Memo to Public Files

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From: Kenneth Hogan
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Haro, A., D. Degan, J. Horne, B. Kulik, and J. Boubee. 1999. An Investigation of the Feasibility of Employing Hydroacoustic Monitoring as a Means of Detecting the Presence and Movement of Large, Adult Eel (Genus Anguilla). Internal Report No. 99-01. Conte Anadromous Fish Research Center. Turners Falls, Massachusetts.

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MADISON, MAINE

ABENAKI PROJECT, FERC NO. 2364
ANSON PROJECT, FERC NO. 2365

INTERIM AMERICAN EEL DOWNSTREAM PASSAGE

2005 PILOT STUDY REPORT

January 2006

Prepared by:

Kleinschmidt
Energy & Water Resource Consultants

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AMERICAN EEL DOWNSTREAM PASSAGE

2005 PILOT STUDY REPORT

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EXECUTIVE SUMMARY

The Anson and Abenaki Projects are located on the Kennebec River in central Maine. As part of the new licenses issued by the Federal Energy Regulatory Commission (FERC) for both projects in 2003, MPI is to develop and implement passage and protection measures for outmigrating silver phase American eel (*Anguilla rostrata*). In consultation with natural resource agencies and non-governmental organizations (NGO's) that were part of the Settlement Agreement developed during relicensing, MPI developed a plan to investigate the feasibility of utilizing hydroacoustic technologies to monitor the timing of downstream eel migration. A prototype hydroacoustic system was designed, installed, and tested during August - October of 2005 to detect outmigrating silver American eel (eel) passing the Anson Hydroelectric Project. Specific objectives of this study were to:

1. Empirically verify that eel could be detected by the hydroacoustic system;
2. Experiment with transducer locations and arrays to determine a suitable sampling scenario;
3. Develop specifications and recommendations for deployment of an interim hydroacoustic monitoring system in 2006;
4. Develop methods to recognize echogram and acoustic image patterns of outmigrating eel and other non-target species (*e.g.*, smallmouth bass, chain pickerel);
5. Develop recommendations for turbine and wastegate operational protocols during future eel outmigration periods.

Two different sonar technologies were evaluated: split-beam (in two locations), and a single DIDSON (Dual-Frequency Identification Sonar). Both technologies were installed in the Anson canal and tested during the pilot study

In an initial test, live yellow-phase eel, silver-phase eel, and other non-eel species were tethered and drifted through the acoustic fields to determine the distance from the transducer at which eel could be detected and distinguished from non-eel targets. On DIDSON images, large eel (> 900 mm) could be detected and identified out to a maximum range of approximately 20 meters. Sub-adult eel (< 700 mm) could be detected and identified to a maximum range of 15

meters. The two most important features that allowed confident identification of eel were object shape and serpentine swimming motion. With the split-beam system it was possible to detect eel out to the maximum range sampled (27 m). The features used for positive split-beam identification of eel were more subtle and sometimes more ambiguous than the features used in DIDSON identification. Split-beam characteristics of eel echo traces included a sawtooth pattern of the echo trace and varying echo width.

During the core period of this study (September 19th – October 4th), the natural eel migration in the Kennebec River was monitored with two split-beam systems and one DIDSON. The three acoustic systems sampled simultaneously and covered partially overlapping sample areas. The results from the DIDSON, which sampled the water column from the surface to the bottom, and the bottom-mounted split-beam system, were in good agreement. Both identified well over 200 eel. Based on the results from a system cross-check done to validate the data, the surface-mounted split-beam appeared to have missed a substantial number of eel, partly because of poor echo traces. Analysis of the surface split-beam data was further complicated by a higher proportion of debris and surface noise. Eel did not appear to show a pronounced preference for a particular position in the water column. Most passed downstream during the first two hours after sunset, and the last hour prior to sunrise. Major eel outmigration events appeared to be clustered around a few nights. With approval from the consulting agencies, the monitoring period was curtailed ahead of schedule due to unusually high river flows from heavy rains.

We conclude that both the bottom-mounted split-beam and the DIDSON system allowed consistent identification of eel. Both systems provided a sufficiently large sample size for determining general run-timing and diurnal patterns in the migration of silver eel. The main difference between the two systems was the type of features used for eel identification. Based on feedback from experts in the field of target tracking and classification, we conclude that the type of information provided by the DIDSON data, most notably shape and swimming motion, make it the better candidate for the development of an automated eel-monitoring system, especially when differentiation between eel and debris is a concern, as is the case in the Anson intake canal. DIDSON images also have the advantage that their interpretation is more intuitive as compared to the interpretation of split-beam echograms (which require considerable experience) and quality control is therefore easier.

We recommend that the automated eel-monitoring system should be developed using a DIDSON system. However, we also recommend that one split-beam system be used for one year to supplement the data generated by the DIDSON. This will provide a second year of information on the vertical distribution, independent counts for comparison, and serve as a relatively low-cost insurance policy against accidental DIDSON failure or data loss. Both the DIDSON and the split-beam system should be deployed from the Anson bank to allow easy access.

1.0 INTRODUCTION

On July 25, 2003, the Federal Energy Regulatory Committee (FERC) issued a 50-year license for the Anson Project (104 FERC ¶ 62,060), one of two adjacent projects on the Kennebec River owned and operated by Madison Paper Industries (MPI). MPI, federal, state, and local agencies, as well as non-governmental organizations and members of the public, formed an Applicant Prepared Environmental Assessment Team (Team) to prepare license applications for the Anson and Abenaki Projects. Preliminary plans for fish passage for eel and other species were developed as part of the Team's deliberations.

Article 405 (A) of the FERC license for the Anson Project requires the installation of interim downstream passage facilities for adult silver-phase eel within two years of the effective date of the license (May 1, 2004). The complete text of Article 405, which identifies other requirements for fish passage at the project, is contained in Appendix B. After extensive agency and stakeholder consultation, MPI filed a Study Plan and Implementation Schedule (Plan) pursuant on November 29, 2004, proposing a hydroacoustic monitoring system for detection of downstream migrating adult silver-phase eel approaching the Anson powerhouse as a means to ensure downstream eel passage past the project. The Plan was prepared in consultation with the U.S. Fish and Wildlife Service (USFWS), the Maine Department of Marine Resources (MDMR), and other involved parties, and was approved by FERC on March 15, 2005 (110 FERC ¶ 62,256).

The system proposed by MPI in the Plan included two hydroacoustic transducers coupled to a wireless computer network to provide real-time data to identify the site-specific timing, relative magnitude, and environmental conditions associated with adult silver-phase eel migration in the vicinity of the Anson Project. In its final form, a signal would be received by the powerhouse when a pre-determined number (to be determined in consultation with fishery agencies) of downstream migrating eel targets is reached. The operator would then take action (*e.g.,* alter generation, open wastegates adjacent to the powerhouse) until acoustic monitoring shows an appropriate reduction in number of eel targets (to be determined in consultation with fishery agencies). Additionally, because relatively little is currently known about the migratory behavior of eel in central Maine, a secondary goal of the proposed hydroacoustic system is to provide cumulative downstream eel movement data for use by fishery agencies.

In accordance with the Plan, a prototype hydroacoustic system was designed, installed, and tested from August to October of 2005. The purpose of this report is to document the results of the prototype tests. Testing was conducted in consultation with the fishery agencies to develop a protocol for the implementation of the proposed interim measures for eel passage. The specific objectives of the work conducted in 2005 were to:

1. empirically verify that eel could be detected by the hydroacoustic system,
2. experiment with transducer locations and arrays to determine a suitable sampling scenario;
3. develop specifications and recommendations for the deployment of an interim hydroacoustic monitoring system for 2006;
4. develop methods to recognize echogram and acoustic image patterns of outmigrating eel and other non-target species (*e.g.*, smallmouth bass, chain pickerel);
5. develop recommendations for turbine and wastegate operational protocols during future eel outmigration periods.

According to the license issued by FERC for the project, if interim downstream passage is shown to be at least 80 percent effective, additional measures would not be required for the development of permanent downstream passage facilities for eel.[1] If effectiveness testing indicates that the target thresholds are being met, the hydroacoustic system would operate seasonally between August and November unless testing and agency consultation (required by Article 406 – see Appendix B) indicates another period of operation is justified. Data from this system would be used to define the timing of the outmigration trigger for seasonal implementation of potential passage protection measures, such as the modification of turbine operation, rack overlays, or the development of other methods that may be available in the future.

[1] The effectiveness target for a permanent downstream fish passage was set at 90 percent.

It is anticipated that final hydroacoustic system specifications, based on 2005 proof-of-concept study recommendations, would be fully operational by August 2006. Operational protocols would be filed for Commission approval after formal consultation with the fishery agencies no less than 90 days prior to commencement of operation of the hydroacoustic system. The final system would utilize downstream eel movement data as a trigger for initiating downstream passage measures (*e.g.*, temporary modification of turbine operations, or intake rack overlays combined with opening of a wastegate or spillage).

1.1 Project Description

The Anson Project impoundment encompasses approximately seven miles of the Kennebec River and one-half mile of the Carrabassett River, a major tributary that drains parts of Maine’s western mountains. The Anson dam spans the Kennebec River immediately downstream of the Route 148/201A bridge between the towns of Anson and Madison. The Abenaki Project (FERC No. 2364) is located approximately one-half mile downstream of the Anson Project. Both projects are located in central Maine (Figure 1).

The Anson Project consists of the following principal features: (a) a 630-ft. long concrete gravity dam with three spillway sections that are regulated by a 5.6-ft. high inflatable flashboard system; (b) a 40-ft. wide by 13.5-ft. high inflatable wastegate system; (c) a 250-ft long forebay and trashrack section; (d) a 190-ft. long by 54-ft. wide powerhouse containing five turbine/generator units with a total installed capacity of nine megawatts (MW) and a hydraulic capacity of 6,000 cfs; (e) a reservoir with a surface area of approximately 698 acres and a gross storage capacity of 5,860 acre-feet at a normal pool elevation of 248.15 feet; and (f) appurtenant facilities. The Anson Project has a permanent crest elevation of 242.62 feet. The generating units of the Anson Project are controlled automatically by headpond level sensors. The project turbines have a minimum and maximum hydraulic capacity of 400 and 1,200 cfs.

Operation of the Anson Project does not vary substantially during low, mean, and high water years because the project operates as a run-of-river facility. Seasonal and year-to-year variations in river flows are controlled through upstream storage in the Kennebec watershed at the Flagstaff, Brassua, and Moosehead Projects, which are operated by other licensed hydroelectric corporations. Daily upstream peaking operations are again re-regulated at the Williams Project, which is approximately 10 miles upstream of the Anson Project, so that inflows to the project area are relatively steady. Additionally, MPI operates the Anson Project to minimize the fluctuation of the reservoir surface elevation by maintaining a discharge from the project so that flows immediately below the dam approximate the sum of inflows into the project reservoir.

1.2 Hydroacoustic System Description

Two sonar technologies were evaluated: split-beam and DIDSON (Dual-Frequency Identification Sonar). Split-beam sonar uses one beam divided into four quadrants (left/right, up/down). The small delay between the time when the echo is being received on each quadrant is used, together with range, to determine the position of the target in 3-dimensional space. The returned signals are typically displayed in echograms, which graph echoes over range and time. Split-beam technology was first developed in 1996 (Ehrenberg and Torkelson, 1996) and has been used for a wide variety of fisheries applications, including monitoring in-river escapement of adult salmon, fish stock assessments in lakes, and entrainment studies at hydroelectric projects (Enzenhofer et al., 1998; Mueller and Degan, 2004; Degan and Wilson, 1995; Nestler et al., 1997). The information contained in split-beam data holds indirect clues to the shape and size of the target but, depending on the mix of species present, species identification can be difficult. However, Haro *et al.* (1999) found split-beam sonar to be a useful tool for assessing the spatial and temporal patterns of large (>70 cm) eel in hydroelectric forebays because silver eel provide a readily detectable and relatively distinct echo pattern.

DIDSON is a more recently developed technology, initially developed for the U.S. Space and Naval Warfare Systems Center for harbor surveillance (Belcher et al., 2001; Belcher et al., 2002). Unlike split-beam, DIDSON is an imaging type sonar, which means that it provides video-like images with two spatial dimensions. The images are similar to ultrasound images used in the medical field and are more intuitive to interpret than split-beam echograms. The DIDSON can be operated in two different frequency modes: a high-frequency (1.8 MHz) mode uses an array of 96 beams, each 0.3° wide horizontally and 12° vertically, and a low-frequency mode (1.1 MHz), which uses 48 beams, each 0.6° wide horizontally and 12° vertically. In both frequencies, the total array spans a swath of 30°, which, at 10 m range, is equivalent to a 5 m cross-range coverage or approximately five times as wide as the 6° and 8° split-beams used in this study. The trade-off between the two DIDSON frequencies is resolution versus maximum range. The higher frequency provides higher resolution and more detailed images, but because high-frequency sound is absorbed more readily, it is limited by range. The lower frequency, on the other hand, can sample up to 42 m, but provides a much coarser image. DIDSON systems are increasingly being introduced into fisheries applications (Maxwell *et al.*, 2004; Tiffan *et al.,* 2004), primarily because the images provide information on the shape of the target, and thus generally better identification.

We used both split-beam and DIDSON systems to evaluate the relative trade-offs between these two types of technology for this specific application. We anticipated the DIDSON to have its primary advantages in the intuitive identification of eel and possibly the size of the area sampled, while the split-beam would be able to provide information on the vertical distribution of eel (important for locating a suitable sampling area), be less limited by range, and require considerably less data storage capacity.

A second goal was to assess eel behavior as it pertains to sampling; in particular, the distribution of eel in the water column. A pronounced preference for swimming close to the water surface, for example, would mean that sampling should be concentrated there. Also, evidence of milling behavior or evidence of a high percentage of eel moving upstream through the acoustic fields would indicate that the selected sampling area is not suitable for detecting downstream migrating eel.

1.3 Definitions

The following terms are used throughout the report:

- **Detection**: A target is detected when its trace can be seen on an echogram or DIDSON image. The target's identity (*e.g.*, eel, debris, fish other than eel) may be unknown.
- **Identification (**or **Classification)**: The terms identification and classification are used synonymously. A detected target is identified (classified) when its trace is perceived to have enough features that allow a reasonable determination of the target's identity (*e.g.*, eel, debris, fish other than eel). For a given target, the identification (classification) may be incorrect. An assessment of the identification (classification) accuracy is part of this study.
- **Count**: Count refers to the number of targets identified as eel with a given acoustic system within a given time period. It does not imply a complete count of all eel that passed.

2.0 METHODS

2.1 Equipment Installation and Operation

Three acoustic systems were installed approximately 100 m upstream of the project's intakes. One split-beam (BioSonics DTX 6000) and one DIDSON system were mounted on the right side of the river (facing downstream) and aimed towards the pier on the opposite side; a second split-beam (Simrad EK 60) was mounted on a pier on the left side of the river and aimed towards the right bank (Figure 2.). Equipment configurations and periods of deployment are listed in Table 1. Due to the high lease cost, DIDSON deployment was limited to an initial test in August and the core period of the study, September 19th – October 4th. Data were collected nightly from 17:30 to 8:00 the following morning to include both night and twilight hours.

The installation of the surface transducer mounts on the side walls of the intake canal (Photo 1) required boat access. The installation of the bottom transducer required divers. Transducer pitch angles were selected based on surveyed canal cross-section geometry and estimated effective beam width. The pitch angles of the split-beam transducers were empirically verified on September 19th and 20th through an analysis of observed split-beam angles of a target suspended at known depth and range. A wooden box was installed on each side of the river to protect the streamside equipment (power supply, sounder, network components) from inclement weather and theft.

During high river flows at the end of August, the wet-end connector of the BioSonics transducer cable started to leak. Data collection was interrupted from September 2nd until September 8th, when the flow had subsided enough for divers to replace the damaged cable and transducer. BioSonics data collection was further interrupted on August 30th, due to an object blocking the beam, and on September 13th and 14th, due to intermittent equipment failure.

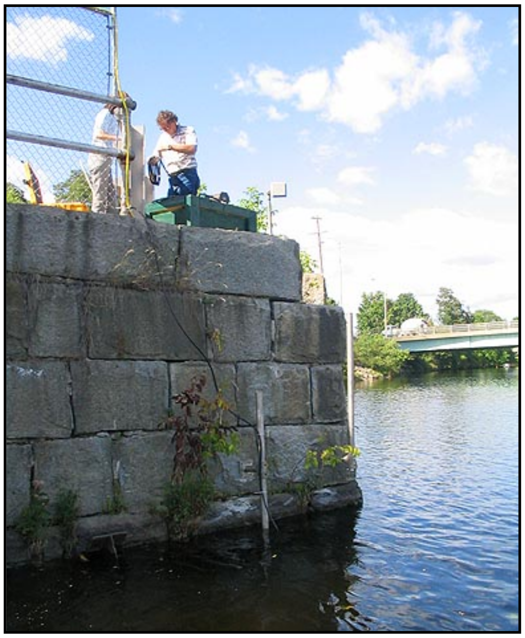

Photo 1. Hydroacoustic transducer mounts, power supply, sounder, and computer network component installation at the Anson Project, Madison, ME.

Data acquisition programs for both split-beam systems were operated by a single PC in the powerhouse, linked through wireless networks to the two echosounders. The DIDSON software was initially run on a laptop computer housed in the stream-side box, but was later transferred to a data acquisition PC in the powerhouse. A wired network linked the PC to the stream-side DIDSON equipment. In addition to the three separate networks for the acoustic systems, the powerhouse PC was also equipped with a cable modem to provide high-speed internet access for remote control and data access (Photo 2.).

Data collection parameters for the BioSonics split-beam system were set to –70dB threshold, 0.200 milliseconds (msec) pulse length, 13 pings per second (pps) ping rate, and a maximum range of 31 m for the surface aim and 27 m for the bottom aim. The Simrad split-beam system was set to 0.256 msec pulse length, 10 pps ping rate, and a maximum range of 33 m. Simrad data acquisition recorded data without threshold, down to the noise floor. The ping rate of both split-beams was limited by reverberation. Several data collection parameters were tested for the DIDSON system to optimize the images for eel detection and identification (Table 2.).

Photo 2. A laptop computer, wireless link, and remote internet system in the Anson powerhouse allowed for local and/or remote operation and monitoring of the hydroacoustic system.

2.2 Analysis of Acoustic Data

DIDSON files were reviewed by scrolling through an echogram-type view of the data and visually identifying potential eel traces based on intensity and shape. Potential eel traces were then further examined in video image mode, which provided information on the physical shape of the object and its type of motion. The date, time, range, and score (based on its echo intensity, shape, and motion) for each identified eel were recorded.

Split-beam data were analyzed with SonarData EchoView® 3.40.47 software. Data were visually examined on synchronized target strength and angle echograms; echo traces identified as eel were tracked with an α,-β-tracking algorithm (Blackman and Popoli 1999) and manually edited (fragments merged, extraneous echoes deleted) where necessary. Fields recorded in the track database included date, time, range, mean target strength, split-beam-x, and –y position, split-beam-α, and -β angles, and direction of movement. Split-beam angular and Cartesian target position was later used to transform positions into river-based coordinates (distance from shore, depth); for the Simrad system an additional rotation was introduced to compensate for the 28° roll angle of the transducer. Target positions in river-based coordinates were examined for the spatial distribution of detected eel.

To minimize the potential for data interpretation bias, core period DIDSON and split-beam data were independently analyzed by different individuals without exchange of information. The counts produced by this initial analysis are referred to as "before system cross-check." Where the beams of two acoustic systems overlapped, individual tracks were matched in a database operation linking records by time and range, with a +/- 30-second margin for time, and +/- 5 meter margin for the range expected for the given geometry of the different systems. After this initial comparison, the data were more thoroughly reviewed by checking each track in the overlapping areas that had not been matched. Where eel tracks were detected on closer inspection, counts were added. These revised counts are referred to as "after system cross-check."

2.3 Tethered Fish Experiments

Tethered fish experiments were performed to determine the spatial detection limits of the hydroacoustic array under various transducer positions. As well, the tethered fish tests were used to detect the distance from the transducers that an eel image could be detected and to test the ability to discriminate between eel and non-eel targets under somewhat controlled conditions. System tests were conducted during the period August 22 to August 25 (Phase 1), and on September 19, 2005 (Phase 2; silver eel only).

Fish were tethered to a monofilament line deployed from a stationary 16-ft. flat-bottomed boat that was moored to a Kevlar tagline strung across the canal. The boat position could be modified, but was positioned facing upstream with the stern resting slightly within or just upstream of the hydroacoustic fields. Each fish was drifted downstream into the hydroacoustic fields, and allowed to swim in position for a period of one to several minutes, or until the fish had become physically exhausted (Photo 3.). Species, lifestage, and total length were recorded for each specimen (Table 3.). Most test specimens were subsequently released into the impoundment individually or in groups to provide supplemental imagery of free-swimming fish. During the second phase of testing (September 19), only images from adult silver-phase eel were collected.

Photo 3. View of a tethered American eel being drifted into position in the hydroacoustic fields.

During Phase 1, American eel and all non-eel targets were collected at night from the Kennebec River using a boat-rigged, pulsed-DC Smith-Root GPP 5.0 boat electrofishing unit. All stunned fish were collected with dip nets with ¼-inch mesh bags and deposited in a live-well filled with aerated ambient water for transport to the study site. Fish were then transferred to one of two 150-gallon plastic tubs with pump-circulated ambient river water. Species tethered included five live eel (total length 450 – 679 mm) and nine individuals representing six other species (largemouth and smallmouth bass, white sucker, chain pickerel, yellow perch and black crappie; total length 200 – 450 mm). Eighteen additional eel were released in to the beam without tethering (Table 3.).

During Phase 2, sixteen adult silver-phase eel of the size class expected during fall migration (approximately 1 m) were obtained from a commercial distributor and transported alive to the project in an aerated 150-gallon plastic tub. All fish were initially held overnight in the same holding system (as described above) to allow for recovery from transport. Tubs were covered with wooden lids and tarpaulins to prevent escape and predation. All eel were held in mesh nylon laundry bags secured with cable ties within the tubs to further prevent escape. Two adult silver-phased eel, both measuring 934 mm, were tethered as before, which allowed for the collection of imagery on adult eel using both hydroacoustic systems. All eel were subsequently released upstream of the hydroacoustic system by gently submerging an opened mesh bag, which allowed eel to freely swim away with minimal handling. Six eel were released in the period from 19:55 – 20:00, approximately 30 m upstream of transducers in mid-channel; five in the period from 20:11 – 20:15, approximately 90-m upstream; and five in the period from 20:25 – 20:29; further upstream, immediately upstream of the highway bridge (approximately 120 m upstream from the transducers).

2.4 Time-Lapse Surveillance Camera

A weatherproof infrared night vision video camera was installed above the entrance of the 5 ft. X 5 ft. sluice gate located adjacent to the project's skimmer wall in an effort to record video imagery of eel to verify results from the hydroacoustic data. The camera was equipped with a timer that allowed recording to begin automatically from 1830 to 0630 on a nightly basis. The system was also wired to a video time-lapse recorder that allowed for footage to be recorded at a higher frequency. All tapes were reviewed upon completion of the evening's video sampling. Six nights of imagery were recorded during the period October 3rd to October 8th.

2.5 Environmental Data

Information describing the climatic and hydrologic conditions during the study period was gathered from real-time monitoring data at the Anson Project powerhouse and from the Mercer Weather Station, (http://www.wunderground.com/), a weather monitoring station that is located within approximately ten miles of the study site. Meteorologic information for Mercer is collected using Davis Weather Monitor II software, and the information is updated daily. Weather data from the Mercer Weather Station was compared to archived data for Portland, Maine, as recorded by the National Oceanic and Atmospheric Administration to evaluate for accuracy and precision for the study period. Variables recorded included river flow and temperature, air temperature, precipitation, cloud cover, and moon phase. Environmental data were used to correlate these environmental conditions with eel migration events.

3.0 RESULTS

3.1 Tethered Fish Experiments and Eel Release

An initial test with an 800 mm (TL) dead eel provided good-quality DIDSON images that showed the eel's shape and details of the boat bottom and outboard motor (Figure 3.). On September 19th, two tethered silver eel (each with a total length of 934 mm) were confidently identified in low-frequency mode to approximately 20 m range (Figure 4., Video 1, Video 2). Given the shallow aim (-2°), there was little to no bottom interference and the eel trace showed up well above the dark image background.

The five specimens of live sub-adult eel (total lengths of 450 – 679 mm) were easily recognized on the DIDSON images over a 10-m range interval out to a maximum range of 15 m (Figure 5.). Images in the high-frequency mode show distinct anguilliform swimming motion (*i.e.*, flexing most of the body), which is characteristic for eel (Video 3). However, it became increasingly difficult to identify or even detect sub-adult eel at ranges greater than 15 m.

Seventeen of the 18 free-swimming eel released on August 23rd, were detected by the DIDSON. Thirteen of the 17 detected targets were clearly recognized as eel. The identification of four of the detected targets was ambiguous. Examples are shown in Figure 6, Video 4. Nine of these released eel disappeared from view before reaching the downstream end of the DIDSON beam array.

Non-target species (largemouth and smallmouth bass, yellow perch, chain pickerel, white sucker and black crappie) could be distinguished from eel, especially silver eel, based on the shorter body length and carangiform swimming behavior (*i.e.*, flexing only the tail region). An example for a 450 mm largemouth bass is shown in Video 5. The image of the chain pickerel, an elongated species superficially resembling a small eel, could have been confused for a small eel; however, it does not resemble an eel in swimming form and body motion.

On the BioSonics split-beam echogram, the echo traces of tethered live eel often showed a sawtooth pattern and wide and variable echo width characteristic of large fish with complex body shape and flexing body (Figure 7.). Echo traces were easily detected out to 27 m, the maximum range sampled (Figure 8.).

Six out of the 18 eel released August 23rd were detected by the BioSonics transducer. Although these fish were detected in the beam, none of the traces were long enough to allow confident eel identification; some of the eel traces were potentially masked by air bubbles introduced with the net (Figure 9.). Non-target fish species created echo traces that generally appeared smoother (no sawtooth pattern) and slightly narrower; however, differences were often subtle. An example of a 400 mm white sucker is shown in Figure 10.

Tethered eel traces recorded on the Simrad split-beam system (in place only during the tethering experiment conducted on September 19th) also showed sawtooth patterns and wide and variable echo width, especially when compared to debris tracks (Figure 11).

3.1.1 Identification of Free-Swimming Eel

DIDSON images allowed intuitive and confident identification of eel over a range interval of 5 – 20 m. Three features were key to the positive identification of eel and the discrimination of eel from debris, and in some cases fish other than eel:

1) physical shape of the object;
2) type of swimming motion; and
3) echo intensity.

Confidence in correct eel identification was highest under the following conditions: data collected in high-frequency mode, eel approximately 80 cm or larger (as measured on the image), passing at a distance between 5 and 16 m away from the transducer, and over a dark background (*i.e.*, where sound is not reflected off the bottom) (Figure 12., Figure 13; Video 6, Video 7). Identification was made more difficult by the following factors: eel smaller than 80 cm, passing at short range when the window length was long (*e.g.*, low-frequency mode collecting data from 5 - 25 m); eel traversing the beam diagonally, rather than perpendicular to the beam axis, especially when the direction of movement coincided with the flow vectors (*i.e.*, prevalent direction of debris tracks); eel not displaying anguilliform swimming behavior (on 3 occasions, targets were observed that could be either eel sailing down-river in a stiff body posture or eel-shaped debris); and eel over bright background (*i.e.,* where sound is reflected off the bottom). Eel identification was difficult to impossible at a range of less than 5 m or more than 20 m. Beyond 20 m the cross-range resolution of the images was too poor to identify targets. At ranges closer than 5 m, identification was difficult due to the short trajectory of the targets and the more frequent occurrence of interference between adjacent beams, which created prominent arcs across the entire beam array. At a shallower aiming angle (used from September 19th to September 22nd), two eel were observed at short range that cast visible eel-shaped shadows. (Acoustic shadows are analogous to optical shadows: Sound is blocked by an object, in this example the eel that is located between the source of the sound, *i.e*., the transducer, and the object that would otherwise reflect the sound, in this example the river bottom.)

On several occasions (*e.g.,* October 3rd and 4th), fish other than eel were observed and identified by their tail beat (Video 8). These fish, possibly one individual returning repeatedly, went in and out of the beam periodically and often moved laterally offshore before being swept downstream.

The split-beam system aimed along the bottom (BioSonics) provided echograms of sufficient quality to identify eel at a range greater than 10 m. At shorter range, where the spreading beam is still narrow, eel tracks were too short to be easily distinguished from debris and could also easily be overlooked. The discrimination of eel from debris was less intuitive than with DIDSON data, but was possible. The three main features used for eel identification in split-beam data were 1) the width (range dimension) of the trace, 2) sawtooth pattern, 3) its random variation in range, and 4) the track trajectory. Examples for split-beam echo tracks of eel and debris are shown in Figure 14. No attempt was made to distinguish eel from other fish species, as the distinction appeared too uncertain. Circumstantial evidence from some of the DIDSON footage suggested that fish other than eel tended to hold in the current and display foraging behavior.

The split-beam system that had been aimed along the surface (Simrad) provided poorer echograms. Eel tracks were weaker and therefore more difficult to identify and more easily missed. Analysis of the surface split-beam data was further complicated by a higher proportion of debris and surface noise (Figure 15.).

3.1.2 Comparison of Acoustic Systems

Unless specified otherwise, data are presented by sample date. Each sample spans the period from 17:30 to 08:00 the following day. Dates refer to the start date.

Three systems sampled simultaneously and over partially overlapping sample areas over the core period of the study (September 19th – October 4th). Well over 200 silver eel were conclusively identified during this period. There was good agreement between the bottom split-beam (BioSonics) and the DIDSON systems; the respective total counts before and after cross-check are 254 and 267 for the BioSonics, and 242 and 258 for the DIDSON system (Table 4, Figure 16., Figure 17). The surface split-beam (Simrad) total for the “after cross-check” counts was 227, almost twice as high as 124, the total for “before cross-check” (Table 4, Figure 18.). This indicates that a considerable portion of passing eel had been missed in the initial blind analysis of the Simrad data.

The comparison of counts “after cross-check” showed good general agreement between the three systems, with peaks and troughs in generally good alignment (Figure 19.). Over the core period, eel passage peaked in the nights of September 23rd, 26th and 29th. The DIDSON count for September 29th is biased low because 1.5 hours of data during the peak hours of eel passage (18:30 – 20:00) could not be analyzed due to corrupt files.

3.1.3 Spatial distribution and behavior of eel

Only split-beam data could be analyzed for the vertical and cross-river distribution of detected eel tracks; DIDSON images are 2-dimensional and do not provide information on the vertical position of objects (beam array was aimed close to horizontal). Eel were detected throughout the water column with no pronounced preference for bottom or surface (Figure 20). Any finer details in the distribution pattern need to be interpreted with caution, considering the negative bias in eel detection at short range of either split-beam system and the overall poor detection by the surface split-beam system.

Further examination of selected split-beam tracks indicated that occasionally, individual eel moved vertically in the water column. The DIDSON images showed no clear evidence of this type of behavior, instead showing relatively smooth movement through the beam, either with the flow or sometimes laterally across the channel (also seen on split-beam). Vertical movement may, however, not be obvious on DIDSON images.

Almost all eel detected passed through the sampling area in a downstream direction. Out of the 258 eel counted with the DIDSON over the core period, only 2 were observed swimming upstream; another 3 moved laterally and were lost before an upstream vs. downstream direction of movement could be determined.

3.1.4 Temporal Distribution of Eel and Correlation of Eel Movement with Environmental Conditions

Several environmental factors were examined pertaining to temporal trends in relative abundance of eel in the project area. These included time of day, ambient light, rainfall, cloud cover, moon phase, river flow, and water temperature.

The bottom split-beam (BioSonics) and, where available (August 22nd – 24th), the DIDSON data were used to examine relative eel passage rates over the period August 22nd – October 7th (Table 5., Figure 21.). In addition to the three peaks (September 23rd, 26th and 29th) identified during the core period, the BioSonics data indicated another peak on September 18th. September 26th and 29th coincide with the dates for which the Mercer Weather Station recorded precipitation and the start of water temperature at the Project falling below 65^{o} F (Figure 22.). Another rain event was recorded for September 17th, one day before the first peak detected by the split-beam system. Acoustic data collected after October 8th could not be analyzed for eel counts because it contained too much noise generated by the high flow conditions.[2] Continued rain and high flows in the Kennebec through October jarred the hydroacoustic transducers out of place, thereby effectively ending the study. Personnel from the MDMR and the USFWS were contacted for approval to terminate the pilot study ahead of schedule. Environmental data for the study period is presented in Table 6.

Nightly cloud cover was assigned a rank score. Reported cloud cover conditions from the Mercer Weather Station taken at five-minute intervals were summarized for each daily period 17:30 – 08:00 to arrive at a dominant sky cover classification for that date. Each classification was ranked accordingly, with rain ranking the highest value and clear skies ranking lowest. Periods of rain and cloud cover were associated with a greater number of observations of eel movement (Figure 23). No direct correlation between river discharge and eel movement was observed; however, discharge at Anson ranged from 3,026 to 4,206 cfs and did not vary significantly during the data collection period (Figure 23). Because the core study period was only 16 days in duration (September 19 – October 4), no strong correlation between moon phase and eel movement was

[2] Discharge through the project on October 8th and 9th at times exceeded 26,000 cfs (Photo 4; David Lovley, MPI, *pers. comm.*) due to heavy precipitation (approximately 6 inches).

identified. However, during the three nights when peak movement was observed (9/23, 9/26, and 9/29), the moon was in its last quarter.

Photo 4. Kennebec River at Anson powerhouse with 26,000 cfs spilling, October 8th and 9th, 2005. Simrad unit is positioned on first pier.

3.1.5 Temporal Pattern of Eel Passage

All three sonar systems indicate a consistent pattern in eel passage. Most eel passed during two concentrated time periods (immediately after dark and shortly before dawn) (Table 7., Figure 24.). Between 18:00 and 23:00, 68%, 56%, and 58% of the total counts were registered by the DIDSON, bottom split-beam, and surface split-beam system, respectively. The hours between 04:00 and 07:00 represented an additional 12 % (DIDSON), 15% (bottom split-beam), and 16% (surface split-beam) of each transducer's total count. The balance of eel detections occurred in the hours between these periods, but typically consisted of scattered individual movements.

3.1.6 Videography Footage

Six evenings of footage were recorded at the exit sluice gate located near the intakes at the project in an effort to validate the data recorded by the hydroacoustic system. The infrared light emitted by the video surveillance camera was satisfactory and enabled full review of the recorded nighttime periods. At the end of the core study period during which time the camera was operational, 33 eels were detected by the hydroacoustic system; however, eel were not observed in any of the video footage.

4.0 DISCUSSION

Over the core period of the study, the split-beam system positioned along the bottom and the DIDSON system consistently identified similar numbers of silver eel. Additionally, these two systems provided a sufficiently large sample size for determining general run-timing and diurnal patterns in the migration of silver eel. Based on the cross-check against DIDSON data, the surface-mounted split-beam appeared to have missed a significant proportion of the eel that passed. This may in part have been due to eel facing the transducer at an oblique angle rather than broadside. Analysis of the surface split-beam data was further complicated by a higher proportion of debris and surface noise. We concluded that, under the given site conditions, split-beam sampling along the surface is poorly suited for monitoring migrating eel, at least with the transducer configuration used during this study. Changing the heading (*i.e.*, horizontal angle) and pitch angle of the transducer could potentially improve the detection of eel and reduce surface noise but would not alleviate the problem associated with debris. The DIDSON system appeared better suited for sampling close to the surface. Even when the top edge of the beam array sampled along the surface, DIDSON images appeared to show less debris, partly because of the relatively small physical dimensions of the debris (discussed in more detail below).

Although one advantage of the split-beam system was that it could detect eel over longer-range intervals, we found that this was offset by the split-beam's ineffectiveness at close range (less than 10 m). The bottom split-beam and DIDSON systems achieved similar sample sizes.

A single transducer does not fully cover the entire cross-section of the intake canal. However, the results of this pilot study indicate that:

1. eel passage was relatively uniform throughout the water column and across the channel; and
2. both the bottom split-beam system and DIDSON provide large enough samples (in terms of numbers of eel) to detect the presence of and qualitatively determine the relative abundance of migrating silver eel.

A single transducer should therefore be sufficient to determine run timing and diurnal patterns. A second year of cross-river distribution data should be collected to confirm that eel behavior is similar between years and under different river conditions. While the eel counts generated with the DIDSON and bottom split-beam system were of similar quality, additional issues need to be considered. The ultimate goal of this study is the development of an automated eel detection system.

Although the split-beam has a slight advantage in that tracking algorithms for these types of data have already been developed (Bertsekas 1990, Blackman and Popoli 1999), this advantage is offset by the difficulty of designing a classification system that can reject debris tracks at high enough a rate and still accept enough eel tracks.[3] At the Anson Project site, debris episodes could potentially provide excessive "false-positives." Our conclusion is that it is possible to visually distinguish eel from non-eel tracks on split-beam echograms to a degree comparable to the more intuitive DIDSON images, given enough experience. However, it is difficult to emulate this particular type of visual pattern recognition capability of the experienced human eye.

The DIDSON inherently provides information about the shape and type of motion of the object, a key feature in the discrimination of eel and debris; whereas split-beam data provide only inferential "clues" that can be confounded by object speed and type of motion. Object detection and classification algorithms for DIDSON data are still in their infancy, but can draw on a wealth of existing image analysis techniques. Discussions with individuals with expertise in the development of tracking and classification algorithms for split-beam and DIDSON data (Tim Mulligan and Peter Withler, Pacific Eumetrics Consulting, Ltd., *pers. comm.*) have provided support for our conclusion that DIDSON data are more suitable for the development of an automated eel monitoring system when differentiation between eel and debris is a concern, as is the case at the Anson Project.

[3] A classification system with a false-positive (debris misidentified as eel) rate of 10% would be more than sufficient if the ratio of debris/eel is 1/100, but inadequate when the ratio is in the order of 100/1, as is the case at the project site. In the latter example, disregarding false-negatives, 1000 debris and 10 eel tracks would translate into 110 "eel" counts. The "eel" count would be driven by the number (and changes in the number) of debris tracks detected rather than the number of eel.

Preliminary tests with 2005 study data suggest that an interim automated eel detection system can be achieved for fall 2006 at the Anson Project. Software would be programmed to load data files collected at 15 or 30-minute intervals, identify eel targets, and pass an eel estimate to the operator. In the first trial year, the automation should be checked against a manual count to refine the detection and classification algorithm as more data are collected and experience gained. We anticipate a fully automated system will eventually require only periodic quality control checks of sub-samples. Quality control will be more easily accomplished with the more intuitive DIDSON images, rather than with split-beam data, which requires considerably more experience to interpret.

Of the DIDSON sampling schemes tested, the multiplexing (*i.e.*, sampling alternately with high and low frequency) scheme used from September 30th to October 4th appeared to work best. The low-frequency periods provided a large sample volume. The high-frequency periods provided better identification and helped in the interpretation of the preceding and following low-frequency data, because the predominant types of targets tended to change only gradually over time.

While future automated monitoring efforts should concentrate on the use of the DIDSON system, there is merit in operating one split-beam system for one more year to supplement the DIDSON. This would provide a second year of information on the vertical distribution of eel, provide independent counts for comparison, and serve as a relatively low-cost insurance policy against accidental DIDSON failure or data loss.

We have identified several items that can potentially be improved. DIDSON data requires major data storage capacity: 360 GB total for one month (sampling 17:30 – 8:00), or twice as much when a back-up copy is included. The data load may be significantly reduced by using motion-detect algorithms (already implemented in DIDSON software) that eliminate data from periods when no objects are moving through the beam. Data from 2005 can be used to optimize these parameters.

For purpose of this application, there is no need to monitor the river bottom, since this study indicated that eel were distributed relatively uniformly throughout the water column. A bottom-oriented transducer is logistically more difficult as it requires divers to install and adjust. The operation could be further improved by designing transducer mounts that allow aim adjustments to be made from the roadside bank, (*i.e.*, without requiring boat or diver access). Finally, heading and pitch sensors should be used to facilitate the aiming process and to alert operators when the transducer's aim changes.

5.0 RECOMMENDATIONS

Based on the results of this pilot study, we recommend the following measures for the installation of an interim downstream eel passage hydroacoustic system:

5.1 Type of Equipment

- use of DIDSON as primary source for eel counts;
- sample one more year with a split-beam system (in addition to the DIDSON) to obtain information on vertical distribution and independent target counts for comparison; the split-beam system also serves as a low-cost backup for any failure or data loss associated with the DIDSON.

5.2 Sampling Location and Aim

- for the DIDSON system, use same location and aim as was used September 22^{nd} – October 4^{th}, 2005; use multiplexing sampling scheme similar to the one used September 30^{th} – October 4^{th}, 2005;
- for the split-beam system, use right bank and mount on the side-wall at mid-water elevation; aim for the middle of the water column, overlapping the DIDSON sampling area.

5.3 Development of Automated Eel-Detection System

- develop automated detection programming (version 1) using 2005 DIDSON data;
- test and refine detection accuracy during 2006.

5.4 Monitoring Period

- The monitoring period should target approximately an eight-week period extending from late August through late October, with specific dates to be determined in consultation with MDMR and USFWS.

5.5 Miscellaneous

- test motion-detect algorithms to reduce DIDSON data volume;
- test protocol for data transmission link to operator;
- design transducer mounts that allow aim adjustments from the roadside bank (*i.e.*, without requiring boat or diver access);
- use heading and pitch sensors to confirm aim and to alert operators to changes in the aim.

6.0 AGENCY CONSULTATION

Copies of the draft study plan and implementation schedule for upstream and downstream eel passage, which proposed the interim hydroacoustic system, were circulated to Maine Department of Environmental Protection (MDEP), Maine Atlantic Salmon Commission (MASC), the Maine Department of Marine Resources (MDMR), the Maine Department of Inland Fisheries and Wildlife (MDIFW), the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) on September 24, 2004. By letter dated September 28, 2004, MDEP deferred to MDMR and USFWS for technical aspects of the plans. By letter dated October 18, 2004, MASC also deferred to MDMR and USFWS for technical comments. In telephone discussion on October 25, 2004, MDMR stated that they had no comments on the plan.

By letter dated November 18, 2004, USFWS provided the following comment in regards to the hydroacoustic system:

> Pg. 7, 3.2. Interim Downstream Eel Passage Plan - *We concur with the proposed utilization of hydroacoustic transducers at the upstream Anson forebay to detect silver eel outmigration during the August through November period. The plan indicates that data from the eel passage monitoring system will be used to trigger the planned nighttime generation shutdown with concurrent wastegate flow release in order to facilitate safe downstream passage of adult migratory silver eels at both the Anson and Abenaki projects. We note that MPI proposes to install a prototype hydroacoustic monitoring system in the Anson project forebay for testing during the late summer or early fall of 2005, following consultation with fisheries agencies. We look forward to working with MPI on the design and testing of this plan.*

On August 5, 2005, a study work plan and a site visit invitation were sent to the consulting agencies so that the design of the system could be viewed (Appendix A). MPI did not specifically request comments on the work plan because the concept of the study had already been discussed with and agreed to by agencies. On August 25, 2005, agency personnel from the MDMR viewed the installed and operational hydroacoustic pilot system at the Anson Project, as well as associated imagery from Phase 1 of the testing. It was concluded that the pilot design of the system was satisfactory. In early October, personnel from MDMR and the USFWS were contacted for consultation regarding early termination of the study due to repeated high-flow events in the Kennebec River.

7.0 LITERATURE CITED

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8.0 TABLES

Table 1. Acoustic system configurations and dates of deployment (Each sample spans the period from 17:30 to 8:00 the following day), Anson Project American eel downstream passage study, August – October 2005.

Acoustic System	Configuration	Sample Dates
DIDSON	mounted approximately 30 cm below the water surface and 40 cm away from the side wall; -2° pitch angle;	8/22 – 8/24
DIDSON	mounted approximately 30 cm below the water surface and 40 cm away from the side wall; -14° pitch angle	9/19 – 9/21
DIDSON	mounted approximately 30 cm below the water surface and 40 cm away from the side wall; -8° pitch angle (top edge of the beam aimed along the surface)	9/22 – 10/4
Split-beam BioSonics	6° CIRCULAR 201 KHZ TRANSDUCER; MOUNTED APPROXIMATELY 20 CM BELOW THE WATER SURFACE AND 40 CM AWAY FROM THE SIDE WALL; -3° PITCH ANGLE (TOP EDGE OF THE BEAM AIMED ALONG THE SURFACE)	8/22 – 8/24
Split-beam BioSonics	6° circular 201 kHz transducer; mounted on the river bottom; 5° pitch angle (bottom edge of the beam aimed along the bottom)	8/25 – 9/2
Split-beam BioSonics	4°x 8° elliptical 201 kHz transducer; mounted on the river bottom with the long beam axis close to horizontal; 5° pitch angle;	9/8 – 10/7
Split-beam Simrad	7° circular 120 kHz transducer; mounted approximately 20 cm below the water surface; -4° pitch angle (top edge of the beam aimed along the surface) 28° roll angle to fit mounting plate;	9/9 – 10/7

Table 2. DIDSON data collection parameters - each sample spans the period from 17:30 to 8:00 the following day, Anson Project American eel downstream passage study, August - October 2005.

Frequency (MHz)	Frame Rate (fps)	Start Range (m)	Window Length (m)	Sample Dates
1.1	5	10	20	8/22 – 8/23
1.1	5	1	40	8/24
1.1	5	1	40	9/19
1.1	6	10	20	9/20
1.8	6	5	15	9/21
1.1	5	10	20	9/22 – 9/24
1.8-1.1 multiplex (30 minutes each)	6	high: 5 low: 5	high: 10 low: 20	9/25 – 9/27
1.8-1.1 multiplex (30 minutes each)	7	high: 2 low: 5	high: 10 low: 20	9/28 – 9/29
1.8-1.1 multiplex (15 minutes each)	7	high: 2 low: 5	high: 10 low: 20	9/30 – 10/4

Table 3. Fish evaluated during testing of the hydroacoustic system, Anson Project American eel downstream passage study, August - October 2005.

Species	Total Length (mm)	Lifestage	Date of Test
American eel*	800	adult (silver)	8/24/2005
American eel	600	juvenile (yellow)	8/24/2005
American eel*	650	juvenile (yellow)	8/24/2005
American eel*	679	juvenile (yellow)	8/24/2005
American eel	460	juvenile (yellow)	8/24/2005
American eel*	625	juvenile (yellow)	8/24/2005
American eel*	630	juvenile (yellow)	8/24/2005
American eel	410	juvenile (yellow)	8/24/2005
American eel	430	juvenile (yellow)	8/24/2005
American eel	450	juvenile (yellow)	8/24/2005
American eel	500	juvenile (yellow)	8/24/2005
American eel	400	juvenile (yellow)	8/24/2005
American eel	380	juvenile (yellow)	8/24/2005
American eel	380	juvenile (yellow)	8/24/2005
American eel	<= 400 (n=10)	juvenile (yellow)	8/24/2005
American eel	679	juvenile (yellow)	8/25/2005
Largemouth bass*	375	adult	8/24/2005
Largemouth bass*	450	adult	8/24/2005
White sucker*	400	adult	8/24/2005

Species	Total Length (mm)	Lifestage	Date of Test
Smallmouth bass*	320	adult	8/24/2005
Smallmouth bass*	260	adult	8/24/2005
Smallmouth bass*	200	adult	8/24/2005
Chain pickerel*	280	juvenile	8/24/2005
Yellow perch*	270	adult	8/24/2005
Black crappie*	290	adult	8/24/2005
American eel*	934	adult (silver)	9/19/2005
American eel*	934	adult (silver)	9/19/2005

** tethered with rod and reel*

Table 4. **Core period (9/19/05 – 10/04/05) American eel counts before and after system-cross check, Anson Project American eel downstream passage study, August - October 2005.**

	Surface split-beam Simrad		Bottom split-beam BioSonics		DIDSON	
	before	**after**	**before**	**after**	**before**	**after**
19-Sep	6	8	6	6	6	6
20-Sep	10	11	-	0	9	9
21-Sep	4	10	14	14	6	6
22-Sep	6	7	18	19	12	13
23-Sep	9	24	13	16	29	30
24-Sep	8	14	12	15	18	18
25-Sep	7	22	25	30	29	32
26-Sep	6	26	36	37	32	35
27-Sep	13	20	13	17	12	14
28-Sep	15	19	24	24	15	17
29-Sep	19	30	52	54	35	36
30-Sep	7	12	14	15	12	13
1-Oct	3	8	16	16	10	11
2-Oct	3	6	3	4	8	8
3-Oct	5	6	2	2	6	6
4-Oct	3	4	6	7	3	4
Totals	**124**	**227**	**254**	**276**	**242**	**258**

Table 5. Study period (August 22, 2005 – October 7, 2005) American eel counts (counts shown for the core period were generated after the system cross-check), Anson Project American eel downstream passage study.

Date	DIDSON	BioSonics 6° circular split-beam surface	BioSonics 6° circular split-beam bottom	BioSonics 4°x8° elliptical split-beam bottom	Simrad 7° circular split-beam surface
22-Aug	2	0	-	-	-
23-Aug	5	2	-	-	-
24-Aug	2	3	-	-	-
25-Aug	-	-	9	-	-
26-Aug	-	-	4	-	-
27-Aug	-	-	1	-	-
28-Aug	-	-	0	-	-
29-Aug	-	-	0	-	-
30-Aug	-	-	-	-	-
31-Aug	-	-	2	-	-
1-Sep	-	-	2	-	-
2-Sep	-	-	6	-	-
3-Sep	-	-	-	-	-
4-Sep	-	-	-	-	-
5-Sep	-	-	-	-	-
6-Sep	-	-	-	-	-
7-Sep	-	-	-	-	-
8-Sep	-	-	-	9	-
9-Sep	-	-	-	8	-
10-Sep	-	-	-	9	-
11-Sep	-	-	-	11	-
12-Sep	-	-	-	3	-
13-Sep	-	-	-	-	-
14-Sep	-	-	-	-	-
15-Sep	-	-	-	6	-
16-Sep	-	-	-	9	-
17-Sep	-	-	-	7	-
18-Sep	-	-	-	32	-
19-Sep	6	-	-	6	8
20-Sep	9	-	-	0	11
21-Sep	6	-	-	14	10
22-Sep	13	-	-	19	7
23-Sep	30	-	-	16	24
24-Sep	18	-	-	15	14
25-Sep	32	-	-	30	22
26-Sep	35	-	-	37	26
27-Sep	14	-	-	17	20
28-Sep	17	-	-	24	19
29-Sep	36	-	-	54	30
30-Sep	13	-	-	15	12
1-Oct	11	-	-	16	8
2-Oct	8	-	-	4	6

Date	DIDSON	BioSonics 6° circular split-beam surface	BioSonics 6° circular split-beam bottom	BioSonics 4°x8° elliptical split-beam bottom	Simrad 7° circular split-beam surface
3-Oct	6	-	-	2	6
4-Oct	4	-	-	7	4
5-Oct	-	-	-	1	-
6-Oct	-	-	-	2	-
7-Oct	-	-	-	1	-
Totals	**267**	**5**	**24**	**374**	**227**

Table 6. Environmental conditions during the core study period (September 19, 2005 – October 4, 2005) at the Anson Project and as recorded at the Mercer Weather Station.

Date	Avg. Daily Air Temp. (F)	Daily Precip (in.)	Water Temp. (F)	River Flow (CFS)	Cloud Cover	Moon Phase
9/19/2005	64	0.00	69	3677	Clear	-
9/20/2005	62	0.03	68	3501	Overcast-Broken Clouds	-
9/21/2005	66	0.00	68	3428	Clear	-
9/22/2005	66	0.00	68	3500	Clear-Few Clouds	Equinox
9/23/2005	65	0.00	68	3456	Rain (followed by clearing)	-
9/24/2005	53	0.00	68	3370	Clear-Overcast	-
9/25/2005	53	0.00	68	3328	Overcast-Clear	Last Quarter
9/26/2005	62	0.28	65	3297	Overcast-Rain	-
9/27/2005	60	0.00	65	3266	Clear	-
9/28/2005	58	0.00	65	3300	Clear-Few Clouds	-
9/29/2005	57	0.64	65	3431	Clear (with late rain)	-
9/30/2005	49	0.00	63	3622	Clear	-
10/1/2005	52	0.00	61	4206	Clear	-
10/2/2005	60	0.00	62	4115	Clear	-
10/3/2005	60	0.00	63	3230	Clear-Overcast	-
10/4/2005	62	0.00	64	3172	Overcast -Clear	-

Table 7. Diurnal (17:30 – 8:00) pattern of American eel relative abundance observed during the Anson Project American eel downstream passage study, August – October, 2005.

	BioSonics		**DIDSON**		**Simrad**	
Hour	**average eel count**	**percent of total count**	**average eel count**	**percent of total count**	**average eel count**	**percent of total count**
17	0.5	3%	0.1	1%	0.3	2%
18	1.4	8%	0.3	2%	0.4	3%
19	3.9	21%	4.6	28%	2.8	20%
20	3.1	16%	3.4	21%	2.6	19%
21	1.5	8%	1.6	10%	1.1	8%
22	0.7	4%	1.2	7%	1.1	8%
23	1.2	6%	0.6	4%	0.8	5%
0	1.1	6%	0.4	2%	0.8	5%
1	0.9	5%	0.6	4%	0.4	3%
2	0.8	4%	0.8	5%	0.8	5%

	BioSonics		DIDSON		Simrad	
Hour	average eel count	percent of total count	average eel count	percent of total count	average eel count	percent of total count
3	0.3	2%	0.6	4%	0.5	4%
4	1.5	8%	1.4	8%	1.1	8%
5	0.9	5%	0.5	3%	0.6	4%
6	0.4	2%	0.1	0%	0.6	4%
7	0.5	3%	0.1	0%	0.2	1%

9.0 FIGURES

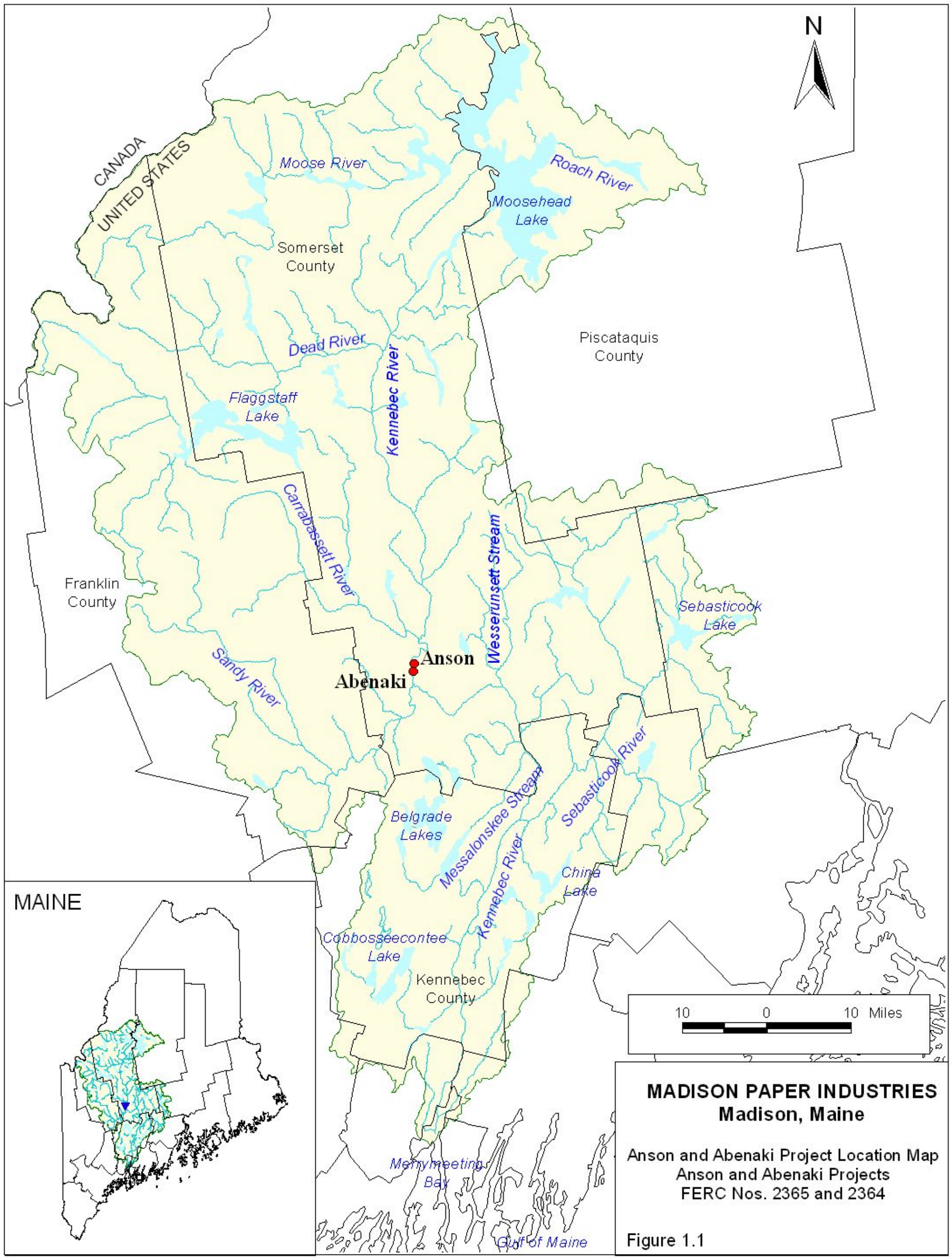

Figure 1. Anson and Abenaki Projects, Kennebec River, Somerset County, Maine.

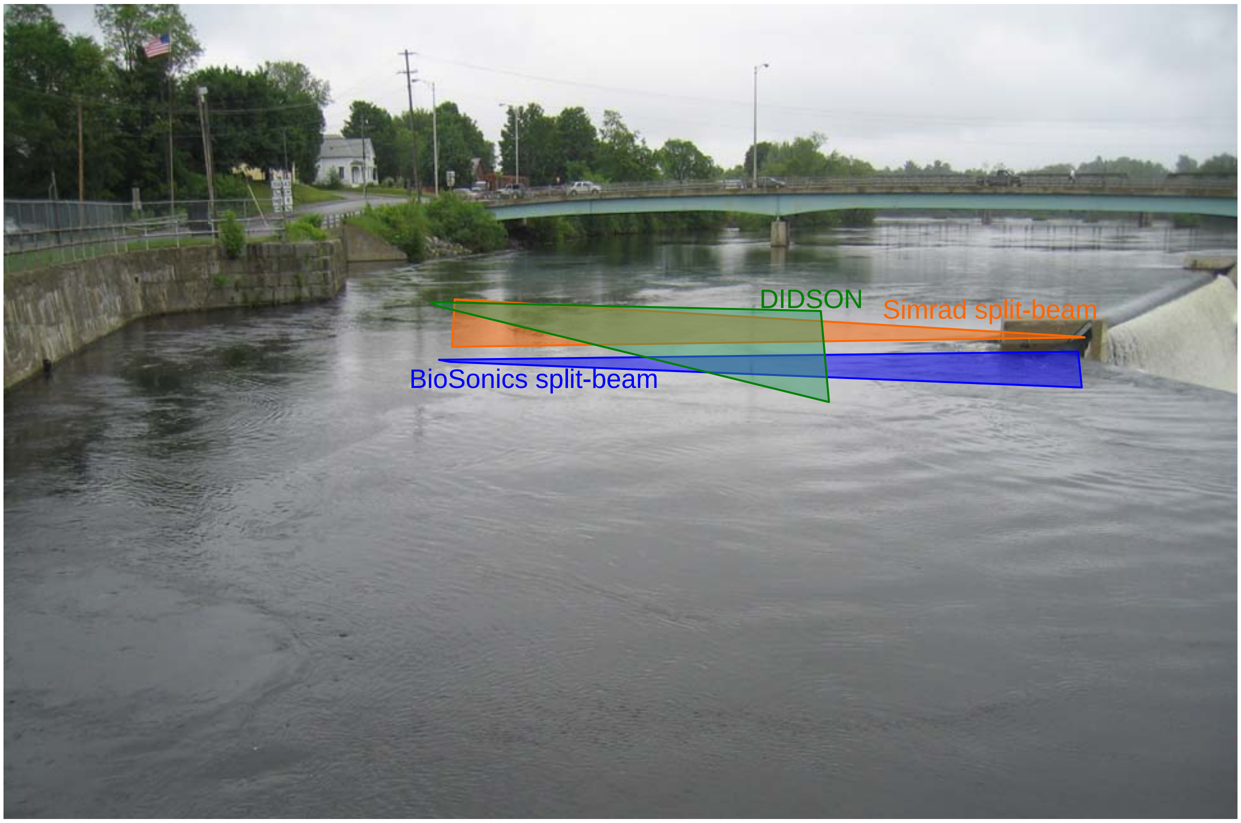

Figure 2. Approximate locations and aims of acoustic systems used. View is looking upstream from the Anson powerhouse, the spillway is on the right, Anson Project American eel downstream passage study, August – October, 2005.

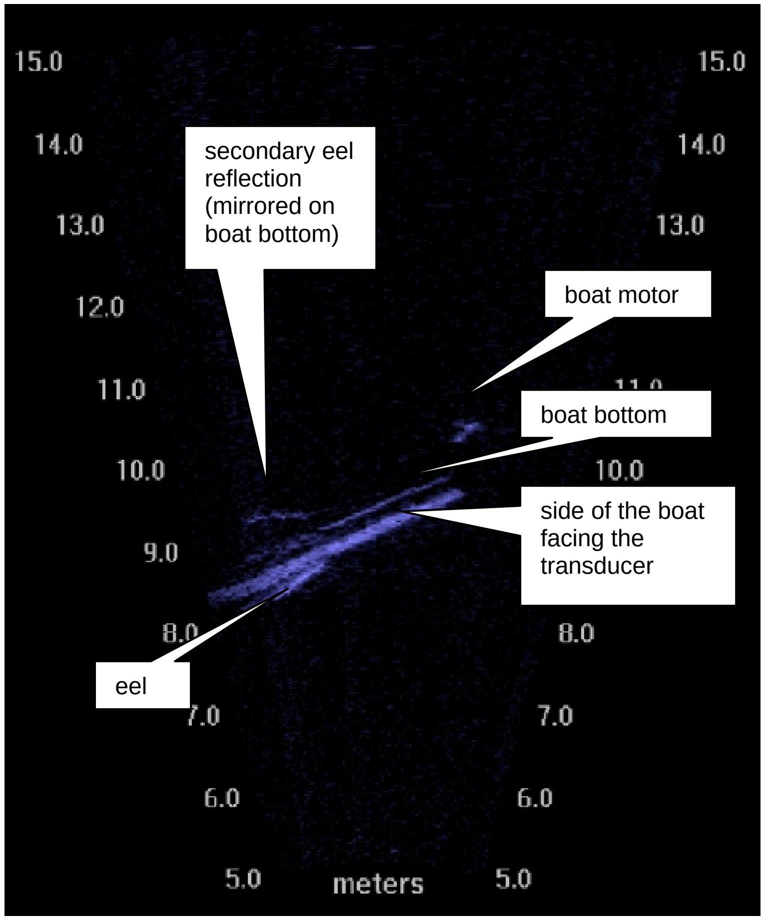

Figure 3. **DIDSON high-frequency image of tethered dead 800 mm eel and details of the boat, Anson Project American eel downstream passage study, August – October, 2005.**

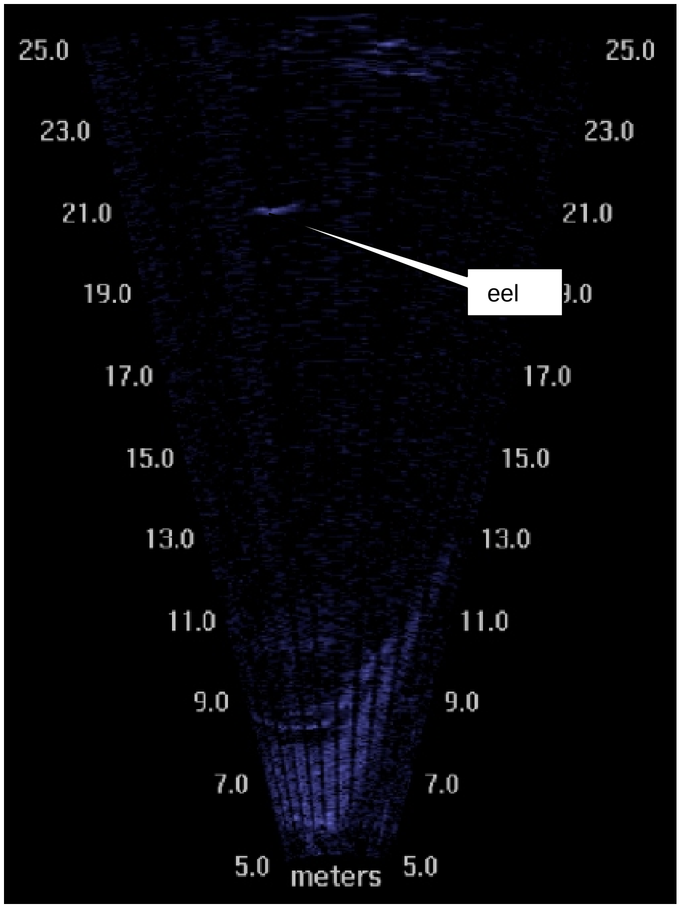

Figure 4. DIDSON low-frequency image of live tethered 934 mm eel at 21 m range, Anson Project American eel downstream passage study, August – October, 2005.

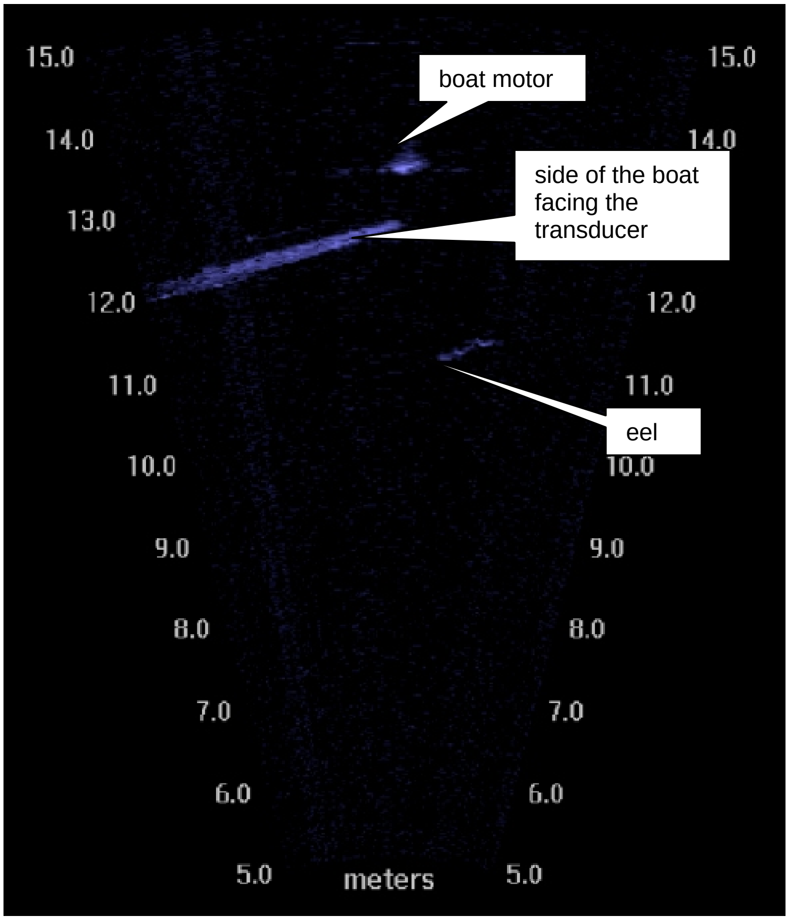

Figure 5. DIDSON high-frequency image of live tethered 679 mm eel at 11 m range, Anson Project American eel downstream passage study, August – October, 2005.

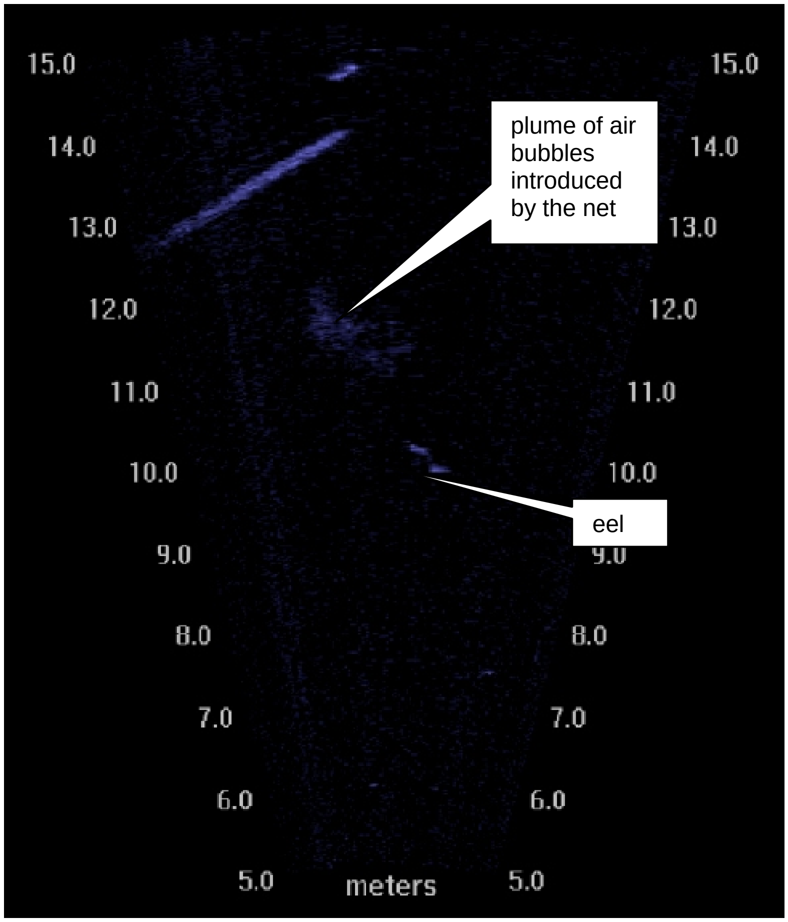

Figure 6. DIDSON high-frequency image of released eel swimming away from the boat, Anson Project American eel downstream passage study, August – October, 2005.

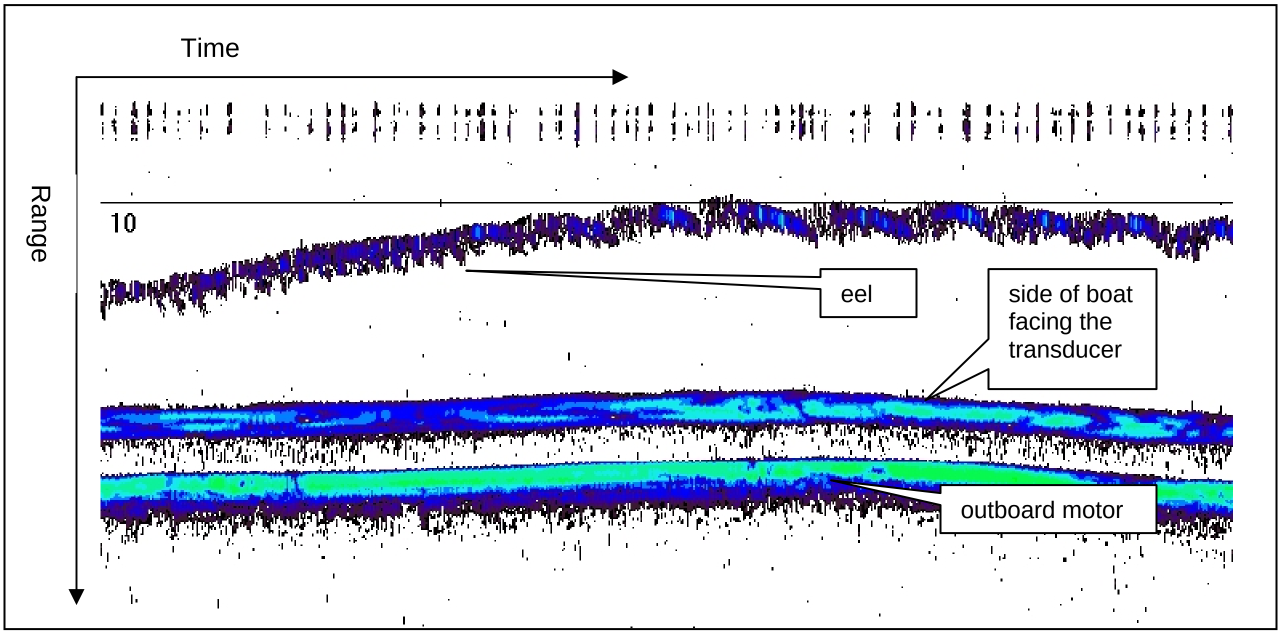

Figure 7. **BioSonics split-beam echogram of live tethered eel (679 mm) at 11 m range (eel echo trace shows sawtooth pattern and wide and variable echo width characteristic of large fish with complex body shape), Anson Project American eel downstream passage study, August – October, 2005.**

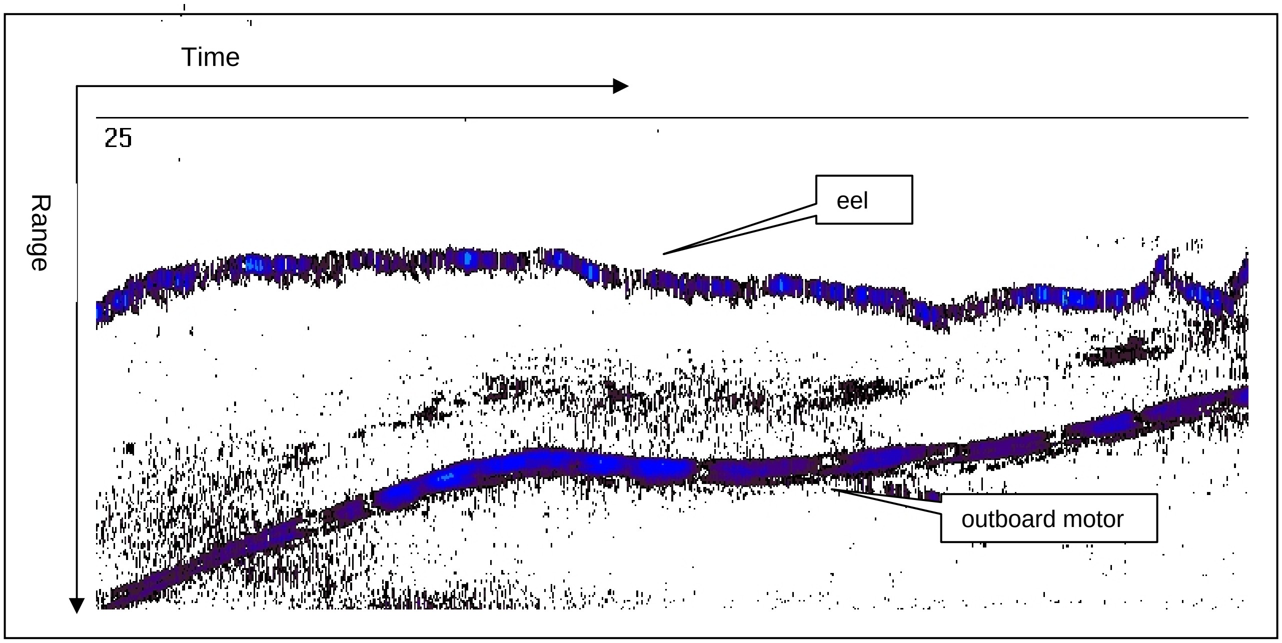

Figure 8. **BioSonics split-beam echogram of live tethered eel (679 mm) at 26 m range (eel echo trace shows moderate amount of sawtooth pattern and echo width characteristic of large fish with complex body shape), Anson Project American eel downstream passage study, August – October, 2005.**

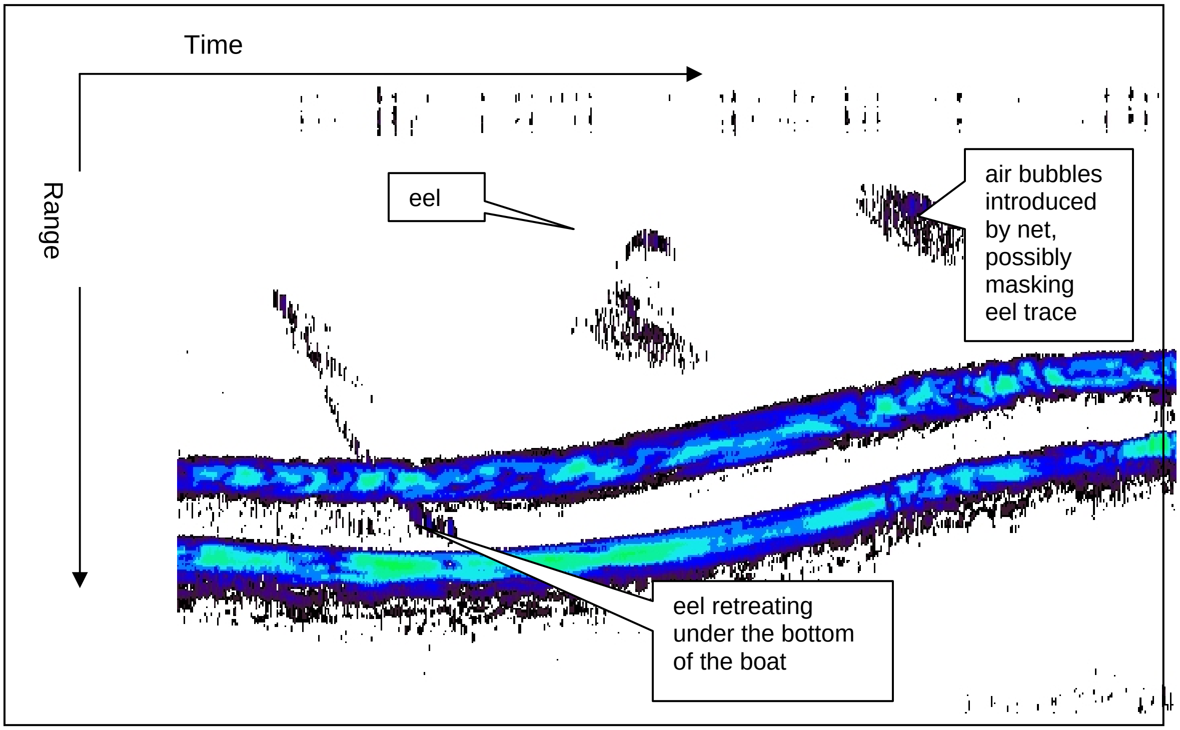

Figure 9. **BioSonics split-beam echogram of released eel swimming underneath the boat, Anson Project American eel downstream passage study, August – October, 2005.**

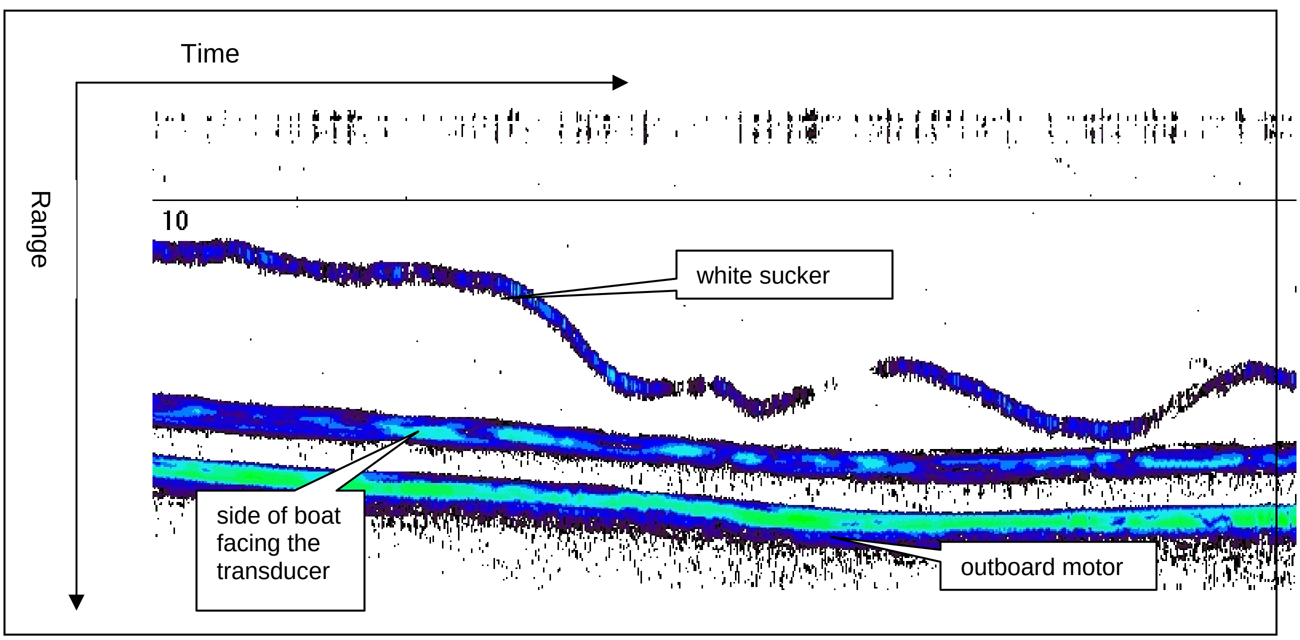

Figure 10. **BioSonics split-beam echogram of live tethered white sucker (400 mm), Anson Project American eel downstream passage study, August – October, 2005.**

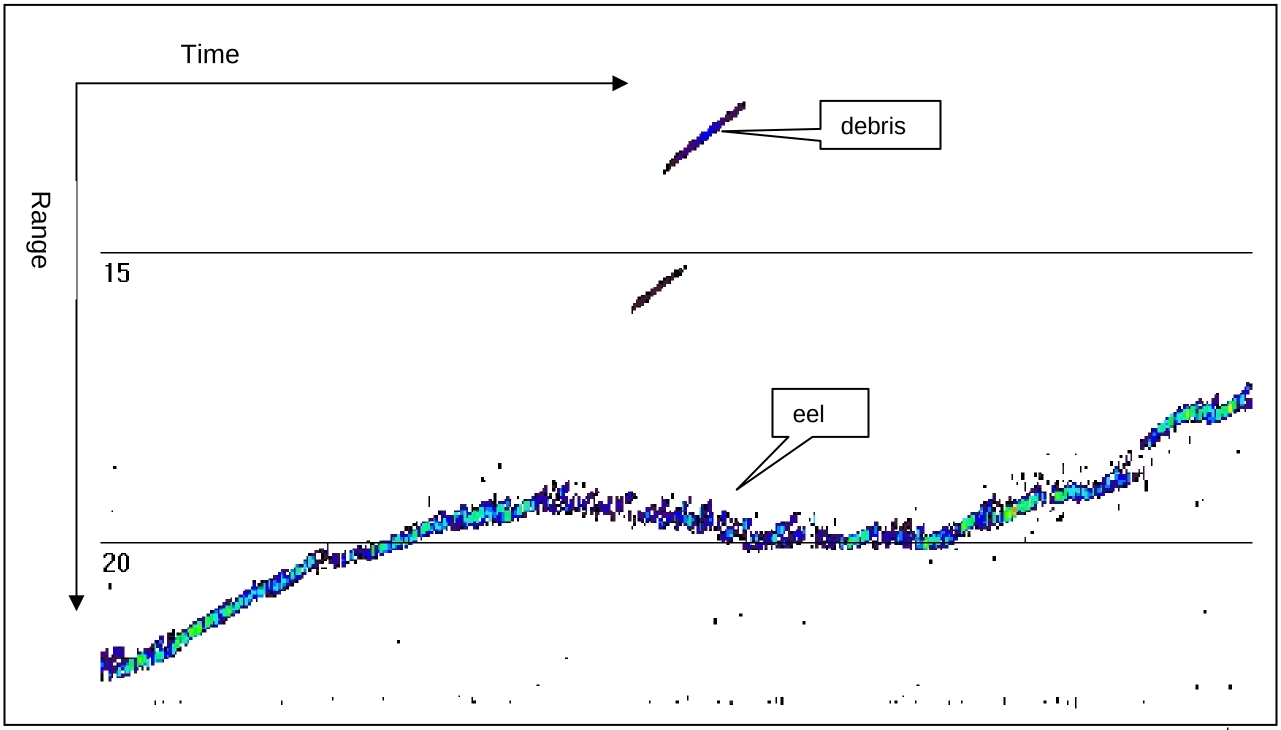

Figure 11. Simrad split-beam echogram of live tethered eel (934 mm) at 20 m range. (eel echo trace shows sawtooth pattern and wide and variable echo width characteristic of large fish with complex body shape. By comparison, debris echoes form straight, narrow track with constant echo width), Anson Project American eel downstream passage study, August – October, 2005.

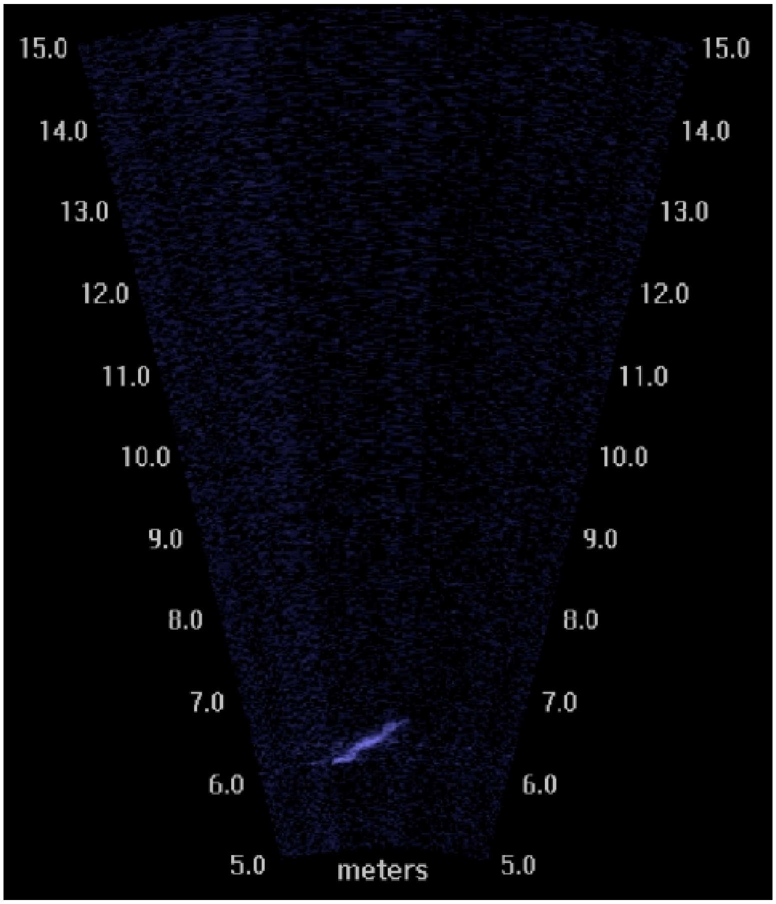

Figure 12. DIDSON high-frequency image of free-swimming native eel, Anson Project American eel downstream passage study, August – October, 2005.

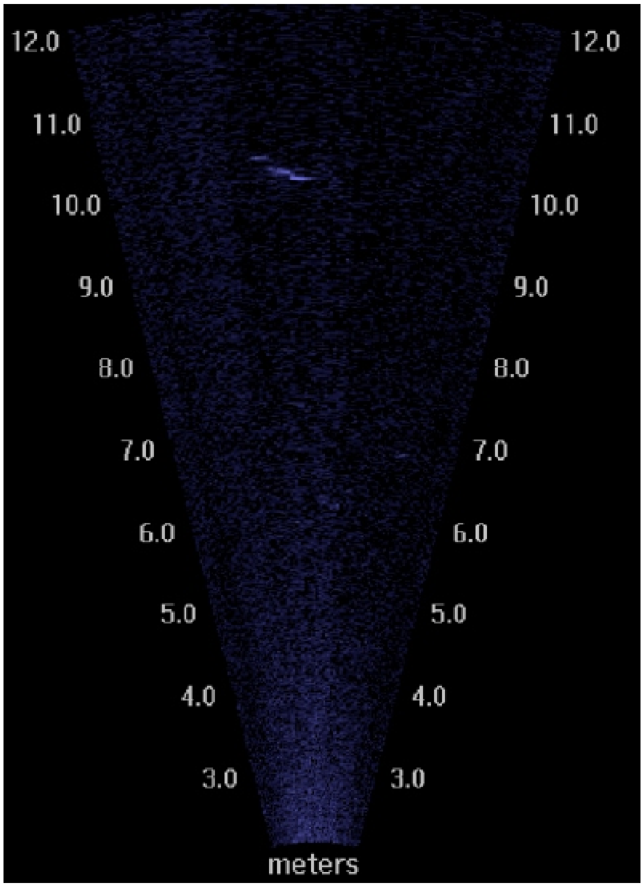

Figure 13. DIDSON high-frequency image of free-swimming native eel, Anson Project American eel downstream passage study, August – October, 2005.

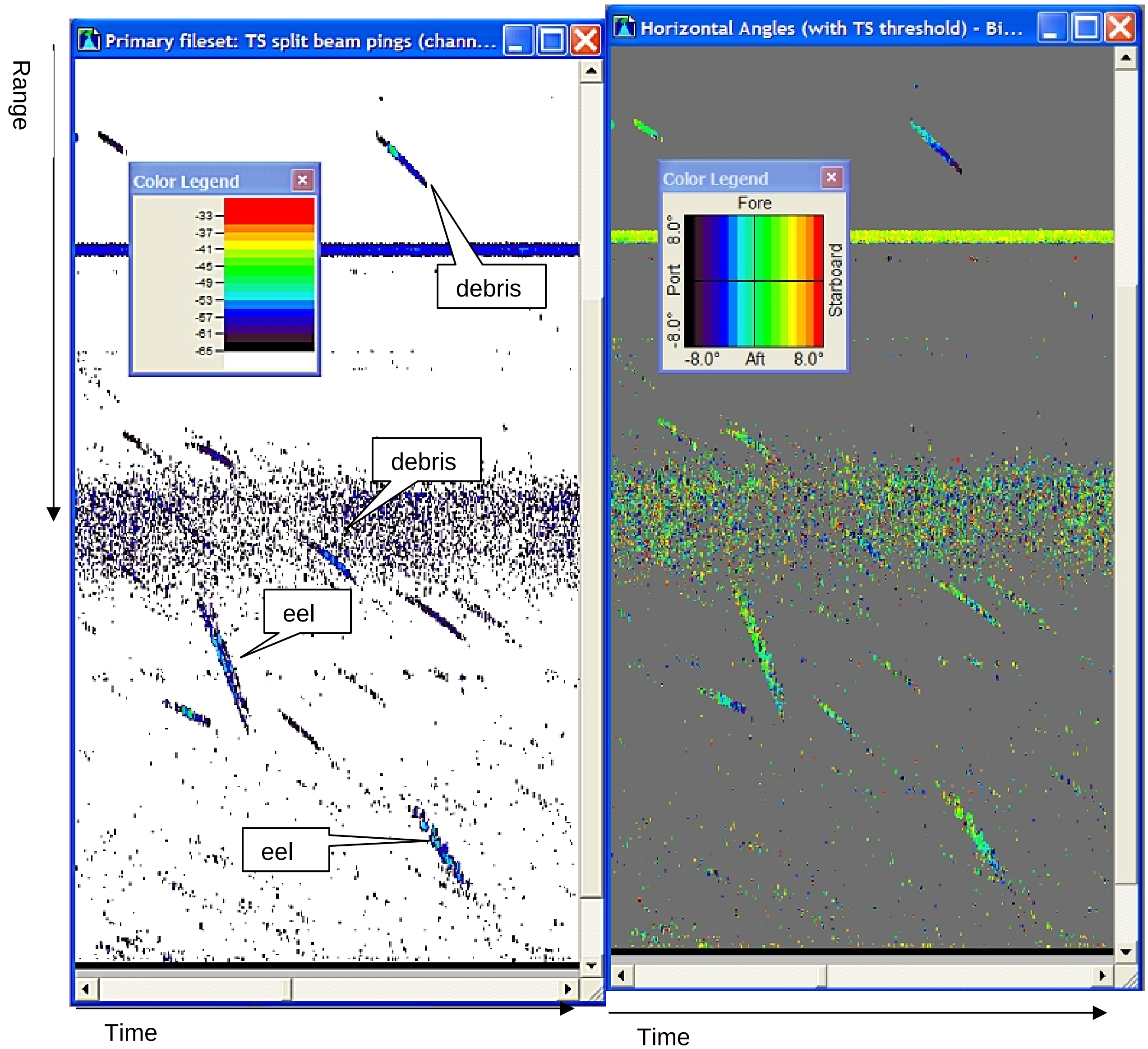

Figure 14. BioSonics split-beam echograms of free-swimming native eel. The echogram on the left is color-coded by acoustic target strength (dB). The echogram on the right shows the same data, color-coded by horizontal split-beam angle, with warm colors indicating the upstream side of the transducer. Tracks progressing from warm to cold colors are targets moving downstream, tracks changing colors in the reverse order (none shown) would indicate target is moving upstream. Note the sawtooth pattern of the eel tracks, compared to the smooth appearance of the debris tracks, Anson Project American eel downstream passage study, August – October, 2005.

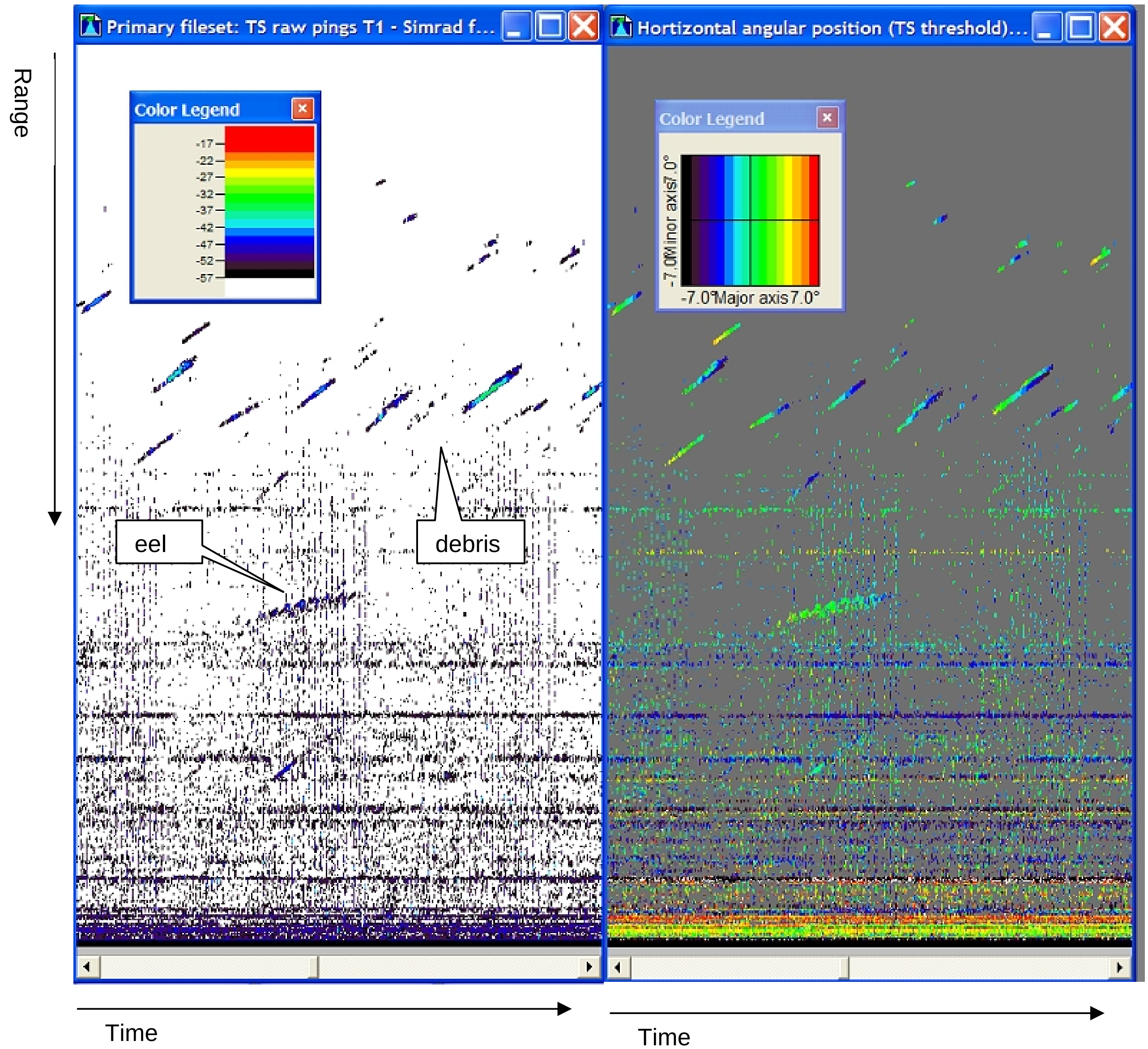

Figure 15. **Simrad split-beam echograms of free-swimming native eel. The echogram on the left is color-coded by acoustic target strength (dB). The echogram on the right shows the same data, color-coded by horizontal split-beam angle, with warm colors colors indicating the upstream side of the transducer. Tracks progressing from warm to cold colors are targets moving downstream, tracks changing colors in the reverse order (none shown) would indicate target is moving upstream. Note the sawtooth pattern of the eel tracks, compared to the smooth appearance of the debris tracks, Anson Project American eel downstream passage study, August – October, 2005.**

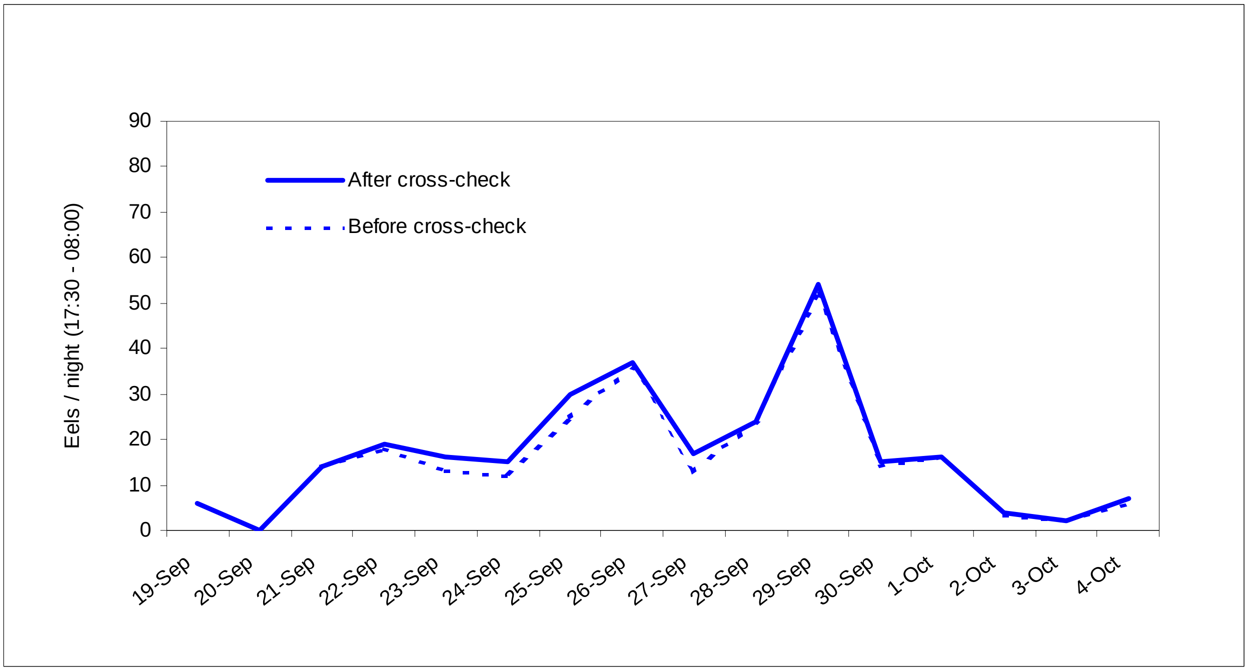

Figure 16. The number of eel counted with split-beam sonar (BioSonics) aimed along the bottom, before and after system cross-check, Anson Project American eel downstream passage study, August – October, 2005.

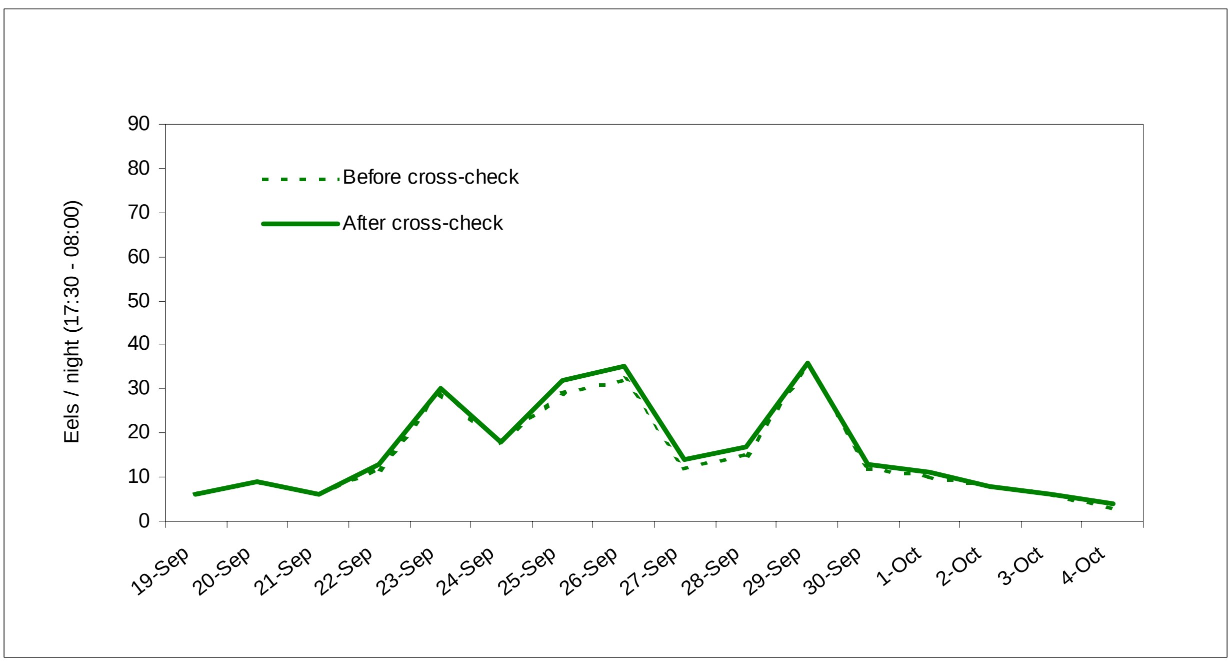

Figure 17. The number of eel counted by imaging sonar (DIDSON) before and after system cross-check, Anson Project American eel downstream passage study, August – October, 2005.

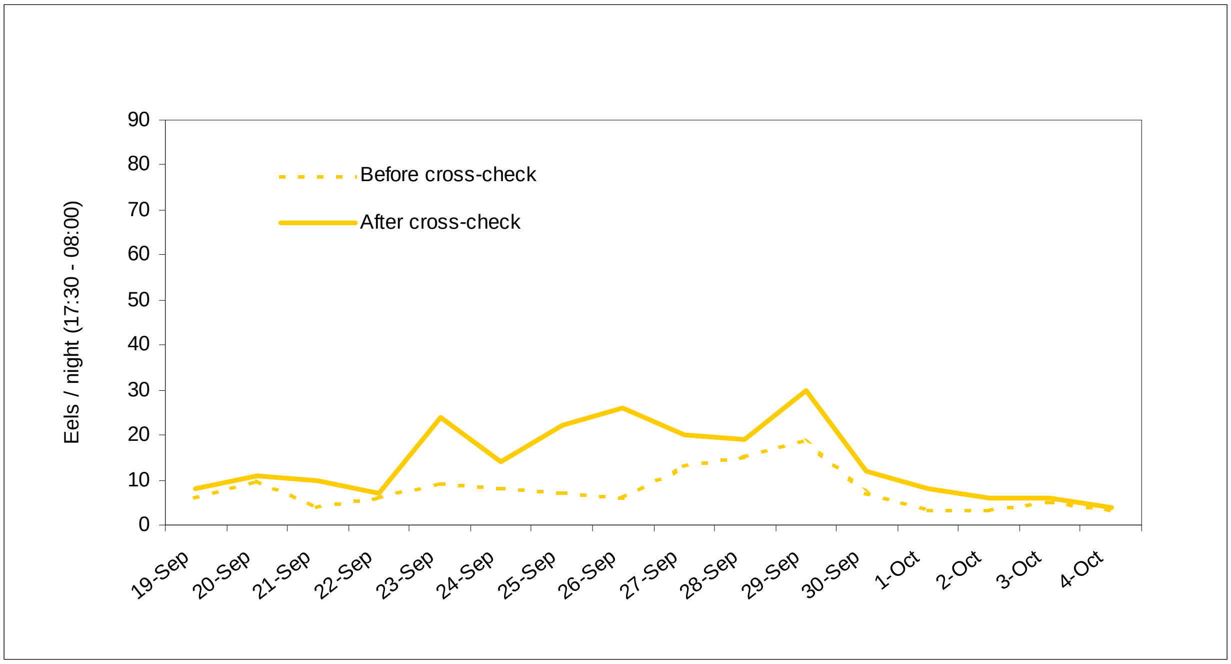

Figure 18. The number of eel counted with split-beam sonar (Simrad) aimed along the surface, before and after system cross-check, Anson Project American eel downstream passage study, August – October, 2005.

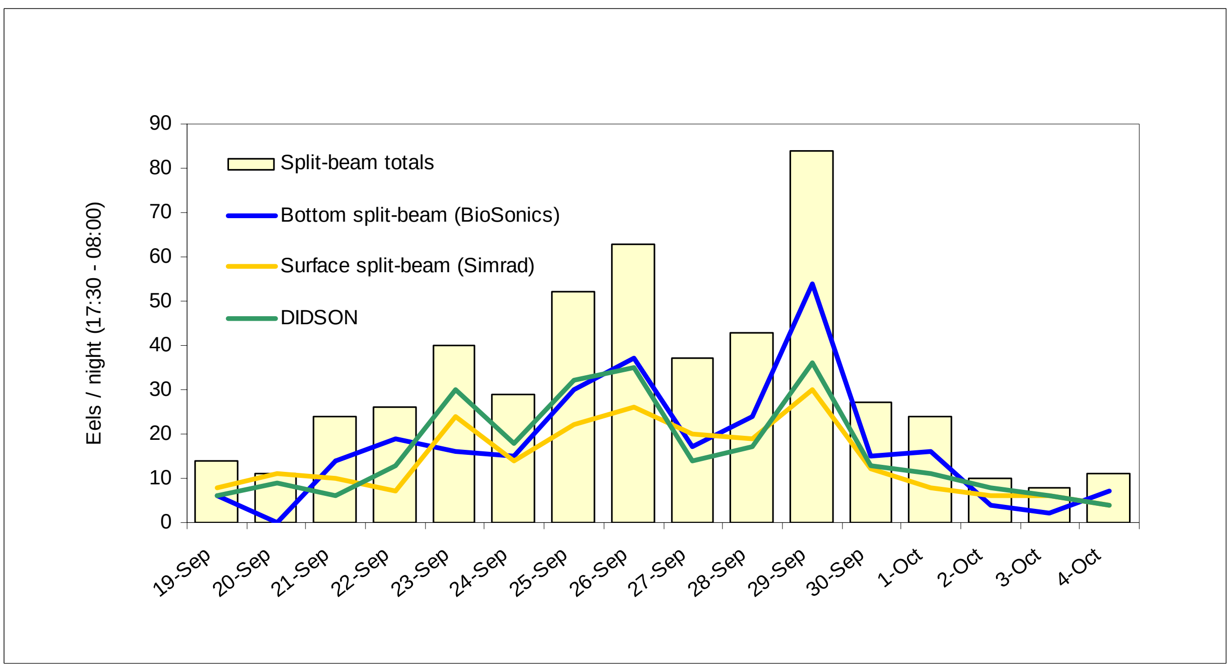

Figure 19. Comparison of the number of eel counted with split-beam and DIDSON sonar after system-check, Anson Project American eel downstream passage study, August – October, 2005.

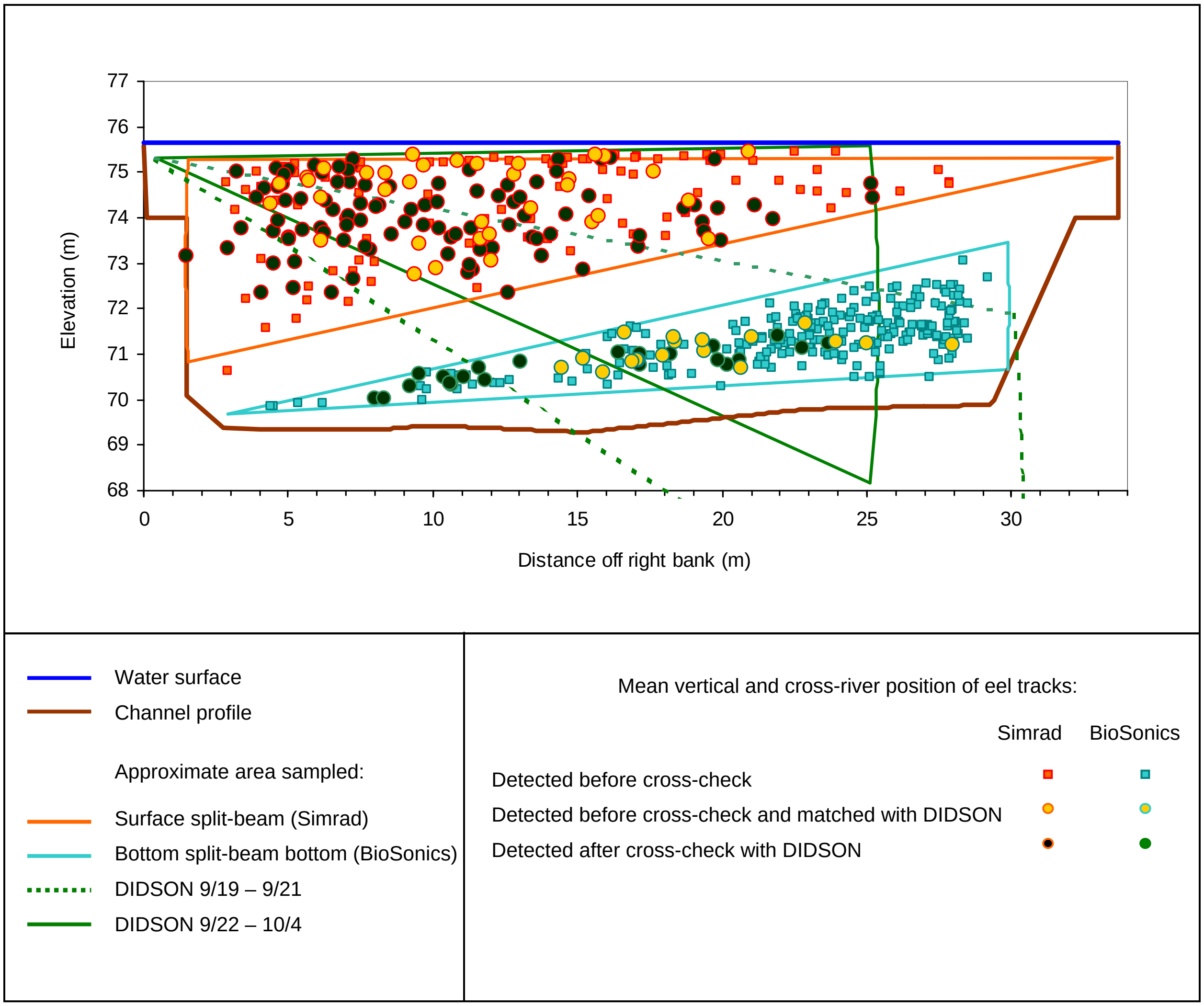

Figure 20. **Mean vertical and cross-river position of eel tracks detected with split-beam sonars aimed along the surface and the bottom, Anson Project American eel downstream passage study, August – October, 2005.**

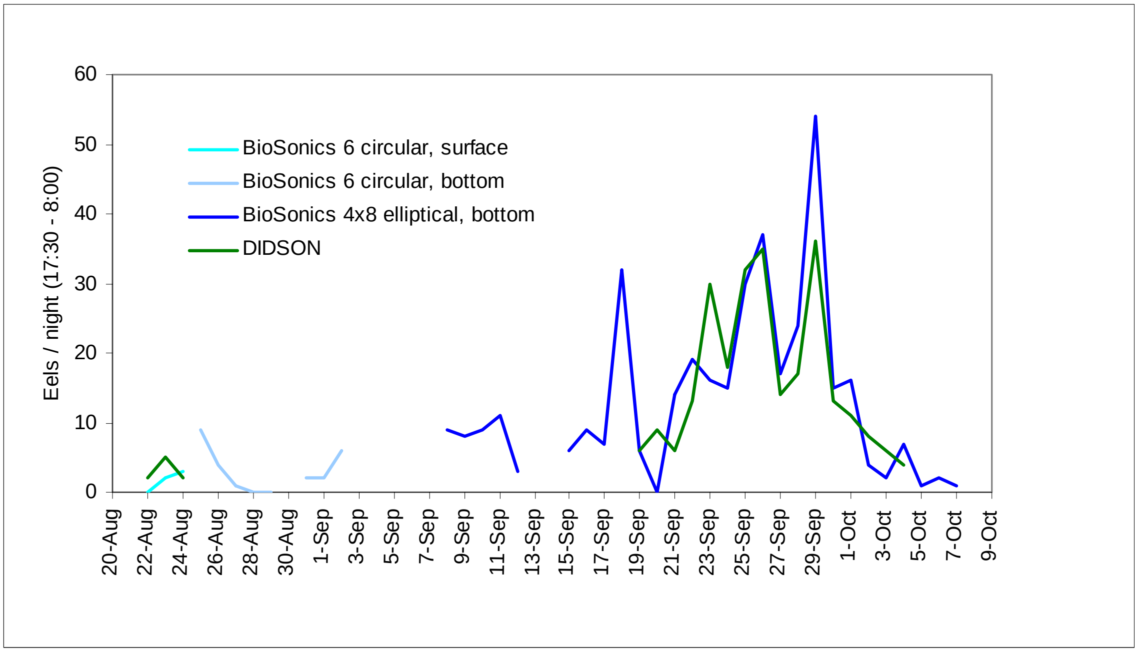

Figure 21. **The number of eel counted over the entire study period, Anson Project American eel downstream passage study, August – October, 2005.**

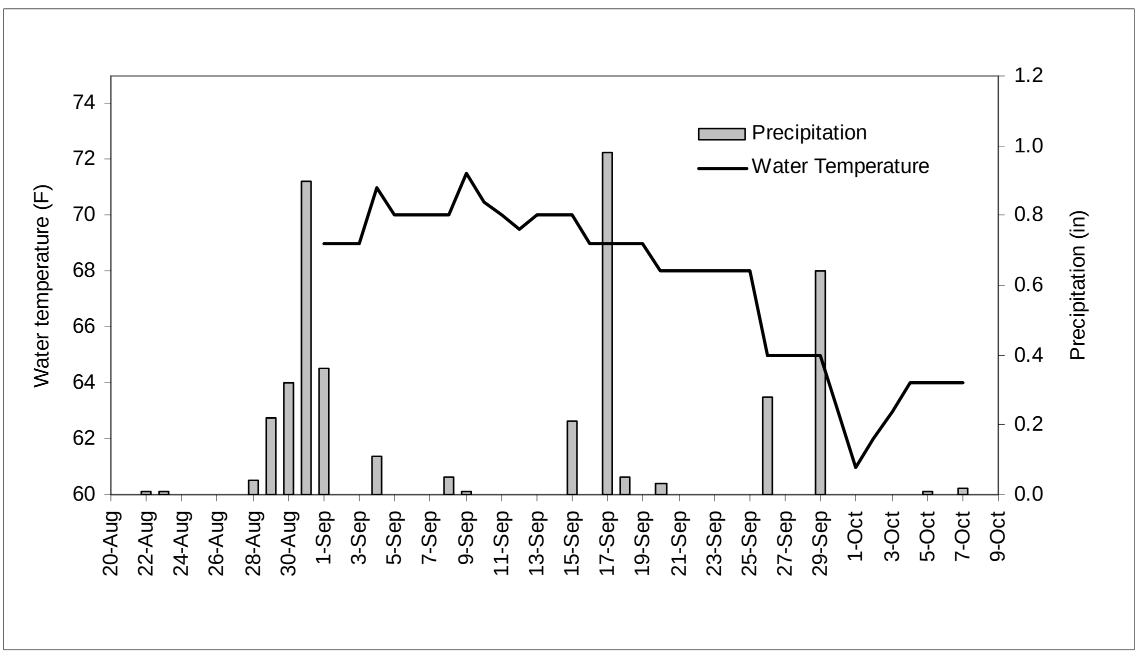

Figure 22. **Water temperature at the Anson powerhouse and precipitation reported at the Mercer Weather Station, Anson Project American eel downstream passage study, August – October, 2005.**

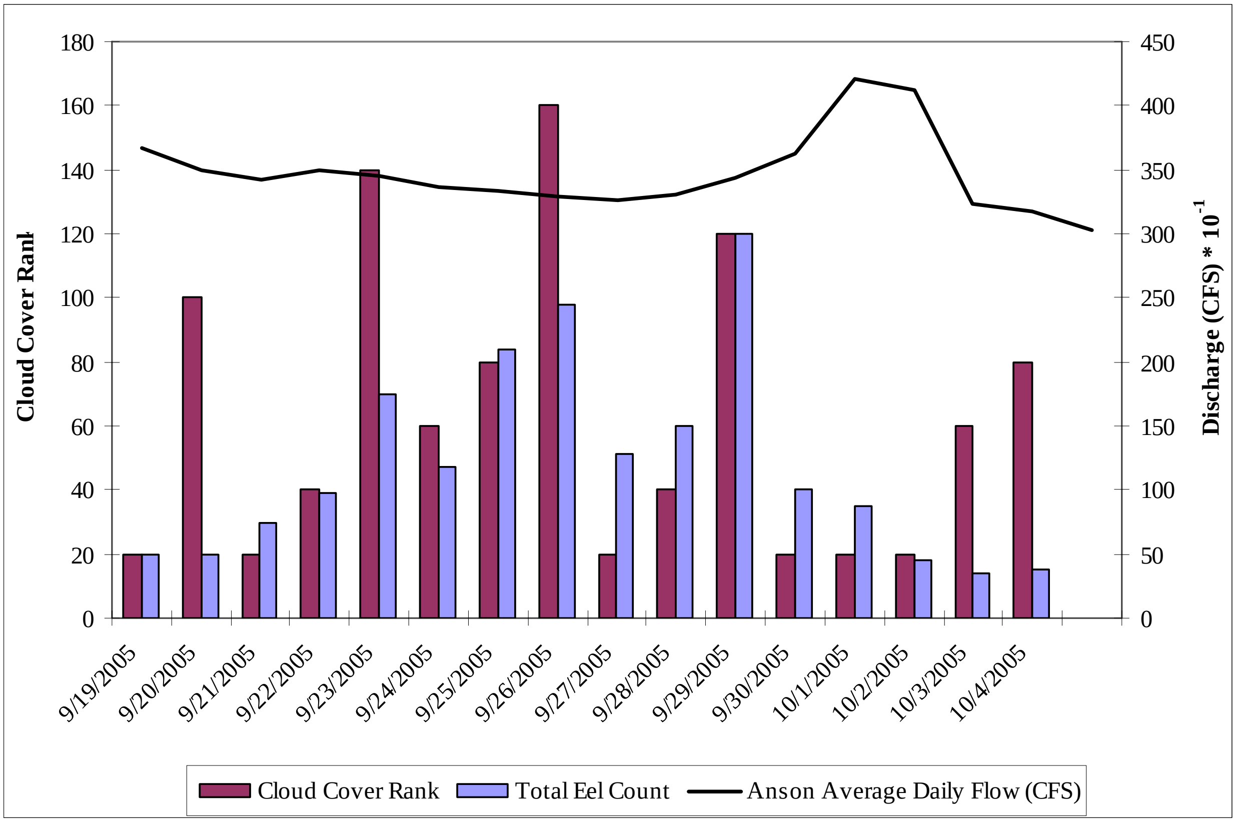

Figure 23. Correlation between Anson Station discharge, cloud cover, and total eel count during the core sample period, Anson Project American eel downstream passage study, September 19 - October 04, 2005.

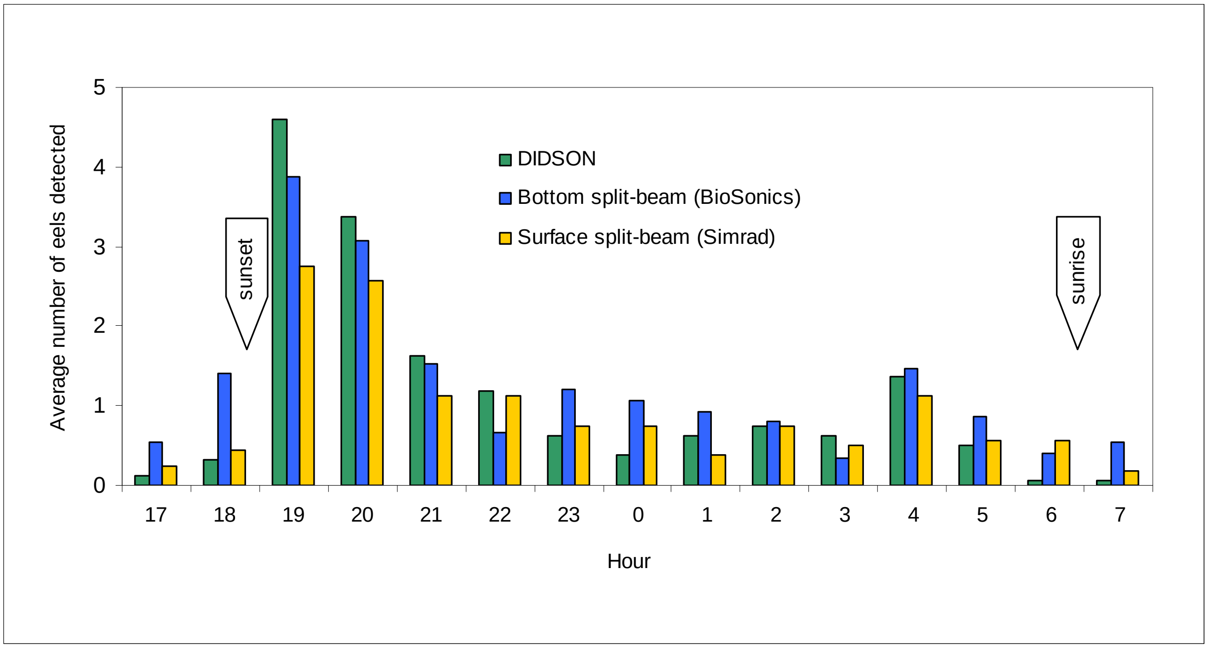

Figure 24. **Diurnal (17:30 – 8:00) pattern of the number of eel counted, Anson Project American eel downstream passage study, August – October, 2005.**

9.1 Index of DIDSON Videos

Note: HF in file name indicates images were taken in high-frequency mode, LF indicates low-frequency mode

Reference	File Name	Description
1	2005-09-19_153559_LF_934eel_15m.avi	tethered eel (934 mm) at 15 m range
2	2005-09-19_153559_LF_934eel_20m.avi	tethered eel (934 mm) at 20 m range
3	2005-08-23_124405_HF_679eel_11m.avi	tethered eel (679 mm) at 11 m range, boat;
4	2005-08-23_125700_HF_630eel_released.avi	released eel (630 mm) and air bubbles
5	2005-08-23_153129_LF_450LMB.avi	tethered largemouth bass
6	2005-09-26_013000_HF_perfect_track.avi	high-quality image of free-swimming native eel at 6 m range
7	2005-09-30_043000_HF_10m_towards_xducer.avi	high-quality image of free-swimming native eel at 10.5 m range
8	2005-09-26_063000_HF_other_fish.avi	fish other than eel, note tail-beat

APPENDIX A

AGENCY CONSULTATION

Kleinschmidt
Energy & Water Resource Consultants

August 5, 2005

VIA EMAIL

Anson Project, FERC No. 2365
Abenaki Project, FERC No. 2364
American Eel Downstream Passage Pilot Study

To Distribution List:

Attached is a brief pilot study plan for the installation and calibration of hydroacoustic equipment in the forebay of the Anson Project during the week of August 22, 2005. This plan is being provided to the agency members of the Fish Passage Team for their information, along with an invitation to visit the project to review and discuss the pilot study installation.

Madison Paper Industries (MPI) is not specifically requesting comments on the attached plan because the concept of the study has already been discussed with and agreed to by agencies, but we would appreciate your being available on site to offer comments on the installation. This pilot study is an experimental installation at the Anson Project, but is based on previous lab studies that have shown successful detection of eels using hydroacoustics. As noted in the attached work plan, results of the pilot study will be provided to agencies in late 2005 for review and discussion in the context of planning for future efforts in 2006.

We expect that **Thursday, August 25, 2005** will be the best day for agency personnel to visit the site to review the installation and discuss the technical and logistical criteria that govern the location and configuration of the installation. MPI and consultant personnel will be at the site from **10:00 am to 2:00 pm** to provide a tour of the installation and answer questions.

Sincerely,

KLEINSCHMIDT ASSOCIATES

Brandon H Kulik

Brandon H. Kulik
Senior Fishery Biologist

BHK:mt
Enclosure
cc: Christopher Bean, David Lovley, Donald Degan, Andrew Sims, Andrew Qua

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MADISON PAPER INDUSTRIES

MADISON, MAINE

ABENAKI HYDROELECTRIC PROJECT
(FERC NO. 2364)

ANSON HYDROELECTRIC PROJECT
(FERC NO. 2365)

AMERICAN EEL FISH DOWNSTREAM PASSAGE PILOT STUDY

2005 WORK PLAN

JULY 2005

Prepared by:

Kleinschmidt
Energy & Water Resource Consultants

MADISON PAPER INDUSTRIES
MADISON, MAINE

ABENAKI HYDROELECTRIC PROJECT
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2005 WORK PLAN

MADISON PAPER INDUSTRIES
MADISON, MAINE

AMERICAN EEL FISH DOWNSTREAM PASSAGE PILOT STUDY

2005 WORK PLAN

1.0 BACKGROUND

The Anson Project is one of two adjacent projects on the Kennebec River owned and operated by Madison Paper Industries (MPI). The Abenaki Project (FERC No. 2364) is located approximately one-half mile downstream of the Anson Project (Figure 1). The Anson Project impoundment encompasses approximately 7 miles of the Kennebec River and 0.5 miles of the Carrabassett River. The Anson dam spans the Kennebec River immediately downstream of the Route 148/201A bridge between Anson and Madison. The Abenaki Project impoundment encompasses approximately 0.5 miles of the Kennebec River from immediately below the Anson tailrace to the Abenaki dam. On July 25, 2003, the FERC issued a new license for these projects.

The new license issued for the Anson and Abenaki projects contemplated the installation of interim downstream passage for adult silver-phase American eel (eel). The specific requirements for this work plan were detailed in a study plan pursuant to Article 405 (A), which was filed on November 29, 2004 and was approved by FERC on March 15, 2005 (110 FERC ¶62,256). The plan, prepared in consultation with agencies, proposed a hydroacoustic system to detect downstream migrating silver eels approaching the Anson powerhouse so that operation of both projects can be managed to promote downstream eel passage. The final system will provide real-time data to minimize lost generation during eel outmigration past the project, and provide downstream eel movement data utilized as a trigger for initiating downstream passage measures (*e.g.*, temporary turbine shutdown or intake rack overlays combined with opening of a waste gate or spillage).

As described in the plan, a hydroacoustic monitoring pilot study will be conducted in summer/fall 2005. During testing, specifications and orientation of the hydroacoustic gear will be tested; recommendations for a full-scale prototype will be based on recommendations of the pilot study. A summary report will be provided to agencies for review and discussion. If the agencies find the recommended system and methodology satisfactory, the final system equipment and configuration will then be installed and calibrated prior to the 2006 outmigration season.

2.0 PILOT STUDY WORK SCOPE AND SCHEDULE

This work plan summarizes the scope of work to be performed in support of the 2005 pilot study. The goals and objectives of the study are to:

- empirically verify that eels can be detected by the hydroacoustic system(s);
- experiment with various transducer locations and arrays to determine the best configuration to detect eels approaching the project intake area, and;
- develop specifications and recommendations for the monitoring system to be deployed during 2006.

The study will be jointly conducted by MPI, Kleinschmidt Associates, and Aquacoustics. Aquacoustics specializes in using hydroacoustic systems to monitor movements of various fish species in connection with studies such as population assessments and fish passage effectiveness. In order to assess the feasibility of utilizing hydroacoustics to detect eels, the following methods will be conducted:

1. Two types of transducers will be evaluated (split beam; Didson).
2. The test array will include paired horizontally-oriented transducers aimed at a roughly perpendicular angle to the entrance flow at Anson near the ME-16 bridge.
3. Transducers will be mounted on poles that will be movable, but anchored. This will facilitate experimentally positioning the beam depth and angle to seek optimal acoustic coverage of the water column.
4. Once a satisfactory array is functioning, the system will be tested over the course of the next series of days. To test the system:
    a. It will be calibrated with a standard acoustic target object.
    b. Specimens of adult-sized eel and other representative common fish from this river reach that could be present and provide false targets (*e.g.*, smallmouth bass, trout, white sucker, etc.) will be collected from the study

site vicinity for target testing.[1] Each test specimen will be measured, weighed and kept alive in an aerated holding tub.

c. During tests, each specimen will be placed in a mesh bag or cage so that it can be freely floated through the acoustic field in a variety of water column positions and vertical/horizontal orientations relative to the acoustic beam axis. A series of passes with each specimen will be made to collect data to distinguish the adult eel acoustic signature from acoustic patterns of non-target species.

d. Prevailing station operation will be recorded and correlated with test conditions.

5. After the week of testing, the data will be examined to determine final specifications for the fall monitoring set-up; however, the splitbeam sonar system will remain in place after the August setup and sample through the fall monitoring period.

6. The fall emigration period is anticipated to commence in late September; the exact week will be set later and hinge on ambient fall conditions. Monitoring will continue from the end of the test period through the conclusion of the fall emigration period (November).

7. Trained technicians will trouble-shoot, maintain and download data through the expected eel migration period.

8. If possible, a sampling net will be placed in the outfall from the trash sluice gate at the end of the skimmer wall to empirically correlate passage of eels to potentially verify the eel targets. The net would be retrieved and checked daily.

Upon completion of this effort, a report of results, including recommendations for a full-scale monitoring system, will be drafted and provided to agencies for review in late 2005 or early 2006. The report and recommended plan for the 2006 effort can be discussed and, if possible, agreed to at the annual Anson-Abenaki Fish Passage Team meeting (scheduled to occur in the

[1] Fish will be collected using boat electrofishing, which may also provide an indication of the relative abundance of eels available in the project impoundment for natural migration during the second stage of the study later in the year.

first quarter of 2006 as soon as possible after the annual KHDG Meeting).

3.0 AGENCY INVOLVEMENT

This plan is being provided to the agency members of the Fish Passage Team as a courtesy. While MPI is not specifically requesting comments because the concept of the study has already been discussed with and agreed to by agencies, comments on the plan are welcome. This pilot study is experimental, though previous lab studies have shown successful detection of eels using hydroacoustics. Agency representatives will be invited to visit the site to observe operation of the system(s) once they are in place and operational. As noted above, results will be provided to agencies for review and discussed in the context of planning for future efforts in 2006.

APPENDIX B

LICENSE ARTICLES

Article 405. The licensee shall design, install, operate, and maintain passage facilities to provide efficient upstream and downstream passage for American eel and Atlantic salmon past the project. The designs for the interim downstream fishway for American eel and upstream fishways for American eel and Atlantic salmon shall conform to the preliminary layout presented in "Fish Passage and Protection Alternatives Assessment and Plan", prepared for Madison Paper Industries, Madison, Maine by Kleinschmidt, Pittsfield, October, 2001 unless the licensee and consulting agencies concur that alternative design layouts are appropriate.

(A) Within six months of the effective date of this license, the licensee shall file, for Commission approval, final plans and implementation schedules to install, operate, and maintain upstream and interim downstream passage facilities for American eel as provided for in Condition Nos. 3.A and 3.B of Appendix A. Within two years of the effective date of this license, upstream and interim downstream passage facilities for American eel shall be installed and operational at the project.

(B) Not less than 90 days before the start of construction of permanent downstream passage facilities for American eel at the project, as provided for in Condition Nos. 3.A and 3.B of Appendix A, the licensee shall file, for Commission approval, a preliminary fishway design and a final plan and implementation schedule to install, operate, and maintain such facilities.

(C) Within six months of being given written notice by the Maine Atlantic Salmon Commission and the U.S. Fish and Wildlife Service, that sustained annual stocking of Atlantic salmon above the project has begun or will begin within two years, the licensee shall file, for Commission approval, a preliminary fishway design and a final plan and implementation schedule to install, operate, and maintain interim passage facilities for Atlantic salmon. The licensee shall consult with the two agencies annually to determine the schedule for such sustained annual stocking. The design of the facility may be integrated with the interim downstream passage facilities for American eel.

(D) Not less than 90 days before the start of construction of upstream and permanent downstream passage facilities for Atlantic salmon at the project, as provided for in Condition Nos. 4.A and 4.B of Appendix A, the licensee shall file, for Commission approval, final plans and implementation schedules to install, operate, and maintain such facilities. The licensee shall also file a preliminary fishway design for the permanent downstream passage facility.

(E) The licensee shall install and operate the upstream passage facility for Atlantic salmon, as provided in Condition No. 4.B of Appendix A, within two years following written certification by the U.S. Fish and Wildlife Service and the Maine Atlantic Salmon Commission that 226 returning Kennebec River Atlantic salmon [from the Lockwood Project (FERC No. 2574) fishlift or other lower Kennebec River trap and truck facility or fishway] have been released into the Kennebec River watershed above the Weston dam (FERC No. 2325) in any single season.

(F) The licensee shall consult annually with the Maine Atlantic Salmon Commission, the Maine Department of Marine Resources, the Maine Department of Inland Fisheries and Wildlife, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service whenever interim downstream passage facilities for American eel and Atlantic salmon are operational at the project and shall make reasonable changes to interim downstream operations or design as mutually agreed to with the consulting agencies and approved by the Commission.

(G) The licensee shall prepare the plans and schedules for installing, operating, and maintaining passage facilities for American eel and Atlantic salmon and post-installation changes in operations or designs in such facilities in consultation with the Maine Atlantic Salmon Commission, the Maine Department of Marine Resources, the Maine Department of Inland Fisheries and Wildlife, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service for review prior to filing with the Commission for approval. The licensee shall include with each plan documentation of consultation on the completed plan after it has been prepared and provided to the agencies, and specific descriptions of how the agencies' comments were addressed in the plan. The licensee shall allow a minimum of 30 days for the agencies to comment and to make recommendations prior to filing the plan with the Commission for approval. If the licensee does not adopt a recommendation, the filing shall include the licensee's reasons, based on project-specific information.

The Commission reserves the right to require changes to the plans. The licensee shall not implement a plan until the licensee is notified by the Commission that the plan is approved. Upon Commission approval, the licensee shall implement the plan, including any changes to the plan required by the Commission.

Article 406. The licensee shall conduct testing of the effectiveness of interim and permanent upstream and downstream fish passage facilities following their construction, in consultation with the Maine Atlantic Salmon Commission, the Maine Department of Marine Resources, the Maine Department of Inland Fisheries and Wildlife, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service as described below. The purpose of the effectiveness testing is to determine the efficiency of both interim and permanent fish passage facilities to allow movement of Atlantic salmon and American eel past the project. Efficiency targets are 80 percent for interim facilities and 90 percent for permanent facilities, subject to confirmation through testing that the targets are reasonably achievable and scientifically valid for the species being tested. The efficiency targets may be revised following consultation and agreement among the licensee and the consulting agencies. Any such change shall be included in the licensee’s annual report to the Commission under Article 407 below.

(A) Interim downstream passage facilities. The licensee shall conduct radio telemetry studies, or other comparable studies agreeable to the licensee and the consulted agencies, and approved by the Commission [see 406(C) below], of the efficiency of interim downstream passage facilities for both American eel and Atlantic salmon for up to three years following the commencement of operation of those facilities for the respective species. For American eel, these studies are expected to take place in 2007, 2008, and 2009. For Atlantic salmon, the studies shall take place when the U.S. Fish and Wildlife Service and the Maine Atlantic Salmon Commission determine, after consultation with the licensee, that a sufficient number of appropriate salmon smolt are available for testing. The results of such studies shall be reviewed annually by the licensee and the consulted agencies, and study protocols and methodologies in any subsequent years adjusted as appropriate.

If the results of the efficiency studies indicate that a passage efficiency of 80 percent has been achieved for each species, the licensee shall maintain and operate the interim facility as built and have no further obligations for downstream American eel or Atlantic salmon passage until permanent facilities are installed after 2020. If efficiency is determined to be less than 80 percent for either species, the licensee shall work with the consulted agencies to develop a plan to modify the facilities or project operations. The plan shall be implemented after approval by the agencies, and the licensee shall then conduct additional studies, to be approved by the agencies, for up to three more years, using radio telemetry or other comparable studies, to assess downstream passage efficiency for both species. For American eel, the additional studies are expected to take place in 2010, 2011, and 2012. For Atlantic salmon, the studies would occur in the three years following the first three-year study period.

If efficiency is again determined to be less than 80 percent for either species, the licensee shall again work with agencies to determine a plan to modify downstream passage facilities or project operations. The plan shall be implemented after approval by the consulted agencies and the Commission [see 406(C) below]. The licensee may elect to conduct further studies of the efficiency of the facilities, in consultation with agencies. If further studies of efficiency for eel passage are not pursued, the licensee shall contribute funding in the amount of $12,500 annually for the Anson Project to an Eel Research and Enhancement Fund, continuing at the same annual rate (i.e., without application of any escalation rate) in subsequent years until permanent downstream passage facilities for American eel are installed. The fund shall be administered by a Committee composed of the Maine Department of Marine Resources, the U.S. Fish and Wildlife Service and the licensee.

(B) Permanent passage facilities. The licensee shall conduct post-construction studies of any permanent upstream and downstream fish passage facilities to monitor the facilities' effectiveness in achieving a target of 90 percent efficiency in the movement of American eel and Atlantic salmon through the facilities. At least six months prior to the completion of construction of any permanent upstream and downstream fish passage facilities after the project, and after consultation with and approval of the Maine Atlantic Salmon Commission, the Maine Department of Marine Resources, the Maine Department of Inland Fisheries and Wildlife, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service and approval by the Commission [see 406 (C) below].

(C) Study plans. The licensee shall prepare the plans in 406 (A) and (B) in consultation with the Maine Atlantic Salmon Commission, the Maine Department of Marine Resources, the Maine Department of Inland Fisheries and Wildlife, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service. The licensee shall include with each plan documentation of consultation on the completed plan after it has been prepared and provided to the agencies, and specific descriptions of how the agencies' comments were addressed in the plan and schedule. The licensee shall allow a minimum of 30 days for the agencies to comment and to make recommendations prior to filing the plan with the Commission for approval. If the licensee does not adopt a recommendation, the filing shall include the licensee's reasons, based on project-specific information.

The Commission reserves the right to require changes to the plans. The licensee shall not implement a plan until the licensee is notified by the Commission that the plan is approved. Upon Commission approval, the licensee shall implement the plan, including any changes to the plan required by the Commission. If the results of monitoring indicate that changes in project structures or operations, including alternative flow releases, are necessary to protect fish resources, the Commission may direct the licensee to modify project structures or operations.

Prior to making any deposits to the fund, the licensee shall convene a meeting of the other members of the Committee to establish by-laws and other operational procedures to govern the activities of the Committee. The operating procedures shall include a provision that decisions by the Committee regarding releases of monies from the fund shall be by consensus, and in the event that the Committee cannot reach consensus within a reasonable period of time, then a decision regarding release of monies from the fund shall be deemed to have been made by the Committee when a two-thirds vote has been achieved. The operating procedures shall also establish the frequency of meetings and the responsibility for chairing the meetings. Meeting notices and minutes shall be provided by the licensee and annual reports shall be filed with the Commission and the Maine Department of Environmental Protection by the licensee.

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An Investigation of the Feasibility of Employing Hydroacoustic Monitoring as a Means to Detect the Presence and Movement of Large, Adult Eels (Genus *Anguilla*)

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Cabot Station forebay, Connecticut River, Turners Falls, MA

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An Investigation of the Feasibility of Employing Hydroacoustic Monitoring as a Means to Detect the Presence and Movement of Large, Adult Eels (Genus *Anguilla)*

I INTRODUCTION

The management and conservation of world wide eel populations has become an issue of heightened concern in recent years, especially in North America, Europe, Asia and New Zealand. In the U.S., concerns have been raised regarding a significant increase in commercial harvest throughout most of the species' North American range, and a growing perception that recruitment to the fishery is declining at least in some river basins. Although the extent of, and causes for, this apparent decline are not documented, in recent years there has thus been growing concern among resource management agencies that greater measures must be taken to conserve remaining eel resources (ASMFC, in prep.). Fishery managers have expressed concern over potential human impacts, including mortality due to commercial over-exploitation, pollution, habitat destruction, and upstream and downstream passage at dams.

As a consequence, resource agencies have in some instances requested downstream passage improvements for adult emigrant eels at dams. However, most conventional fish passage designs are historically based on the biological and behavioral requirements of anadromous salmonids and clupeids. Recent observations indicate that eel migration patterns differ from those exhibited by anadromous fishes, and eel movements may vary site-specifically; thus conventional passage designs employed for other species may not effectively attract and pass eels. Little detailed behavioral information exists regarding eel movements during migration.

Examples of information important to the downstream eel passage issue are: Are eel outmigration movements primarily nocturnal or diurnal? Will eels respond predictably to light, sound, hydraulic or other stimuli? Where in the water column do eels swim when migrating? Do they "search" for a particular downstream outlet or attempt to pass whatever intake location they happen to encounter? What attracts or repels eels in a forebay? Do eels school or move individually? Will they pass via spillways and gates?

Study methods to reveal the run timing, behavior, spatial and temporal patterns of eel movements during emigration have thus far been limited to transmitter tagging and anecdotal observation. Thus conclusive information regarding eel movement at dams is limited. Haro and Castro-Santos (1997) investigated adult American eel (*Anguilla rostrata*) movements in a Connecticut River canal, using acoustic and radio telemetry. Barbin et al. (1998) also employed acoustic tags to investigate silver-phase American eel movements in the Penobscot River, Maine. However, telemetry methods have limitations, such as:

(a) small sample size,
(b) potential for alteration of the behavior of test specimens,
(c) limited resolution of spatial data,
(d) potentially high labor and material costs if the study objective is to track a significant number of eels and/or monitor movement for an extended time

period,
(e) loss of signals in deep water intakes and/or acoustic or electrical interference,
(f) tag transmitter or retention failure potentially confounding results, and
(g) difficulty in discerning individual or school responses.

An alternate method for observing the movement, spatial and temporal patterns of fish is hydroacoustic surveillance. This method has been successfully used to both enumerate and evaluate movements of migratory salmonids and clupeids. In general, hydroacoustics works best when:

(a) the fish target of interest has echo characteristics that separate it from other species by acoustic size or pattern, or by behavior (temporally or spatially),
(b) the acoustic environment has a low signal to noise ratio allowing one to sample target organisms without interference from acoustic scatterers in the environment, and
(c) targets from the fish of interest are separated from structures, surface and bottom interfaces.

Although it has never been applied to the aquatic movements of eels, hydroacoustic monitoring has the potential to define critical aspects of eel behavior relative to fish passage if it can acceptably detect eel targets under a suitable range of conditions. Brandt (unpublished data) experimentally used hydroacoustics to survey for eels in an open ocean environment. However, the feasibility of hydroacoustic sampling for eels in freshwater has not been explored, although it potentially represents an effective way to evaluate riverine movement, responses at instream barriers, and stimuli.

Hydroacoustic monitoring has several inherently advantageous characteristics:

(a) it can record the spatial patterns of individual or large numbers of targets over time without intrusive transmitters or risk of altering the behavior of the test subject
(b) a large area of river and/or any depth of intake or canal, etc. can be monitored
(c) real-time movements can be field-observed and recorded
(d) fixed aspect monitoring can be automated to operate indefinitely, minimizing labor costs associated with long-term data gathering

Hydroacoustic monitoring also has potential limitations:

(a) target discrimination is based on interpretation of fish echo patterns, which in turn can be influenced by localized environmental or physical site factors
(b) spatial sampling may require making and testing assumptions, or additional validation with supplementary field techniques
(c) it may be difficult to satisfactorily ensonify the entire passage zone of interest – i.e., fish located along walls, stream bottoms, or in zones of turbulence may not be detectable.

II OBJECTIVES

The primary objective of this pilot study is to evaluate whether adult eel echoes (corresponding in size to eels migrating downstream) can be discriminated from other common acoustic targets under both laboratory and field conditions. The focus of this study is limited to evaluating parameters necessary only for the purpose of gathering information on eel echo characteristics, spatial and temporal movement, and swimming behavior of eels in a riverine environment. Evaluation of methods to develop a quantitative estimate of the number of eels passing a point of interest, another potentially valid use of acoustic sampling, is beyond the scope of this investigation.

We have chosen to characterize acoustic echos from American eels and develop a mathematical acoustic model for this and two additional species of Australasian freshwater eels; the shortfinned (*A. australis*) and longfinned (*A. dieffenbachii*) eel. The latter two species are under similar impact from hydroelectric development and loss of habitat, and the acoustic estimates will be useful for future hydroacoustic surveys in New Zealand and Australia.

In this report we will:

(a) identify target strength and echo characteristics of adult eel under various orientations to the transducer,
(b) evaluate an application of using a fixed-aspect hydroacoustic system to detect in-field eel movements,
(c) derive a mathematical (Kirchoff-ray mode) model to estimate backscatter as a function of eel length, aspect, and acoustic frequency, and,
(d) provide recommendations specifically for applied use of hydroacoustic monitoring for evaluation of behavior and timing of eel movement.

III METHODS

Study Sites

Estimates of eel target strength were performed at the S. O. Conte Anadromous Fish Research Center (CAFRC), Turners Falls, Massachusetts. Live adult American eels were obtained from the Millers River (tributary of the Connecticut River, Franklin County, Massachusetts) and Cobbosee Stream (tributary of the Kennebec River, Kennebec County, Maine) in July and August, 1998. Eels were held unfed in concrete flow-through holding ponds (Burrows and Chenoweth 1970) at the CAFRC facility and supplied with ambient Connecticut River water (21 - 24 °C). Hydroacoustic calibration and target strength tests were performed in an isolated section of a second holding pond (Fig. 1) measuring 10 m x 1.75 m x 2 m water depth on August 27 and 28 (water temperature 24 °C). Monitoring of downstream migrant eel passage was performed in the forebay of Cabot Station, a 51 megawatt hydroelectric facility 0.5 km downstream of the Conte Laboratory on the Connecticut River (Fig. 2).

Eel Target Strength Determination

We used a Biosonics DT6000 digitial echosounder (DT Acquisition v3.05 software) with a 420 kHz split beam transducer (6° x 12° beam width) mounted at one end of the holding pond 1 m from the bottom. A standard spherical calibration target with known echo image characterisitics was suspended on the axis of the acoustic beam. The acoustic environment was placid and clear (i.e., water not flowing, and debris-free). It was necessary to subdue test specimens so that the fish would remain in the beam long enough for the desired number of pings to be collected. Eels were anesthetized in MS-222 or killed immediately before testing and suspended vertically in the water at mid depth (approximate center of transducer beam) from a bracket located above the pond by an attached single monofilament nylon line at a horizontal distance of 7 m from the transducer. We sampled with both 0.4 and 0.5 msec pulse widths at a sample rate of 5 pings/second. Target strengths (dorsal and lateral aspects) were measured for six test eels of varying sizes (350, 355, 580, 610, 670, and 685 mm SL). Test eels were then transported on ice to an x-ray facility and radiographs were taken of dorsal and lateral aspects of each fish. We used a Summit Innovet LX125V x-ray machine with the following settings: 300 mA, 1/120 second exposure, 30 kBp (small eels), 40 kPb (large eels).

Cabot Station Forebay Monitoring
To qualitatively verify the relative abundance of eels in the forebay during the hydroacoustic surveillance period, an underwater closed-circuit video camera was installed in the bypass weir to record passage of eels and other fishes. The bypass weir is located at the southern end of the station intake, and was outside the ensonified zone of the forebay (Fig. 2). The bypass weir was illuminated by a 1000-watt mercury vapor and 1000 watt sodium vapor lamp that are used for attraction of juvenile anadromous clupeids to the bypass. A sampling device that intercepts all fish passing the bypass is located downstream of the bypass weir. To enhance image contrast, a 1-m wide band extending across the floor of the bypass weir and the wall opposite the camera was painted white. Video recording was performed using time lapse video recorders (12 h mode; approximately 4 frames/sec) capable of logging the date and time of each passage event. Video recording was begun on 9 September and ended 14 November, but only during the night hours (17:00 to 05:00). Temperature data from the Cabot Station canal were logged on an hourly basis for the duration of the study. Flow data from the Connecticut River mainstem were obtained from the USGS gauging station at Montague City (2 km downstream of Cabot Station). Additional flow data were collected from the USGS gauging station on the Millers River, a tributary of the Connecticut River, at Erving, MA (10 km upstream from Cabot Station). The Millers River is not subject to alteration of flow by hydropower facilities. Daily rainfall data from a NOAA weather station in Sunderland, MA (approximately 20 km from Cabot Station) were obtained from the NOAA Climatic Data Center.

A field test to detect potential acoustic eel targets was performed in the forebay of Cabot Station. The objective of this test was to determine if it was feasible to qualitatively gather information on the timing and magnitude of eel movement in a section of the forebay with the type of acoustic equipment and target strength information gathered in the test pond. The test was performed using the same echosounder, 420 kHz split beam transducer, and software that was used in target strength estimation tests. The transducer was mounted from a steel pole next to a concrete forebay wall 6.5 m upstream of the trash racks at a depth of 1 m. The transducer beam was oriented across the forebay at an angle 12° upstream from a line parallel to the racks (Fig. 2), and downward at an angle of 5°. This configuration allowed us to sample at maximum range (45 m) across the forebay in an area just upstream of the trash racks, where eels have been observed at the surface swimming against the flow. The far end of the beam cone also sampled from the surface to the bottom (10 m). Precise beam position was determined by suspending a lead target at known three-dimensional positions relative to the transducer, recording target strengths for a two minute period, and calculating beam position based on a matrix of target position and strengths.

Hydroacoustic monitoring for eel targets in the forebay began on 17 September and terminated on 5 October. The echosounder sampled at 5 pings/second with a threshold of –50 dB and pulse width of 0.4 msec. Because of the large quantities of data collected, the threshold was increased to –41 dB during the overnight period of 23 - 24 September. The threshold was reduced back to -50 dB on 24 September, since data analysis revealed tracking of fish was not consistent with earlier data analysis at –50 dB. Monitoring was performed at night only, from sundown to sunrise (from approximately 18:30 to 06:30) daily. Hydroacoustic data were downloaded from the control computer on a daily basis, stored to disk, verified, and sent to Aquacoustics, Inc. for processing and analysis.

Acoustic Model
Dorsal and lateral radiographs of five American eels that were used in the target strength determination tests were converted to digital silhouettes by tracing the outer edges of bodies (not including fins) and swimbladders. Additional radiographs and tracings of one longfinned and two shortfinned eels were provided by J. Boubee, National Institute for Water and Atmospheric Research (NIWA), Hamilton, New Zealand. Tracings were then scanned and digitized at 1-mm resolution along the medial axis of the fish body using an automated algorithm. Dorsal and lateral body outlines traced on velum were used to check accuracy of body edge delineation on radiograph tracings.

IV DATA ANALYSIS

Eel Target Strength Determination
We analyzed eel target strengths by processing the data files through BioSonics DT Analyzer Version 3.1.1 software and outputting a database with echo location, target strength, and range. This database was filtered to remove targets other than from the eel as well as targets greater than 3 dB off axis (see *Results* section). The remaining targets are averaged to provide mean target strength for each eel sampled. These data are then regressed with the Log_{10} (total length) of the eel.

Cabot Station Forebay Monitoring
Videotapes from the Cabot Station bypass camera for the period from 18 September to 4 October were reviewed in their entirety (17:00 to 05:00) at approximately 5X normal speed. Fish passing the weir were identified to species (when possible) and recorded along with time of passage. A second reviewer assisted in identifying objects or fish that could not be characterized by the first reviewer. Counts of eels were summed on a daily and hourly basis; hourly counts were analyzed to determine patterns of frequency in eel passage over the nocturnal observation period. Because river flows increased significantly after 9 October, we also reviewed videotapes for the early evening hours (17:00 to 22:00) for the period from 5 October to 22 October in order to compare eel counts at the bypass during this freshet.

We analyzed the Cabot Station forebay acoustic data through BioSonics DT Vtracker Version 0.98 software and output a database with tracked fish target strength, range, number of pings for each fish, and direction of travel through the beam. Because most downstream migrant eels captured at the Cabot bypass sampler are greater than 70 cm TL, we filtered these tracked fish by selecting only those exceeding a mean target strength of -32.3 dB (70 cm) and –28.8 dB (100 cm). Counts of tracked fish were summed on a daily and hourly basis; daily and hourly counts were analyzed to determine patterns of frequency in eel passage over the period sampled and the nocturnal observation period.

Acoustic Model

A Kirchhoff-ray mode (KRM) model (Clay and Horne 1994) was used to estimate dorsal and lateral backscatter as a function of fish length, aspect, and acoustic carrier frequency for each eel. The KRM model coherently sums backscatter from a set of fluid-filled cylinders representing the body and a set of gas-filled cylinders representing the swimbladder. The model is parameterized for each eel and lengths are scaled for comparison. Full details of the model can be found in Clay and Horne (1994), Jech et al. (1995), or Horne and Jech (1999). Model backscatter values have been shown to match field measurements (Clay and Horne 1994; Jech et al. 1995) and the model has been applied to other species at numerous frequencies (Jech et al. 1995; Horne and Jech 1999). To quantify variation in backscatter amplitudes among American eels, the mean and standard deviation backscatter was predicted for dorsal and lateral orientation as a function of eel length, aspect, and acoustic wavelength. The fit of the model to measured target strengths was compared by plotting mean dorsal and lateral backscatter curves at 420 kHz and superimposing mean dorsal and lateral target strength values from five eels measured at the CAFRC holding pond. Trends in American eel backscatter response curves were compared to backscatter response curves of longfinned and shortfinned eels.

V RESULTS

Eel Target Strength Determination

Observed target strengths from backscatter measurements of individual eels in the holding pond varied by as much as 20 dB within sets of dorsal or lateral measurements. There were no consistent trends in amplitudes of dorsal (Fig. 3a) or lateral (Fig. 3b) backscattered echoes over time for each fish. Target strength measures also varied as a function of angle off the acoustic axis. Changes in angle off axis are due to lateral movement by the fish relative to the transducer face. To limit the amount of lateral movement included in the target strength data sets, only target strength measurements located within 3 degrees of the acoustic axis (i.e. the half power points of the transducer beam pattern) were included in comparison with predicted echo amplitudes. At a distance of 6.5 meters, this includes all targets within a 1.37 m swath along the wide axis (i.e. x-y plane) of the acoustic cone. Backscattered echo amplitudes also varied as a function of range from the transducer (Fig. 4a, b). Changes in distance from transducer also results because of movements or swaying by the animal. To limit the amount of range variability in acoustic measurements, observed target strength data sets were also filtered to include all targets at the modal range and those within 2 cm of the modal distance (Table 1). The combination of these two filters reduced the number of targets included in average target strength and variance calculations within data sets.

The mean target strength for both dorsal and lateral aspect along with combined dorsal and lateral aspect for each of the 8 eels sampled is regressed with the total length (cm) for each eel. The three regression equations generated are:

$$TS = 19.80 \, LOG(L) - 68.95 \text{ for dorsal aspect}$$

$$TS = 19.78 \, LOG(L) - 69.12 \text{ for lateral aspect}$$

$$TS = 22.42 \, LOG(L) - 73.59 \text{ for a combined aspect.}$$

These equations were used to generate a predicted acoustic target size for eels expected in the Cabot Station forebay during sampling in September and October 1998. Differences among the predicted length for the three equations was 3 cm at –32 dB to 10 cm at –29 dB for the lengths of eels found in the bypass during the sample period. Love's (1977) any aspect equation

$$TS = 20 \, LOG(L) - 69.23$$

predicts similar lengths to the eel equations derived from our tests (Table 2). Since we could not determine which aspect the acoustic system was sampling the eels in the forebay area, we used the combined equation to predict lengths for data analysis.

Cabot Station Forebay Monitoring
Field conditions (temperature, flow, and rainfall) for the months of September and October are given in Figs. 5a and b. Water temperatures were above normal and flows were below normal for the survey period. Drifting debris was relatively minimal throughout the survey period, and consisted largely of clumps of aquatic macrophytes (primarily *Vallisneria.* sp.) up to 0.5 m in diameter.

During video monitoring, night illumination of the bypass weir and water clarity were always sufficient to view completely across the 2.5 m weir, although not all fish-like objects could be identified to species (25.7 % of total number of identifiable and unidentifiable fish). Numbers of eels passing the weir on a nightly basis were relatively low (< 1 eel/h) during the period of hydroacoustic sampling (Tables 3 and 4, Fig. 6). A small increase in the number of eels at the bypass was noted on 1 October. However, counts of eels at the bypass weir on 8 October were an order of magnitude higher than on previous nights when hydroacoustic sampling was ongoing. Overall movement of eels through the bypass tended to occur in the early evening hours (Fig. 7).

Filtering the hydroacoustic data by size range produced varying results. The temporal distribution of tracked fish greater than 70 cm in the Cabot Station forebay indicated a peak in activity on the morning of September 23 and evening of September 24 (Table 3, Fig. 6a). A peak in numbers of targets greater than 100 cm occurred on September 23 and 24 (Table 4, Fig. 6a). The highest target detection rate occurred between 18:00 and 20:00 hours (Fig. 7a). Plotting the range and depth distribution for fish greater than 100 cm showed no trends for range across forebay or depth strata (Fig. 8). Fish greater than 100 cm did show a propensity for clumping as we observed 5 fish within a 7-minute period after sunset on September 23 (Fig. 9). Sample size for acoustics was

894 tracked fish greater than 70 cm and 84 greater than 100 cm (these only comprised 2% of the total fish tracked during the period).

Length distribution data from bypass sampler collections made in 1996 and 1997 was similar to that estimated from acoustically tracked fish (Fig. 10). Daily run timing for eels in the bypass was somewhat similar to acoustically tracked fish greater than 70 cm, but more closely resembled distribution for fish greater than 100 cm (Fig. 6a,b). Diel movements of acoustically tracked eels and eels observed in the bypass also showed some similarity (Fig. 7a,b), but the relationships between both daily and diel acoustic and video counts were low ($r^2 < 0.1$) and not statistically significant ($p < 0.05$).

Acoustic Model

Lengths of the five modeled American eels ranged from 362 mm to 691 mm with a mean length of 540 mm. The swimbladder of each fish is located below the spinal column in the anterior half of the body (Fig. 11). All swimbladders used in modeling exercises remained inflated in the radiographs. Anterior pneumatic ducts and swimbladders contained variable amounts of air.

The general shape of backscatter response surfaces was similar among and between dorsal (Fig. 12) and lateral (Fig. 13) orientations for all American eels. All fish were modeled at a length of 540 mm, through an aspect range of 70° to 110°, and an acoustic frequency range of 12 kHz to 420 kHz. Backscatter amplitudes were uniformly low at large deviations from horizontal (i.e., orthogonal to the incident acoustic wave front), and increased to a maximum near 90° (Table 5). This represents a fish orthogonal to a transducer face with no difference in the angle of swimbladder relative to the fish body. Along the fish length (L) to acoustic wavelength (λ) axis, if fish length L is kept constant, a higher L/λ value corresponds to a higher acoustic carrier frequency. Keeping the frequency constant illustrates the effect of changes in fish length on echo amplitude. Overall, there is less influence of fish aspect on target strength at low L/λ values. Throughout the L/λ range, the response surface is symmetric about the peak echo amplitude in dorsal and lateral backscatter response curves. The quasi-periodic peaks and valleys along the 90° aspect angle correspond to areas of constructive and destructive backscatter interference. Peak dorsal backscatter amplitudes exceed maximum lateral amplitudes for all eels.

Similarities and differences among laterally and dorsally oriented backscatter curves are clarified in the mean and standard deviation backscatter response surfaces. Amplitudes and variability in the dorsal orientation average surfaces (Fig. 14a) exceed those in the average lateral orientation plots (Fig. 14b). The decreased dependence of backscatter amplitude on aspect at low L/λ values is present in both surfaces. Peak amplitudes at any L/λ value occur at approximately 90° and decrease symmetrically as aspect angle deviates from horizontal. Standard deviation values are highest along aspect angles approximating 90°. A second area of high variability occurs in both orientations at aspects of 80° and L/λ values greater than 50. Variability in backscatter amplitudes is low at both orientations at aspects that deviate greater than 5° from horizontal.

The fit of the Kirchhoff-ray mode backscatter models to measured target strengths was examined by plotting predicted and observed mean target strength values at 420 kHz as a function of eel length over a range of 350 mm to 700 mm for dorsal and lateral orientations (Fig. 15). Dorsal and lateral predicted backscatter amplitudes non-monotonically increase as fish length increased. Predicted target strengths ranged from approximately -30 dB at 700 mm to -42 dB at 350 mm. At lengths greater than 400 mm, predicted dorsal backscatter amplitudes always exceeded predicted lateral backscatter amplitudes. With the exception of the second smallest eel (355 mm), observed mean lateral backscatter amplitudes always exceeded observed mean dorsal target strengths. Observed dorsal mean target strengths were biased low relative to the KRM model while observed lateral mean target strengths were biased high relative to the predicted backscatter.

American eel predicted backscatter response curves differed from the New Zealand longfinned and shortfinned eel backscatter response curves. The New Zealand longfinned eel dorsal response surface (Fig. 16), modeled at a fish length of 1260 mm, is distinctly different from the American eel response surfaces. The longfinned eel response surface contains a strong peak amplitude of 0.283 (-8.9 dB) at 92^{o} aspect and a L/λ value of 252 (292 kHz). Backscatter amplitudes remain high at larger L/λ values but are relatively low at other aspect and L/λ combinations. Reduced scattering length values drop rapidly when aspect deviates from horizontal. The shortfinned eel dorsal response surface (Fig.17) contains features similar to those observed in the American eel response surface. Backscatter from the shortfinned eel swimbladder was modeled as three separate chambers that included the anterior pneumatic duct. Backscatter amplitude was not as dependent on aspect at low L/λ values as it was at higher L/λ values. Predicted reduced scattering length peaked (0.128, -20.18 dB) at 376 kHz and 89^{o} aspect. Maximum backscatter amplitudes generally increased with increasing L/λ values and decreased as aspect angles deviated from horizontal.

VI DISCUSSION

Eel Target Strength Determination
Target strengths as determined from testing in the holding ponds yielded predictive equations that were similar to Love's (1977) any-aspect equations for a generalized fish. This result makes it impossible to discriminate eels from other similarly-sized fishes based on target strength alone. However, the abundance of non-eel species present in the Cabot canal that are larger then 70 cm TL (e.g., adult common carp (*Cyprinus carpio*), northern pike *(Esox lucius*), large adult smallmouth bass (*Micropterus dolomieui*), and walleye (*Stizostedion vitreum*); A. Haro, pers. obs.) is low, and few if any fish of this size were observed in the bypass. Variability in measured TS between eels within the 50 – 100 cm size range could probably be reduced by additional estimates of TS from a larger sample size. A test environment with less acoustic reverberation than the Burrows ponds would also reduce variability of TS estimates.

Cabot Station Forebay Monitoring
Given the results of the target strength estimates, there was no method to unequivocally determine whether "eel-sized" targets were in fact migrant eels, since TS of other species known to be present in the Cabot forebay are comparable to those measured for smaller eels. However, some indirect evidence supports the possibility that most of the eel-sized targets were in fact eels: 1) eels comprised the greatest proportion of large fish species observed at the bypass weir, and; 2) vertical and horizontal distribution of eel-sized targets within the forebay was uniform, which

reflects behavior of radio-tagged eels in the forebay observed in previous telemetry studies (Haro and Castro-Santos 1997). From nighttime visual observations at Cabot Station, smallmouth bass tend to be surface- or bottom-oriented; distribution of walleye and other species is unknown. There is also the possibility that large targets could have been debris (e.g., clumps of aquatic macrophytes), but we noted that most drifting debris occurred in the upper meter of the water column, while eel-sized targets occurred at all depths.

On a nightly basis, the number of acoustic targets per unit time did not match counts at the bypass weir. Low numbers of eels passing the bypass weir during the acoustic survey period (only several per night) may have contributed to this lack of correlation. Environmental conditions that promote downstream migration in eels (Vρllestad et al. 1986) were not favorable during the two week monitoring period, as river flow and water temperature decrease were minimal. Also, we did not observe the high numbers (>10 per night) of eels passing the bypass weir that we recorded during high flow/rainfall dates after 8 October, or in previous years' monitoring of the bypass sampler. Relationships between the diel (hourly) video and acoustic counts are better, and the general trend (highest numbers of eels and targets in the early evening) also reflects catch patterns at the bypass sampler in previous years.

Also, canal flows were not constant during the two week hydroacoustic monitoring period, as Cabot Station generation typically varies throughout the day during low-flow period. Higher canal flows may have inherently been associated with higher target counts per unit time. The lack of accurate forebay flow data (both magnitude and flow field characteristics) prevented us from analyzing the count data with respect to flow. Fish in the forebay may have been counted more than once by repeatedly passing through the acoustic beam over time. Greater than 95% of all eels counted in the bypass weir were swept into the bypass channel and did not return to the forebay, and hence were counted only once. Because of these additional complicating factors, strong relationships between acoustic and bypass counts may not be expected, but a gross trend might have been evident had a larger peak in downstream movement (such as occurred on 8 October) occurred during the survey. It should also be noted that estimation of accurate counts or density of eels in the Cabot forebay were not objectives of the study, and are beyond the scope of this effort. However, it appears from our results that the presence or absence of eels in the forebay and their spatial distribution can be inferred by hydroacoustic methods.

Acoustic Model

Predicted mean backscatter amplitudes differed from those measured in the CAFRC Burrows ponds. The American eels used in target strength experiments were large targets relative to the operating frequency of the echosounder. L/λ values used in the predicted and observed target strength comparison ranged from 98 to 192. Large length to wavelength ratio values indicate that echo returns from a single animal may be recorded as multiple targets and could potentially contribute to the variability observed in measured target strengths. Variability in maximum backscatter amplitudes in individual and mean predicted backscatter response curves also suggests that no specific frequency will maximize echo returns from all eels. The effect of fish aspect on echo amplitudes from dorsally or laterally oriented animals is consistent at all fish lengths and acoustic frequencies. An additional explanation for the mismatch in observed and predicted target strengths is the use of a shallow concrete pond to measure dorsal and lateral backscatter. Reverberation within the pond and the short range from transducer to target potentially contributed to the over 20 dB in target strength range observed in each set of target strength measurements.

A third procedural step that potentially contributed to the mismatch in target strengths is the time delay between target strength measurements and x-rays. Several hours elapsed between time of measurement at ambient water temperature, to storage in an ice-packed cooler, to x-ray at room temperature. The swimbladders of American eels are physostomous with a large duct joining the swimbladder and the oesophagus. The duct appears as a separate chamber and serves as a primitive lung (Steen 1963). It is not known if live eels change the volume of gas in the swimbladder and pneumatic duct while exposed to air for extended periods.

Comparison of target strengths between measured and modeled American eels ranged from 350 mm to 700 mm. This length range bracketed the range of lengths used to model eel backscatter response curves with the KRM models. Clay and Horne (1994) compared predicted target strengths of Atlantic cod (*Gadus morhua*) to maximum target strengths measured by Nakken and Olsen (1977). They found that a KRM model of a 38 cm fish matched observed scattering over a range of 8 cm to 100 cm. Since American eel swimbladder angles do not appear to vary dramatically from horizontal, modeled target strengths could be extrapolated beyond the range of lengths used in the model. High variability observed in measured target strengths and the non-monotonic increase in target strength with fish length reduces the predictive value of the KRM model.

Dorsal backscatter response curves for New Zealand shortfinned and longfinned eels were based on a single animal. The x-ray of the longfinned eel in a curled position increased the difficulty of constructing a straight body form. The large size (1260 mm) of the longfinned eel greatly increased the predicted target strength relative to the predicted target strengths of the American eels. Higher geometric scattering frequencies result in higher predicted backscatter amplitudes. Modeling the swimbladder of the shortfinned eel as three separate chambers did not appear to influence the character of the backscatter response curve. Features in the shortfinned response curve were similar to those observed in the American eel backscatter response curves. The anterior pneumatic duct was more apparent in the shortfinned eel radiograph than in any other eel radiograph. General anatomical arrangement of swimbladder, pneumatic duct, and relative position of swimbladder in body cavity was similar among American, longfinned, and shortfinned eels.

VII RECOMMENDATIONS

At present, it appears that hydroacoustics can be used as a qualitative tool to determine the spatial and temporal patterns of behavior of large (> 70 cm) eels in hydroelectric forebays. Verification of targets remains a critical aspect to the usefulness of hydroacoustic data, and concurrent monitoring of actual eel abundance (e.g., by video, netting, visual observation) should be performed as part of a hydroacoustic survey protocol. Where possible, the method of verification should be carefully chosen to most accurately reflect abundance of targets as determined by acoustic monitoring.

Also, discrimination of eel targets from those of other fishes remains problematic, but is also site-specific. In some circumstances, downstream migrant eels may be the largest or most abundant large targets in a survey area, adding confidence to positive identification of targets as eels (in most cases, however, this will be the exception). Where possible, we recommend that TS measurements of species that may potentially confound identification of acoustic targets be made.

Other confounding factors in a hydroacoustic survey will be water turbulence and turbidity, and the presence of drifting debris. In the case of this study, these effects were minimal, but it is generally accepted that peak downstream movements of eels will occur when these conditions may at times be at their worst for acoustic monitoring (i.e., high flows).

Additional acoustic modeling should improve discrimination among eel and other acoustic targets. Empirical verification of model target strength estimates with further in-situ measurements of eels would help to refine the current model. Comparison of American eel predicted and observed target strengths to those of other species found in the same water is the most prudent next step. If frequency-dependent target strengths differ among species then acoustic targets may be classified based on echo amplitudes or comparison of frequency-dependent echo amplitudes at more than one frequency. If target strengths are not radically different among species then quantitative measures of the echo envelope (i.e. the time-dependent amplitude of a received pulse) must be used to discriminate individual or groups of targets. Further analysis of the current dataset should be undertaken to determine whether other echo characteristics, such as pulse length, multiple echo reflection from a single eel, or behavior of eels passing through the beam can provide clues to differentiate eels from other fish targets. Future studies should include sampling with short pulse lengths to create multiple echoes from a single eel target. Additionally, quantitative information may be available at some intakes with trashrack openings that would exclude fish with target strengths similar to adult eels, yet allow eels to pass through.

VIII ACKNOWLEDGEMENTS

We express our sincere thanks to the Electric Corporation of New Zealand for supporting this study, and specifically to Dave Roper and Don Scarlet of ECNZ for assisting with the development of study objectives and target strength measurements. Sandra Howie of Aquacoustics, Inc. assisted with TS estimation, equipment setup and calibration at Cabot Station, and processing of hydroacoustic data. Ted Castro-Santos and Christopher Koch of CAFRC also assisted with eel collection, TS measurement, forebay monitoring, and data archiving. Theresa Guckian performed digitization of American, longfinned, and shortfinned eel tracings. Tom Shepard of the USGS Eastern Regional Office supplied river flow data. Our thanks also to Northeast Utilities Service Company for their cooperation, support, and use of the Cabot Station facility.

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Table 1. American eel (*Anguilla rostrata*) lengths, orientations (dor = dorsal, lat = lateral), number of original target strength measurements, number of filtered target strength measurements, original mean target strength $\overline{TS}$ ± standard deviation sd, filtered $\overline{TS}$ ± sd, and corresponding KRM predicted $\overline{TS}$ ± sd based on five American eel radiographs.

Fish Length (mm)		No. Original Targets	No. Filtered Targets	Original $\overline{TS} \pm sd$	Filtered $\overline{TS} \pm sd$	Predicted $\overline{TS} \pm sd$
350	dor	562	149	-41.4 ± 3.15	-38.5 ± 1.98	-39.5 ± 4.85
	lat	672	130	-40.0 ± 3.77	-38.0 ± 1.90	-42.7 ± 5.63
355	dor	893	105	-37.1 ± 3.63	-36.0 ± 1.86	-39.1 ± 2.27
	lat	758	162	-39.4 ± 3.46	-40.2 ± 2.80	-41.6 ± 4.10
580	dor	915	682	-38.4 ± 4.39	-38.7 ± 4.18	-35.4 ± 5.63
	lat	799	260	-35.5 ± 4.59	-35.9 ± 4.01	-34.7 ± 3.19
610	dor	430	250	-36.2 ± 3.58	-34.6 ± 2.42	-33.1 ± 2.75
	lat	488	165	-32.4 ± 4.94	-29.1 ± 2.95	-40.7 ± 11.56
670	dor	908	127	-34.3 ± 4.69	-29.6 ± 1.93	-35.5 ± 12.38
	lat	773	219	-30.7 ± 4.80	-28.5 ± 2.63	-38.5 ± 8.79
685	dor	1231	444	-34.6 ± 4.73	-33.2 ± 3.57	-33.4 ± 11.59
	lat	896	200	-34.2 ± 4.53	-33.8 ± 3.74	-31.5 ± 2.61

Table 2. Predicted lengths (cm) for eels using the three target strength/length regression equations generated from data collected in the Burrows ponds in August 1998 and Love's any aspect equation.

Target size (dB)	Combined Aspect	Dorsal Aspect	Lateral Aspect	Love's Any Aspect
-36	47	46	47	46
-35	53	52	53	51
-34	58	58	60	58
-33	65	65	67	65
-32	72	73	75	73
-31	79	83	85	82
-30	88	93	95	92
-29	97	104	107	103
-28	108	117	120	115
-27	120	131	135	129
-26	133	148	151	145

Table 3. Fish activity as measured by hydroacoustics in the Cabot Station forebay September 17 through October 5, 1998. These data represent the number of fish greater than 70 cm, with the converted total lengths from an acoustic target strength relationship for eels (TS = 22.42LOG(L) - 73.59) generated at the Conte Lab prior to field sampling. Note that counts during the period from the evening of 23 September through the morning of 24 September are abmormally high (probably due to alteration of echosounder threshold settings during this period), and were omitted from the dataset in further analyses.

Hour	17-Sep	18-Sep	19-Sep	20-Sep	21-Sep	22-Sep	23-Sep	24-Sep	25-Sep	26-Sep	27-Sep	28-Sep	29-Sep	30-Sep	1-Oct	2-Oct	3-Oct	4-Oct	5-Oct	Hourly Mean Rate
0		1.0	0.0	1.0	6.0	0.0	2.0	18.0	0.0	1.0	3.0	0.0	9.0	2.0	4.0	8.0	4.0	0.0	2.0	3.4
1		0.0	1.0	0.0	0.0	2.0	7.0	15.0	1.0	4.0	1.0	3.0	12.0	1.0	1.0	8.0	1.0	5.0	2.0	3.6
2		0.0	4.0	2.0	1.0	1.0	4.0	26.0	1.0	0.0	3.0	2.0	1.0	6.0		3.0	3.0	2.0	0.0	3.5
3		0.0	1.0	0.0	1.0	1.0	3.0	42.0	4.0	2.0	5.0	0.0	2.0	3.0	2.0	4.0	3.0	2.0	0.0	4.2
4		0.0	2.0	1.0	3.0	5.0	0.0	48.0	0.0	0.0	4.0	1.0	2.0	5.0	5.0	2.0	2.0	4.0	0.0	4.7
5			1.0	3.0	0.0	7.0	0.0	58.0	0.0	0.0	2.0	1.0	0.0	2.0	3.0	3.0	2.0	3.0	1.0	5.1
6			1.0	1.0	0.0	0.0	2.0	36.0	2.0	0.0	0.0	0.0	0.0	4.0	2.0	2.0	0.0	4.0	0.0	2.9
7				0.0			4.0								0.0	0.0				1.5
8							2.0									2.0				2.0
9							2.0													2.0
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
18	0.0			2.0	2.0		26.0	0.0	4.0	0.0	0.0	2.7				2.7	2.7	2.7		3.6
19	0.0	1.0		3.0	9.0		45.0	6.0	0.0	5.0	0.0	13.0	1.3	4.0		15.0	5.0	4.0		7.8
20	2.0	2.0	2.0	4.0	6.0		37.0	16.0	3.0	6.0	2.0	8.0	2.0	6.0	8.0	10.0	5.0	1.0		7.2
21	4.0	0.0	0.0	3.0	5.0	3.0		15.0	0.0	7.0	5.0	9.0	2.0	8.0	4.0	3.0	2.0	2.0		4.2
22	5.0	1.0	1.0	2.0	4.0	0.0		4.0	4.0	6.0	3.0	6.0	3.0	4.0	4.0	1.0	5.0	0.0		3.1
23	1.0	0.0	1.0	4.0		3.0		5.0	0.0	2.0	0.0	4.0	3.0	5.0	4.0	3.0	1.0	2.0		2.8
Daily Mean rate	2.1	0.5	1.7	2.0	3.8	2.3	10.0	22.6	1.3	2.8	2.3	4.0	3.4	4.2	3.3	4.6	2.9	2.3	0.8	4.3

Table 4. Fish activity as measured by hydroacoustics in the Cabot Station forebay September 17 through October 5, 1998. These data represent the number of fish greater than 100 cm, with the converted total lengths from an acoustic target strength relationship for eels (TS = 22.42LOG(L) - 73.59) generated at the Conte Lab prior to field sampling. Note that counts during the period from the evening of 23 September through the morning of 24 September are abmormally high (probably due to alteration of echosounder threshold settings during this period), and were omitted from the dataset in further analyses.

Hour	17-Sep	18-Sep	19-Sep	20-Sep	21-Sep	22-Sep	23-Sep	24-Sep	25-Sep	26-Sep	27-Sep	28-Sep	29-Sep	30-Sep	1-Oct	2-Oct	3-Oct	4-Oct	5-Oct	Hourly Mean Rate
0		0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0	1.0	0.4
1		0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0	1.0	0.0	0.3
2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0		0.0	1.0	0.0	0.0	0.2
3		0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.3
4		0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.2
5			0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.2
6			0.0	1.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.4
7				0.0			0.0								0.0	0.0				0.0
8							0.0									0.0				0.0
9							0.0													0.0
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
18	0.0			2.0	0.0		0.0	0.0	4.0	0.0	0.0	0.0				0.0	0.0	0.0		0.3
19	0.0	0.0		1.0	0.0		14.0	0.0	0.0	0.0	0.0	1.0	0.0	2.0		4.0	0.0	0.0		1.5
20	2.0	0.0	0.0	0.0	0.0		10.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0		0.9
21	0.0	0.0	0.0	0.0	1.0	0.0		2.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0		0.4
22	0.0	0.0	0.0	0.0	1.0	0.0		2.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0		0.2
23	0.0	0.0	0.0	0.0		0.0		2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0		0.2
Daily Mean rate	0.3	0.0	0.2	0.2	0.3	0.0	2.1	1.3	0.2	0.1	0.2	0.2	0.2	0.3	0.2	0.9	0.2	0.3	0.2	0.4

Table 5. Predicted minimum and maximum reduced scattering lengths RSL and corresponding target strengths TS, aspect angles θ (degrees), and acoustic frequencies *f* (kHz) of five dorsally and laterally oriented American eels (*Anguilla rostrata*). All backscatter amplitudes were estimated using a Kirchhoff-ray mode backscatter model (Clay and Horne 1994) and digitized radiographs of each fish. All fish were modeled at a length L of 0.54 m. Reduced scattering lengths can be converted to target strengths TS (dB) using: TS = 20 log(RSL) + 20 log (L).

Fish Length (mm)	Orientation	RSL_{min}	TS_{min} (dB)	θ_{min} (deg)	f_{min} (kHz)	RSL_{max}	TS_{max} (dB)	θ_{max} (deg)	f_{max} (kHz)
366	dorsal	0.0000554	-90.48	110	104	0.0951	-25.79	87	308
	lateral	0.0000761	-87.72	72	120	0.0758	-27.76	90	124
372	dorsal	0.000211	-78.86	75	156	0.0760	-27.73	90	28
	lateral	0.000330	-74.98	79	24	0.0654	-29.04	89	332
608	dorsal	0.0000662	-88.93	110	156	0.107	-24.76	89	68
	lateral	0.000190	-79.78	107	80	0.0763	-27.70	89	44
660	dorsal	0.0000599	-89.80	110	40	0.116	-24.06	88	344
	lateral	0.0000478	-91.76	110	128	0.0868	-26.58	90	168
691	dorsal	0.000103	-85.1	110	12	0.110	-24.52	89	148
	lateral	0.000285	-76.26	110	48	0.0793	-27.37	89	120

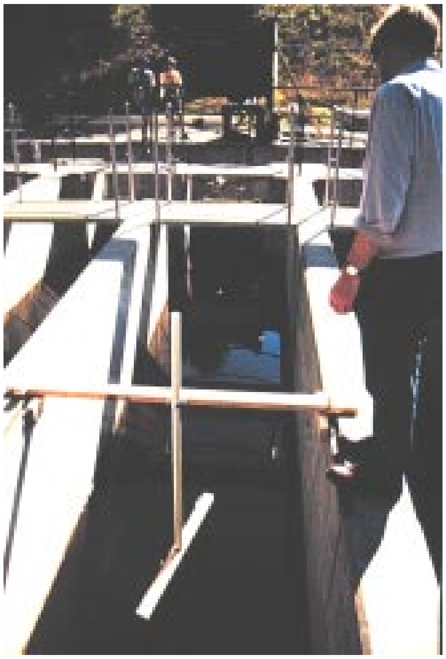

Figure 1. Acoustic measurement of eels in the Burrows pond at the Conte Laboratory. Anesthetized or freshly killed eels were suspended vertically from the rotating frame in the foreground, allowing for measurement of target strength in dorsal and lateral aspects. The transducer (not visible) was mounted at the far end of the pond at mid-depth.

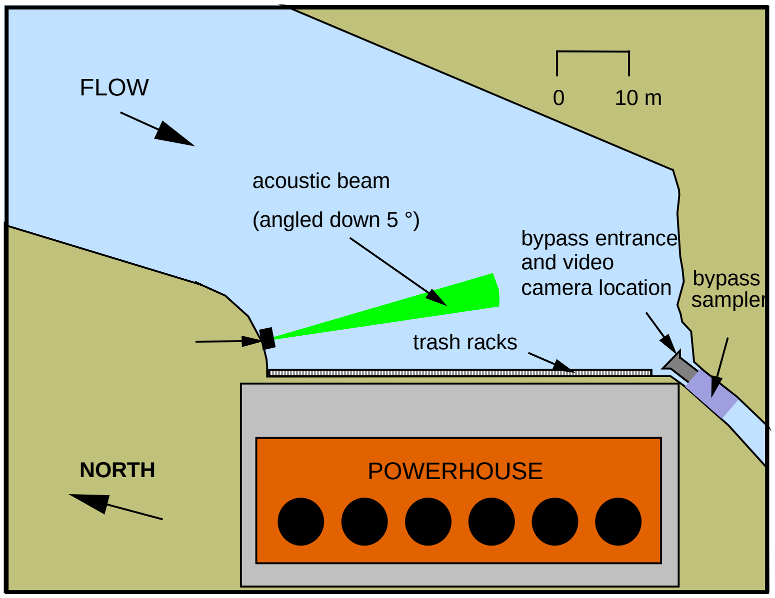

Figure 2. Plan view of Cabot Station forebay showing position of transducer, orientation of acoustic beam, and bypass. Forebay depth is approximately 10 m.

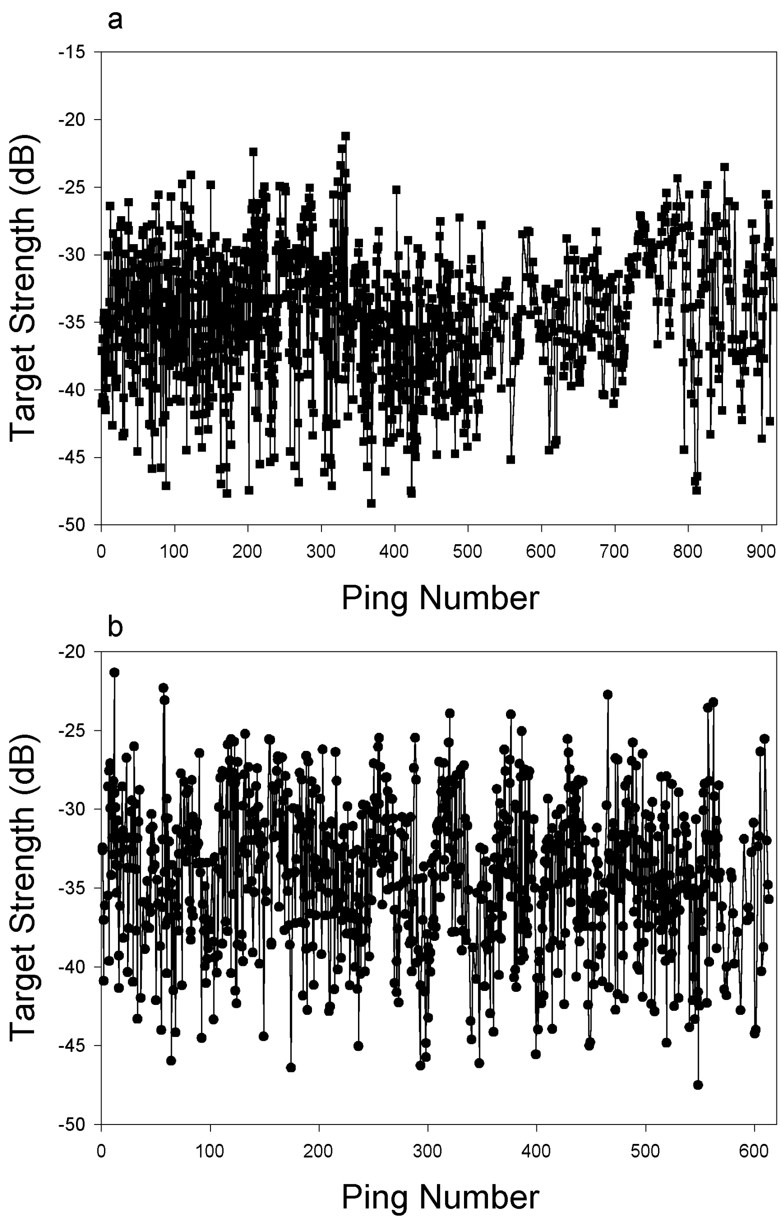

Figure 3. Observed target strengths (dB) of a 685 mm a) dorsally and b) laterally oriented American eel plotted as a function of pulse number.

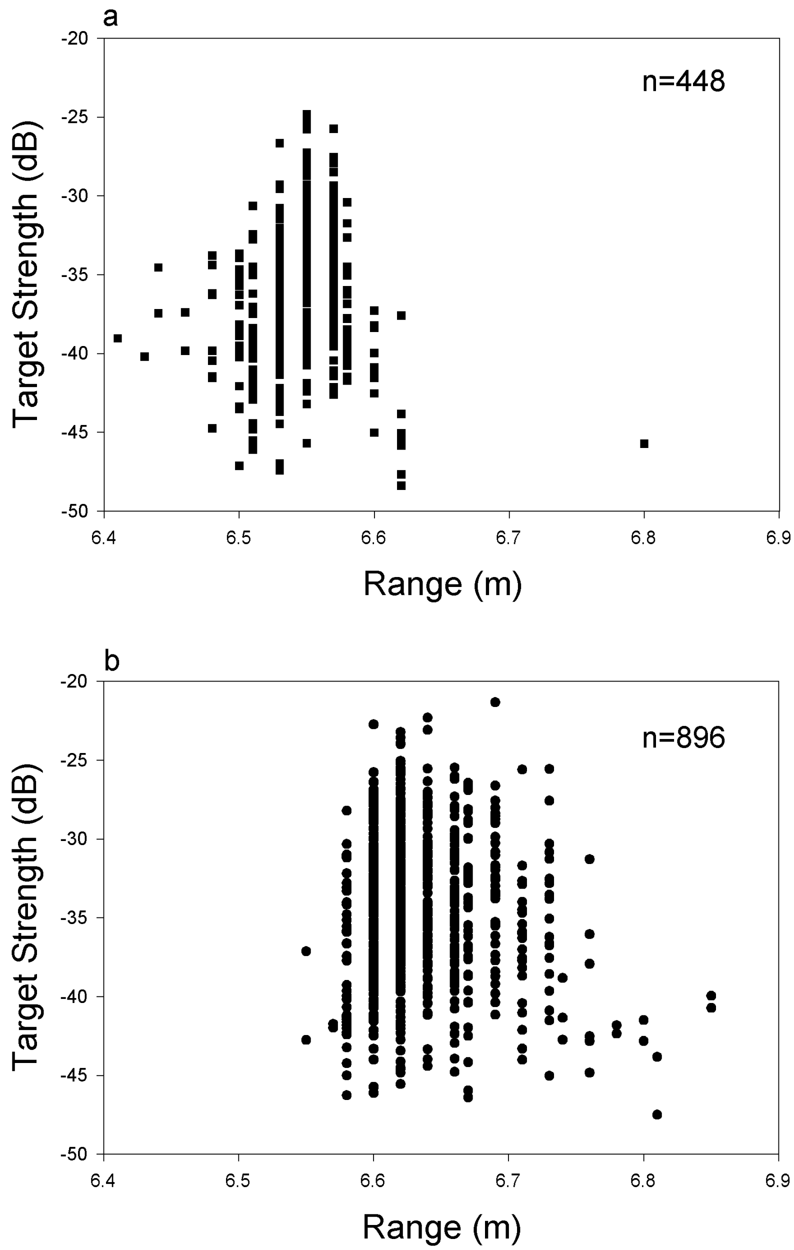

Figure 4. Observed target strengths (dB) of a 685 mm a) dorsally and b) laterally oriented American eel plotted as a function of range (m) from transducer.

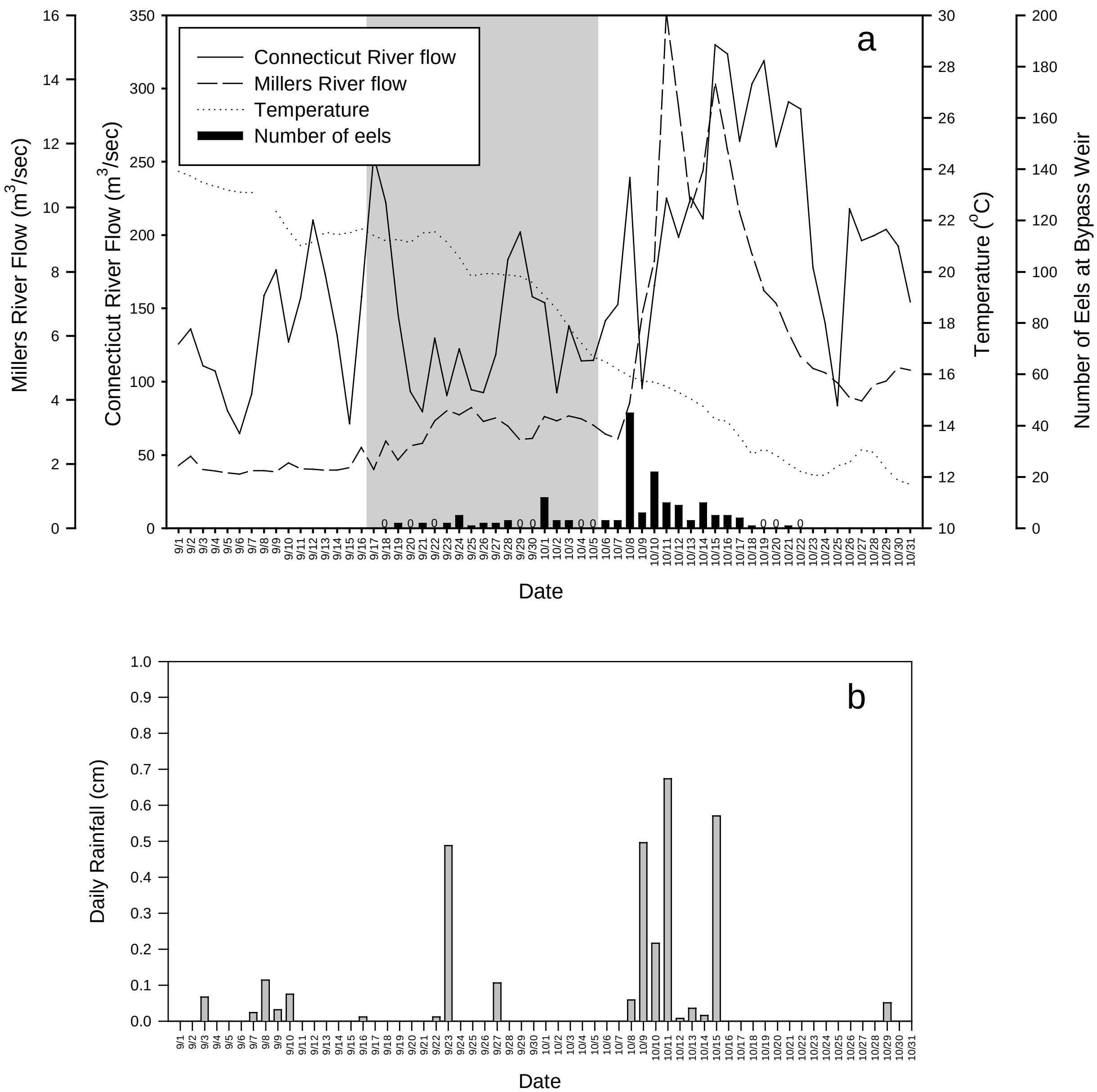

Figure 5. (a) Flow and temperature data from the Connecticut and Millers Rivers, September – October, 1998, and video counts of eels at the Cabot bypass weir during the evening hours (17:00 – 22:00). Gray zone indicates period of hydroacoustic monitoring; videotapes were analyzed only for the period from 18 September to 22 October. (b) Daily rainfall data from Sunderland, Massachusetts.

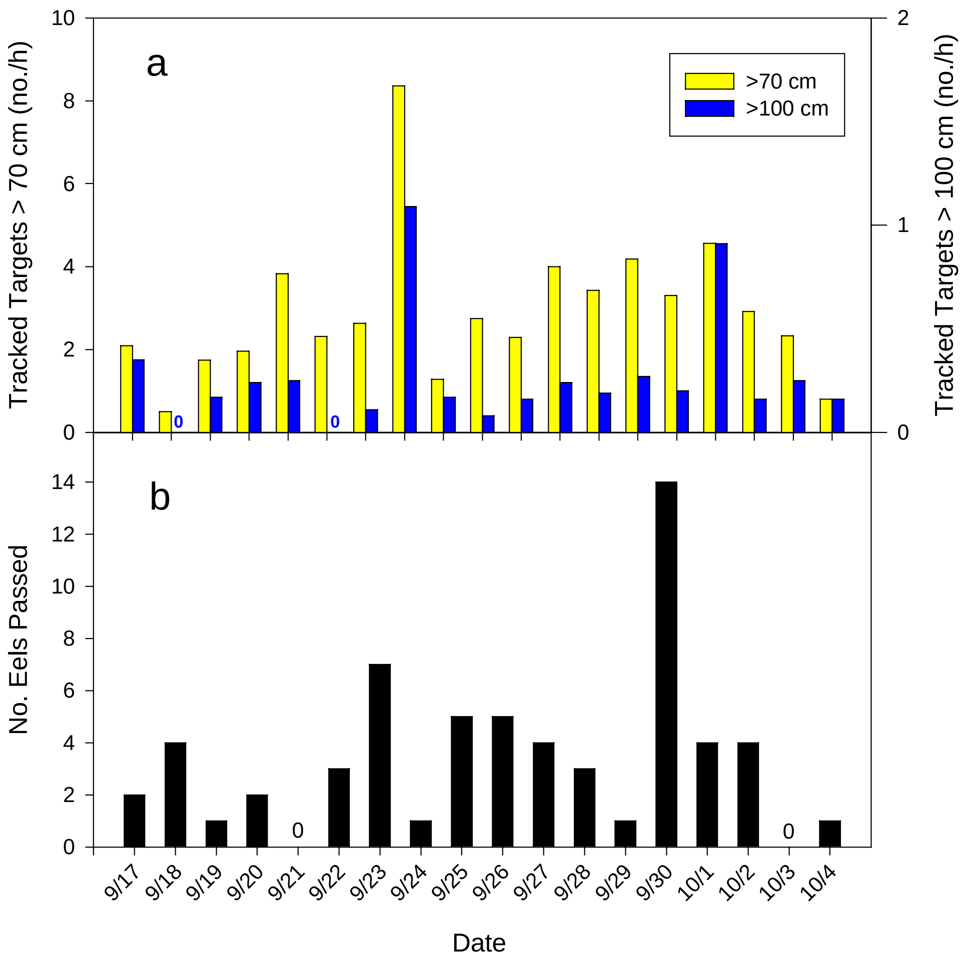

Figure 6. Distribution of nightly counts (00:00 to 06:00 and 18:00 to 23:59 within a single date) of (a) acoustically tracked targets and (b) counts of eels via video at the Cabot bypass sampler.

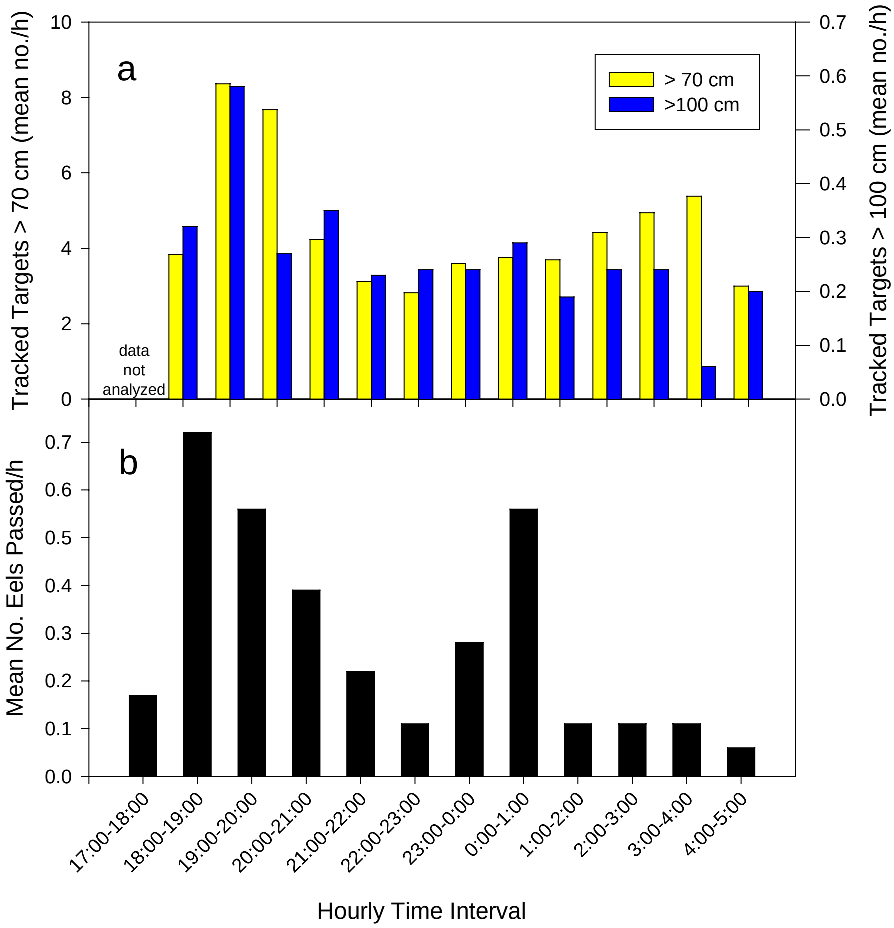

Figure 7. Diel distribution of (a) mean number of acoustically tracked targets and (b) video counts of eels the Cabot bypass sampler from 17 September to 4 October. Acoustic data from 17:00 to 18:00 were not analyzed due to incomplete sampling (no data from 6 of 18 days) during this time interval.

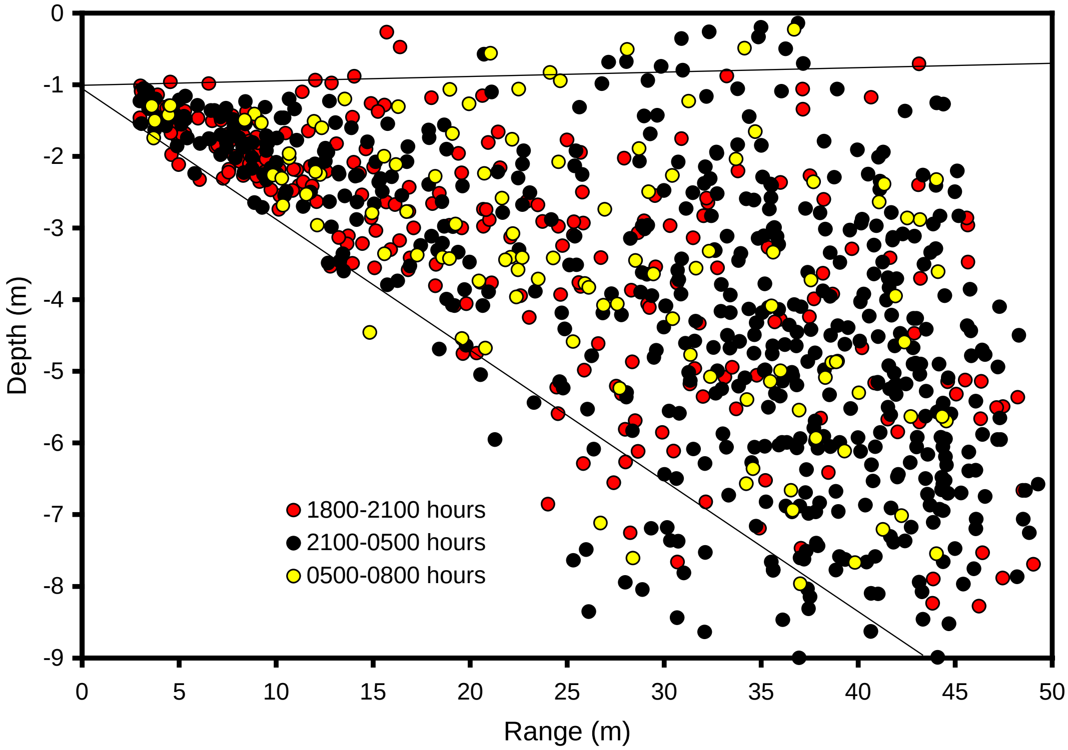

Figure 8. Range and depth distribution of tracked fish > 70 cm grouped by 3 intervals. The sample area for the transducer beam is depicted with the solid lines extending from the transducer (mounted at range 0 and depth of 1 m).

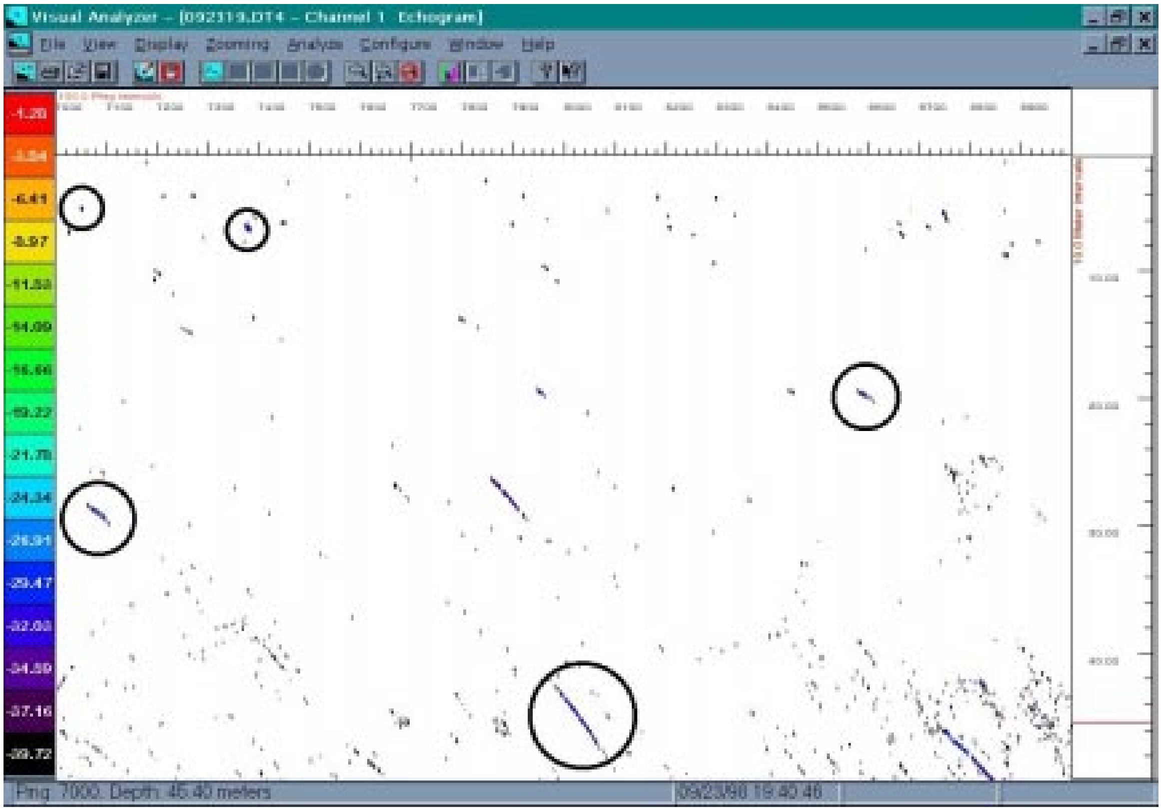

Figure 9. Echogram of tracked targets, September 23, 19:23 – 19:30 hours. Targets (circles) exceeded a target strength of –28.8 dB (100 cm).

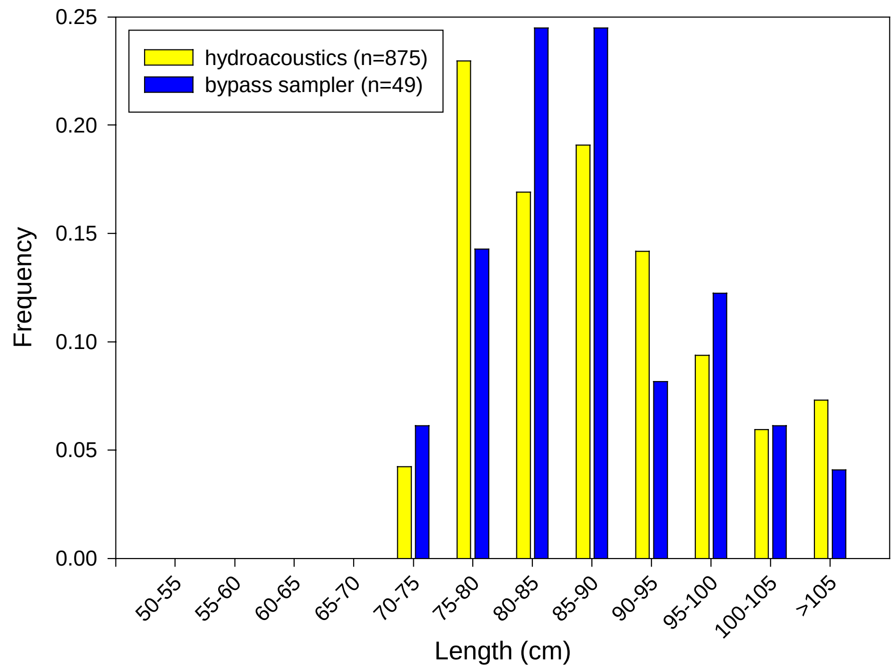

Figure 10. Distribution of lengths of eels captured at the Cabot Station bypass sampler in 1996 and 1997 and estimated by 1998 hydroacoustic target strength. Hydroacoustic data only includes targets >70 cm.

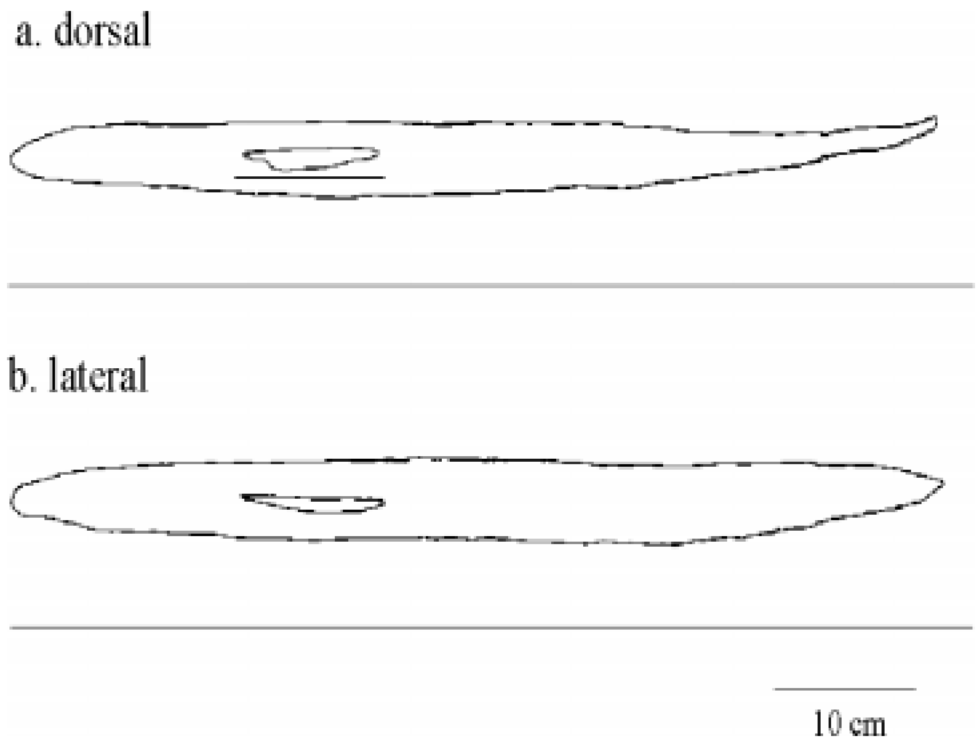

Figure 11. Schematic diagrams of a) dorsal and b) lateral orientations of a 660 mm American eel (*Anguilla rostrata*) body and swimbladder. Silhouettes are traced from radiographs, scanned, and then digitized at 1 mm resolution

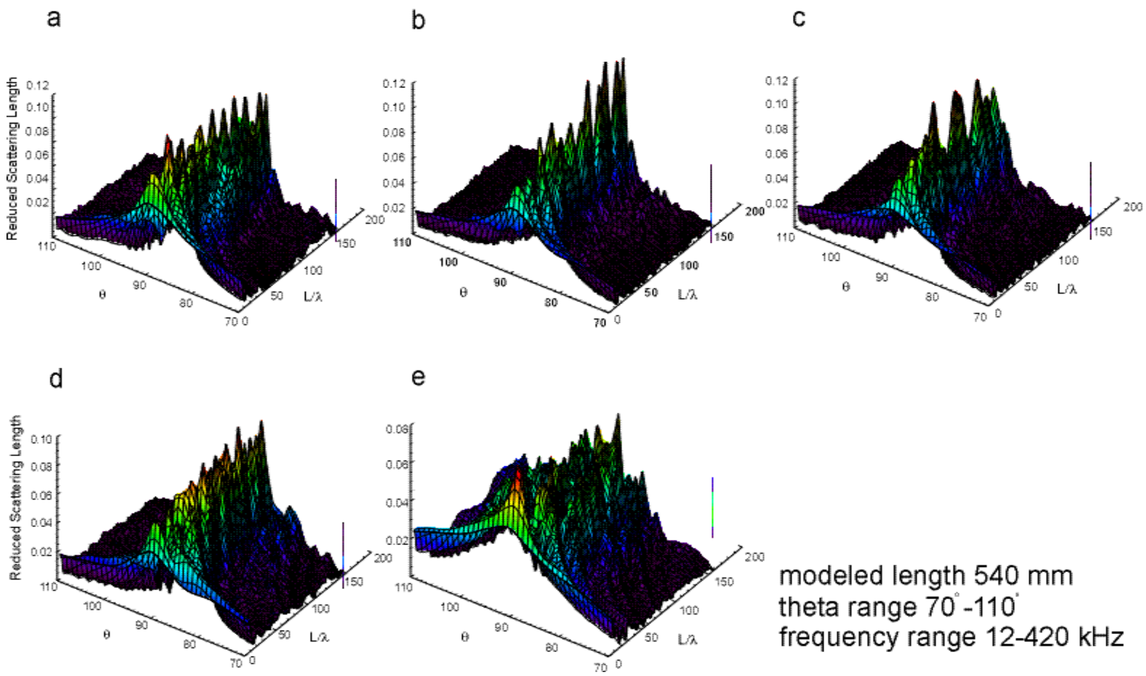

Figure 12. Kirchhoff-ray mode predicted dorsal, reduced scattering lengths of five American eels (*Anguilla rostrata*) as a function of fish aspect θ, length L, and acoustic wavelength λ. All eels were modeled at a length of 540 mm, an aspect range of 70 ° to 110°, and a frequency range of 12 kHz to 420 kHz. Original eel lengths were: a) 608 mm, b) 660 mm, c) 691 mm, d) 366 mm, and e) 372 mm.

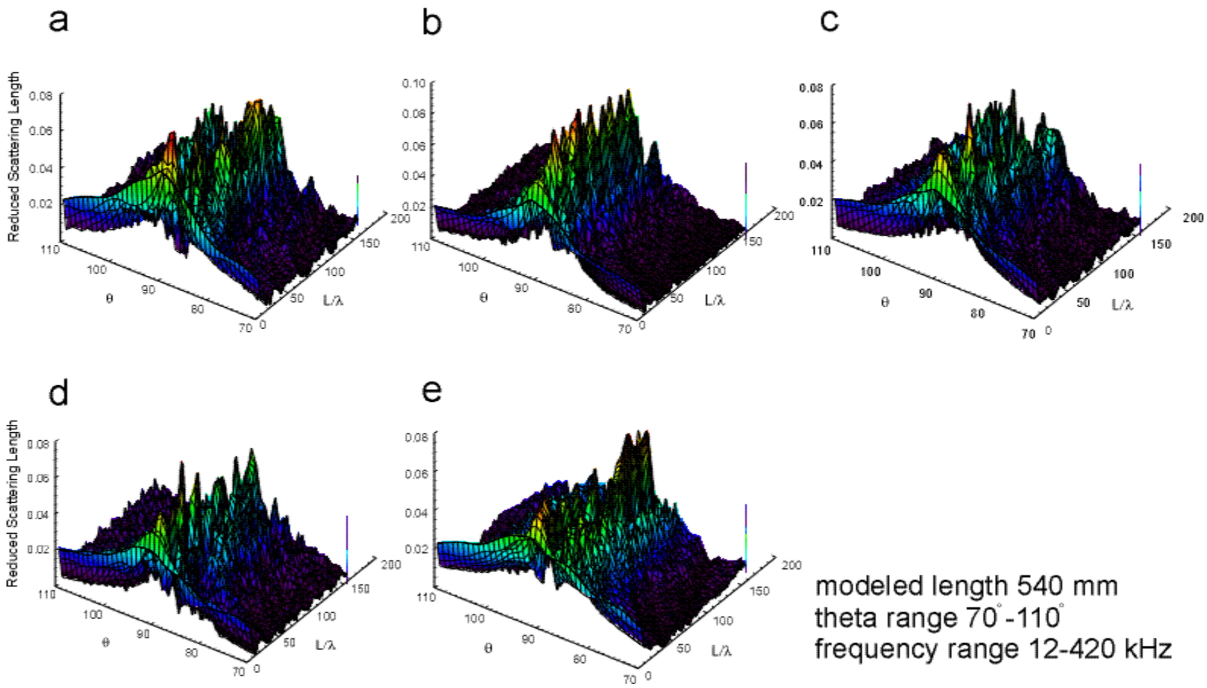

Figure 13. Kirchhoff-ray mode predicted lateral, reduced scattering lengths of five American eels (*Anguilla rostrata*) as a function of fish aspect θ, length L, and acoustic wavelength λ. All eels were modeled at a length of 540 mm, an aspect range of 70° to 110°, and a frequency range of 12 kHz to 420 kHz. Original eel lengths were: a) 608 mm, b) 660 mm, c) 691 mm, d) 366 mm, and e) 372 mm.

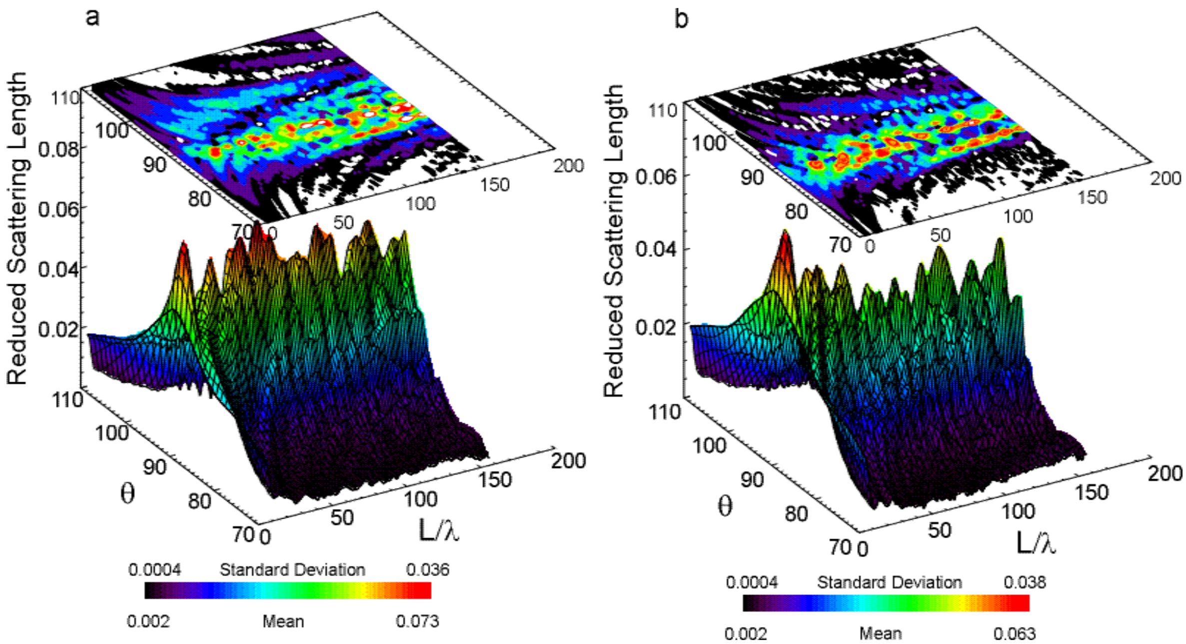

Figure 14. Kirchhoff-ray mode predicted mean and standard deviation reduced scattering lengths of five American eels (*Anguilla rostrata*) from a) dorsal and b) lateral perspectives. Reduced scattering lengths are plotted as a function of fish aspect θ, length L, and acoustic wavelength λ. All eels were modeled at a length of 540 mm, an aspect range of 70° to 110°, and a frequency range of 12 kHz to 420 kHz.

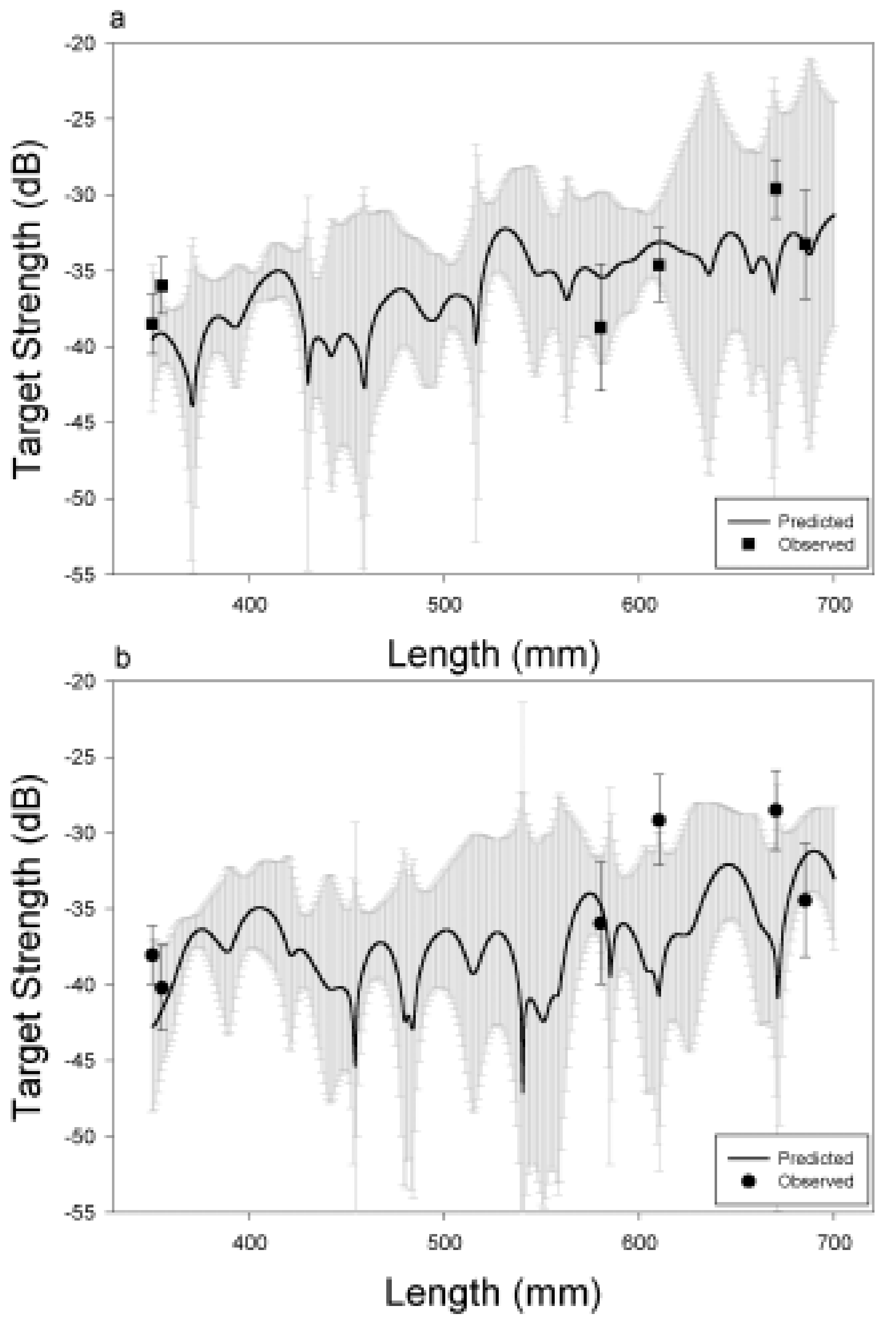

Figure 15. Kirchhoff-ray mode 420 kHz predicted a) dorsal and b) lateral mean and standard deviation target strengths of five American eels (*Anguilla rostrata*) (from Figs. 4 and 5) plotted as a function of fish length. Observed dorsal and lateral mean and standard deviation target strengths are overlayed for six eels used in target strength measures.

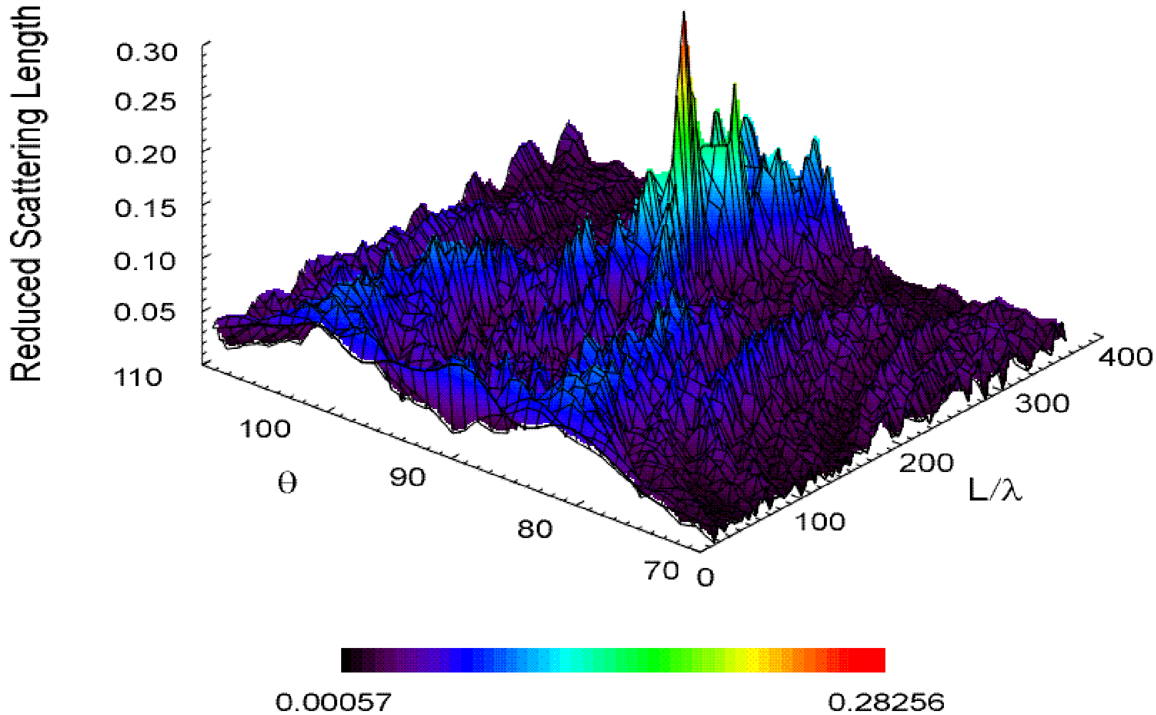

Figure 16. Kirchhoff-ray mode predicted dorsal, reduced scattering lengths of a New Zealand longfinned eel (*Anguilla deiffenbachii*) as a function of fish aspect θ, length L, and acoustic wavelength λ. The eel was modeled at a length of 1260 mm, an aspect range of 70° to 110°, and a frequency range of 12 kHz to 420 kHz.

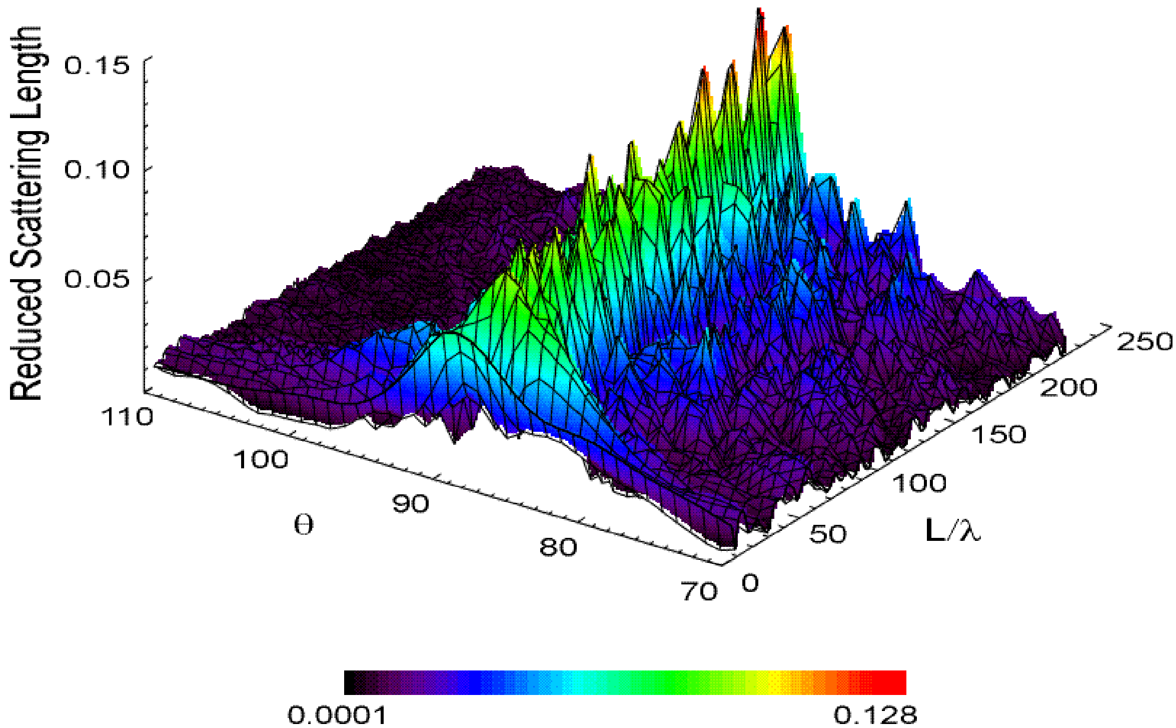

Figure 17. Kirchhoff-ray mode predicted dorsal, reduced scattering lengths of a New Zealand shortfinned eel (*Anguilla australis*) as a function of fish aspect θ, length L, and acoustic wavelength λ. The eel was modeled at a length of 765 mm, an aspect range of 70^{o} to 110^{o}, and a frequency range of 12 kHz to 420 kHz.

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