Updated Study Plan

Study 5: Sturgeon Distribution and Project Interaction Study Plan

Lawrence Hydroelectric Project

(FERC No. 2800)

Prepared by:

HDR and Normandeau Associates Environmental Consultants

ASA Analysis & Communication, Inc

Prepared for:

Essex Company, LLC
A subsidiary of Patriot Hydro, LLC

Patriot Hydro

1 Sturgeon Distribution and Project Interaction Study

1.1 Study Requests

Essex filed a PAD with the Commission on June 16, 2023 and the PSP on November 28, 2023 and the RSP on April 10, 2024. The Commission's August 15, 2023 SD1 and November 28, 2023 SD2 identified a variety of aquatic resource issues to be analyzed in the EA for the Project relicensing. The USFWS, MA DMF, MassWildlife, and NHFGD subsequently submitted formal requests to determine the presence and movement of sturgeon downstream of and within the Lawrence Project boundary, as shown in Table 10-1. Essex is proposing this study in response to these study requests and study recommendations made by FERC in the SPD issued on May 10, 2024.

Table 1-1. Aquatic Resource Study Request

Requestor	Requested Study	Date
USFWS	Sturgeon Distribution and Project Interaction Study (USFWS Letter Request No. 7)	October 16, 2023
NMFS	Sturgeon Distribution and Project Interaction Study (NMFS Letter Request No. 3) Comments on the Revised Study Plan for the Lawrence Hydroelectric Project (P-2800-054)	October 16, 2023 April 24, 2024
MassWildlife	Sturgeon Distribution and Project Interaction Study (MassWildlife Letter Request No. 7)	October 16, 2023
NHFGD	Sturgeon Distribution and Project Interaction Study (NHFGD Letter Request No. 7)	October 16, 2023

1.2 Goals and Objectives

The goal of this study is to determine if Atlantic (*Acipenser oxyrinchus oxyrinchus*) or shortnose sturgeon (*A. brevirostrum*) are interacting with the Lawrence Project. Specifically, this study is intended to inform on the presence of Atlantic and shortnose sturgeon within the Project boundary and in the reach downstream.

1.3 Study Area

The study area will include the section of the Merrimack River located immediately downstream of the Essex Dam, extending downstream to the Lawrence I-495 Bridge (an estimated reach length of 1.5 miles).

1.4 Background and Existing Information

The Merrimack River downstream from the Lawrence Project has an amphidromous population of shortnose sturgeon (Kieffer and Kynard 1993). A study of the overwintering population of sturgeon in the Merrimack counted 3,786 individuals in 2020-2021 season and 3,424 individuals in the 2022-2023 season (Stantec 2023). Shortnose sturgeon movement in the lower Merrimack has been documented up to the I-495 Bridge in Lawrence (Stantec 2023) with documented spawning occurring near Haverhill between river kilometer 30 and 32 (Kieffer and Kynard 1996). The detections at the I-495 Bridge in Lawrence occurred during the spawning season, suggesting that habitat between the I-495 bridge and the Essex Dam may be used for spawning or pre-spawning habitat. Post-spawn and juvenile shortnose sturgeon are present in the river throughout the year (Kieffer and Kynard 1993).

The Merrimack River downstream from the Lawrence Project is utilized by Atlantic sturgeon from late May to early October for foraging (Kieffer and Kynard 1993; Wippelhauser et al. 2017). Kieffer and Kynard (1993) found that sub-adult Atlantic sturgeon used only one discrete section of the Merrimack River each year. Sub-adult Atlantic sturgeon during study were determined to frequent the “lower islands” section of the Merrimack River, located between river kilometers 5-10 and approximately 25 km downstream from Essex Dam. Overwintering in the Merrimack River has been documented for one individual (Wippelhauser et al. 2017).

1.5 Project Nexus

The Lawrence Project is located within the historical range for both Atlantic and shortnose sturgeon and the dam and powerhouse define the upstream boundary of NMFS-designated critical habitat for Atlantic sturgeon. Data collected as a part of this study will provide a baseline to inform on the presence of these species immediately downstream of the dam and to determine if measures are necessary to minimize potential effects for any new license issued for the Project.

1.6 Methodology

The Sturgeon Distribution and Project Interaction Study will consist of three methodologies:

1. mobile side-scan sonar (SSS) surveys conducted in the 1.5-mile reach of Merrimack River between Essex Dam and the Lawrence I-495 Bridge, from late-March through early May (river conditions permitting);

2. a pilot study in 2025 to determine feasibility of using fixed-location sonar to detect and identify artificial targets of similar size and shape as sturgeon in the tailrace and, if feasible, monitor for the presence sturgeon in the tailrace from mid-March through early November 2026; and

3. tag sturgeon with acoustic transmitters and install acoustic receivers in the tailrace and downstream reach to monitor from mid-March to early-November (as river conditions allow).

1.6.1 Mobile Side-Scan Sonar Surveys of Sturgeon

1.6.1.1 Survey Design

The primary objective of these repeated mobile surveys is to determine the presence or absence of sturgeon along a 1.5-mile river reach between the Project and the Lawrence I-495 Bridge. If present, the detected sturgeon will be georeferenced and counted.

The survey will use similar equipment, software, and techniques used in previous SSS mobile surveys of Atlantic and shortnose sturgeon in the Merrimack River (Stantec 2023) and other rivers (Flowers and Hightower 2013, 2015; Kazyak et al. 2020). An aluminum flat-bottom vessel (approximately 6 m in length) with a Bimini top will be outfitted with a pole-mounted 600 and 1600-kHz dual-frequency EdgeTech 4125i SSS system (or equivalent).

Assuming safe river flow and weather conditions, a total of six weekly surveys will be completed from the vicinity of the tailrace (but not within the tailrace due to safety concerns and navigation hazards) downstream to the Lawrence I-495 Bridge for approximately 1.5 river miles (2.4 km) from late March through early May 2025. This period is the known spawning and foraging season for sturgeon in the Merrimack River. Each survey event will be completed within a single sampling date and will cover the full 1.5-mile reach. The vessel will survey in navigable waters along parallel transects running longitudinally up and down the river. A set of four to five longitudinal transects should provide full coverage of the Merrimack River throughout the study reach given the 350–450-foot channel width. At an average survey speed of 4 knots (6.8 fps), each longitudinal transect should take approximately a half hour to one hour, or half the day to finish the transects. One or more surveys may be re-scheduled in coordination with the Project if river conditions compromise safety or survey conditions.

For each survey date, Essex will report the recorded Project inflow (cfs), generation flow (cfs), estimated spill flow (cfs) and spill gate status. The water temperature at the time of the survey will also be recorded.

1.6.1.2 SSS Data Analysis and Reporting

SonarWiz software (Chesapeake Technology, Inc.) will be used to process the georeferenced mosaic of sonar imagery. Each SSS data file will be reviewed and potential sturgeon targets identified. For each sturgeon located, the date, time, GPS coordinates, estimated total length, and data quality (e.g., “yes” sturgeon, “maybe sturgeon”, “no” sturgeon) will be recorded from the acoustic target or shadow. Sturgeon target identification and classification will be made based on the following characteristics: high reflectivity (echo strength), elliptical body shape, posterior dorsal fin, heterocercal tail, snout shape, and fin placement (Kazyak et al. 2020). Sturgeon are expected to be approximately between 80 and 110 cm (2.6-3.6 ft) in total length based on previous shortnose sturgeon measurements downriver (Stantec 2023). Sturgeon identification will be made by two independent reviewers, and any discrepancies will be reviewed further and resolved by a third person. The report will include counts of identified sturgeon in both tabular and graphical form across the five survey events. The scope of the analysis and report for the mobile SSS surveys will not include abundance estimates. Mapping will be provided to highlight the spatial distribution of observations. Sturgeon counts may not necessarily reflect the number of unique individuals. The draft report will also summarize survey conditions (i.e., inflow, Project operations, etc.).

1.6.2 Fixed-Location Sonar Monitoring in the Tailrace

1.6.2.1 A Two-Phase Approach

The objectives for the fixed sonar monitoring are to (1) determine if sturgeon are present in the tailrace from mid-March through early November and, if present, (2) determine how they are distributed in the tailrace for purposes of informing the potential design and location of a fishway. Essex is proceeding with a different methodology than the fixed-location SSS that FERC recommended in the Study Plan Determination (SPD) for Study 5 because fixed-location SSS is an untested stationary application with unknown performance, is likely to yield less-than-desirable image resolution and spatial coverage, and poses logistical/environmental challenges. Given that using a fixed-SSS array to monitor sturgeon distribution and behavior in a tailrace is inconsistent with generally accepted scientific practice (Haxton et al. 2024; Munnelly et al 2024), a two-phase approach will be taken that includes a pilot study in 2025 to assess the site conditions and test performance of two sonar technologies more suitable for this task; and, if deemed feasible from the pilot study, monitoring for the presence of sturgeon in the tailrace from mid-March through early November 2026. See Section 10.8 for additional discussion of alternative approaches.

1.6.2.2 Sampling Design

2025 (Year 1)

During 2025, the pilot study will evaluate deployment options and suitable locations in the tailrace for a fixed-location sonar installation, and will test target detection and identification performance of two sonars at multiple sampling configurations (Langkau et al. 2012; Gurshin et al. 2017). If the sonar can’t be securely mounted in an area with minimal turbulence, upwelling, entrained air bubbles or debris, then an eight-month deployment would be considered not feasible because of the high likelihood of severe equipment damage from hydraulic stresses and collision of large objects and limited detectability of sturgeon echoes from turbulence and acoustic interference (e.g., bubbles, debris field). One potential result is that some areas within the tailrace will not be feasible to sample due to turbulence and noise (e.g., bubbles, debris) throughout the water column, but monitoring could be possible for some portion of the tailrace.

The likelihood of detecting sturgeon and correctly differentiating between sturgeon and other objects of similar size (e.g., a submerged branch) is important and may depend on the sonar location, sampling volume (i.e., range, field of view, direction), and the sonar specifications (e.g., resolution, sampling rate, transmit power, etc.). Data will be collected by deploying artificial targets within the field of view of the sonar(s) at known times and depth. Artificial targets will consist of 1-meter sturgeon silhouette templates, custom-poured life-size lures, and/or other objects (e.g., other fish shaped templates, PVC pipe, waterlogged branches).

One of the sonars to be tested will be the Adaptive Resolution Imaging Sonar (ARIS) with 1100 and 1800 kHz modes (Sound Metrics, Inc.; Belcher et al. 2001). The ARIS is the manufacturer's successor to the dual-frequency identification sonar (DIDSON), which, together with the DIDSON, have become accepted remote sensing technologies for successfully detecting and identifying sturgeon (Izzo et al. 2022; Haxton 2024; Munnelly et al. 2024; Figure 10-4 to 10-6). The effective sampling range may vary based on conditions but should be between 10 and 15 m for detection and identification. The ARIS has two beam modes: 48 beams with a 0.6° beam width and 96 beams with a 0.3° beam width. The field of view can be adjusted vertically to 1°, 3°, 8°, 14° or 28° and horizontally from 15° with a telephoto lens to the standard width of 28°.

The second imaging sonar to be tested will be selected on, in part, price and availability shortly prior to the study. Imaging sonar alternatives include the Teledyne Blueview MK2 series, Tritech Gemini 1200ik, Blueprint Subsea Oculus M-series, or equivalent. There are several Blueview MK2 models that provide dual-frequency modes of 900 and 2200 kHz and have a 130° field of view (Figure 10-7). The Gemini 1200ik model can operate at 720 or 1200 kHz over a 120° field of view (Figure 10-8). The Oculus M1200d can operate at 1,200 kHz or 2,100 kHz and has either 60° or 120° field of view (Figure 10-9).

2026 (Year 2)

Assuming sonar monitoring in the tailrace is determined feasible by the pilot study, sonar choice, deployment method (and modifications if needed), and sampling configuration will be based on the results of that study. There will likely be areas of the tailrace not observable by the sonar, either because of range limitations for confident sturgeon detection and identification, or areas with strong turbulence or elevated background noise levels (Figure 10-10). Sonar monitoring may spatially subsample the tailrace into two or more areas defined by the pan and tilt angles, which over the hour may reasonably collect representative data over a large portion of the tailrace ("entire tailrace to the extent practical").

Data collection will be planned from mid-March through early November. Site visits by a single staff member twice per week to inspect equipment and data collection status, organize data, retrieve back-up data to bring back the office, and inspect the transducer condition (and clear it off debris if needed). However, if environmental conditions jeopardize the sonar equipment and/or data collection (Figure 10-11), then periodically supervised sampling during day and night sampling periods per week will be considered in lieu of continuous data collection. Data will be automatically backed up on site and remote access to the data collection computer will allow staff to monitor system health, inspect data quality, and adjust settings as needed from the office.

1.6.2.3 Imaging Sonar Data Analysis and Reporting

A qualitative and quantitative assessment of target detection and identification will be made that examines background noise, coverage, maximum detection/identification range, and effectiveness of identifying known targets and agreement between two independent reviewers. Data processing will use automated procedures to remove background noise, remove empty frames, detect and track targets, and extract a subset of image data for manual inspection (Munnelly et al. 2024). Operational data such as inflow, generation flow, estimated spill flow, fish passage flow, and canal flow will be requested from Essex and summarized for the periods corresponding to the field testing the tailrace.

1.6.3 Acoustic Telemetry

1.6.3.1 Receiver Array

Movements of tagged sturgeon at each location will be detected by an InnovaSea 69 kHz VR2W or VR2Tx acoustic receiver. Essex will install and maintain acoustic receivers at four locations downstream of Essex Dam: the I-495 Bridge in Lawrence, the Duck Bridge, the Route 28 Bridge, and the Lawrence Project tailrace (Figure 10-12). Receivers will either be installed in an upward facing manner using a multiple anchor deployment system (I-495 Bridge, Duck Bridge, and Route 28 Bridge) or in a downward facing manner on a fixed mount (Project tailrace). Receivers will be installed from mid-March through early November, as river conditions allow and data files will be offloaded from each receiver once monthly during the monitoring period.

In general, 69kHz receivers are not recommended for use in the immediate vicinity of hydroelectric projects due to increases in ambient noise levels as well as potential reflection of the signal off of hard surfaces. In a comparative study looking at detection range of 69 kHZ acoustic receivers in impoundment versus close proximity to a hydroelectric project, Babin et al. (2019) noted better performance of “high power” transmitters versus “low power” transmitters[1] and the hydropower site had generally lower detection ranges in comparison to the impoundment site, with an estimated 8%–95% decrease in detection probability at least partially attributable to the presence of the facility.

As outlined in the Phase 2 study plan for the Diadromous Fish Behavior, Movement and Project Interaction Study, Essex will also deploy an array of up to 25 JSATS (Juvenile Salmon Acoustic Telemetry System) acoustic receivers manufactured by Advanced Telemetry Systems (ATS) in the Merrimack River downstream of Essex Dam. This array

[1] High power tags are set by the manufacturer to output an acoustic signal which propagates farther underwater than low power tags.

will include detection locations at the I-495 Bridge in Lawrence, confluence with the Spicket River, the Duck Bridge, the Parker Street Bridge, and Route 28 Bridge. In addition, a grid deployment of ATS receivers in the powerhouse tailrace will provide detection information to estimate 2D positioning information for fish carrying JSATS transmitters during the Diadromous Fish Behavior, Movement and Project Interaction monitoring period from late-April through early July, 2025.

1.6.3.2 Tagging

Up to 45 sturgeon (15 adult Shortnose Sturgeon, 15 juvenile Shortnose Sturgeon, and 15 juvenile or subadult Atlantic Sturgeon) will be tagged in the Haverhill region of the Merrimack River during spring 2025. All gill net collections, handling, and tagging will be performed by staff from the U.S. Geological Survey's (USGS) Conte Lab who are in possession of an active handling permit for both sturgeon species in the Merrimack River. Essex will coordinate the purchase of acoustic transmitters. Adult Shortnose and juvenile or subadult Atlantic Sturgeon will be internally tagged with V16-69 kHz acoustic transmitters manufactured by Innovasea and programed to utilize the high power setting for the initial 730-day period with a transmission delay varying randomly between 30 and 90 seconds (mean 60 seconds) and a transmission delay varying randomly between 150 and 210 seconds (mean 180 seconds) for the remainder of the transmitter life after the first 730 days (estimated total tag life = 6 years). Juvenile Shortnose Sturgeon will be internally tagged with V13-69 kHz acoustic transmitters manufactured by Innovasea and programed to utilize the high power setting with a transmission delay varying randomly between 30 and 90 seconds (mean 60 seconds) (estimated total tag life = 344 days).

In addition to the V16-69 kHz transmitters, Essex will purchase 15 ATS model SS400 transmitters and provide to USGS to insert into adult Shortnose Sturgeon captured and tagged using the 69 kHz Innovasea transmitters during spring 2025. The SS400 transmitters produce a signal at a fixed interval (3.0 seconds for this study) by inducing high-frequency (416.7 kHz) vibrations in the water and are less prone to poor performance in the increased ambient noise levels associated with hydroelectric projects.

1.6.3.3 Data Analysis

Data collected from the 69 kHz Innovasea receivers installed downstream of Essex Dam will be downloaded in the field on a monthly basis. Data files will be combined and filtered for individual transmitter IDs released by USGS during the spring 2025 tagging effort or existing from previous USGS tagging efforts in the Merrimack River. Essex will coordinate with NMFS and the USGS to ensure all potential sturgeon transmitter IDs are considered during the data review. Detection data for sturgeon carrying 69 kHz transmitters will be summarized to define the seasonality and upstream extent of fish presence. Essex will report inflow, generation discharge, spill discharge, fish passage flows, and status of the crest gates (to the extent feasible) during any periods of residence for sturgeon in the receiver array.

Details related to the data processing and reporting for diadromous fish carrying JSATS transmitters and present in the reach downstream of Essex Dam are detailed in

Appendix A of the Diadromous Fish Behavior, Movement and Project Interaction Study filed as part of the Initial Study Report. Data collected from JSATS transmitters potentially carried by Shortnose Sturgeon into the acoustic array for this study will be processed and reported following those methodologies.

1.7 Schedule, Level of Effort, and Estimated Cost

The Sturgeon Distribution and Project Interaction Study will be initiated during spring 2025 and may continue in 2026, if warranted (Table 10-2). The mobile SSS surveys will be conducted approximately weekly from late March through early May 2025 (weather permitting). This field effort, including a day on the water for reconnaissance and testing of operations, will be approximately seven 12-hour days. Tentatively, in August or September 2025, a pilot study will be conducted to test the feasibility of a long-term deployment of a stationary imaging sonar in the tailrace for eight months during 2026. The number of field days at the powerhouse to prepare and conduct the pilot study will be approximately five days. Assuming the pilot study demonstrates feasibility, long-term sonar monitoring of sturgeon in the tailrace will begin mid-March 2026 and continue through early November 2026. The effort to set up and maintain the long-term sonar monitoring effort will be subject to the pilot study results and other site and environmental factors. Acoustic telemetry receivers (Innovasea 69 kHz) will be installed downstream of Essex Dam during mid-March and maintained through early November (as river conditions allow). USGS will be responsible for the collection and tagging of all sturgeon released as part of this study with that effort being initiated during late-April to early May 2025.

The cost in 2025 for the components of the Sturgeon Distribution and Project Interaction Study, as described in this updated Study Plan, is estimated at approximately $170,000 for the mobile SSS sturgeon surveys, $145,000 for the pilot study for sonar monitoring in the tailrace, and $110,000 for the telemetry, which sums to approximately $425,000. If the results of the pilot study demonstrate monitoring in the tailrace is feasible, then the cost for the long-term sonar monitoring in 2026 is estimated at approximately $500,000.

Table 1-2. Schedule[1] of the Sturgeon Distribution and Project Interaction Study

Study Component	Frequency (Approx.)	Period
Mobile SSS Surveys	Weekly (n=6)	31 March –9 May 2025
Fixed-location Sonar Monitoring in the Tailrace: Pilot Study (Phase 1)	5-6 days	August – September 2025
Fixed-location Sonar Monitoring in the Tailrace: Pilot Study (Phase 2)	Continuous	Mid-March – early November 2026 (to be determined based on Phase 1)

Study Component	Frequency (Approx.)	Period
Acoustic telemetry	Continuous	Mid-March – early November 2025

[1] Timing or frequency may be adjusted based on actual river flow conditions, ice cover, and inclement weather.

1.8 Discussion of Alternative Approaches

The proposed methods for this study are consistent with accepted professional practices. The overall approach is commonly used in relicensing proceedings and is consistent with generally accepted methods for, and analytical techniques used by, federal and state agencies. In addition, the proposed methods for the mobile SSS survey and telemetry are consistent with FERC study requirements under the ILP. However, an alternative approach was developed for long-term sonar monitoring in the tailrace to more effectively meet the objectives.

FERC recommended that Essex install a fixed SSS array in the tailrace to monitor, to the extent possible, the entire tailrace for sturgeon from spring through fall. This request was in part based on NMFS comments on the Proposed Study Plan which claimed that a fixed SSS array is a tested methodology suitable for the tailrace to quantify abundance and movement of sturgeon, citing a study by Izzo et al. 2021. However, the study by Izzo et al. 2021 and 2022 used a Dual-frequency Identification Sonar (DIDSON), along with telemetry, to continuously monitor for sturgeon for 30 to 40 days per season from early May to early June (as opposed to 8 months). In addition, the DIDSON was deployed in that study near the riverbank on the main stem of the river and not within a turbulent tailrace of a hydroelectric dam. FERC and the other agencies cited no other FERC relicensing studies that used or required a fixed-SSS array to monitor sturgeon in a tailrace. Based on literature searches and discussion with a SSS vendor, there were no examples to justify recommending the untested application of a fixed-SSS array to study sturgeon from spring through fall in the tailrace at the Project.

A fixed-location SSS array may not provide the desired imagery of the tailrace to detect and identify sturgeon to achieve the study's objectives. In a standard mobile survey application, SSS imagery used to identify the characteristic sturgeon body shapes and acoustic shadows are from compositing images from a narrow fan-like field of view and are taken every second or faster as the SSS array travels over the space being surveyed. The SSS imagery of sturgeon seen further downriver in Stantec (2023) was taken from a moving vessel and was constructed by stitching sequential georeferenced single transmissions that are each effectively 1 pixel high by many pixels wide in resolution. If the SSS array is in a fixed position, SSS imagery would need to be constructed from ping-based or time-based indices (not georeferenced) and would rely on sturgeon moving through the ensonified swath at a reasonable speed to make visualization of the body and shadow representative for sturgeon identification. In other words, a fixed-location SSS would repeatedly sample the same physical space defined by the swath angle and the narrow receiving beam angles. A characteristic body shape or shadow of a sturgeon may only be recognizable if the fish swims through the field of view at a certain speed. Too slow, it would appear elongated and exaggerated log-like object. Too fast, it would be a shorter reflection (a blip).

An eight-month deployment from March through November would require adequate planning and additional resources at a cost higher than estimated in the SPD. The equipment would be exposed to a meaningful risk of damage and loss due to ice, debris, and high flows. Such conditions necessitate a custom designed and fabricated metal mounting or rail system affixed to the concrete structure of the dam, which requires additional time and expense. The lack of detailed bathymetry, varying surface water elevation, and unknown effects from mechanical/electrical noise from powerhouse operations also introduce uncertainties that should be examined and tested prior to an investment in a potential long-term deployment of sonars.

Given that using a fixed-SSS array to monitor sturgeon distribution and behavior in a tailrace is inconsistent with generally accepted scientific practice, an alternative is proposed that would include a pilot study in 2025 to assess the site conditions and test performance of two sonar technologies more suitable for this task. Based on the information from the pilot study, the long-term deployment would take place in 2026 assuming its feasibility had been demonstrated by the pilot study. The anticipated outcome is to determine which sonar has better resolution, capabilities, and target detection, but another potential outcome may be discovering that minimal useful data can be collected from within the tailrace environment due to flow, entrained bubbles, or turbulence over an eight-month period.

Figure 1-1. Photo of the Edgetech 4125i 600/1600 kHz side-scan sonar (SSS) with cable and topside processor to be used in the mobile SSS survey.

Figure 1-2. Example of side-scan sonar (SSS) transects (yellow lines) for detecting the presence or absence of sturgeon between Essex Dam and the I-495 bridge.

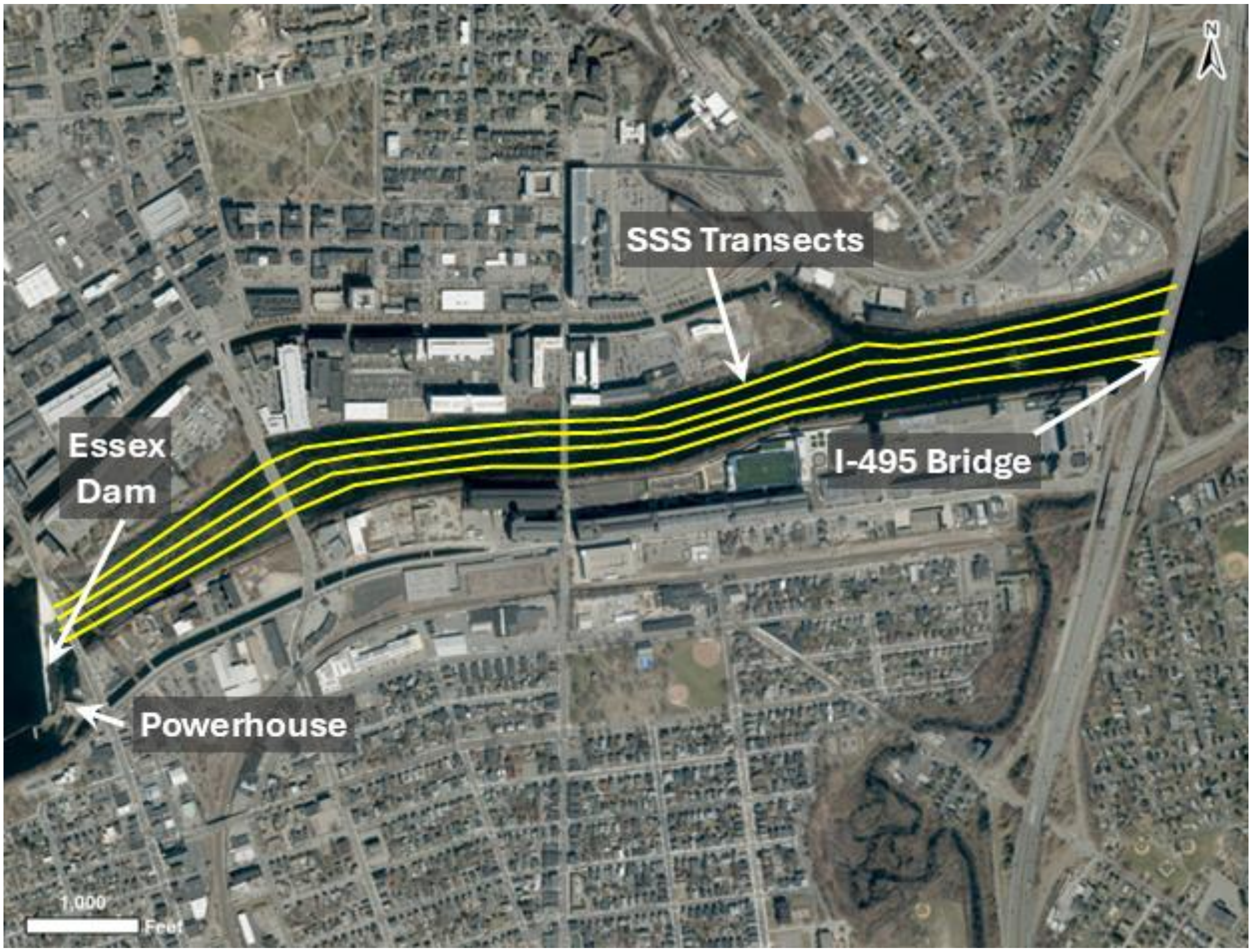


Figure 1-3. Examples of Edgetech SSS imagery of sturgeon in the Merrimack River near Haverhill, Massachusetts (image from Stantec 2023).

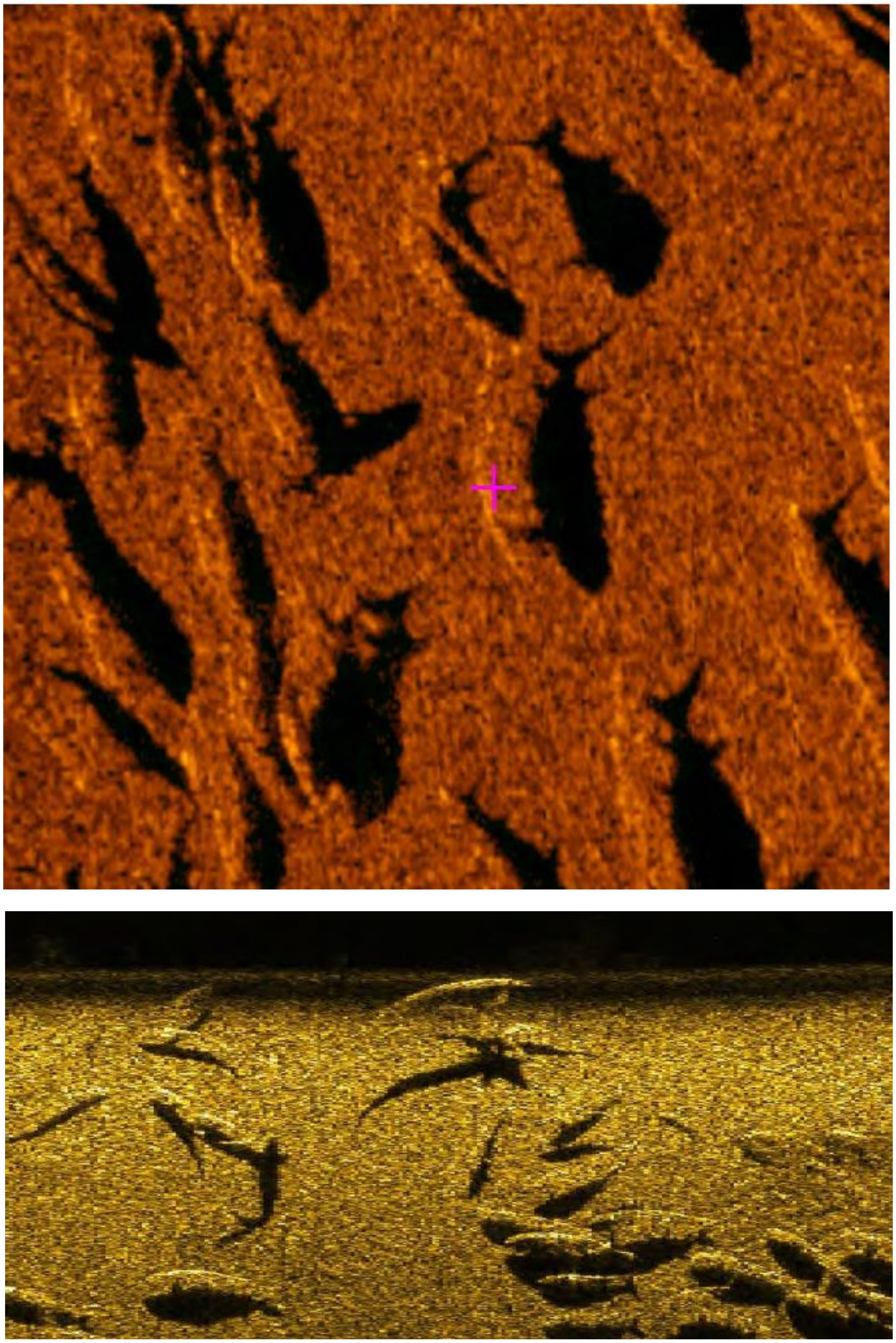


Figure 1-4. Example ARIS image showing a discarded tire.

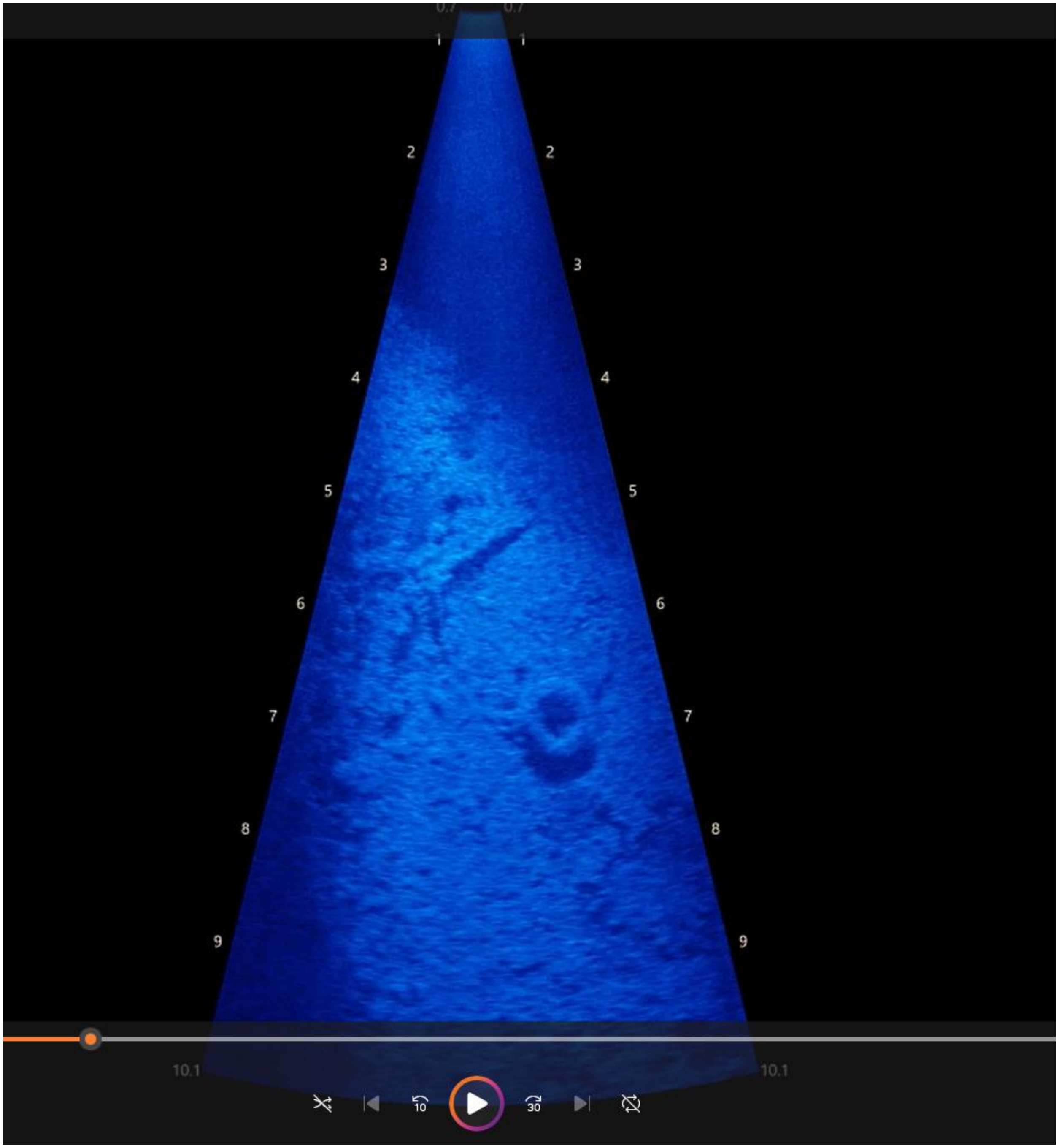


Figure 1-5. Example of a 1.8-MHz DIDSON image of Atlantic Sturgeon at (a) 120 cm in total length (TL) and (b) 140 cm TL.

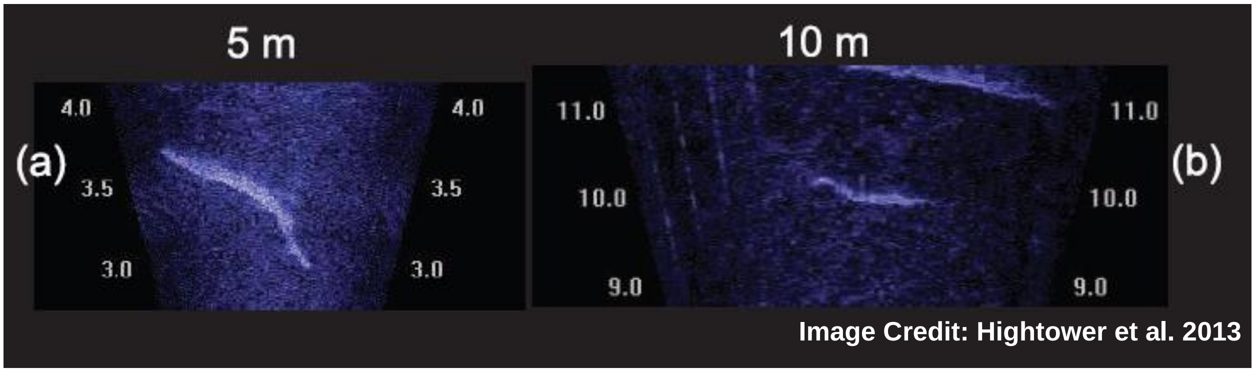


Image Credit: Hightower et al. 2013

Figure 1-6. Example of a DIDSON image of sturgeons.

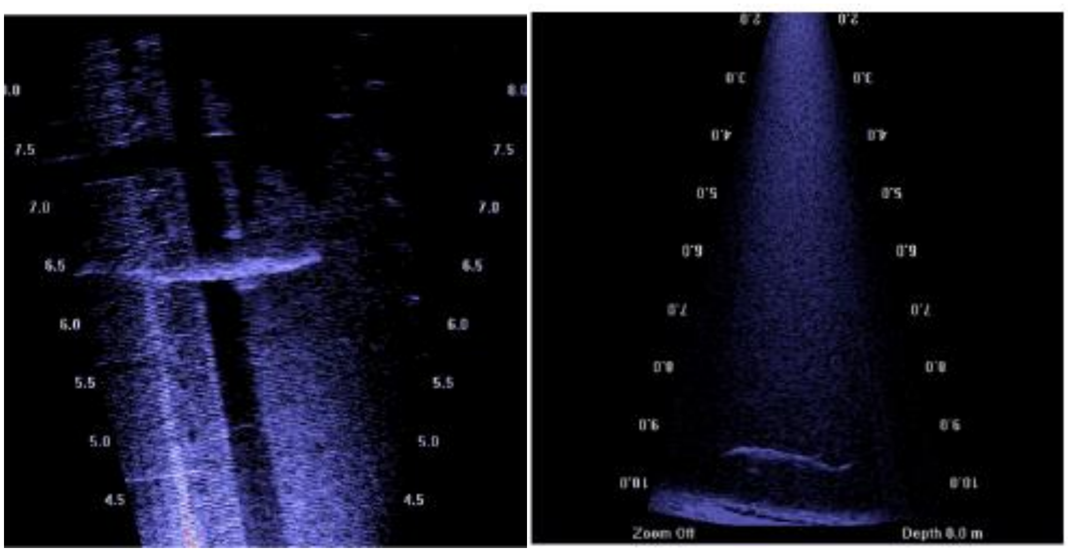


Image Credit: www.soundmetrics.com

Figure 1-7. Example of Teledyne Blueview M900-2250-130 2D Imaging Sonar of a sunken wooden barge.

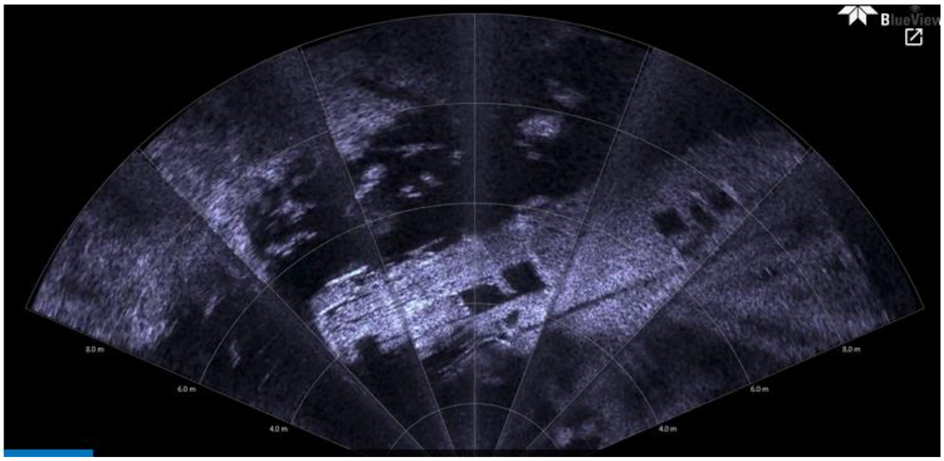


Image Credit: tritech.co.uk

Figure 1-8. Example image from a Tritech Gemini 720i Imaging Sonar of a 2.1-m lemon shark (*Negaprion brevirostris,* left) and a 1.5-m sandbar shark (*Carcharhinus plumbeus,* right).

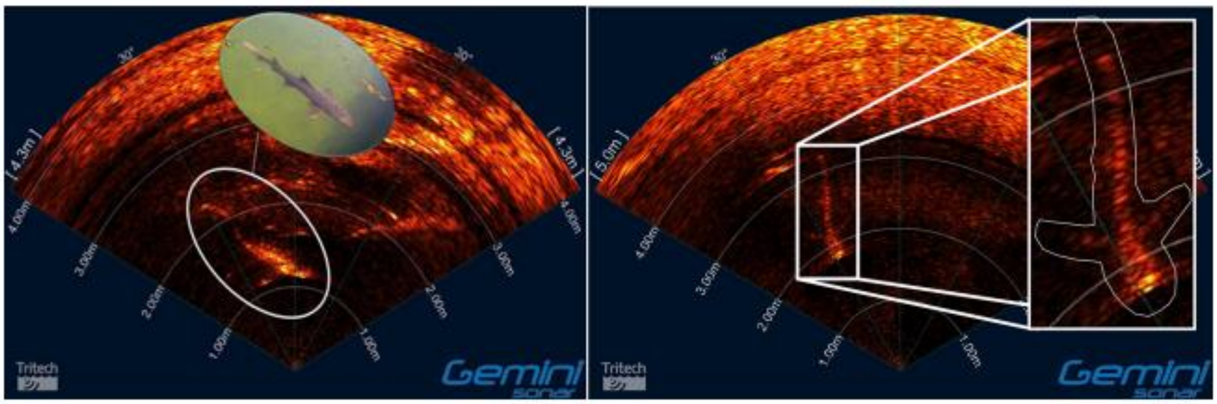


Image Credit: Parsons et al. 2017

Figure 1-9. Example image from a Blueprint Oculus M1200D Imaging Sonar of a diver (top) and school of fish (bottom).

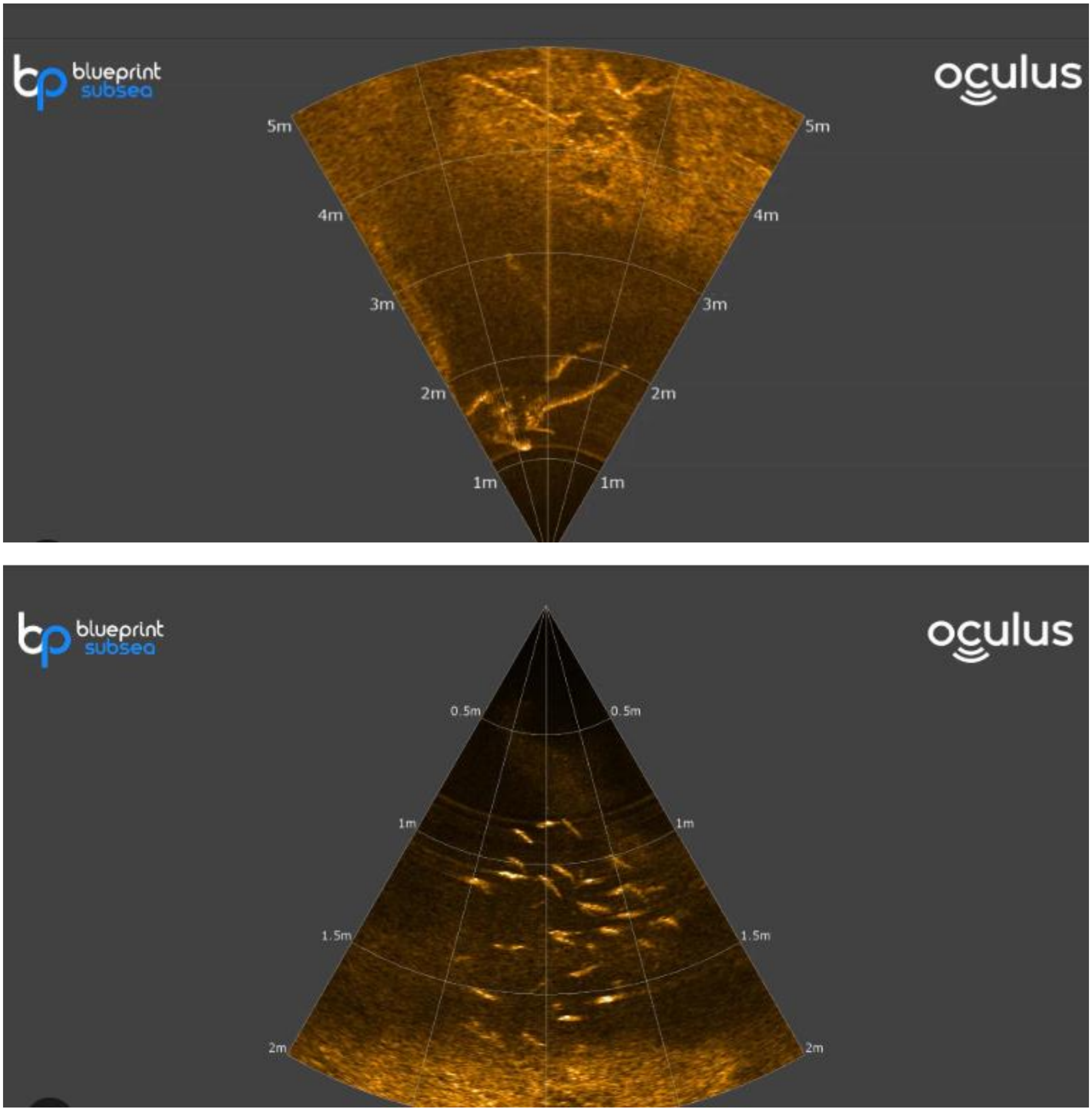


Image Credit: www.deeptrekker.com

Figure 1-10. Approximate map of the horizontal field of view for each sonar considered for long-term sonar monitoring in the tailrace at the Lawrence Hydroelectric Project. Blue outlines show examples of different pointing angles of the ARIS.

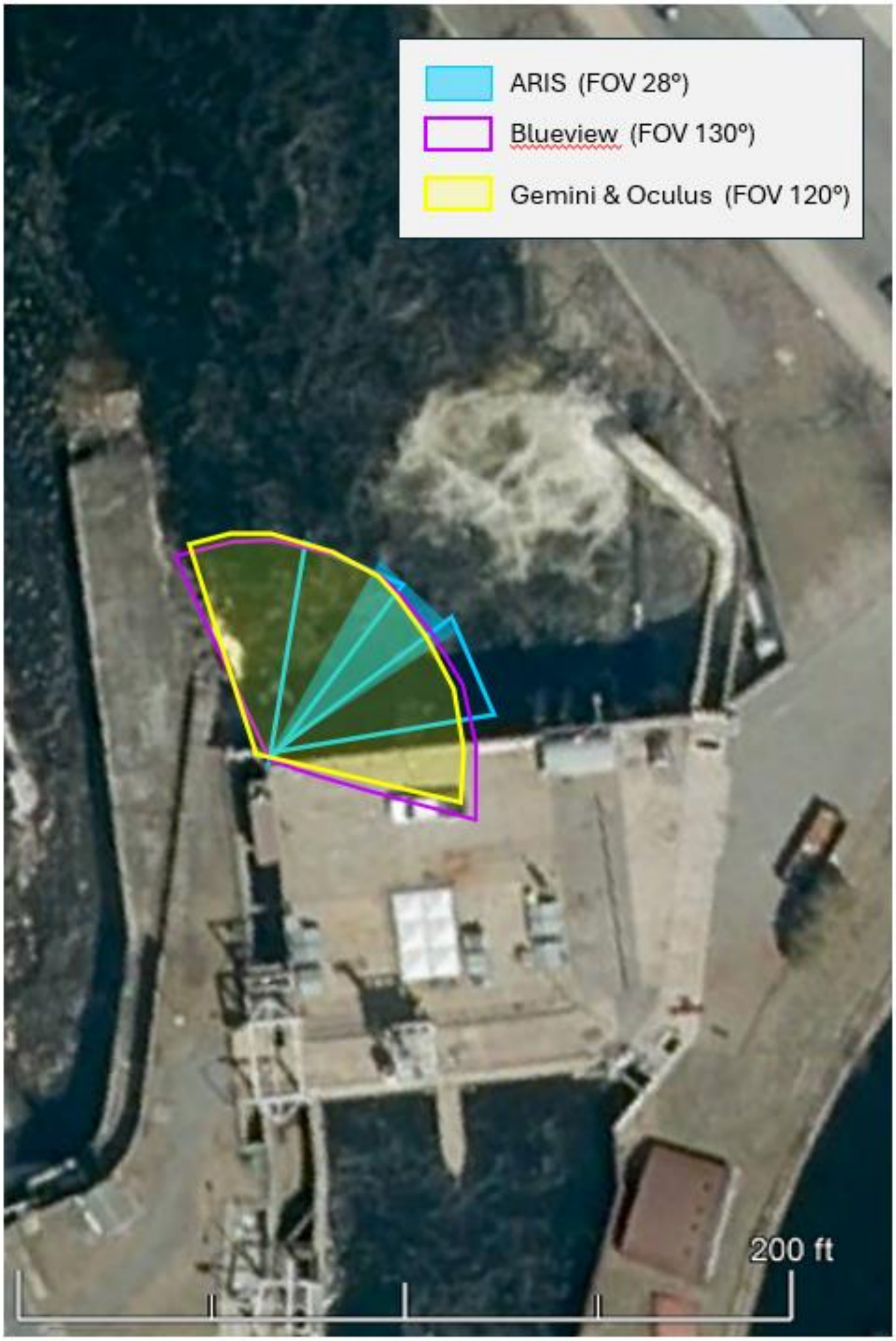
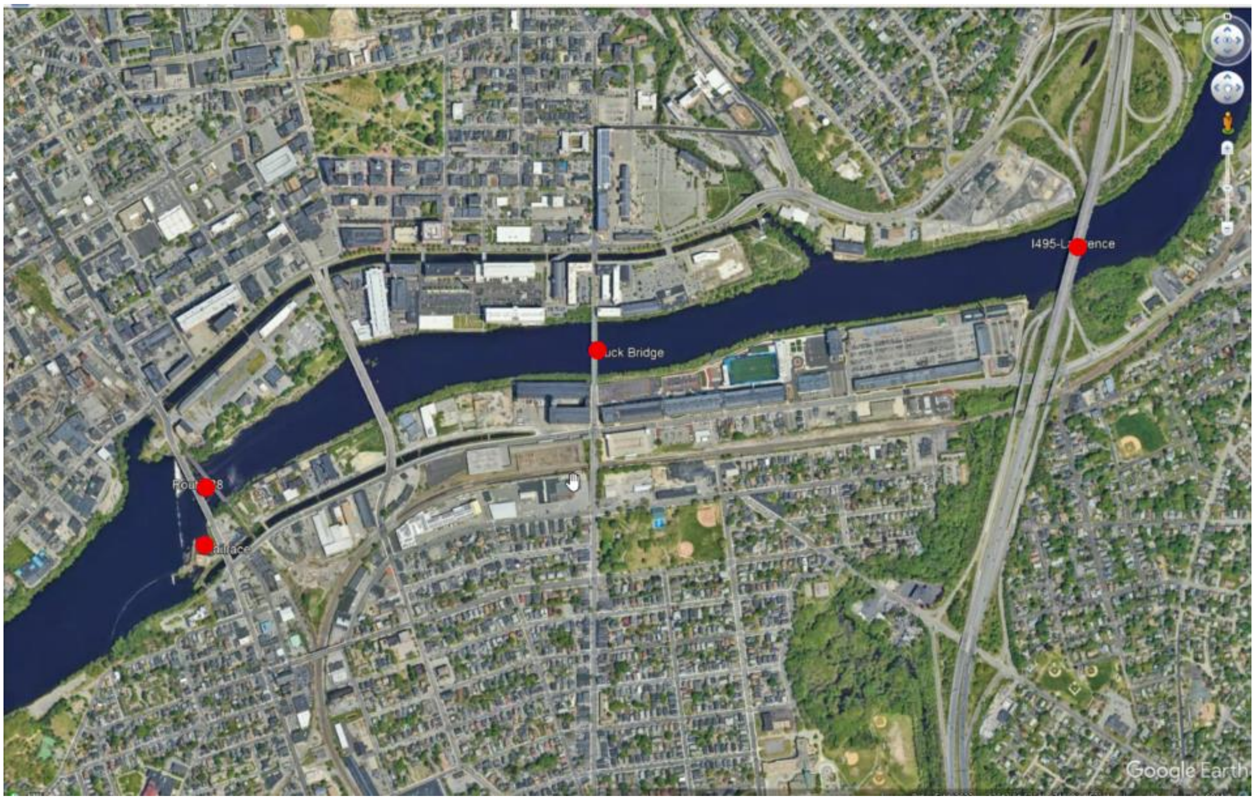


Figure 1-11. Examples of flow conditions within the tailrace at the Lawrence Hydroelectric Project.

Image Credit: Google Earth

Figure 1-12. Acoustic receiver (69 kHz) deployment locations downstream of the Essex Dam on the Merrimack River for monitoring tagged Shortnose and Atlantic Sturgeon.



1.9 References

Babin, A., L. Fitzpatrick, T. Linnansaari, and R.A. Curry. 2019. Detection range of acoustic receivers in a large hydropower reservoir. Fishes 4: 1-10.

Belcher, E., B. Matsuyama and G. Trimble. 2001. Object identification with acoustic lenses. MTS/IEEE OCEANS 2001. Honolulu, HI. November 5-8, 2001

Connolly, R.M., K.I. Jinks, A. Shand, M.D. Taylor, T.F. Gaston, A. Becker, and E.L. Jinks. 2023. Out of the shadows: automatic fish detection from acoustic cameras. Aquatic Ecology 57: 833-844.

Flowers, H. J., and J. E. Hightower. 2013. A novel approach to surveying sturgeon using side-scan sonar and occupancy modeling. Marine and Coastal Fisheries 5: 211-223.

Flowers, H. J., and J. E. Hightower. 2015. Estimating sturgeon abundance in the Carolinas using side-scan sonar. Marine and Coastal Fisheries 7: 1-19

Gurshin, C., Degan D., and Mueller, A.M. 2017. Assessment of Technologies to Study Downstream Migrating American Eel Approach and Behavior at Iroquois Dam and Beauharnois Power Canal. EPRI, Palo Alto, CA. 3002009406.

Haxton, T., J Gessner, T. Friedrich. 2024. A review of the assessment techniques used for population monitoring at different life stages of sturgeons. Environmental Reviews 32:91-113.

Izzo, L.K., G.B. Zydlewski, and D.L. Parrish. 2022. Combining fixed-location count data and movement data to estimate abundance of a lake sturgeon spawning run: a framework for riverine migratory species. Canadian Journal of Fisheries and Aquatic Sciences 79: 925-935

Kazyak, D.C., Flowers, A.M., Hostetter, N.J., Madsen, J.A., Breece, M., Higgs, A., Brown, L.M., Royle, J.A., and Fox, D.A. 2020. Integrating side-scan sonar and acoustic telemetry to estimate the annual spawning run size of Atlantic sturgeon in the Hudson River. Canadian Journal of Fisheries and Aquatic Sciences 77(6): 1038-1048.

Langkau, M. C., H. Balk, M. B. Schmidt and J. Borcherding. 2012. Can acoustic shadows identify fish species? A novel application of imaging sonar data. Fisheries Management and Ecology 19(4): 313-322.

Munnelly, R.T., J.C. Castillo, N.O. Handegard, M.E. Kimball, K.M. Boswell, and G. Rieucau. 2024. Applications and analytical approaches using imaging sonar for quantifying behavioural interactions among aquatic organisms and their environment. ICES Journal of Marine Science 81: 207-251.

Parsons, M.J., E. Fenny, K. Lucke, S. Osterrieder, G. Jenkins, B.J. Saunders, P. Jepp, I.M. Parnum. 2017. Imagining marine fauna with a Tritech Gemini 720i Sonar. Acoustics Australia 45: 41-49.

Stantec. 2023. Merrimack River Shortnose Sturgeon Monitoring, 2020-2022. Prepared for the Massachusetts Department of Transportation.