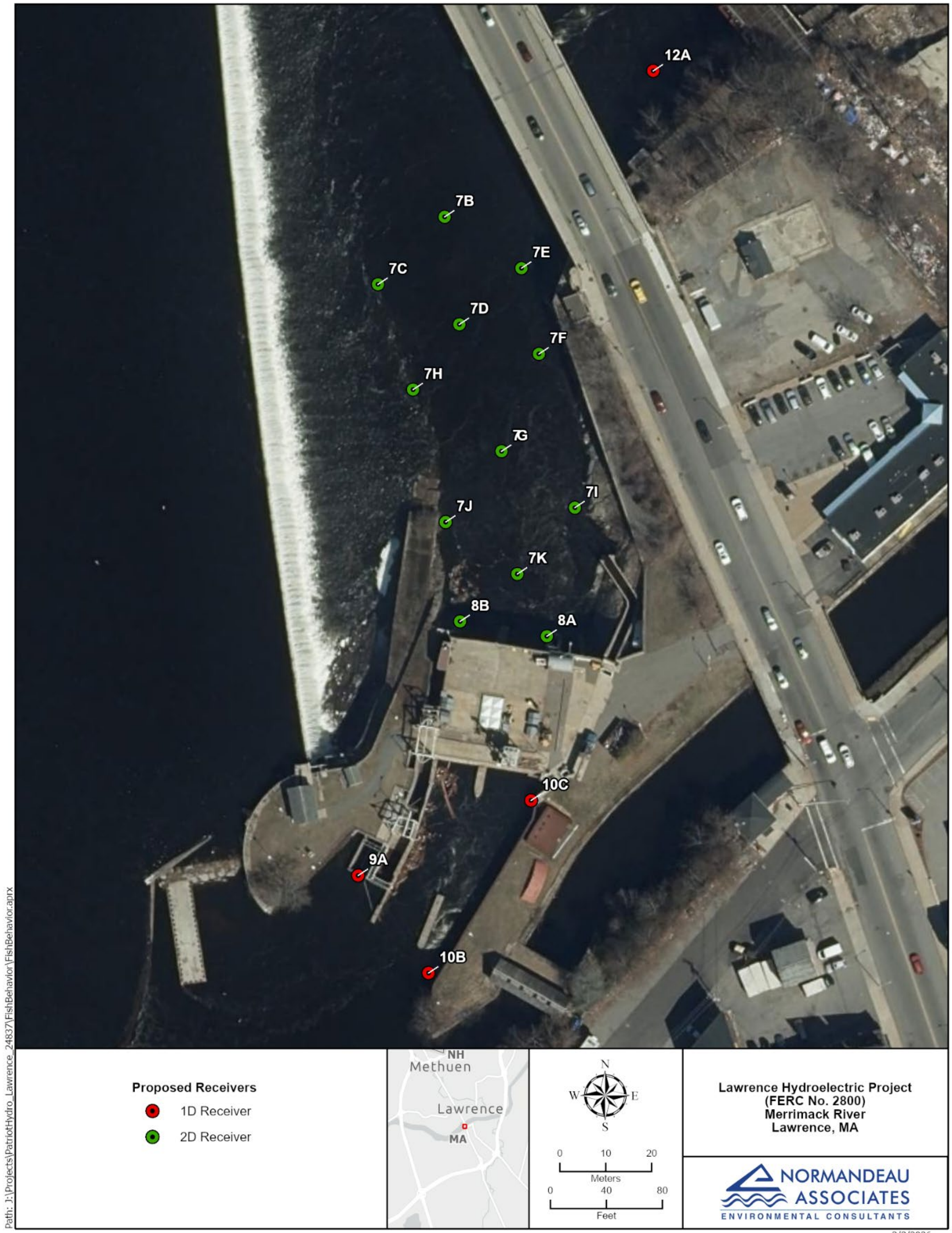

Figure 4-1. Planned acoustic receiver installation positions for the 2D component of the Lawrence Project Interaction Study.

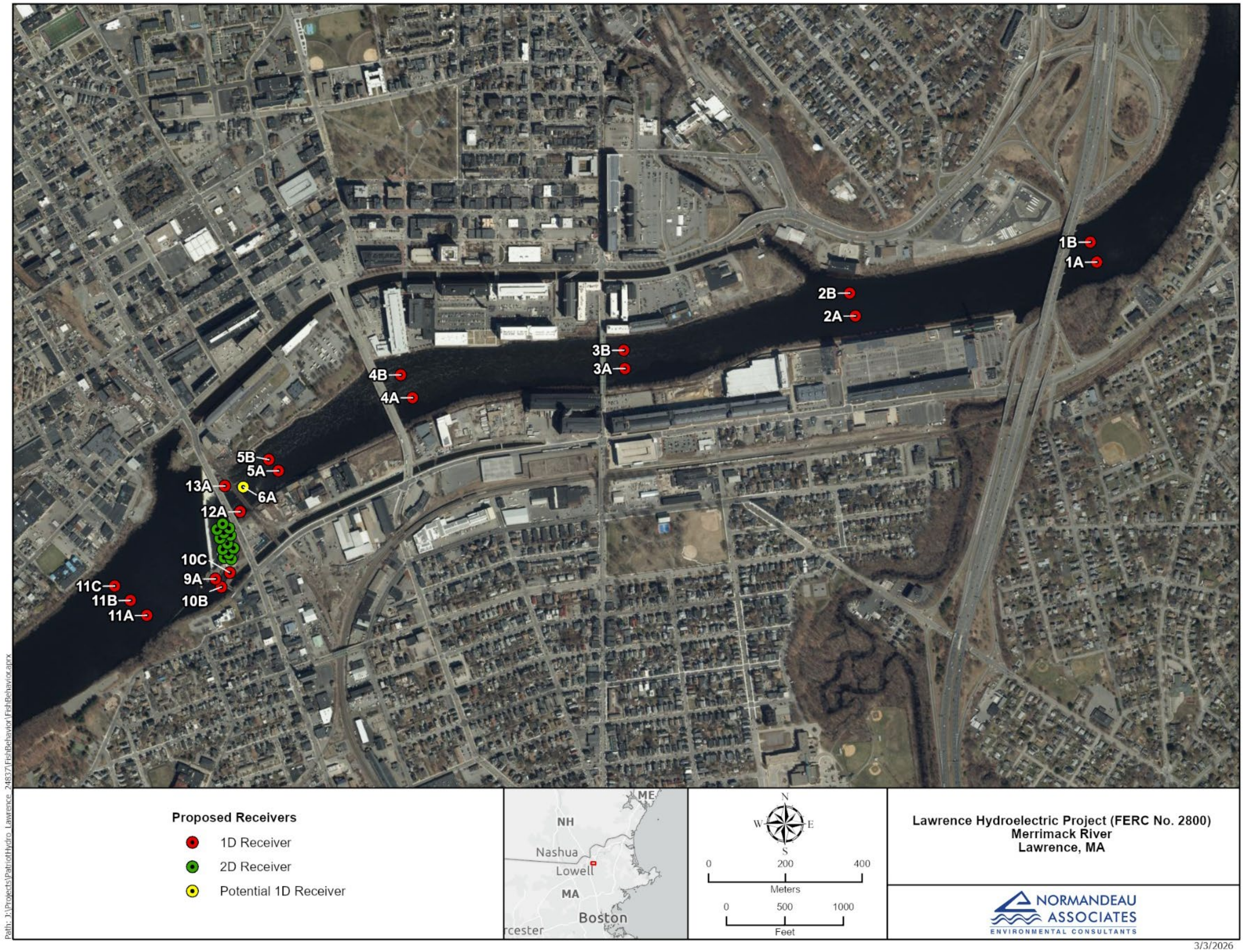

Figure 4-2. Planned acoustic receiver installation positions for the 1D component of the Lawrence Project Interaction Study.

4.3 Tagging and Release Procedures

Fish collected for tagging were obtainedfrom the reach of the Merrimack River downstream of the Project extending from the Union Street Duck Bridge downstream to the Lawrence I-495 Bridge. Boat electrofish sampling within this reach was used for the collection of each test species. Following capture, fish were immediately placed in a large, onboard, flow-through live well. Fish were then transported to a second boat-based tagging crew located along the northern bank just upstream from the confluence of the Spicket River (approximately one mile downstream of the dam). Fish were quickly transported by dip net into a floating net pen which allowed for recovery from collection in ambient river water. Each fish was visually assessed to ascertain their suitability for tagging. Any individuals exhibiting excessive scale loss or other signs of significant stress were not considered and were released back into the river untagged. Individuals deemed acceptable for tagging were quickly measured (total length, nearest mm), and sex was determined (when possible) by gently expressing eggs or milt from running-ripe fish. Species was recorded at the time of tagging. All tagging utilized either a hollow needle or scalpel to create a small incision in the body wall with the insertion point located at the end of the pectoral fins, offset from the ventral midline. The transmitter was then carefully inserted into the body cavity. Due to the minimal size of the incision, no sutures were necessary to close the cut[1]. Following tagging, study fish were immediately released back into the Merrimack River, and the date/time of release was recorded.

The target number of tagged individuals by species and transmitter type are presented in Table 4-1.

Table 4-1. Target number of test fish by species and transmitter type proposed for collection and tagging associated with the Lawrence Project Interaction Study.

Species	Target No. Tagged	Transmitter Model	
		SS300	SS400
Alewife	345	145	200
Blueback Herring	345	145	200
American Shad	200	100	100
Striped Bass	100	50	50

[1] Note: American shad were dual tagged, receiving both an acoustic JSATS transmitter as well as a radio tag. Radio tags were inserted gastrically at the same time shad were internally tagged with the JSATS transmitter. Shad carrying radio tags were part of a larger sample size of tagged fish evaluated as part of the Upstream Anadromous Fish Passage Assessment.

4.4 Data Collection

Data was off-loaded from the SR3001 autonomous acoustic receivers using a laptop computer at the conclusion of the study. River conditions during the 2025 study period and the associated lack of on-water access into the tailrace channel was the significant driver for that decision. Shore-based SR3017 acoustic receivers were periodically visited during the study period to ensure operation and data was opportunistically downloaded during those visits. Within a data file, transmitter detections were stored as a single event (i.e., single data line). Each event included the date and time of detection, receiver serial number, unique transmitter code, and pressure reading (only SS300 transmitters).

In addition to acoustic telemetry data, river and Project operations data representative of the full duration of the evaluation period were obtained. Mainstem river temperature was recorded via a continuous logger installed at the Project. Hourly records of inflow, discharge (canal, fish lift, downstream bypass, turbine, and spill), and tailwater and impoundment elevations were obtained from Essex at the completion of the study period.

4.5 Data Processing

Acoustic telemetry files were first processed by filtering software. Detections of released tag codes from each receiver were extracted and the presence of any multipath detections was determined. Multipath detections occur when signals bounce off dam structures, resulting in detection times that are typically slightly later than those from the direct signal path between the tag and receiver. Following identification and removal of any multipath detections, a PRI filter was applied to eliminate false positive detections following techniques outlined in Deng et al. 2015 or Nebiolo and Meyer 2021. The PRI filter leveraged the expected transmission pattern of transmitters to distinguish valid signals from noise. It evaluated a set of transmitter detections within a predefined time window, calculated as: nominal PRI × 1.3 × 12 + 1 seconds. For a sequence of detections to pass the PRI filter, there needed to be at least four valid detections that aligned with the expected PRI pattern within the time window. The output from this filtering process was a "cleaned" dataset of accepted tag detections and events from each receiver.

4.6 Movement Analysis

4.6.1 Approach Behavior

Acoustic tagged fish were released ~1.0 mile downstream of Essex Dam at a location approximately central between Station 2 and Station 3. Upon release, tagged fish were free to move upstream or downstream from the release site and the pattern of movement within the mainstem Merrimack River was monitored via a series of 1D "gate" locations (i.e., Stations 1, 2, 3, 4, and 5). Upon approaching Essex Dam, movement to proximate regions in the vicinity of the Route 28 Bridge were to be recorded by Station 6A (center channel), Station 12A (river right – powerhouse side of channel), and Station 13A (river left – spill side of channel). The 2D receiver array (Stations 7 and 8) was installed to provide a robust analysis of fish positions within the tailrace channel and upstream fishway near field attraction flow region. For the subset of tagged fish which entered the fish lift and exited upstream, the set of forebay receivers (Stations 9 and 10) were used to determine whether that individual successfully continued upstream or was entrained through the powerhouse and returned downstream, which could be via the turbines or downstream bypass. The three receivers comprising Station 11 were used to inform on individuals which moved into the lower Lawrence impoundment.

Detection information obtained from the installed receiver array was used to construct an encounter history for each individual test fish. These encounter histories were assembled as the series of sequential detection ("1")/no detection ("0") records for each individual fish between the release location and uppermost detection location:

- Known release location (=1 for all fish);
- Station 3 – Upstream of Spicket River confluence (0 or 1);
- Station 4 – Upstream of Duck Bridge (0 or 1);
- Station 5 – Upstream of Parker Street Bridge (0 or 1);
- Station 6 – Downstream of Route 28 Bridge (0 or 1);
- Station 7 – Powerhouse tailrace (0 or 1);
- Station 8 –Upstream fish lift nearfield region (0 or 1);
- Station 9 – Lawrence fish lift upstream exit flume (downstream end) (0 or 1);
- Station 11 – Lawrence impoundment (downstream end) (0 or 1);

These encounter histories formed the basis of a Cormack Jolly Seber (CJS) model constructed in Program MARK (White and Burnham 1999) which provided estimates for upstream approach rates (*Phi*) and detection (*p*) probabilities of tagged test fish released downstream of Lawrence. The estimates of *Phi* generated by the CJS model represent the probability of movement between a selected monitoring station and the adjacent upstream monitoring station. The detection probabilities estimate the likelihood that a tagged fish was detected at a particular monitoring station given that it had successfully ascended upstream and reached that point. The resulting model allowed for evaluation of approach upstream towards and through the Essex fish lift

To evaluate upstream approach rates, a suite of candidate models were developed based on whether passage likelihood, recapture (i.e., detection), or both varied or were constant among stations. Models included:

- *Phi*(*t*)*p*(*t*): upstream movement and recapture allowed to vary between receiver stations;
- *Phi*(t)*p*(.): upstream movement allowed to vary between stations; recapture constant between stations;
- *Phi*(.)*p*(*t*): upstream movement constant between stations; recapture allowed to vary between stations;

- *Phi*(.)*p*(.): upstream movement and recapture constant between stations;

Where;

- *Phi* = probability of upstream movement
- *p* = probability of detection
- (*t*) = parameter varies
- (.) = parameter is constant

4.6.2 Downstream Reach Utilization

The "cleaned" dataset output from the data filtration process outlined in Section 4.5 was reviewed and the full time series of detections among available receivers was compiled on an individual fish basis. For each tagged fish, the full time series of detections from initial to last was reviewed and the occurrence of any transition points from the detection region of one receiver station to an adjacent receiver station were identified. For each fish, the full duration of time spent within the acoustic array (bounded by Station 1 on the downstream end and Station 8 on the upstream end) was partitioned based on the identified transition points. To accomplish this, the interval between each set of consecutive detections at a unique receiver station was calculated. For each identified "transition" a duration was calculated between the final detection at Station X and the initial detection at Station Y. Each unique duration was then assigned to one of the general downstream zones based on the location of the initial detection in the duration calculation. For the example in Figure 4-3, fish ID 100 was initially detected at Station X at 12:52:43 and a transition to Station Y was identified at 12:54:36. The sum of zone intervals indicated a total duration of time in the vicinity of Station X of 53 seconds and at Station Y for 124 seconds. Assuming this set of detections represented the full duration of time spent in the acoustic array for fish ID 100, the total time at large would be calculated at 177 seconds with ~30% of that time spent in downstream zone X and ~70% of that time spent in downstream zone Y.

Fish ID	Station	Time Stamp	Interval (s)
100	X	5/1/2025 12:53:43	-
100	X	5/1/2025 12:53:46	3
100	X	5/1/2025 12:53:52	6
100	X	5/1/2025 12:53:57	5
100	Y	5/1/2025 12:54:36	39
100	Y	5/1/2025 12:55:25	49
100	Y	5/1/2025 12:55:28	3
100	Y	5/1/2025 12:55:37	9
100	X	5/1/2025 12:56:40	63

Fish ID	Site	Interval Sum(s)
100	3	53
100	4	124

Figure 4-3. Planned acoustic receiver installation positions for the 1D component of the Lawrence Project Interaction Study.

For this analysis the general downstream zones were defined as:

- Station 1 – downstream of the Lawrence I-495 Bridge
- Station 2 – Downstream of the Spicket River confluence
- Station 3 – Upstream of Spicket River confluence
- Station 4 – Upstream of Duck Bridge
- Station 5 – Upstream of Parker Street Bridge
- Station 6 – Downstream of Route 28 Bridge
- Station 7 – Powerhouse tailrace
- Station 8 –Upstream fish lift nearfield region

Patterns in cumulative time spent among the general downstream zones were evaluated on a species basis as well as temporally over the course of the study period.

4.6.3 2D Tailrace Movement Patterns

As outlined in the RSP, data files from hydrophones comprising the 2D array in the powerhouse tailrace were to be imported into R statistical software for analysis using a "time of arrival" methodology to determine the X-Y position of a fish for each of ping emitted from its transmitter at a three second PRI. For the full duration of residence time for a fish present within the bounds of the 2D array in the powerhouse tailrace, a latitude and longitude were to be determined as long as three or more receivers successfully detected the single transmission. For each fish that spent time within the 2D array, positions over time were to be determined and available for mapping within predetermined subsections of the tailrace. For individuals carrying the SS300 transmitter with pressure sensor, fish depth was to be estimated based on the recorded pressure reading associated with each tag transmission.

Following the determination of transmitter positions, acoustic data was to be presented in two formats: bin densities and density plots. Bin densities were intended to provide the percentage of tagged fish that were detected in each of the bins of space in the 2D array region (e.g., within a 3m square grid). The percentage of tagged fish detected in each bin were to be recorded (by species) over the duration of the study and the percentage displayed on a color scale overlaid on the grid map. The use of bins was intended to reduce the potential for a single fish to skew the results as its presence in an area is only counted a single time. This approach was to provide insight into the spatial use of the 2D array area by test fish, rather than the amount of time spent in a particular area.

Density plots were to be developed to present positions of tagged fish in the 2D array area and incorporate a temporal component of the detection data. Since these would include multiple detections for an individual, there was potential for data presented in this manner to be skewed by individual fish which may spend long periods of time in certain areas.

5 Results

5.1 Merrimack River Conditions

Hourly flow data was obtained from the USGS streamflow gaging station on the Merrimack River in Lowell, MA (USGS No. 01100000) for the period from April 20 to July 25, 2025, and was prorated by a factor of 1.02 to approximate inflows at the Lawrence Project. Figure 5–1 presents the prorated Lawrence inflow and associated water temperature (as measured using an Onset HOBO Tid-Bit located just upstream of the Essex Dam). Merrimack River inflow at Lawrence peaked at over 47,000 cfs on May 11 and inflow was consistently higher than the 25% exceedance value (i.e., 15,208 cfs; May flow duration curve; Figure 5-2) for the remainer of the month. Inflow at Lawrence remained high into the month of June, remaining at levels higher than the monthly 25% exceedance value until the latter part of the month (i.e., 8,151 cfs; June flow duration curve; Figure 5-3).

Water temperature at the Project increased over the course of the monitoring period. The mean daily temperature ranged between 12.9ºC and 17.3ºC among dates where diadromous fish tagging efforts were conducted downstream of the Project.

5.2 Project Operations

Total river flow, as distributed among available conveyance routes at Lawrence for the period from April 20 to July 25, is presented in Figure 5-4. Spill flow was present at Lawrence from early May through late June, encompassing all tagging dates for fish downstream of the Project. Spill flow for the dates of on-water receiver installation (April 24 and 25) was relatively low (daily mean = 1,300 to 1,500) which permitted access for crews to boat upstream of the Route 28 Bridge and operate in the tailrace region. Mean daily spill flow did not return to a discharge comparable to that observed during the on-water equipment installation dates until June 21.

With regard to fish passage, operations at the Lawrence upstream fish lift were initiated on April 15. Lift operations were suspended starting on May 8 and running through May 15 to accommodate river flows in excess of 25,000 cfs. Following the continued period of elevated river flow, the fish lift was offline on June 21 and the morning of June 22 while operations crews dewatered the lower flume for debris removal. The downstream bypass was open from the onset of the Project Interaction Study period and was set to pass 160 cfs. Essex shutdown their downstream fish passage facilityfor the spring season on July 15. Fish lifting continued at a reduced lifting interval (twice daily) from July 15 to August 6 to facilitate upstream American eel passage.

Turbine generation occurred near continuously during the 2025 Project Interaction Study. Unit 1 was online for the duration of the season and Unit 2 was online through June.

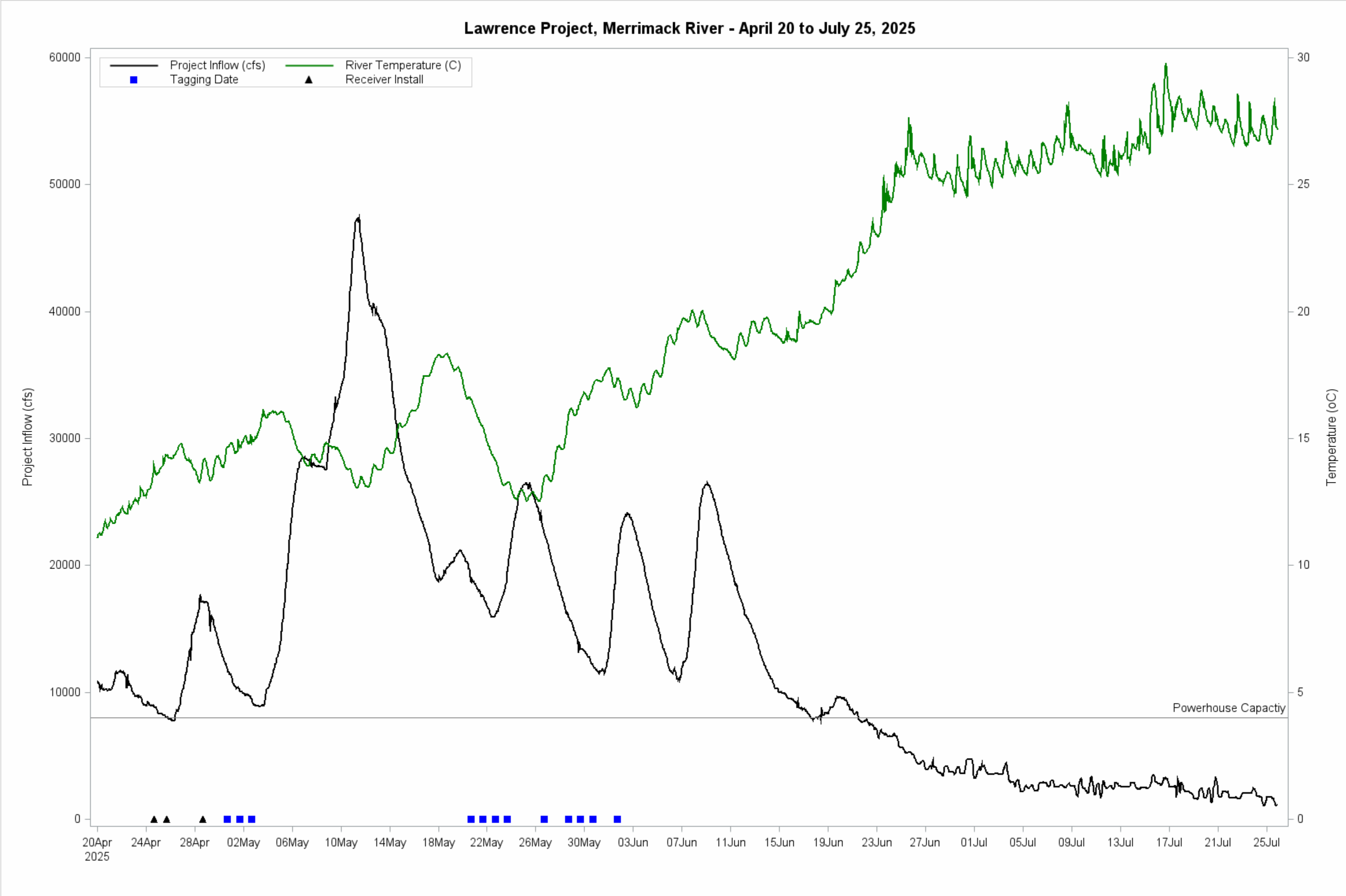

Figure 5-1. Merrimack River discharge and water temperature at Lawrence for the period April 20 to July 25, 2025.

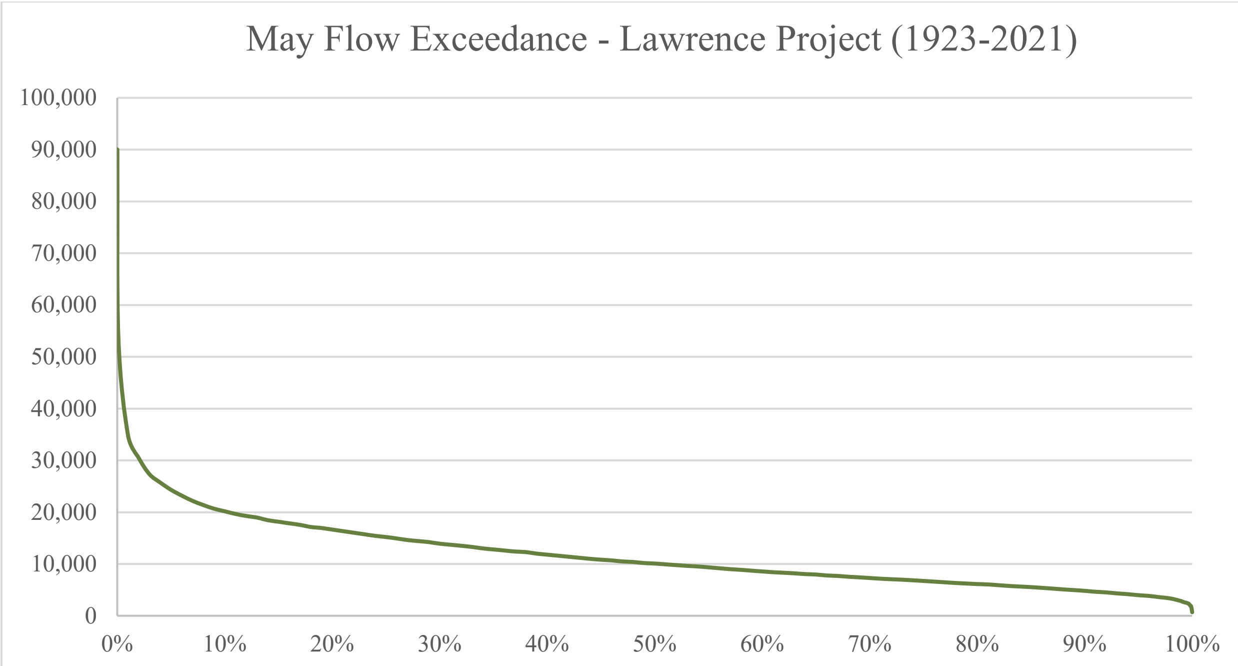

Figure 5-2. Flow duration curve for the Lawrence Hydroelectric Project during the month of May (1923-2021 flow set).

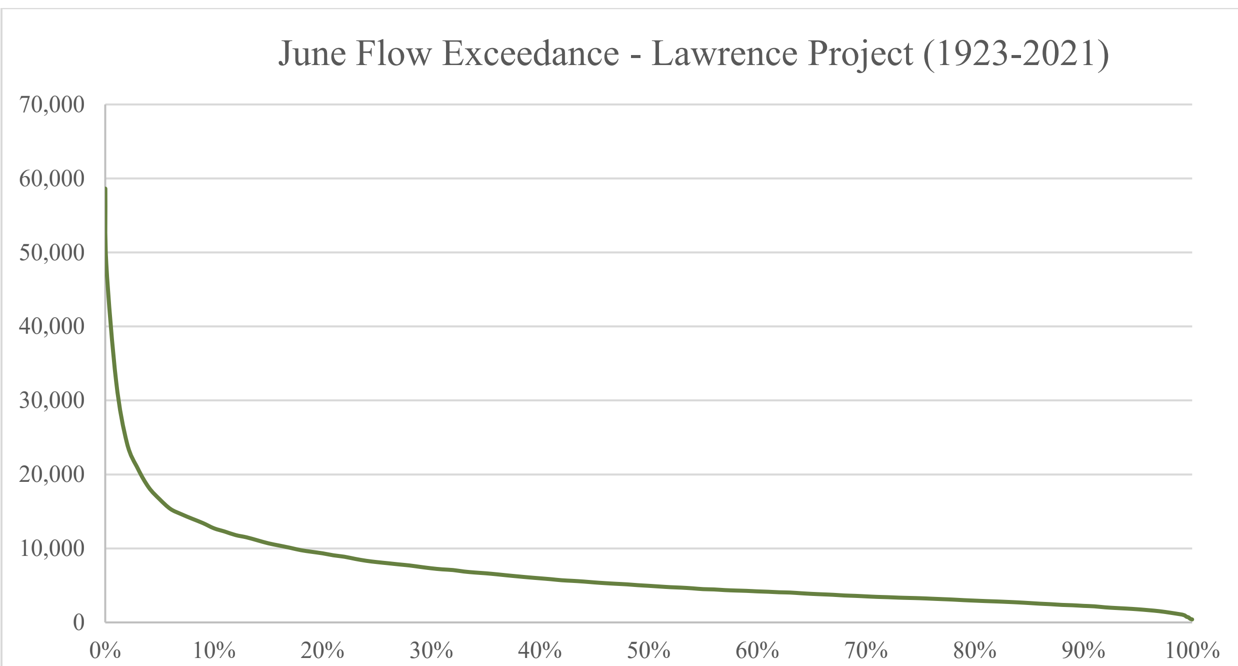

Figure 5-3. Flow duration curve for the Lawrence Hydroelectric Project during the month of June (1923-2021 flow set).

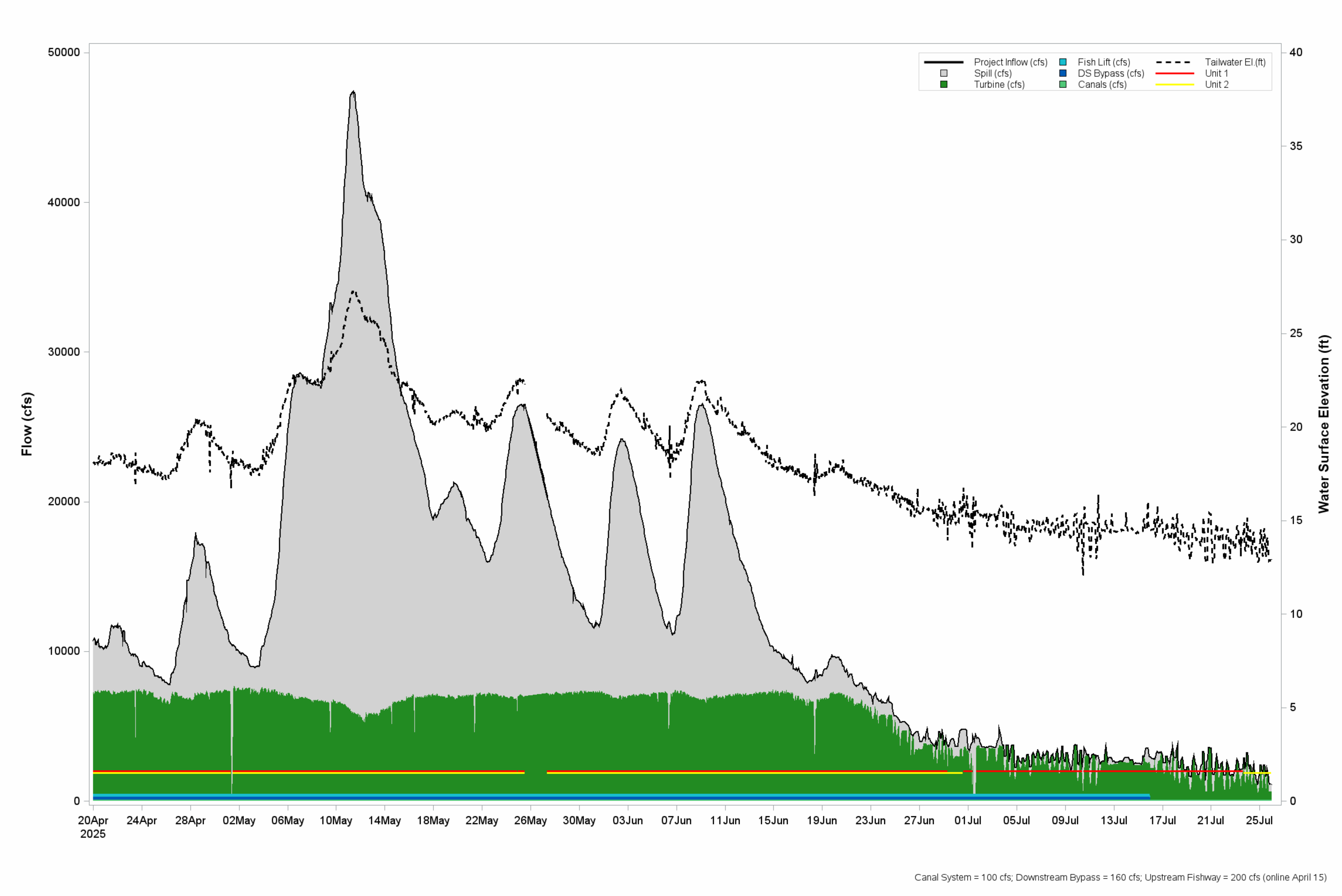

Figure 5-4. Lawrence inflow distribution, turbine operation, and tailwater elevation for the period April 20 to July 25, 2025.

5.3 Acoustic Receiver Installation and Operation

A total of 31 JSATS acoustic receivers were installed at locations upstream and downstream of the Essex Dam over three dates during late April and one date during early May. Table 5-1 summarizes the deployment date, receiver type (autonomous SR3001 or cabled SR3017) and the intended data collection type (2D vs. 1D) for each location. The final array design is outlined in Figures 5-5 and 5-6 and in general, mirrored what was proposed in the RSP. Final installation locations for autonomous receivers were dictated by river depth and flow conditions as the SR3001 receivers are close to 30 inches tall and require approximately five feet of water for deployment. The following array modifications were made to accommodate field conditions encountered during the installation period.

- River flow and depth prevented the installation of an autonomous receiver proposed in the RSP within the region immediately downstream of the Route 28 Bridge (Station 6A; Figure 4-2). To accommodate this, the proposed receiver was installed slightly downstream from that location (Station 6A; Figure 5-6).
- River depths limited options for the installation of a two-receiver gate proposed in the RSP in the area immediately downstream of the Parker Street Bridge (Stations 5A and 5B; Figure 4-2). To accommodate this, a single receiver was installed at a point downstream from Station 6A and upstream of the Duck Bridge (Station 5A; Figure 5-6).
- Due to river depths the two-receiver gate proposed in the RSP in the area immediately downstream of the Parker Street Bridge (Station 4A and 4B; Figure 4-2) was shifted slightly downstream (Stations 4A and 4B; Figure 5-6).

The full 2D receiver array was installed and operational on April 28. Shortly thereafter, Merrimack River flows increased significantly, reaching a maximum of about 46,000 cfs n May 11, and spill was present at the Lawrence Project well into June (Figure 5-1; Figure 5-2) which completely eliminated any access to autonomous receivers installed as part of the 2D array in the powerhouse tailrace and reduced visibility of and access to autonomous receivers installed at mainstem locations intended to inform on 1D positioning of tagged fish. Recovery of deployed autonomous receivers was conducted during the latter part of July (Table 5-1). The high discharge and non-laminar flow conditions in the Lawrence powerhouse tailrace during the 2025 upstream passage season were unsuitable for the deployment and operation of autonomous JSATS receivers. These conditions resulted in catastrophic damage to and or loss of 10 of the 13 autonomous receivers installed as part of the array intended to collect 2D information from the Project tailrace (Table 5-1). With the exception of Station 6A, located slightly downstream of the Route 28 Bridge, all autonomous receivers installed at mainstem locations were successfully recovered in working condition. It is assumed that despite the heavy river discharge through the mainstem of the Merrimack both upstream and downstream of Essex Dam for the majority of the study period, the flows at the non-tailrace deployment locations were more laminar in nature which resulted in a lower incidence of significant damage.

Table 5-1. Deployment and retrieval information for JSATS acoustic receivers associated with the 2025 Lawrence Project Interaction Study.

Deploy Date	Data Type	Rx Type	Station Name	Latitude	Longitude	Recovery Date	Final Status
4/24/2025	1D	SR3001	1A	42.708270	-71.135170	7/23/2025	Recovered
4/24/2025	1D	SR3001	1B	42.708460	-71.135400	7/23/2025	Recovered
4/24/2025	1D	SR3001	2A	42.705520	-71.143930	7/23/2025	Recovered
4/24/2025	1D	SR3001	2B	42.705830	-71.144120	7/23/2025	Recovered
4/24/2025	1D	SR3001	3A	42.704360	-71.151170	7/23/2025	Recovered
4/24/2025	1D	SR3001	3B	42.704810	-71.151000	7/23/2025	Recovered
4/24/2025	1D	SR3001	4A	42.704200	-71.154930	7/23/2025	Recovered
4/24/2025	1D	SR3001	4B	42.704570	-71.154900	7/23/2025	Recovered
4/24/2025	1D	SR3001	5A	42.702760	-71.162550	7/23/2025	Recovered
4/24/2025	1D	SR3001	6A	42.702200	-71.163650		Lost
4/25/2025	1D	SR3001	11A	42.698314	-71.167940	7/23/2025	Recovered
4/25/2025	1D	SR3001	11B	42.698718	-71.168462	7/23/2025	Recovered
4/25/2025	1D	SR3001	11C	42.699093	-71.168968	7/23/2025	Recovered
4/25/2025	1D	SR3001	12A	42.700608	-71.165100		Lost
4/25/2025	2D	SR3001	7B	42.700484	-71.165617		Lost
4/25/2025	2D	SR3001	7C	42.700317	-71.165633	7/22/2025	Recovered
4/25/2025	2D	SR3001	7D	42.700233	-71.165368		Lost
4/25/2025	2D	SR3001	7E	42.700226	-71.165256		Lost
4/25/2025	2D	SR3001	7F	42.700207	-71.165207		Lost
4/25/2025	2D	SR3001	7G	42.700026	-71.165292		Lost
4/25/2025	2D	SR3001	7H	42.699945	-71.165483		Lost
4/25/2025	2D	SR3001	7I	42.699882	-71.165135		Lost
4/25/2025	2D	SR3001	7J	42.699804	-71.165477		Lost
4/25/2025	2D	SR3001	7K	42.699848	-71.165325		Lost
4/25/2025	2D	SR3001	7L	42.699701	-71.165138		Lost
4/25/2025	2D	SR3017	8A	42.699664	-71.165248	7/24/2025	Recovered
4/25/2025	2D	SR3017	8B	42.699705	-71.165460	7/24/2025	Recovered
4/28/2025	1D	SR3017	10A	42.699317	-71.165291	7/24/2025	Recovered
4/28/2025	1D	SR3017	10B	42.699016	-71.165530	7/24/2025	Recovered
4/28/2025	1D	SR3001	9A	42.699204	-71.165718	7/24/2025	Recovered
5/2/2025	1D	SR3001	13A	42.701099	-71.165967		Lost

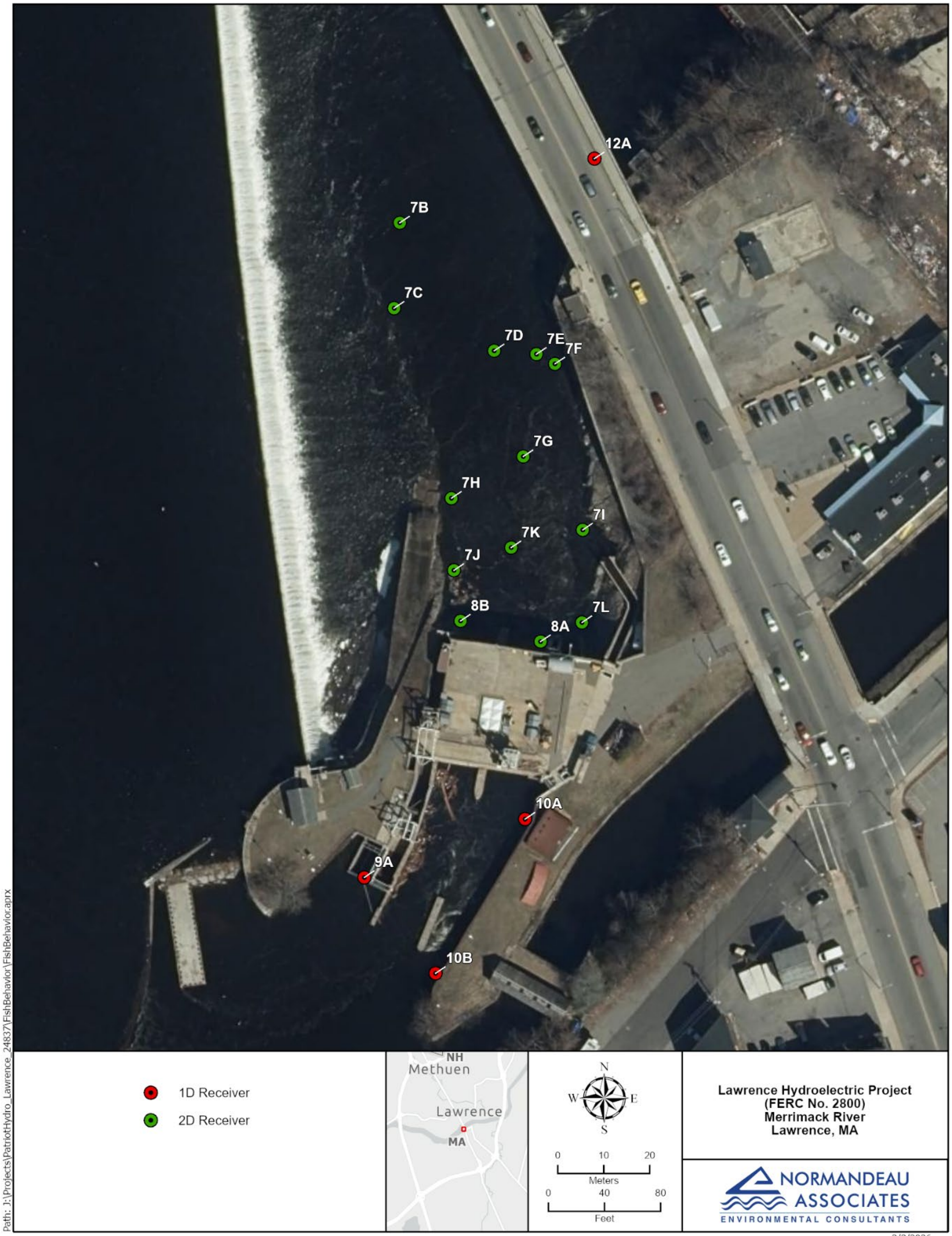

Figure 5-5. Final acoustic receiver installation positions for the 2D component of the Lawrence Project Interaction Study.

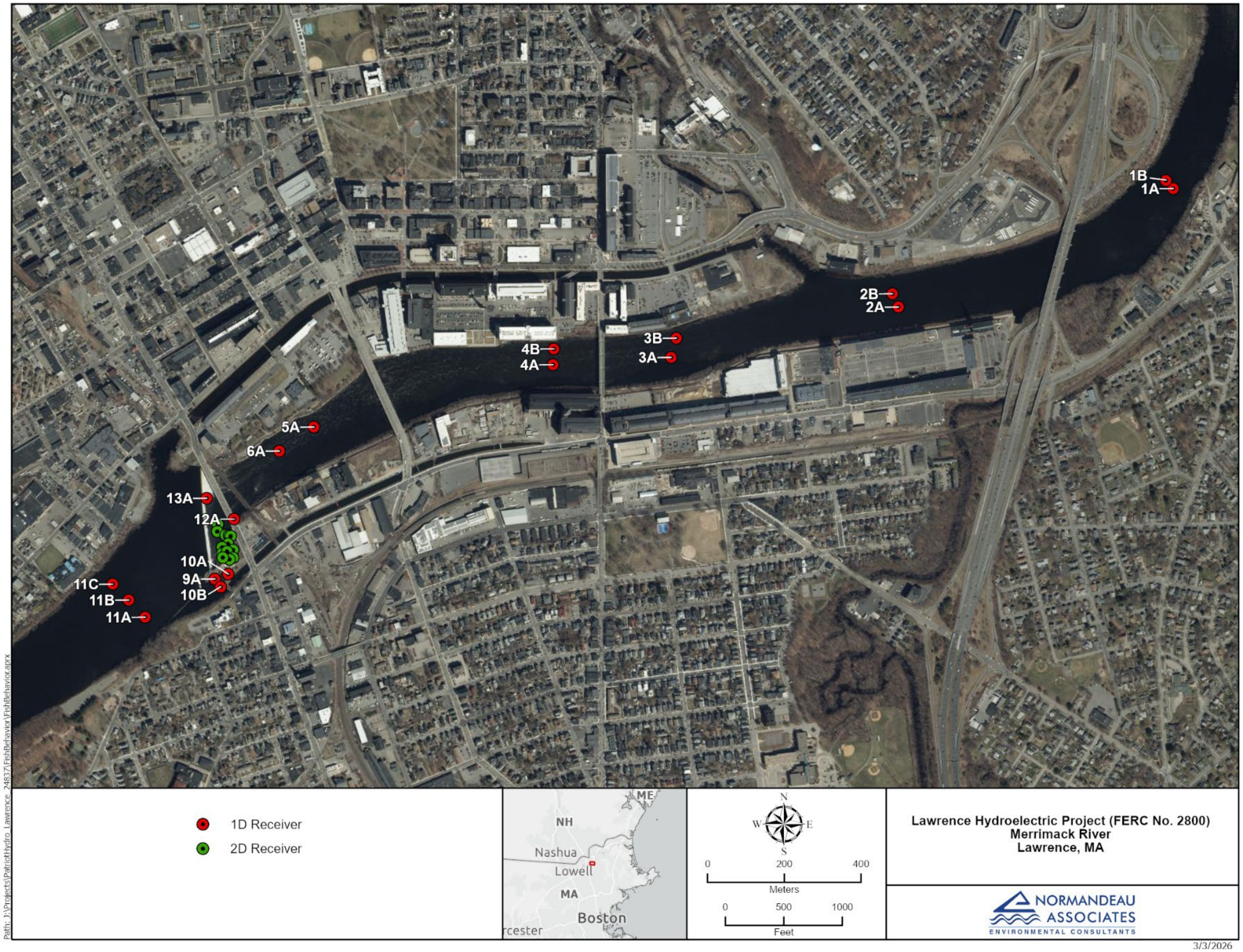

Figure 5-6. Final acoustic receiver installation positions for the 1D component of the Lawrence Project Interaction Study.

5.4 Collection, Tagging, and Release

5.4.1 Alewife

A total of 335 alewife were acoustically tagged following collection via boat electrofishing in the section of the Merrimack River downstream of Essex Dam extending from just upstream of the confluence with the Spicket River to the Lawrence I-495 Bridge (approximately 1.0 to 1.4 miles downstream of Essex Dam; Table 5-2). Most alewife were collected and tagged during late April and early May. Transmitter types were distributed near to the ratio outlined in the RSP (Table 4-1) with a total of 144 model SS300 transmitters (with pressure transducer) deployed and a total of 191 model SS400 transmitters deployed. The mean total length for tagged alewife was 293 mm, and the sex ratio of collected individuals was slightly skewed towards male fish (55% of individuals).

River herring (alewife and blueback herring) were initially observed in the Lawrence fish lift on April 22 with the mid-point of cumulative returns occurring on May 4 (Figure 5-7). Tagging and release of river herring downstream of Essex Dam took place on dates corresponding to the 5th–90th percentiles of the 2025 passage returns at the Lawrence lift.

5.4.2 Blueback Herring

Blueback herring were primarily collected via boat electrofishing in the section of the Merrimack River downstream of Essex Dam extending from just upstream of the confluence with the Spicket River to the Lawrence I-495 Bridge (approximately 1.0 to 1.4 miles downstream of Essex Dam) during the latter third of May. A total of 300 individuals suitable for tagging were equipped with either a model SS300 pressure sensor transmitter (n = 143) or a model SS400 transmitter (n = 157). Blueback herring ranged in length from 223 to 297 mm (mean = 252) and most individuals tagged (61%) were male.

5.4.3 American Shad

A total of 199 American shad were acoustically tagged following collection via boat electrofishing in the section of the Merrimack River downstream of Essex Dam extending from just upstream of the confluence with the Spicket River to the Lawrence I-495 Bridge (approximately 1.0 to 1.4 miles downstream of Essex Dam; Table 5-4). The majority of American shad were collected and tagged on seven dates during the period from May 20 to May 29. Transmitter types were evenly distributed between model SS300 (with pressure transducer; n =100) and model SS400 (n = 99). The mean total length for tagged shad was 480 mm, and the sex ratio of collected individuals was skewed towards male fish (73% of individuals).

American shad were initially observed in the Lawrence fish lift on May 1 with the mid-point of cumulative returns occurring on June 3 (Figure 5-8). Tagging and release of American shad downstream of Essex Dam took place on dates corresponding to the first quarter of the 2025 passage returns at the Lawrence lift.

5.4.4 Striped Bass

Striped bass were collected via boat electrofishing in the section of the Merrimack River downstream of Essex Dam extending from just upstream of the confluence with the Spicket River to the Lawrence I-495 Bridge (approximately 1.0 to 1.4 miles downstream of Essex Dam) during late May. A total of 100 individuals suitable for tagging were equipped with either a model SS300 pressure sensor transmitter (n = 49) or a model SS400 transmitter (n = 51). Striped based tagged as part of the Project Interaction Study ranged in length from 365 to 1,067 mm (mean = 734).

Table 5-2. Summary of alewife tagged and released as part of Phase 2 of the Lawrence Project Interaction Study, 2025.

Release Date	No. Fish	Tag Type		Sex		Total Length (mm)		
		SS300	SS400	%M	%F	Min.	Max.	Mean
30-Apr	39	39	0	51%	49%	275	333	302
1-May	145	105	40	55%	45%	255	331	296
2-May	50	0	50	66%	34%	268	332	296
20-May	6	0	6	33%	67%	265	310	288
21-May	36	0	36	39%	61%	261	327	291
23-May	24	0	24	58%	42%	238	319	277
26-May	34	0	34	62%	38%	255	307	286
28-May	1	0	1	100%	0%	-	268	-
All	335	144	191	55%	45%	238	333	293

Table 5-3. Summary of blueback herring tagged and released as part of Phase 2 of the Lawrence Project Interaction Study, 2025.

Release Date	No. Fish	Tag Type		Sex		Total Length (mm)		
		SS300	SS400	%M	%F	Min.	Max.	Mean
1-May	6	4	2	80%	20%	242	272	259
20-May	1	1	0	100%	0%	-	250	-
21-May	44	35	9	43%	57%	228	297	259
23-May	2	0	2	100%	0%	242	244	243
26-May	15	13	2	73%	27%	235	288	256
28-May	53	52	1	55%	45%	223	270	250
29-May	97	38	59	62%	38%	226	287	250
30-May	34	0	34	88%	12%	237	291	254
1-Jun	48	0	48	56%	44%	229	271	253
All	300	143	157	61%	39%	223	297	252

Table 5-4. Summary of American shad tagged and released as part of Phase 2 of the Lawrence Project Interaction Study, 2025.

Release Date	No. Fish	Tag Type		Sex		Total Length (mm)		
		SS300	SS400	%M	%F	Min.	Max.	Mean
30-Apr	1	1	0	100%	0%	-	454	-
20-May	28	28	0	71%	29%	415	559	481
21-May	34	34	0	56%	44%	427	555	492
22-May	5	5	0	80%	20%	466	500	476
23-May	31	31	0	61%	39%	416	526	468
26-May	36	1	35	83%	17%	397	564	481
28-May	41	0	41	80%	20%	413	540	484
29-May	23	0	23	87%	13%	419	545	467
All	199	100	99	73%	27%	397	564	480

Table 5-5. Summary of striped bass tagged and released as part of Phase 2 of the Lawrence Project Interaction Study, 2025.

Release Date	No. Fish	Tag Type		Total Length (mm)		
		SS300	SS400	Min.	Max.	Mean
20-May	27	26	1	365	975	718
21-May	23	23	.	557	1,067	750
22-May	6	.	6	672	829	730
23-May	22	.	22	634	959	729
26-May	20	.	20	583	801	726
28-May	2	.	2	782	1,016	899
All	100	49	51	365	1,067	734

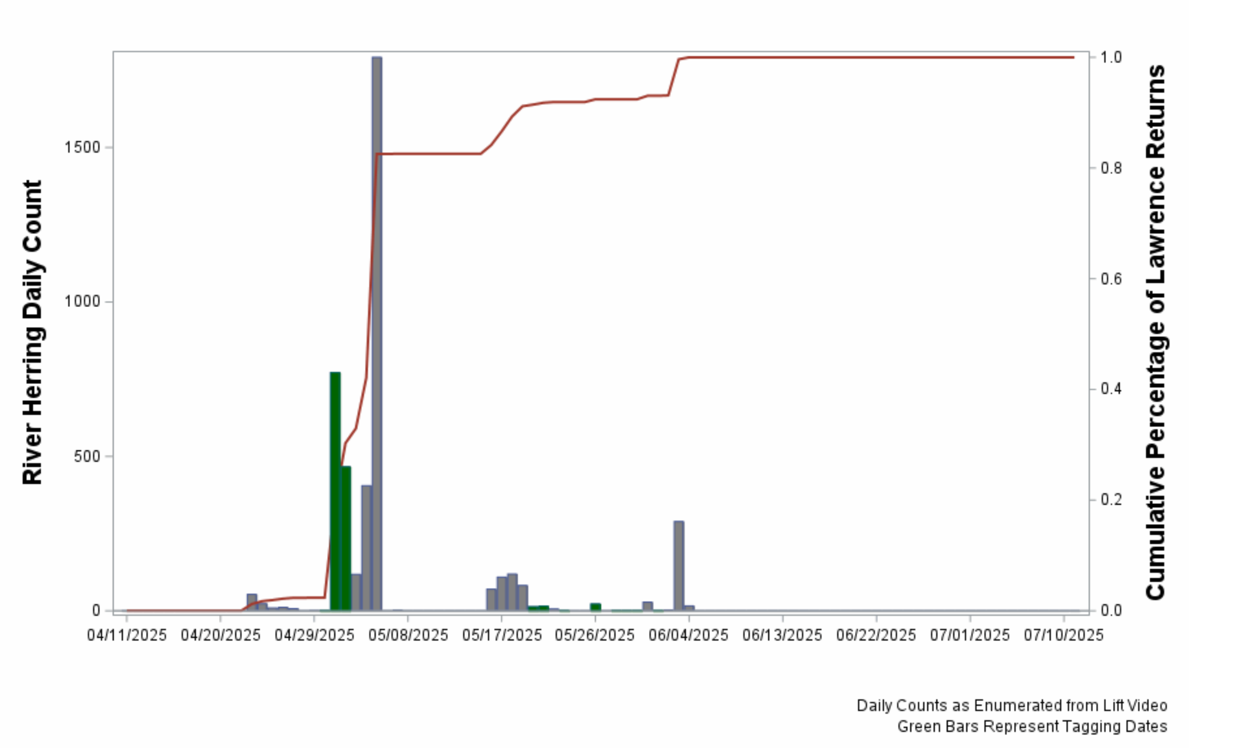

Figure 5-7. Daily count and cumulative percentage of river herring (alewife and blueback herring) returns to the Lawrence fish lift for the 2025 passage season.

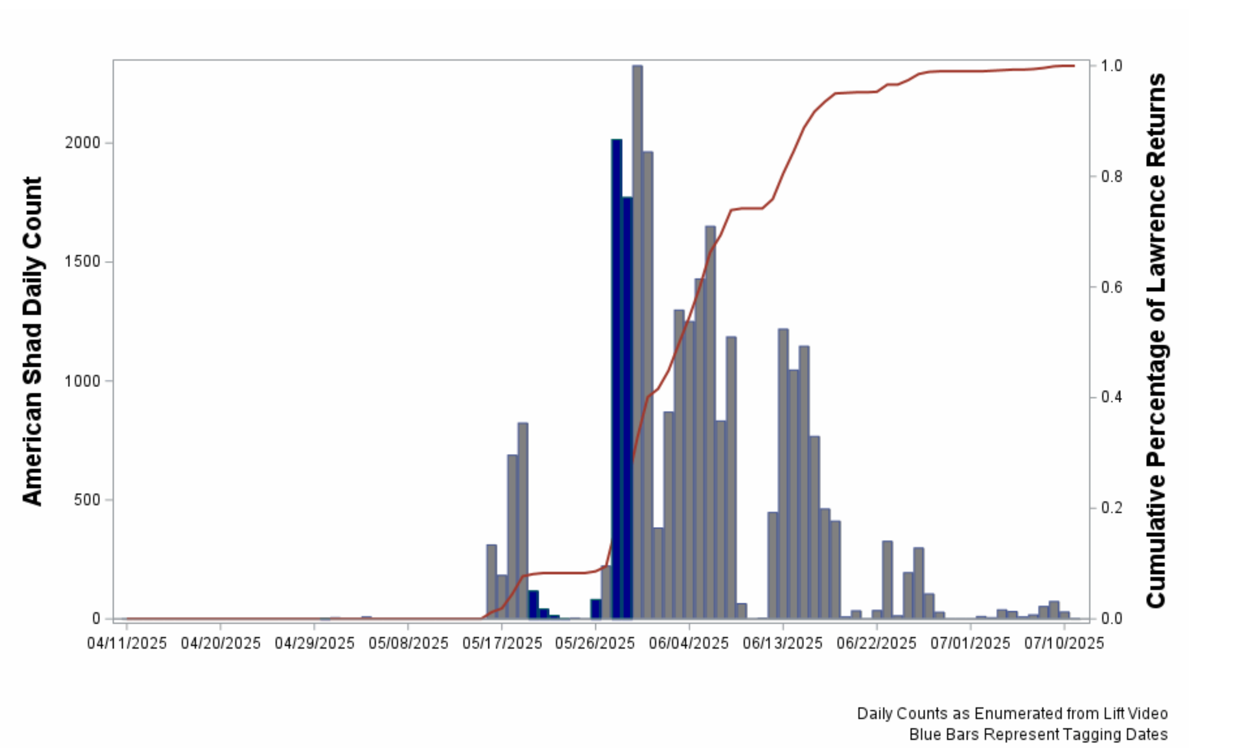

Figure 5-8. Daily count and cumulative percentage of American shad returns to the Lawrence fish lift for the 2025 passage season.

5.5 Movement Analysis

As outlined in Section 5.3 and identified in Table 5-1, high flow conditions in the Lawrence powerhouse tailrace during the 2025 upstream passage season were unsuitable for the deployment and operation of autonomous JSATS receivers and resulted in catastrophic damage to and or loss of 10 of the 13 autonomous receivers installed as part of the array intended to collect 2D information. In addition to the destroyed 2D acoustic receivers, autonomous receivers installed to assess movement to proximate regions in the vicinity of the Route 28 Bridge were also lost (i.e., Station 6A, Station 12A, and Station 13A). As a result, the methodologies developed based on the originally installed array design to assess approach behavior (i.e., those presented in Sections 4.6.1 through 4.6.3 of this report) were modified as needed to still provide some descriptive data to characterize species movement in the reach downstream of Essex Dam. Based on the magnitude of receiver loss associated with the receiver array in the Lawrence powerhouse tailrace, estimates of tagged fish 2D or 3D positions were not possible for the 2025 study effort.

5.5.1 Approach Behavior

A total of 934 diadromous fish were tagged with acoustic transmitters during the spring sampling effort downstream of Essex Dam (Table 5-6). Of those individuals, valid detection data was recorded for 95% of individuals (887 out of 934 fish). When considered by species, there were no valid data records for 3% of acoustically tagged alewife, 6% of acoustically tagged blueback herring and American shad, and 9% of acoustically tagged striped bass. In addition, 1% of tagged alewife, 5% of tagged blueback herring, 9% of tagged American shad and 12% of tagged striped bass moved downstream following tagging (as evidenced by only valid detections at Stations 1 and 2) and did not contribute to the evaluation of approach behavior towards Lawrence.

Table 5-6. Species counts for number tagged, number detected, and numbers of individuals demonstrating upstream or downstream movement as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Species	Number of Individuals			
	Total	No Valid Data Records	Downstream	Upstream
Alewife	335	10	5	320
Blueback Herring	300	17	16	267
American Shad	199	11	17	171
Striped Bass	100	9	12	79
All Species	934	47	50	837

For each species, a CJS model was developed to describe the probability of upstream movement for an individual ascending upriver towards Stations 3 through 11.

Alewife

The CJS model *Phi*(t)*p*(t) provided the best fit for the observed mark-recapture data representing upstream alewife movement following tagging and release downstream of the Essex Dam. Table 5-7 summarizes the stepwise probabilities of success for alewives to move upstream from the release location to the exit from the upstream fish lift (i.e. Station 9). Estimates of passage probabilities for tagged alewife were consistent for the full reach of the study zone from immediately upstream of the release location (i.e., Station 3) to the nearfield region associated with the attraction flow for the upstream fish lift entrance (i.e., Station 8), ranging between 0.687 to 0.844. The lowest probability of movement success was estimated for the likelihood of an individual alewife to move from the nearfield fish lift attraction region (i.e., Station 8) to the upstream exit of the fish lift (i.e., Station 9).

Detection probabilities specific to tagged alewife observed for receiver(s) installed at Stations 3 through 8 ranged from 0.911 to 1.000 (Table 5-8). The lowest detection probability was estimated for Station 5, which consisted of only a single autonomous receiver. All other receiver stations installed within the main channel of the Merrimack consisted of at least two autonomous units.

Table 5–7. Reach-specific passage probability estimates (Phi), standard errors and 95% confidence intervals for tagged alewives approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

River Reach	*Phi*	SE	95% CI	
Release to Station 3	0.955	0.011	0.927	0.973
Station 3 to Station 4	0.734	0.026	0.680	0.781
Station 4 to Station 5	0.687	0.032	0.621	0.746
Station 5 to Station 7	0.844	0.031	0.773	0.895
Station 7 to Station 8	0.779	0.036	0.700	0.842
Station 8 to Station 9	0.019	0.013	0.005	0.072

Table 5–8. Receiver-specific passage probability estimates (P), standard errors and 95% confidence intervals for detection of tagged alewives approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Monitoring Station	*P*	SE	95% CI	
Station 3	1.000	0.000	1.000	1.000
Station 4	0.950	0.017	0.903	0.975
Station 5	0.911	0.024	0.850	0.949
Station 7	0.962	0.019	0.904	0.986
Station 8	1.000	0.000	0.000	1.000
Station 9	1.000	0.000	1.000	1.000

Blueback Herring

The CJS model *Phi*(t)*p*(t) provided the best fit for the observed mark-recapture data representing upstream blueback herring movement following tagging and release downstream of the Essex Dam. Table 5-9 summarizes the stepwise probabilities of success for blueback herring to move upstream from the release location to the lower tailrace (i.e. Station 7).

Estimates of passage probabilities for tagged blueback herring were fairly consistent for the reach of the study zone from immediately upstream of the release location (i.e., Station 3) to the lower end of the tailrace channel (i.e., Station 7), ranging between 0.357 to 0.520. A lack of any valid detections for tagged blueback herring at the upstream stations (i.e., Station 9 or Station 11) prevented model estimation of the probability for blueback herring to move from the detection region of Station 7 (the lower tailrace) to that of Station 8 (nearfield region associated with the attraction flow for the upstream fish lift entrance). However, an estimate based strictly on the raw counts of blueback herring at both locations indicated that 26% of tagged individuals present at Station 7 were subsequently detected at Station 8.

Detection probabilities specific to tagged blueback herring observed for receiver(s) installed at Stations 3 through 7 ranged from 0.684 to 1.000 (Table 5-10). The lowest detection probability was estimated for Station 5, which consisted of only a single autonomous receiver.

Table 5–9. Reach-specific passage probability estimates (Phi), standard errors and 95% confidence intervals for tagged blueback herring approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Station Reach	*Phi*	SE	95% CI	
Release to Station 3	0.890	0.018	0.849	0.921
Station 3 to Station 4	0.383	0.032	0.323	0.447
Station 4 to Station 5	0.357	0.062	0.247	0.485
Station 5 to Station 7	0.520	0.100	0.331	0.704

Table 5–10. Receiver-specific passage probability estimates (P), standard errors and 95% confidence intervals for detection of tagged blueback herring approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Monitoring Station	*P*	SE	95% CI	
Station 3	1.000	0.000	1.000	1.000
Station 4	0.968	0.032	0.804	0.995
Station 5	0.684	0.107	0.452	0.851
Station 7	1.000	0.000	1.000	1.000

American Shad

The CJS model *Phi*(t)*p*(.) provided the best fit for the observed mark-recapture data representing upstream American shad movement following tagging and release downstream of the Essex Dam. Table 5-11 summarizes the stepwise probabilities of success for shad to move upstream from the release location to the exit from the upstream fish lift (i.e. Station 9). Estimates of passage probabilities for tagged shad were low for individuals moving between the first two receiver locations encountered (i.e., Station 3 and 4) then consistent for the reach of the study zone from Station 4 to the nearfield region associated with the attraction flow for the upstream fish lift entrance (i.e., Station 8), ranging between 0.565 to 0.691. The low probability of movement success between Stations 3 and 4 was likely related to the collection and tagging process which frequently results in American shad altering the upstream movement. A probability of 0.269 was estimated as the likelihood of an individual American shad to move from the nearfield fish lift attraction region (i.e., Station 8) to the upstream exit of the fish lift (i.e., Station 9).

The single detection probability for receivers installed at Stations 3 through 9 was 0.911 (Table 5-12).

Table 5–11. Reach-specific passage probability estimates (Phi), standard errors and 95% confidence intervals for tagged American shad approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Station Reach	*Phi*	SE	95% CI	
Release to Station 3	0.929	0.040	0.799	0.977
Station 3 to Station 4	0.158	0.028	0.111	0.220
Station 4 to Station 5	0.565	0.098	0.374	0.739
Station 5 to Station 7	0.691	0.124	0.416	0.875
Station 7 to Station 8	0.657	0.159	0.324	0.885
Station 8 to Station 9	0.269	0.165	0.066	0.656

Table 5–12. Receiver-specific passage probability estimate (P), standard error and 95% confidence interval for detection of tagged American shad approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Monitoring Station	*P*	SE	95% CI	
Station 3-9	0.911	0.035	0.816	0.960

Striped Bass

The CJS model *Phi*(t)*p*(t) provided the best fit for the observed mark-recapture data representing upstream striped bass movement following tagging and release downstream of the Essex Dam. Table 5-13 summarizes the stepwise probabilities of success for striped bass to move upstream from the release location to the lower tailrace (i.e. Station 7).

Estimates of passage probabilities for tagged striped bass varied for the reach of the study zone from immediately upstream of the release location (i.e., Station 3) to the lower end of the tailrace channel (i.e., Station 7), ranging between 0.296 to 0.979. A lack of any valid detections for tagged striped bass at the upstream stations (i.e., Station 9 or Station 11) prevented model estimation of the probability for that species to move from the detection region of Station 7 (the lower tailrace) to that of Station 8 (nearfield region associated with the attraction flow for the upstream fish lift entrance). However, an estimate based strictly on the raw counts of striped bass at both locations indicated that 38% of tagged individuals present at Station 7 were subsequently detected at Station 8.

Detection probabilities specific to tagged striped bass observed for receiver(s) installed at Stations 3 through 7 ranged from 0.500 to 1.000 (Table 5-14). The lowest detection probability was estimated for Station 5, which consisted of only a single autonomous receiver.

Table 5–13. Reach-specific passage probability estimates (Phi), standard errors and 95% confidence intervals for tagged blueback herring approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Station Reach	*Phi*	SE	95% CI	
Release to Station 3	0.795	0.041	0.702	0.864
Station 3 to Station 4	0.694	0.055	0.577	0.790
Station 4 to Station 5	0.979	0.208	0.000	1.000
Station 5 to Station 7	0.296	0.088	0.156	0.490

Table 5–14. Receiver-specific passage probability estimates (P), standard errors and 95% confidence intervals for detection of tagged blueback herring approaching Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Monitoring Station	*P*	SE	95% CI	
Station 3	0.981	0.018	0.880	0.997
Station 4	0.943	0.039	0.798	0.986
Station 5	0.500	0.125	0.273	0.727
Station 7	1.000	0.000	1.000	1.000

Tailrace Arrival

Figure 5-9 depicts the distribution of dates for which tagged individuals representing each of the study species were initially detected within the powerhouse tailrace region (i.e., Station 7 or Station 8). Detections of tagged alewife in the Lawrence tailrace region occurred predominantly during the early part of May and prior to the suspension of fish lift operations associated with high Merrimack River flows on May 8. Following the reinitiation of tagging efforts downstream of Essex Dam, tailrace arrival distributions for the other three study species peaked during the latter part of May and early June. The peak of tailrace arrival for both blueback herring and striped bass was May 29-30. Arrivals of tagged fish at the Lawrence tailrace occurred during daylight hours for almost all individuals (i.e., 0600 to 2000; Figure 5-10).

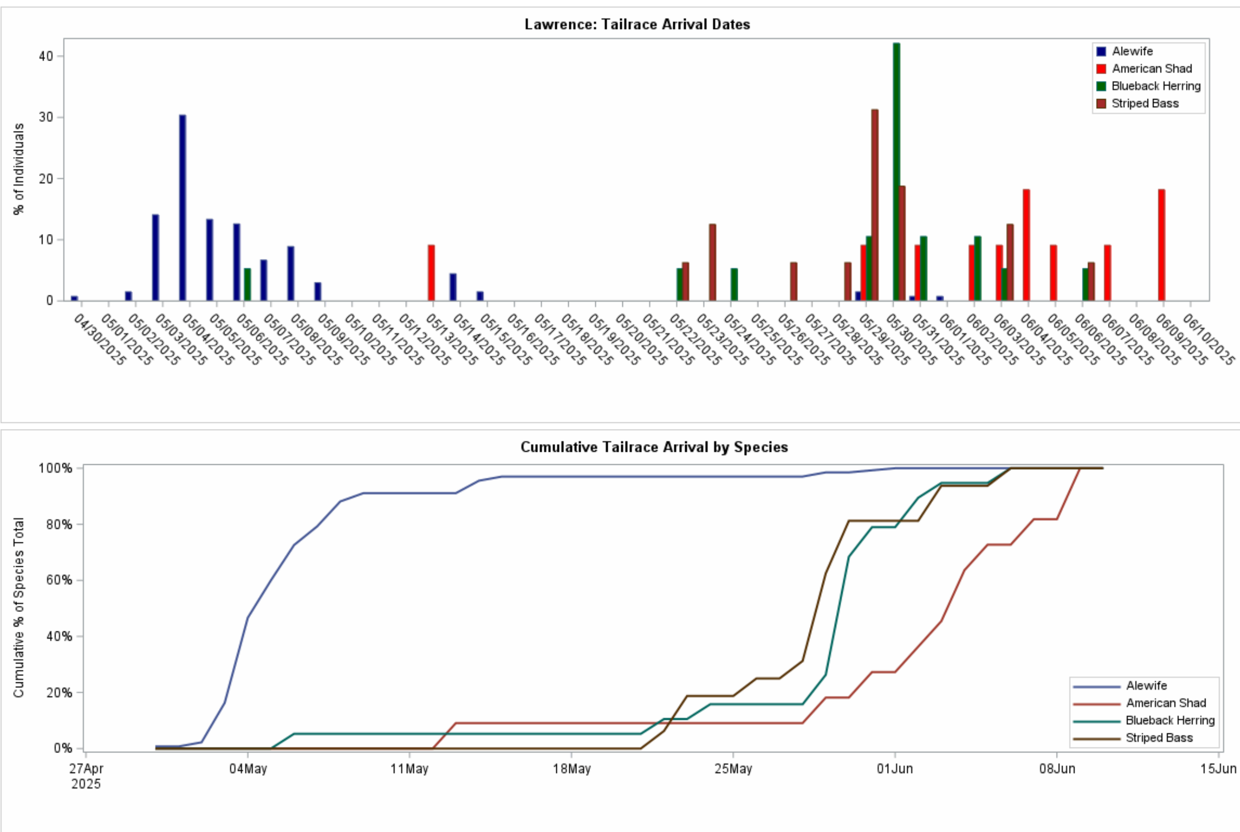

Figure 5-9. Distribution of Lawrence tailrace arrival dates for tagged alewife, blueback herring, American shad and striped bass by date (upper panel) and cumulative (lower panel) as observed during Phase 2 of the Project Interaction Study, 2025.

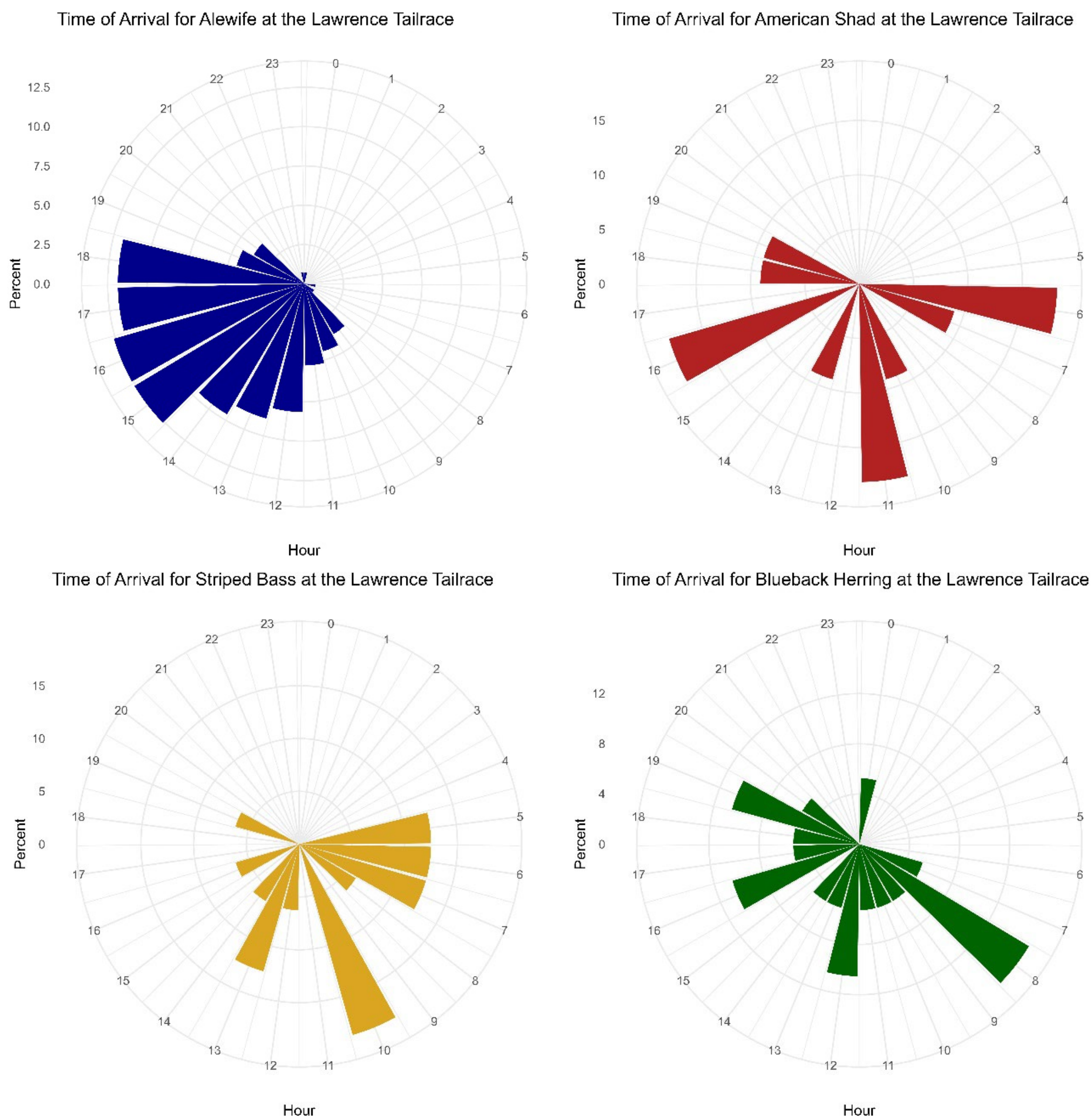

Figure 5-10. Distribution of Lawrence tailrace arrival hours for tagged alewife (blue), blueback herring (green), American shad (red), and striped bass (yellow) as observed during Phase 2 of the Project Interaction Study, 2025.

5.5.2 Downstream Reach Utilization

Time at large was calculated for each tagged individual as the duration from initial tag and release until the final detection among the stationary receivers installed downstream of Essex Dam (Table 5-15). A Kruskal–Wallis test showed a statistically significant difference in median values among the four species ($H(3) = 141.25$; $p < 0.0001$). Pairwise comparisons using the Dwass–Steel–Critchlow–Fligner test indicated that the median values of time at large for alewife and striped bass were longer than those for American shad and blueback herring. The median time at large did not differ between tagged alewife and striped bass or between tagged American shad and blueback herring.

Table 5–15. Minimum, 25th percentile, median, 75th percentile, and maximum values for time at large by species downstream of Essex Dam as observed during Phase 2 of the Lawrence Project Interaction Study, 2025.

Species	Time at Large (hours)				
	Min	Q25	Median	Q75	Max
Alewife	0.1	7.9	78.0	318.3	681.0
American Shad	0.1	2.6	6.8	63.4	631.8
Blueback Herring	<0.1	4.2	12.1	32.5	413.9
Striped Bass	0.5	21.8	159.8	456.7	824.9

Proportional time spent among downstream river reaches as defined by detections at the stationary receivers (i.e., Station 1 upstream through Station 8) are summarized in Figure 5-11 for alewife, blueback herring, American shad, and striped bass and represent the relative time spent among those detection locations for the full duration of each individual fish's time at large. Table 5-16 summarizes the 25, 50, and 75th percentiles of observations for each fish species among the seven detection regions over the full course of the monitoring period (late April through late June).

Visual assessment of the Interquartile Ranges (IQR) (i.e., the spread of the central 50% of values) for time spent in the study reach among the downstream regions defined by the stationary receivers shows a relatively high degree of overlap for alewife among all stations except Station 8 (i.e., upstream extent of the tailrace). The proportion of time spent by alewife in the uppermost extent of the tailrace channel was lowest relative to the rest of the monitored reach when considering the full duration of the monitoring period. The IQR values for blueback herring show less overlap for stations in the vicinity of the sampling region (i.e., Stations 2 and 3) than those upstream and closer to the dam (i.e., Stations 4 through 8) suggesting a larger percentage of time at large in the study region was spent towards the downstream end of the reach. A similar pattern to that observed for blueback herring was also observed for American shad. When considering the full course of the monitoring period, the pattern of time spent in the study reach among the downstream regions for striped bass was comparable to that of alewife with fish utilizing most areas of the reach.

Figures 5-12 through 5-20 present the proportional time spent among downstream river reaches as defined by detections at the stationary receivers (i.e., Station 1 upstream through Station 8) for each of the tagged fish species for weekly increments during the study period, starting with the seven day period from April 30 to May 6 (i.e., when tagging was initiated) until the week of June 25 through July 1 (i.e., when the final detections of tagged fish were recorded in the reach). Tables 5-17 through 5-25 summarize the weekly 25, 50, and 75th percentiles of observations for each fish species among the seven detection regions.

Tagging during the early portion of the study (i.e., prior to the large flow event which peaked on May 11) consisted mainly of alewives (see Tables 5-2 through 5-5) and as a result they were the predominant species available to describe utilization of the downstream reach for the first three weeks of May 2025. Visual assessment of the IQRs for time spent in the study reach among the downstream regions defined by the stationary receivers for alewives during those three weeks shows a relatively high degree of time spent towards the upper extent of the reach (i.e., Stations 4 through 8) during the second two weeks of May (Figure 5-12 through Figure 5-14).

Tagging efforts were reinitiated on May 20 (following the return of Merrimack River flows to a safe and workable condition for collection of fish) and the majority of time spent by tagged individuals for each of the four species in the study reach during that week occurred primarily in the lower portion of the monitored reach and away from the Essex Dam and fish lift as evidenced by the IQRs for Stations 1, 2, and 3 (Figure 5-15). River herring (alewife and blueback herring) were present throughout the downstream reach during the last week of May with a large proportion of individuals' time spent in the region adjacent to the Duck Bridge (i.e., Stations 3 and 4; Figure 5-16). Observations of tagged river herring in the study reach after the last week of May were limited to a few blueback herring during early June. The IQR values for American shad during late May and the first part of June show a lower degree of overlap for stations in the downstream section of the monitored reach (i.e., Stations 1, 2 and 3) than those upstream and closer to the dam (i.e., Stations 5, 7, and 8) indicating a tagged shad resided for a larger percentage of their time at large in the study region towards the downstream end of the reach (Figures 5-16 and 5-17). Individual tagged striped bass were present in the study reach from late May through the end of June. Visual examination of the IQRs for striped bass proportional time spent among downstream river reaches as defined by detections at the stationary receivers during that period indicates relatively uniform utilization of that reach during most weeks through the middle of June (Figures 5-16 to 5-18).

Table 5–16. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the full duration of Phase 2 of the Lawrence Project Interaction Study, 2025.

	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	80	0.2	0.6	3.0	2	0.1	0.1	1.5	5	0.0	0.1	0.1	1	38.8	38.8	38.8
Station 7	132	6.4	15.9	27.6	6	1.3	3.7	7.6	11	8.8	17.2	64.4	16	1.3	11.0	23.9
Station 5	146	6.1	10.8	18.0	17	0.7	2.9	8.6	10	3.3	12.3	22.7	22	1.3	4.5	13.3
Station 4	227	4.6	16.9	35.5	91	1.0	4.6	11.2	25	2.2	8.9	33.0	50	2.5	9.9	27.7
Station 3	315	5.0	14.2	39.5	259	6.5	26.4	60.2	161	29.5	57.3	91.0	74	5.1	20.1	44.8
Station 2	308	9.9	21.2	50.7	245	33.5	66.0	89.8	183	8.4	30.4	64.8	85	9.3	30.3	78.6
Station 1	206	1.1	7.4	19.2	48	0.4	2.6	13.5	106	0.8	2.4	34.5	60	0.4	4.1	57.3

Table 5–17. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period April 30 to May 6 during Phase 2 of the Lawrence Project Interaction Study, 2025.

April 30 - May 6, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	20	0.6	2.8	9.6	.	.	.	.	.	.	.	.	.	.	.	.
Station 7	93	3.7	9.2	24.9	1	0.3	0.3	0.3	.	.	.	.	.	.	.	.
Station 5	139	15.9	23.1	36.9	2	4.1	8.2	12.3	.	.	.	.	.	.	.	.
Station 4	165	6.6	11.6	19.1	2	13.9	15.1	16.4	.	.	.	.	.	.	.	.
Station 3	224	6.6	14.1	27.9	5	16.8	44.1	84.9	1	0.2	0.2	0.2	.	.	.	.
Station 2	216	13.4	26.3	49.1	6	15.1	53.1	55.9	1	99.8	99.8	99.8	.	.	.	.
Station 1	143	3.1	9.8	19.3	2	1.7	12.1	22.4	.	.	.	.	.	.	.	.

Table 5–18. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period May 7 to May 13 during Phase 2 of the Lawrence Project Interaction Study, 2025.

May 7 - May 13, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	42	0.5	1.7	15.9	1	0.3	0.3	0.3	.	.	.	.	.	.	.	.
Station 7	93	4.1	23.4	39.1	1	1.7	1.7	1.7	1	1.8	1.8	1.8	.	.	.	.
Station 5	12	9.9	15.9	52.9	.	.	.	.	.	.	.	.	.	.	.	.
Station 4	116	9.7	31.0	59.5	1	35.9	35.9	35.9	1	1.6	1.6	1.6	.	.	.	.
Station 3	114	0.6	2.7	11.3	1	0.4	0.4	0.4	1	1.2	1.2	1.2	.	.	.	.
Station 2	113	3.5	15.1	28.7	1	3.0	3.0	3.0	1	78.4	78.4	78.4	.	.	.	.
Station 1	86	3.9	15.0	30.1	1	58.8	58.8	58.8	1	17.0	17.0	17.0	.	.	.	.

Table 5–19. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period May 14 to May 20 during Phase 2 of the Lawrence Project Interaction Study, 2025.

May 14 - May 20, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	43	0.9	2.5	7.8	.	.	.	.	.	.	.	.	.	.	.	.
Station 7	69	19.8	45.9	72.1	.	.	.	.	.	.	.	.	.	.	.	.
Station 5	7	0.7	6.8	57.7	.	.	.	.	.	.	.	.	.	.	.	.
Station 4	85	8.2	24.1	62.8	1	99.0	99.0	99.0	.	.	.	.	2	16.3	54.1	91.9
Station 3	88	0.5	1.2	4.1	1	0.4	0.4	0.4	16	10.6	16.0	31.4	12	45.9	92.0	100.0
Station 2	84	0.9	3.7	15.0	2	0.5	49.5	98.6	26	68.7	88.7	100.0	11	95.3	99.3	100.0
Station 1	64	0.0	0.0	14.6	2	0.1	0.8	1.4	14	0.2	1.3	8.4	2	0.7	2.7	4.7

Table 5–20. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period May 21 to May 27 during Phase 2 of the Lawrence Project Interaction Study, 2025.

May 21 - May 27, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	.	.	.	.	.	.	.	.	.	.	.	.	1	11.5	11.5	11.5
Station 7	.	.	.	.	1	64.4	64.4	64.4	.	.	.	.	4	22.5	46.8	60.8
Station 5	1	40.8	40.8	40.8	1	8.4	8.4	8.4	.	.	.	.	.	.	.	.
Station 4	49	0.8	8.9	37.4	18	8.5	27.5	41.1	4	0.1	0.5	3.5	20	4.4	16.1	41.4
Station 3	88	10.7	38.3	82.8	55	16.0	34.3	56.4	82	5.5	26.7	62.2	63	7.5	23.8	49.2
Station 2	84	8.7	38.8	75.1	56	25.3	51.4	71.1	100	39.0	77.5	97.0	74	10.0	45.1	91.1
Station 1	37	0.1	1.2	21.9	22	0.2	1.7	23.8	54	0.3	1.1	7.1	39	0.7	63.1	82.7

Table 5–21. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period May 28 to June 3 during Phase 2 of the Lawrence Project Interaction Study, 2025.

May 28 - June 3, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	.	.	.	.	1	0.6	0.6	0.6	1	5.2	5.2	5.2	1	5.8	5.8	5.8
Station 7	2	7.8	22.7	37.7	4	12.4	15.9	17.2	4	0.6	2.7	6.6	11	2.2	2.8	47.1
Station 5	3	2.7	11.7	23.0	13	6.2	13.9	36.7	4	0.9	1.8	6.9	14	3.3	8.4	23.4
Station 4	11	0.5	51.9	98.8	71	1.6	8.0	25.9	12	1.1	7.5	32.2	37	4.4	13.4	30.8
Station 3	10	0.5	7.2	42.2	203	37.2	69.6	92.9	72	5.4	26.9	65.5	39	1.2	10.5	44.9
Station 2	11	0.6	14.5	52.9	186	7.5	25.5	60.7	78	17.5	47.6	78.0	41	3.0	18.7	53.0
Station 1	5	1.4	2.5	7.7	24	2.2	8.5	43.1	35	5.0	19.3	85.9	37	2.2	46.2	85.1

Table 5–22. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period June 4 to June 10 during Phase 2 of the Lawrence Project Interaction Study, 2025.

June 4 - June 10, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	.	.	.	.	.	.	.	.	5	0.3	0.3	5.4	1	99.0	99.0	99.0
Station 7	.	.	.	.	.	.	.	.	9	3.3	6.9	29.8	7	9.4	15.0	43.3
Station 5	.	.	.	.	1	19.5	19.5	19.5	5	6.7	8.0	10.6	9	15.7	23.9	52.6
Station 4	1	100.0	100.0	100.0	3	0.5	80.1	100.0	15	5.7	8.5	14.2	21	4.0	10.0	30.3
Station 3	.	.	.	.	2	0.2	39.0	77.8	22	4.6	10.0	19.3	21	6.3	32.1	61.3
Station 2	.	.	.	.	3	0.2	21.7	100.0	28	24.9	65.3	84.9	21	4.9	29.6	42.7
Station 1	.	.	.	.	1	100.0	100.0	100.0	26	3.3	20.4	72.1	12	7.9	47.5	89.4

Table 5–23. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period June 11 to June 17 during Phase 2 of the Lawrence Project Interaction Study, 2025.

June 11 - June 17, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Station 7	.	.	.	.	.	.	.	.	3	9.6	20.8	27.9	3	0.6	23.6	54.5
Station 5	.	.	.	.	.	.	.	.	3	0.4	16.7	19.8	9	6.1	15.1	98.2
Station 4	.	.	.	.	.	.	.	.	8	5.0	10.4	38.8	17	0.9	12.5	18.8
Station 3	.	.	.	.	.	.	.	.	8	5.0	23.7	42.5	16	0.7	16.5	63.8
Station 2	.	.	.	.	.	.	.	.	9	23.7	41.7	62.6	18	9.9	20.7	60.9
Station 1	.	.	.	.	.	.	.	.	8	13.0	21.6	61.1	10	1.2	17.9	87.5

Table 5–24. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period June 18 to June 24 during Phase 2 of the Lawrence Project Interaction Study, 2025.

June 18 - June 24, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Station 7	.	.	.	.	.	.	.	.	3	9.6	20.8	27.9	3	0.6	23.6	54.5
Station 5	.	.	.	.	.	.	.	.	3	0.4	16.7	19.8	9	6.1	15.1	98.2
Station 4	.	.	.	.	.	.	.	.	8	5.0	10.4	38.8	17	0.9	12.5	18.8
Station 3	.	.	.	.	.	.	.	.	8	5.0	23.7	42.5	16	0.7	16.5	63.8
Station 2	.	.	.	.	.	.	.	.	9	23.7	41.7	62.6	18	9.9	20.7	60.9
Station 1	.	.	.	.	.	.	.	.	8	13.0	21.6	61.1	10	1.2	17.9	87.5

Table 5–25. Number of individuals, 25th percentile, median, and 75th percentile values for the percentage of time at large by species downstream of Essex Dam as observed for the period June 25 to July 1 during Phase 2 of the Lawrence Project Interaction Study, 2025.

June 25 - July 1, 2025																
	Alewife				Blueback Herring				American Shad				Striped Bass			
Station	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75	N	P25	P50	P75
Station 8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Station 7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Station 5	.	.	.	.	.	.	.	.	.	.	.	.	1	96.1	96.1	96.1
Station 4	.	.	.	.	.	.	.	.	.	.	.	.	2	1.4	4.8	8.1
Station 3	.	.	.	.	.	.	.	.	.	.	.	.	2	2.4	12.9	23.5
Station 2	.	.	.	.	.	.	.	.	.	.	.	.	4	0.4	32.9	82.5
Station 1	.	.	.	.	.	.	.	.	.	.	.	.	2	3.4	51.3	99.3

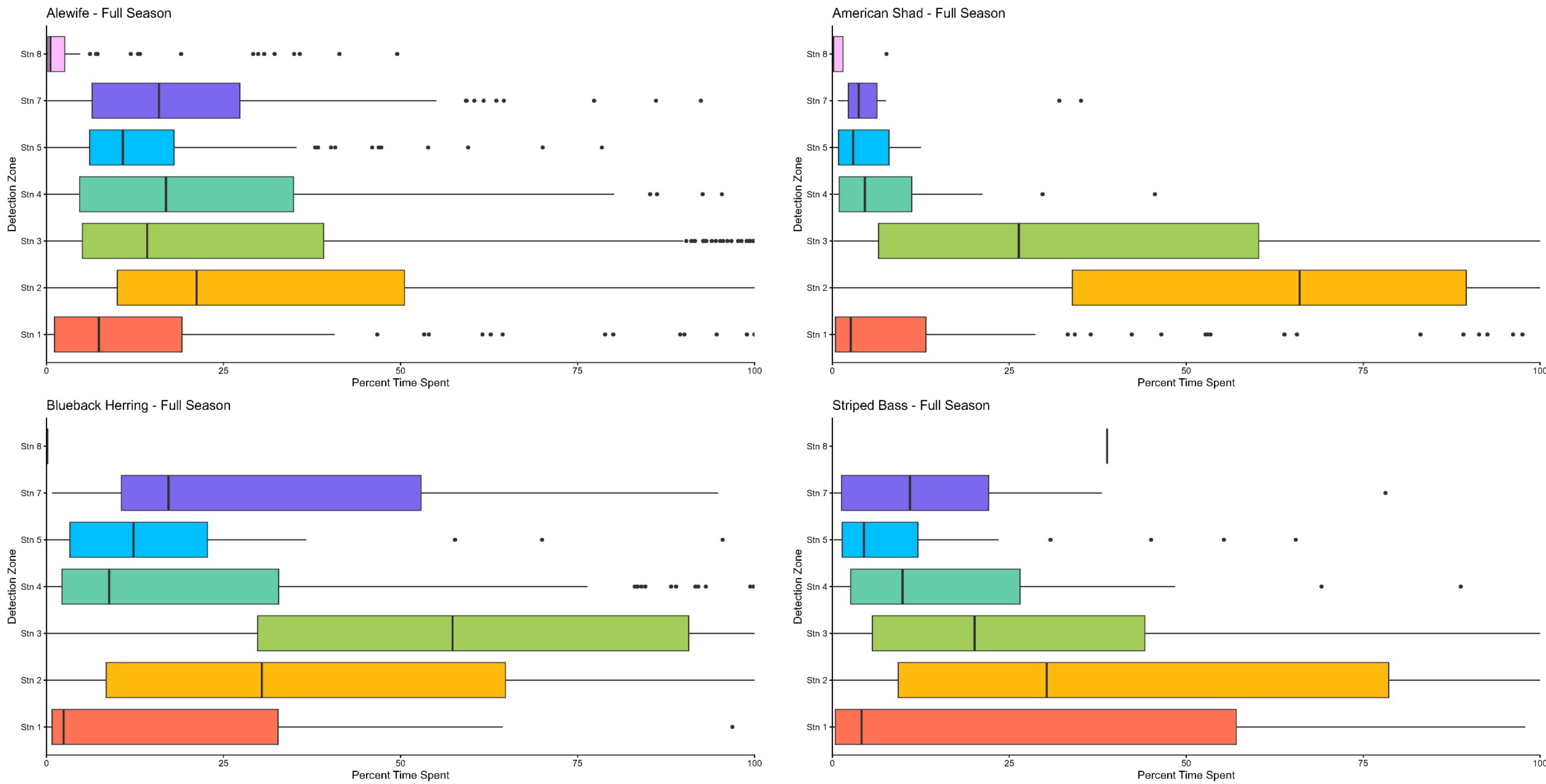

Figure 5-11. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed during the full duration of monitoring during Phase 2 of the Project Interaction Study, 2025.

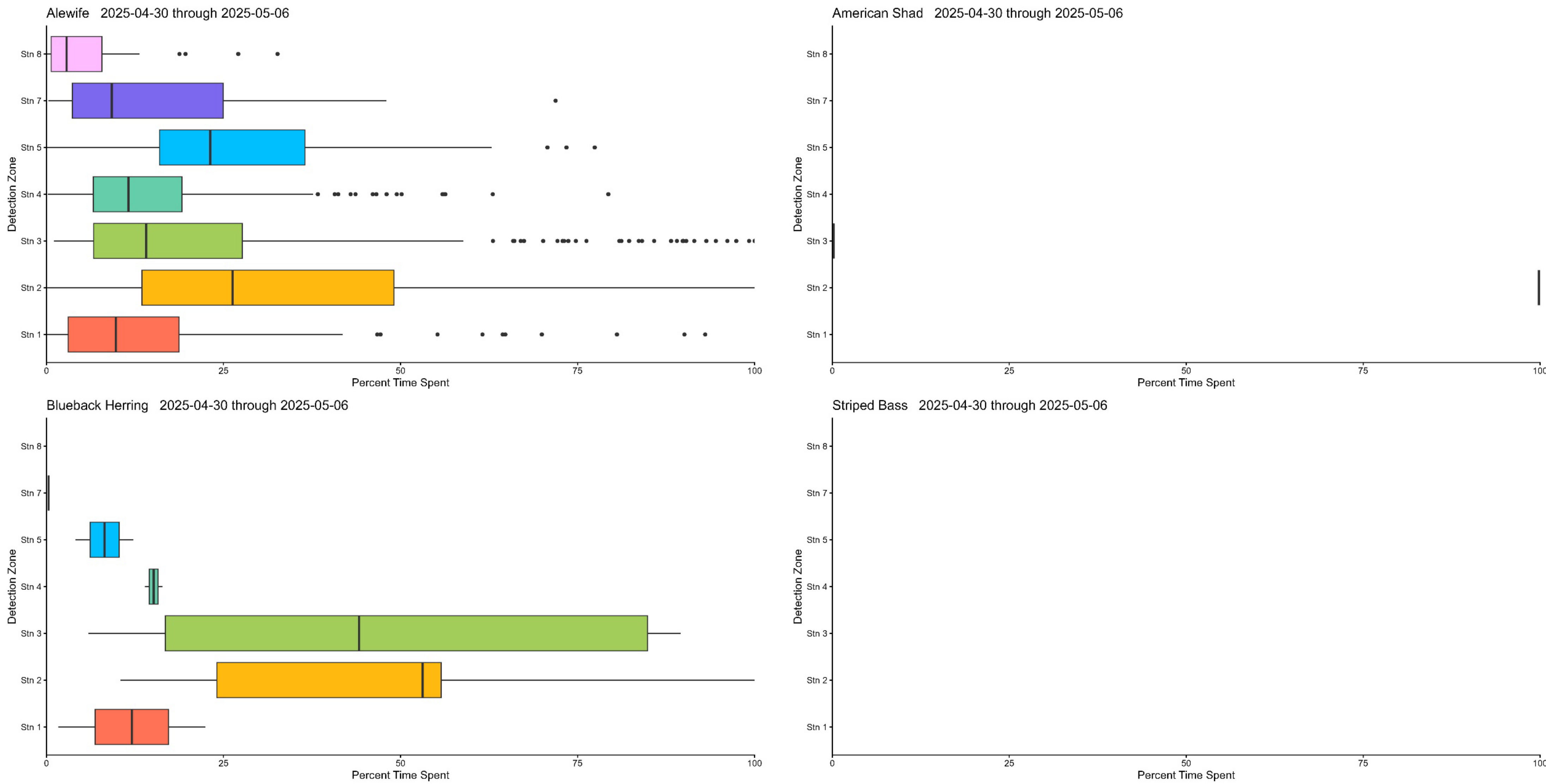

Figure 5-12. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period April 30 to May 6 during Phase 2 of the Project Interaction Study, 2025.

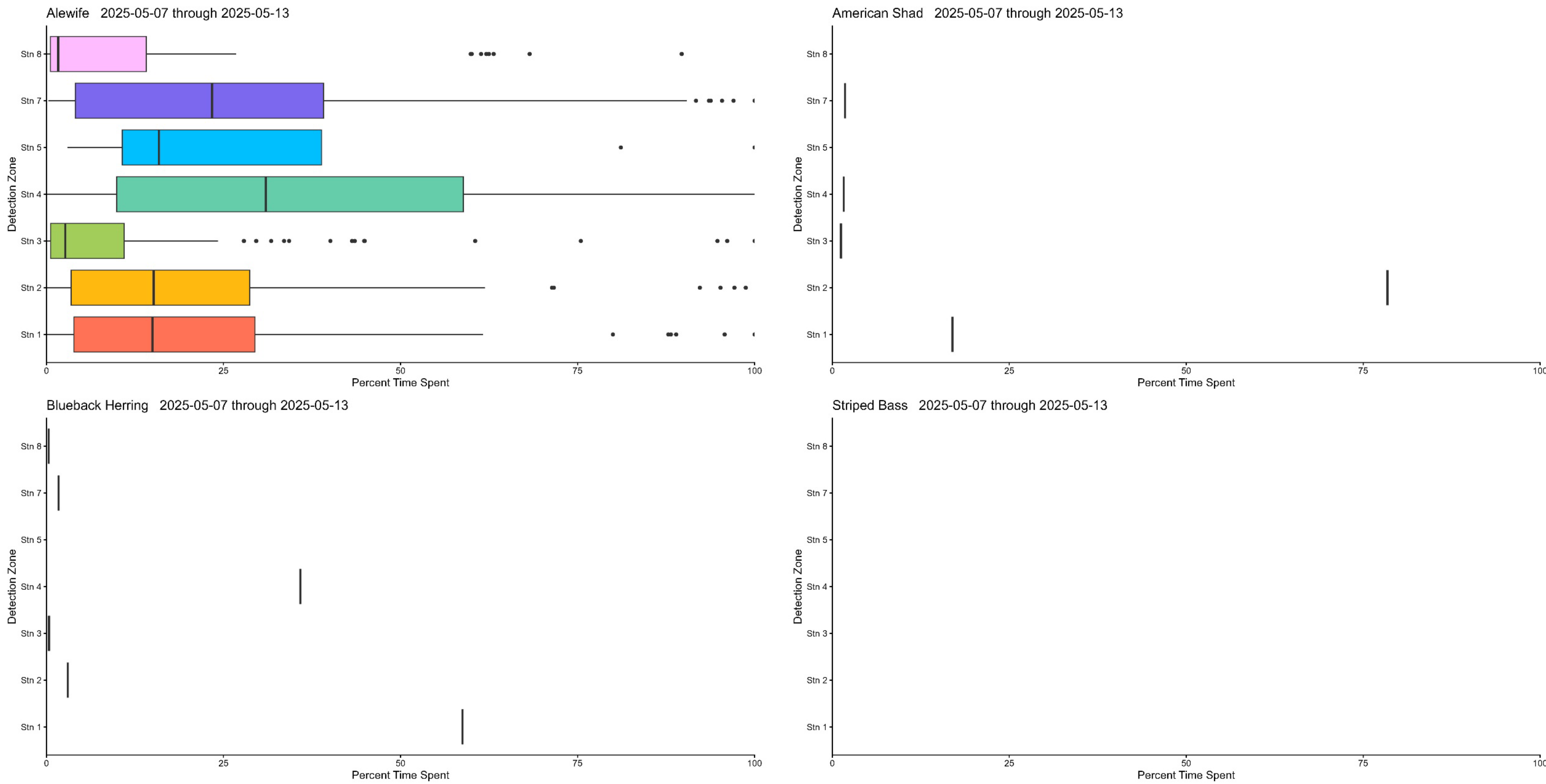

Figure 5-13. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period May 7 to May 13 during Phase 2 of the Project Interaction Study, 2025.

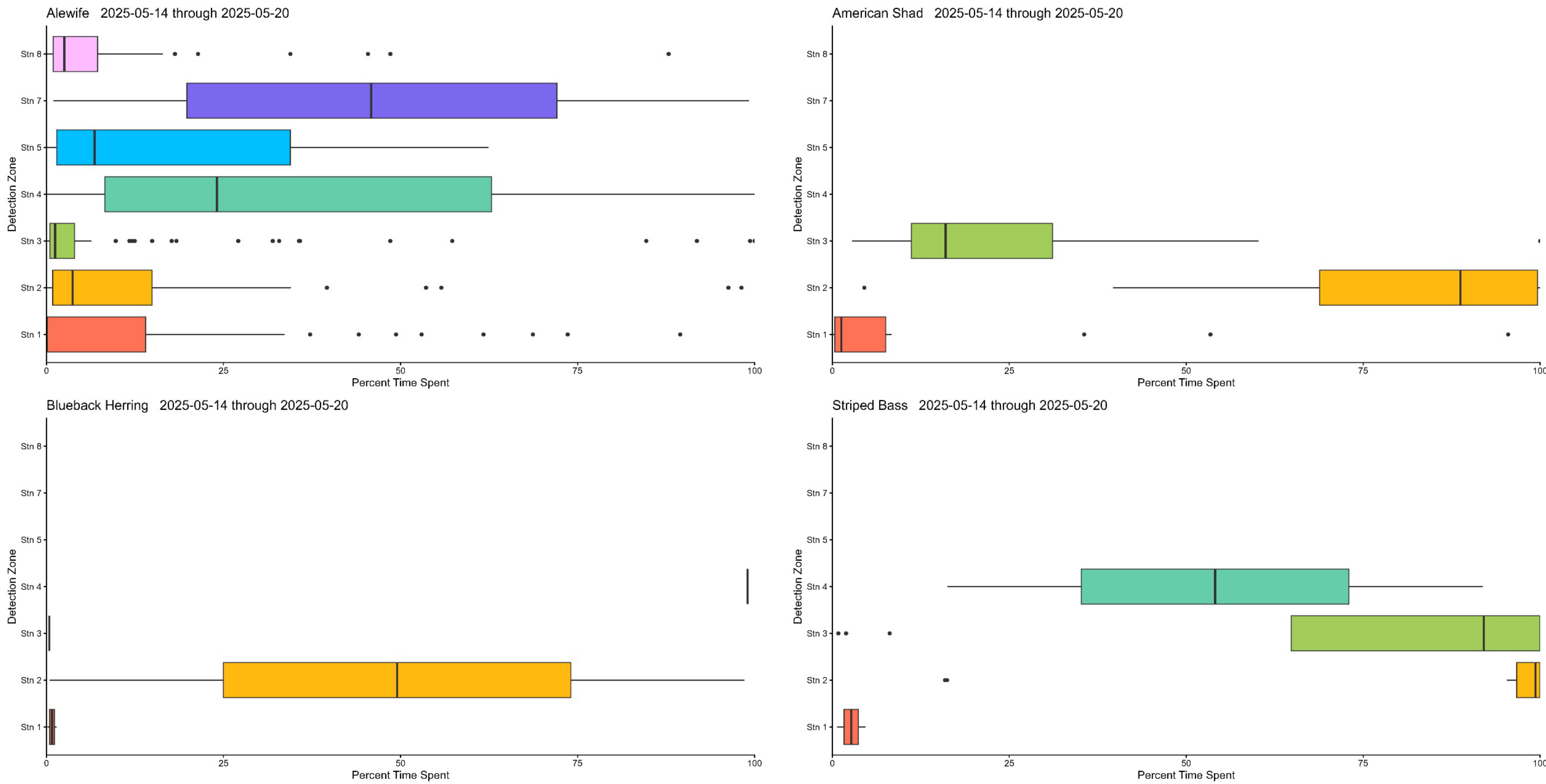

Figure 5-14. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period May 14 to May 20 during Phase 2 of the Project Interaction Study, 2025.

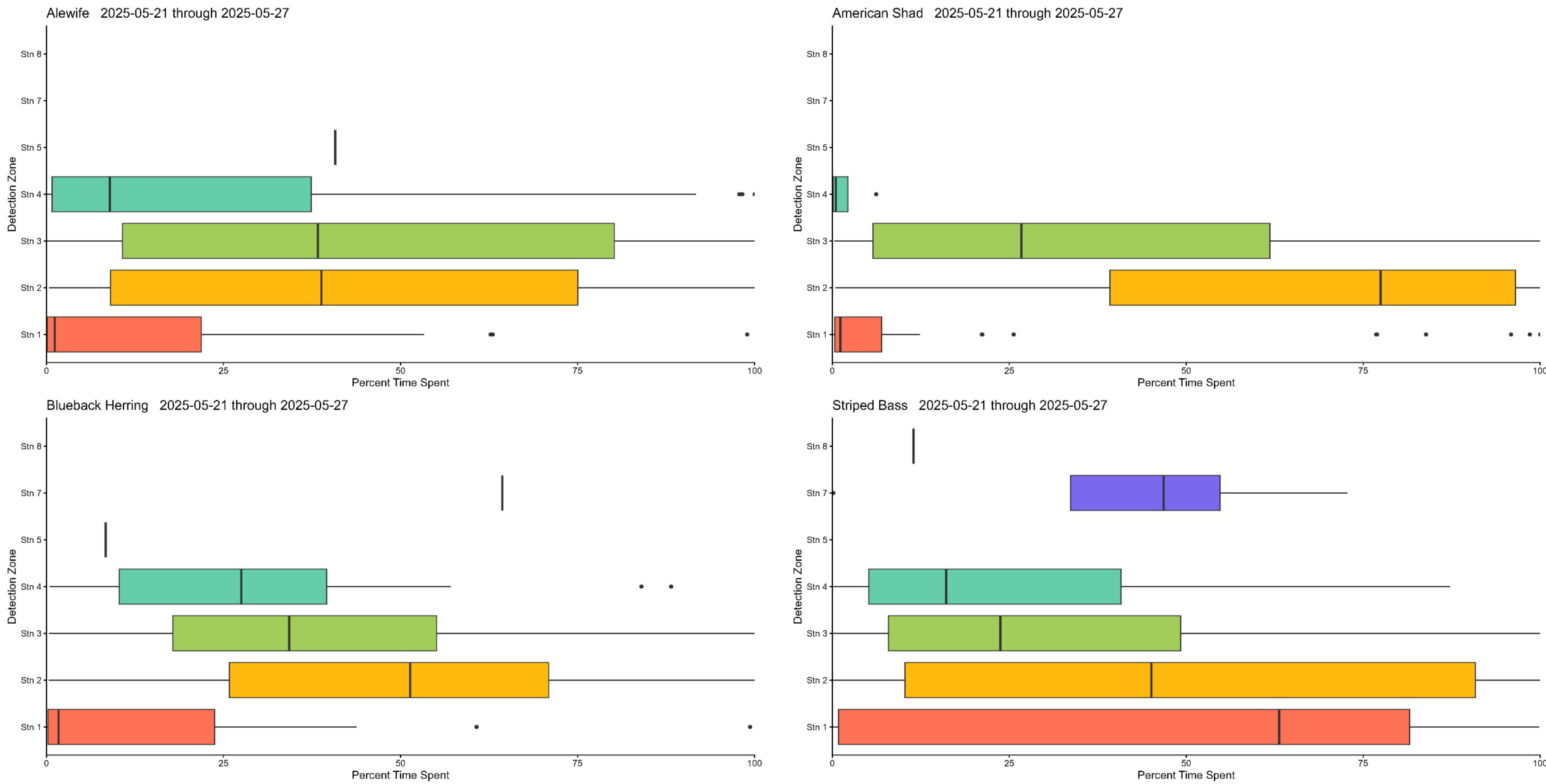

Figure 5-15. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period May 21 to May 27 during Phase 2 of the Project Interaction Study, 2025.

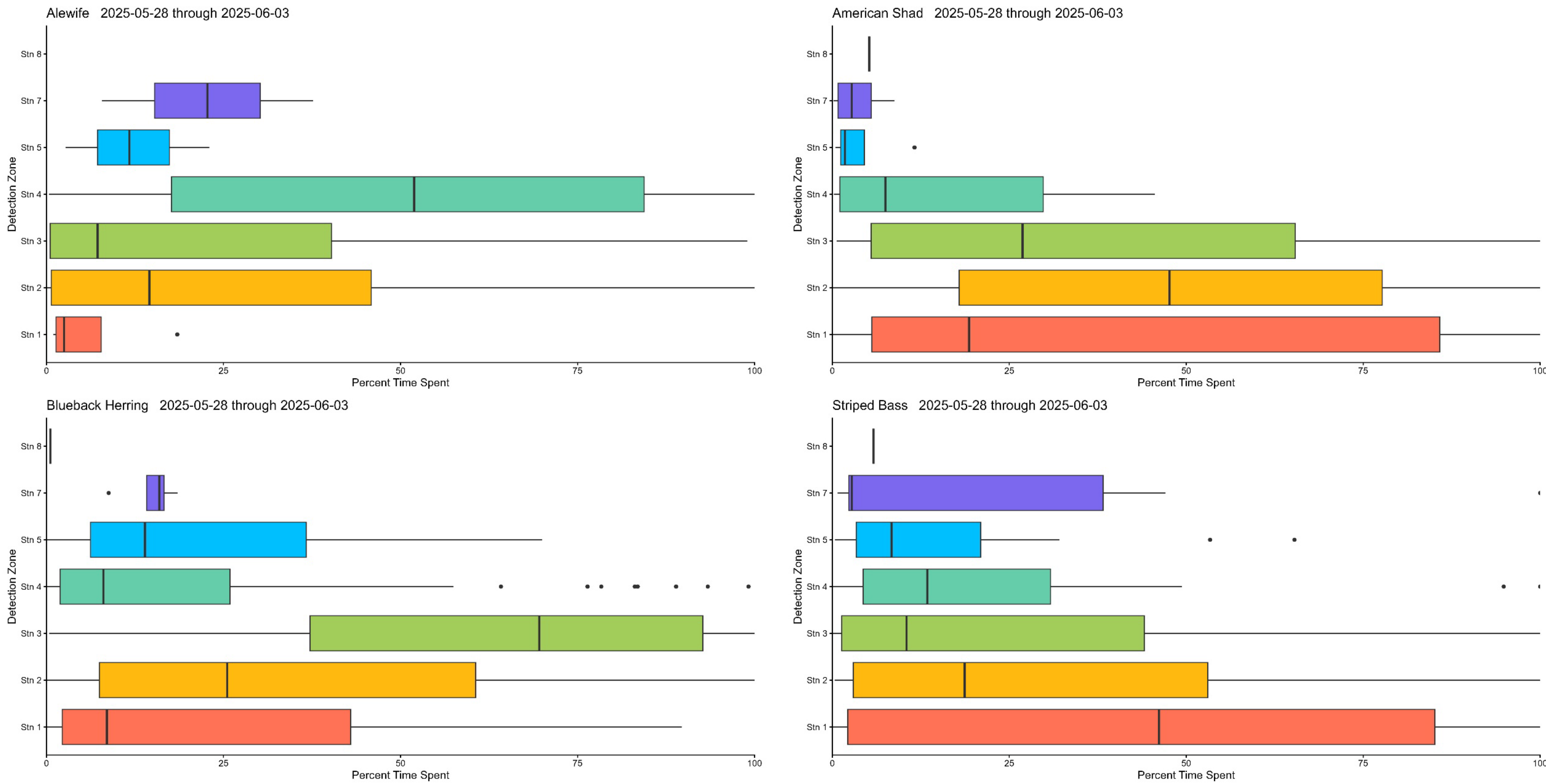

Figure 5-16. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period May 28 to June 3 during Phase 2 of the Project Interaction Study, 2025.

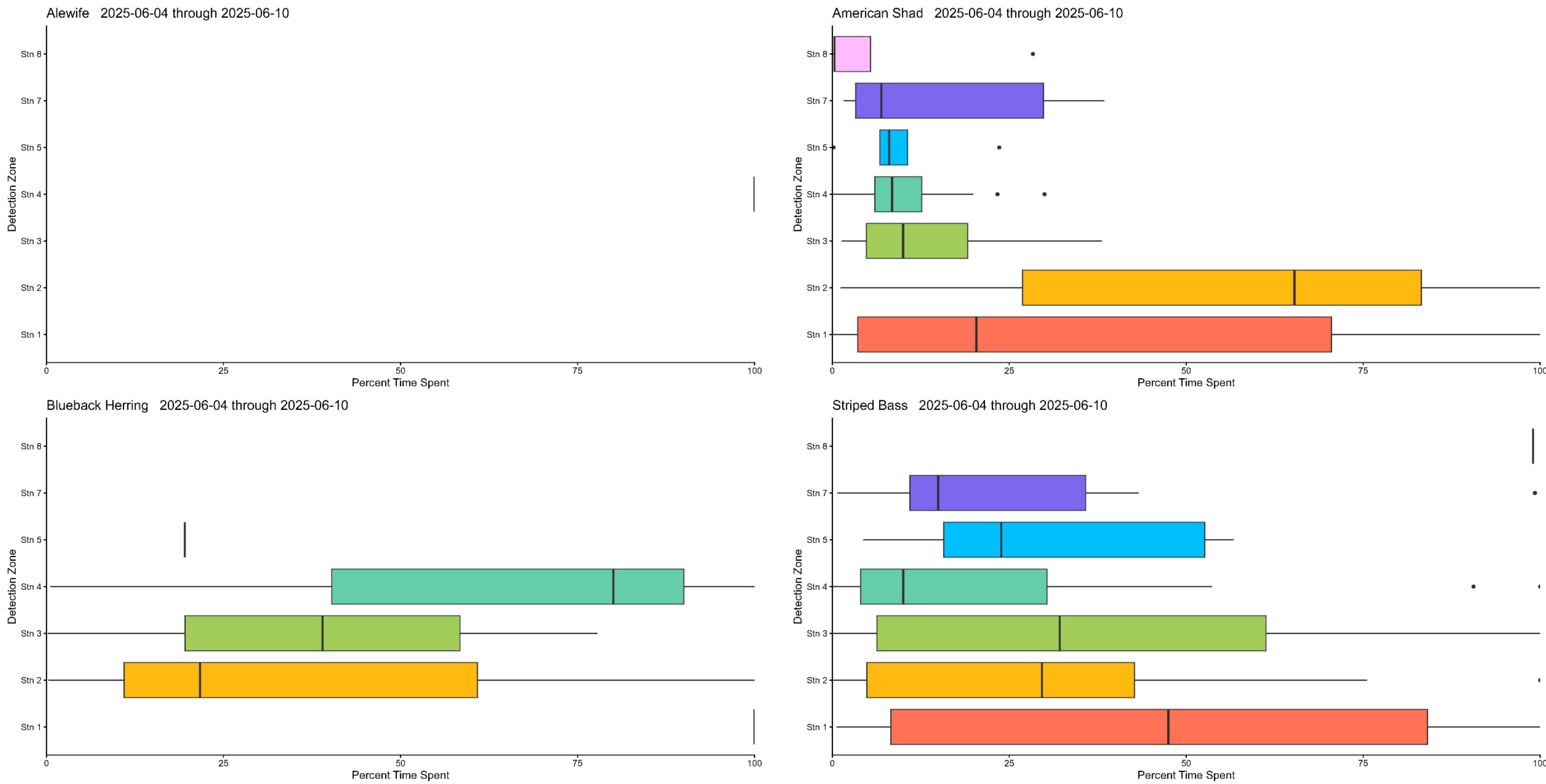

Figure 5-17. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period June 4 to June 10 during Phase 2 of the Project Interaction Study, 2025.

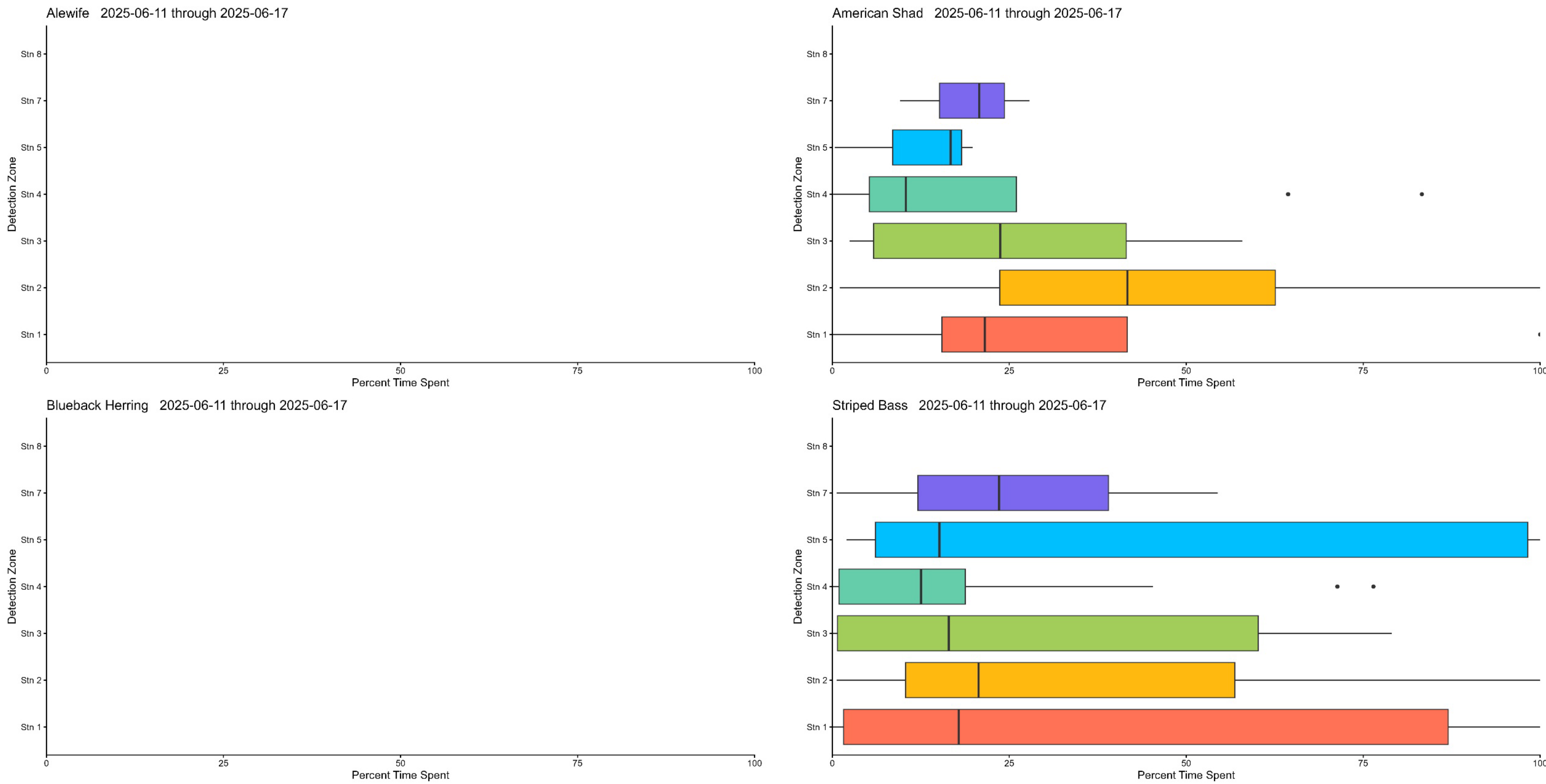

Figure 5-18. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period June 11 to June 17 during Phase 2 of the Project Interaction Study, 2025.

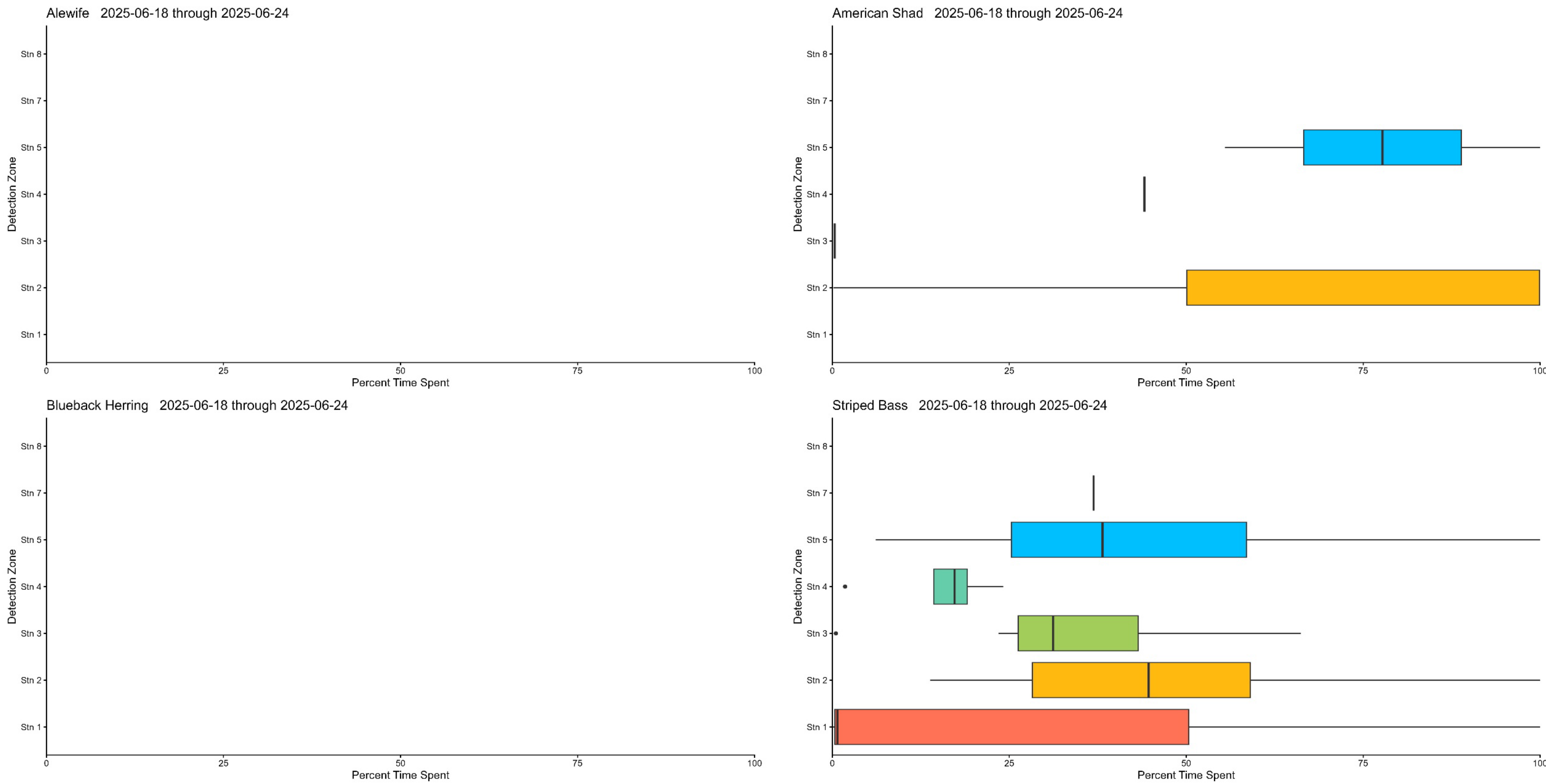

Figure 5-19. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period June 18 to June 24 during Phase 2 of the Project Interaction Study, 2025.

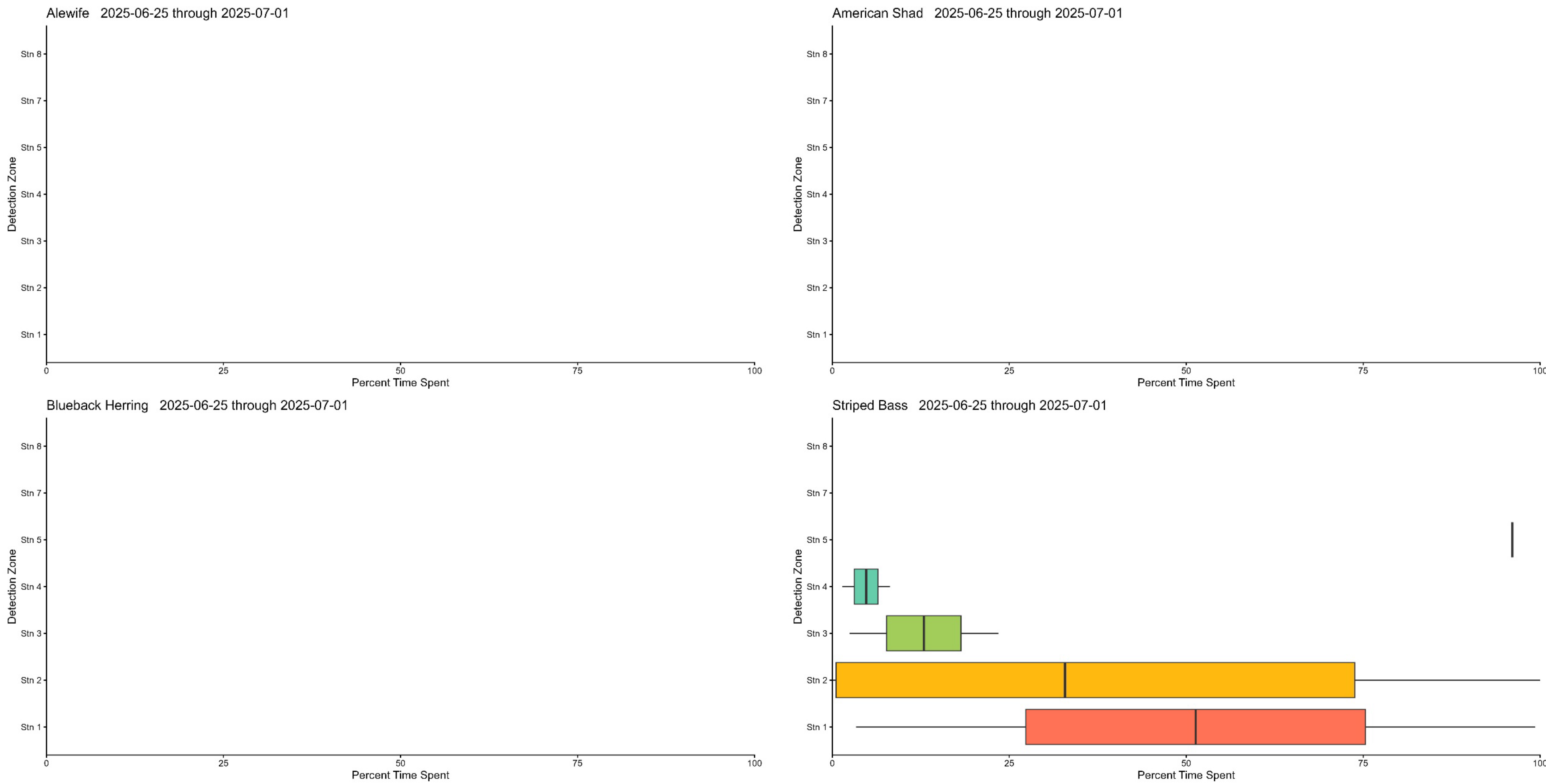

Figure 5-20. Distribution of time at large among regions defined by stationary acoustic receivers in the section of the Merrimack River ranging from downstream of the powerhouse to the Lawrence I-495 Bridge (by species) as observed for the period June 25 to July 1 during Phase 2 of the Project Interaction Study, 2025.

6 Summary

Essex undertook field efforts associated with the execution of Phase 2 of the Diadromous Fish Behavior, Movement, and Project Interaction Study during the 2025 passage season at Lawrence. Prior to the initiation of the release of tagged fish downstream of the Project, a total of 31 JSATS acoustic receivers were installed at locations upstream and downstream of the Essex Dam over three dates during late April and one date during early May. As installed, the array was intended to inform on fish movement to and from the Project via a series of "gate" receivers at points upstream and downstream of the dam and on fish behaviors via a concentrated region with significant overlap intended to provide 2D positioning in the powerhouse tailrace. Receiver placement was informed using information collected during Phase 1 of the Project Interaction Study completed during the 2024 study season.

Tagging took place on 12 dates from late April through early June 2025 and in all a total of 335 alewife, 300 blueback herring, 199 American shad, and 100 striped bass were successfully tagged with an acoustic JSATS transmitters. High flow conditions in the river eliminated the ability to safely boat electrofish for test fish for a 16 day period during the first part of May. Sample collection for test fish resumed when flows receded to a point conducive to on-water sampling on May 20. Tagging efforts were concluded on June 1 and monitoring efforts via the deployed autonomous receivers in-river extended into July. In addition to hampering tagging efforts for part of May, flow conditions downstream of Lawrence (and the presence of spill flows at the dam) completely eliminated any access to autonomous receivers installed as part of the underwater 2D array in the powerhouse tailrace and reduced visibility of and access to autonomous receivers installed at mainstem locations intended to inform on 1D positioning of tagged fish. During receiver retrieval efforts it was determined that the high discharge and non-laminar flow conditions in the Lawrence powerhouse tailrace during the 2025 upstream passage season were unsuitable for the deployment and operation of autonomous JSATS receivers and that those conditions had resulted in catastrophic damage to and or loss of 10 of the 13 autonomous receivers installed as part of the array intended to collect 2D information from the Project tailrace. The magnitude of this receiver loss prevented any ability to inform on 2D fish positions within the tailrace at Lawrence.

Despite the significant damage to receivers associated with the 2D array, all autonomous receivers installed at mainstem locations (with the exception of one) were successfully recovered in working condition and data from these locations were utilized to provide some descriptive data to characterize species movement in the reach downstream of Essex Dam. Initial arrivals of tagged fish at the Lawrence tailrace took place from late April through early June. The initial detection of nearly all tagged fish at the Lawrence tailrace occurred during the daylight hours (i.e., 0600 to 2000). Probabilities of upstream movement for each test species were estimated using a series of Cormack Jolly Seber models. These models estimated the probability of passage for tagged fish from the release location (located just upstream of the confluence with the Spicket River) to Project tailrace (downstream entrance and upstream extent [i.e., vicinity of the fish lift entrance]), and then upstream of the dam. Estimates of passage probabilities for tagged alewife were consistent for the full reach from release to the downstream face of the powerhouse. The estimate of passage success for tagged alewife using the Project fish lift was 1.9%. Passage probabilities for tagged blueback herring to ascend the downstream reaches were slightly lower than that observed for alewife. Of the blueback reaching the receiver positioned at the downstream extent of the tailrace channel, approximately 26% were subsequently detected at the downstream face of the powerhouse (i.e., vicinity of the fish lift entrance). American shad showed a relatively low probability to ascend upstream following tagging (consistent with the known fallback behavior of this species following handling). Despite this, nearly 70% of individuals which reached the downstream end of the tailrace channel were subsequently detected at the next station upstream along the downstream face of the powerhouse (i.e., vicinity of the fish lift entrance) and passage success for those fish via the upstream fish lift was estimated at 26.9%. Striped bass showed movements upstream through the reach below the dam but no individuals were detected passing upstream via the lift.

Time at large was estimated for each tagged fish as the duration from release until final detection within the monitoring array. Based on evaluation of median estimates for time at large, tagged alewife and striped bass were present longer after tagging than was observed for either blueback herring or American shad (both “fragile” species more prone to fallback following handling). Spatial and temporal patterns in the relative proportion of time spent among the downstream regions defined by the stationary receivers were evaluated for each species. In general, alewife and striped bass showed use of all of the downstream regions whereas blueback herring and American shad were somewhat more limited to regions towards the downstream end of the reach. Tagging efforts for both species occurred during the latter part of May and early June. High flow conditions, which prevented tagging during early to mid-portion of May and persisted well into June, were likely an influence on upstream movement of both species through the 1.0-1.4 mile reach between the tagging location and the fish lift.

The temporal review of species use of the downstream reach indicated presence of tagged river herring (both species) into early June. American shad presence was notable from late May through early June and individuals tended to spend a higher proportion of time in the lower portion of the monitored reach. Tagged striped bass were present throughout the downstream reach from initial tagging for the species in late May through June.

7 Variances from the FERC Approved Study Plan

Phase 2 of the Diadromous Fish Behavior, Movement, and Project Interaction Study was conducted following the methodology described an updated study plan outlining the methodologies to address Phase 2 and filed with the Commission as part of the ISR on April 28, 2025, with the following exceptions.

- The updated study plan identified total sample sizes for alewife (n=345), blueback herring (n=345), American shad (n=200), and striped bass (n=100). The final numbers of tagged fish released in the reach downstream of Essex Dam were slightly lower for alewife (n=335), blueback herring (n=300), and American shad (n = 199). Significant efforts to collect fish via boat electrofish for tag and release downstream of the Project took place over 12 days between late April and early June 2025. Merrimack River flow conditions prevented safe and effective sampling downstream of Lawrence for a two-week period during early to mid-May.
- Phase 2 of the Project Interaction Study was intended to collect data to inform on two-dimensional positions of tagged fish within the tailrace channel region downstream of the Lawrence powerhouse. The full 2D receiver array was installed and operational on April 28. Shortly thereafter, Merrimack River flows increased significantly, and spill was present at the Lawrence Project well into June, eliminating access to autonomous receivers installed as part of the 2D array in the powerhouse tailrace and reduced visibility of and access to autonomous receivers installed at mainstem locations intended to inform on 1D positioning of tagged fish. The high discharge and non-laminar flow conditions in the Lawrence powerhouse tailrace during the 2025 upstream passage season were unsuitable for the deployment and operation of autonomous JSATS receivers and resulted in catastrophic damage to and or loss of 10 of the 13 autonomous receivers installed as part of the array intended to collect 2D information from the Project tailrace. As a result, no two-dimensional information was available to include in this report.