ACOUSTIC HYDROPHONE (*IC*LISTEN) DEPLOYED ON AN ATLANTIC STURGEON (*ACIPENSER OXYRINCHUS OXYRINCHUS*) TO MEASURE HABITAT SPECIFIC NOISE IN THE MINAS BASIN, NOVA SCOTIA

by

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ABSTRACT

Electronic tags attached to marine mammals and fish have been developed to sample temperature, pressure (depth), and location. Currently, no tag contains a built in broadband acoustic hydrophone. In this project, as a proof of concept, we attached a full-size high frequency 200 kHz 24-bit smart hydrophone (*ic*Listen) to an Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in order to measure ambient noise from the Minas Basin, Nova Scotia. The front end of the *ic*Listen hydrophone was secured to the Atlantic sturgeon through use of a Velcro strap that went around its abdomen, behind the pectoral fins. A line of dissolving suture thread, which passed through a dorsal scute, secured the back end of the *ic*Listen to the fish. A V13P acoustic tag glued to the exterior of the *ic*Listen was used to track the bioprobe with a VR100 manual tracking unit. Three galvanic releases built into the design corroded after approximately seven hours and released the *ic*Listen from the fish. Syntactic foam allowed the *ic*Listen to float vertically at the surface and a Single Position Only Tag (SPOT-100) then transmitted location signals to the ARGOS satellite system to direct researchers attempting to retrieve the *ic*Listen. Approximately eight hours of acoustic data was collected by the *ic*Listen hydrophone during its deployment. Ambient noise was recorded, including a splash upon release, shrimp snapping, boat engine noise, waves, harbour porpoise clicks, and signals from Vemco acoustic transmitters implanted within other fish. Echolocation clicks from a harbour porpoise (*Phocoena phocoena*) were recorded by the *ic*Listen during two separate interactions, both indicating a possible attempt at communication with an acoustic tag. Ten acoustic transmitters were picked up by the VR100; five from Atlantic sturgeon tagged between 2010 and 2012, and five others from striped bass (*Morone saxatilis*) tagged in 2012. The VR100 identified the IDs of uniquely coded tags, provided a time and location stamp for detections and recorded pressure (depth) readings from some tags. This study provided proof of concept for the deployment of an *ic*Listen hydrophone on a marine bioprobe in order to record ambient acoustic data. Insight into the interactions between marine mammals and acoustically tagged fish was gained, and tag data allowed a rough estimate of untagged Atlantic sturgeon to be calculated for the study site, off Kingsport, Nova Scotia.

INTRODUCTION

History of tagging

Before the development of electronic tagging technology, researchers used conventional tags to gain information on animal movement (Ricker, 1975). Conventional tags are typically made of plastic and carry information such as the researcher's address for fishers to contact if they capture a tagged animal. Data recovered from these experiments included a deployment position and an end point position. Data was often geographically patchy (Lacroix, 2012) because tags were only deployed and recaptured in areas where fisheries were active. Limitations in tag returns also exist when, occasionally, fishers will choose to not return tags if they are not properly invested in the study (Stokesbury et al., 2009). Biases in conventional tag studies exist partially due to this dependence on tag returns from the fisheries (Ricker, 1975).

Recently, the use of new electronic tagging technology has greatly facilitated the acquisition of a wide variety of unbiased data on animal movement, migration and behaviour (Lutcavage et al., 1999, Heupel et al., 2004, Block et al., 2005, Lacroix, 2008, Heupel et al., 2012). Two groups of electronic tags, acoustic and archival, are commonly used in marine research. The global leader in producing acoustic tagging technology is Vemco Ltd. of Halifax, Nova Scotia. Founded in 1979, Vemco has developed a wide selection of acoustic transmitters and receivers with increasingly efficient detection systems. Coded acoustic tags may be attached externally or can be surgically implanted into the peritoneal cavity of aquatic animals. These tags transmit a unique acoustic signal consisting of a series of "pings" which may be picked up by an acoustic receiver (hydrophone) when the fish comes within about 500 m (Stokesbury et al., 2009).

Acoustic receivers will identify a tag based on its unique acoustic pulse and repeat interval, and will then log the tag ID and serial number along with the date, time and the GPS location of the detection. Receivers, such as Vemco's VR2W, may be moored underwater at various sites around a study area for passive recording. Active manual tracking may be performed from a research vessel using a VR100 acoustic receiver. Acoustic tracking can provide researchers with valuable information on the movement patterns of fish around the study site. Furthermore, acoustic tags capable of measuring physical variables of the water column such as temperature and pressure (depth) are also available.

In 1994, the miniaturization of acoustic transmitters to a size in which they could be implanted into wild Atlantic salmon (*Salmo salar*) smolts was a significant development for Vemco and opened new doors for scientists. The increasingly small size, improved shape for greater retention, delayed activation, RCODE system, and extended battery life were all advantageous characteristics of the new acoustic transmitters. A study by Voegeli et al. (1998) that involved surgically implanting dummy transmitters into wild Atlantic salmon smolts, determined that the smaller V8 tags (8 mm diameter and 24 mm length) worked best. The larger tags, with lengths of 28 mm and 32 mm, caused some mortality or were expelled after 5-6 months. The capsule-shaped tags were altered slightly to have smoother, more rounded ends which helped to increase tag retention (Voegeli et al., 1998).

Vemco V8 tags were developed to transmit only after a preset delay so that they could be implanted into hatchery-reared Atlantic salmon smolts before they reached their final stage of smoltification, and the fish could be monitored before release (Voegeli et al., 1998). The V8 tags were found to last about 75 days after release and they had a detection distance ranging between 250 and 500 m, depending on environmental conditions such as water turbulence (Voegeli et al., 1998). The RCODE system used in the V8 tags was developed to overcome the issue of code collision by having code pulses transmit infrequently and at different repeat intervals so that they would not overlap repeatedly (Voegeli et al., 1998). The delayed start and randomization of transmission inside a set window of time extended the battery life of the tags (Voegeli et al., 1998).

Acoustic tags have generally worked best for studies investigating the movement patterns of fish that do not often come to the surface, whereas archival tags have been reserved for surfacing aquatic animals such as marine mammals (Stokesbury et al., 2009). However, some larger pelagic fishes such as sharks, tuna and sturgeon have also been equipped with pop-up satellite archival tags (PSATs). Satellite tags must be attached to large fish externally through the use of a monofilament leader and a stainless steel or titanium dart generally inserted at the base of the dorsal fin in Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*; Erickson et al., 2011), Atlantic bluefin tuna (*Thunnus thynnus*; Block et al., 1998) and Greenland sharks (*Somniosus microcephalus*; Stokesbury et al., 2005). The placement of the tags in this location minimizes contact with the body and reduces disturbance of regular swimming patterns (Block et al., 1998). Satellite tags have also been attached to Atlantic sturgeon by drilling a small hole through a dorsal scute, through which a monofilament leader, covered in shrink-wrap, is looped and then crimped to itself. This method was developed because it was less invasive and more secure (Erickson et al., 2011, Beardsall et al., In Review).

Archival tags use sensors to measure physical variables such as temperature and pressure (depth) as well as to provide geolocation signals (based on ambient light levels). The data stream is archived in the tag to be transmitted either through a satellite or cell phone connection, or downloaded when physically recovered by the researcher. The tag is released from the animal on a pre-programmed date when an electrical signal causes attachment pins to corrode. Once released, the tag floats at the surface with the antenna extending upward and transmits condensed data files that can be relayed to Advanced Research and Global Observation Satellites (ARGOS) as they pass overhead (Block et al., 1998). If the satellite tag is physically recovered, all the raw data it has stored may be downloaded to a computer. However, this can be difficult to accomplish, making satellite tags very expensive to use. Wildlife Computers Ltd. has manufactured a variety of satellite tags, of which the PAT-Mk10 has been deployed on large fish including tiger sharks (*Galeocerdo cuvier*; Holland et al., 2001), Greenland sharks (Stokesbury et al., 2005), Atlantic bluefin tuna (Block et al., 1998, Stokesbury et al., 2004) and Atlantic sturgeon (Erickson et al., 2011). In recent years, the MiniPAT, also manufactured by Wildlife Computers Ltd., has been used more frequently in tracking studies on Atlantic bluefin tuna (Wilson et al., 2011) and American eels (*Anguilla rostrata*; Beguer et al., 2012).

Advances in satellite tag technology have been driven largely by research on Atlantic bluefin tuna. Satellite tags were first deployed on Atlantic bluefin tuna in 1997 to investigate their movements across the Atlantic Ocean and to determine whether the eastern and western stocks overlap (Block et al., 1998). The tags also collected thermal data which provided some insights into bluefin tuna temperature preferences for the warmer water of the Gulf Stream over the shallow continental shelf (Block et al., 1998). Advanced very high resolution radiometer (AVHRR) imagery data confirmed for a few tagged individuals that they were utilizing the Gulf Stream (Block et al., 1998). The satellite tags were secured to the bluefin tuna for up to 90 days and gathered temperature and daily positional data based on light intensity (Block et al., 1998). Only 2 of 37 pop-up satellite tags did not transmit back, perhaps due to tag failure or mortality, however the 95% success rate confirmed the potential for further use of this tagging technology in research with Atlantic bluefin tuna (Block et al., 1998).

In a paper reporting electronic tagging results from the first ten years of the Tag-A-Giant program, Block et al. (2005) reported results from the electronic tags of 772 Atlantic bluefin tuna in the Western Atlantic Ocean. Tagging data revealed that bluefin tuna from the western stock frequented foraging grounds in the Eastern Atlantic Ocean and therefore were being captured and counted against the eastern stock quota, instead of the western stock quota. Therefore, high quotas for bluefin tuna in the Eastern Atlantic Ocean were likely impeding the recovery of the Western Atlantic Ocean stock (Block et al., 2005). This was one of the first demonstrations of the power of electronic tagging technology to influence international fisheries management.

A recently developed combination archival and acoustic tag is the Communicating Histogram Archiving Transmitter (CHAT) which may be prompted to download data to an acoustic receiver only when cued by this device (Stokesbury et al., 2009). This advance would greatly extend the battery life of the tag as it would not be transmitting data continuously, as with acoustic tags, but only when cued to do so. These tags were tested with tiger sharks (Holland et al., 2001). However, researchers found that the data download process took too long and often the mobile fish would move out of range before the process was completed (Stokesbury et al., 2009).

Another recently developed tag, the hybrid “business card” (BC) tag has incorporated elements from acoustic transmitters, satellite tags and receivers into a single device (Holland et al., 2009). BC tags were attached to Galapagos sharks (*Carcharhinus galapagensis*) externally through the use of a titanium steel dart inserted at the base of the dorsal fin (Holland et al., 2009). These tags employ a mobile peer-to-peer (MP2P) technology which enables them to exchange codes (or IDs) with other BC-tagged individuals, as well as pick up codes from acoustically tagged individuals that come within transmission range (Holland et al., 2009). The timing of the encounters may also be recorded by each tag (Holland et al., 2009). However, a significant drawback in the use of BC tags is that they have to be physically recovered in order to retrieve the stored data, which could be difficult for species with unpredictable movements (Holland et al., 2009). Furthermore, the tag batteries did not last beyond four months of deployment, due to the energy intensive short duty cycles, alternating between transmission and listening (Holland et al., 2009). Currently, BC tags are unable to provide positional data (Holland et al., 2009).

Despite these drawbacks, BC tags allow researchers to gain an unbiased understanding of the movement patterns and behaviours of species. They act as mobile receivers that can pick up individuals beyond the range of stationary VR2 receiver arrays, perhaps in more biologically significant locations (Holland et al., 2009). These tags also allow data from many tagged animals to be retrieved by recapturing fewer animals, as BC-tagged individuals serve as marine “bioprobes” (Stokesbury et al., 2009).

Furthermore, these tags may provide important insights into inter-specific interactions such as predator-prey encounters, and intra-specific interactions such as schooling and spawning behaviors (Holland et al., 2009). This kind of information is especially important for improving management and conservation action for threatened or endangered species (Holland et al., 2009).

Electronic tags deployed on aquatic animal "bioprobes" have been developed to sample a wide variety of data including temperature, pressure (depth), location (based on ambient light levels), and acceleration. However, because no tag at this time contains a built-in broadband acoustic hydrophone, a full-size high frequency 200 kHz 24-bit smart hydrophone (*ic*Listen), produced by Ocean Sonics Ltd., a local company from Great Village, Nova Scotia, was attached to an Atlantic sturgeon bioprobe in this study.

Hydrophone technology

Because water is denser than air, sound waves travel much faster in the aquatic environment (about 1500 m/s) than in air, and over much larger distances, even up to 1000 km (VENUS, 2013). Marine mammals, such as whales and dolphins, generally use low frequency sound to communicate over large distances, while high frequency sound (>100 kHz) may be used to detect features of the local environment and search for food (VENUS, 2013). Sound in the ocean generally comes from either marine animals, environmental sources such as rain, wind, waves, and earthquakes, or anthropogenic sources, such as ship engines (VENUS, 2013). The increase in anthropogenic sound in the ocean has generated research into the effects of this sound on a variety of marine animals.

A hydrophone is an underwater microphone that can detect and record acoustic signals (Fox, 2010). When exposed to sound pressure waves arriving from any direction, small electrical currents are produced by certain ceramics due to their piezoelectricity (Fox, 2010). These electrical signals, produced over a wide range of frequencies by the hydrophone, may then be amplified and recorded (Fox, 2010). Hydrophones may also be deployed in an array for "listening" with greater sensitivity (Fox, 2010).

The *ic*Listen HF (high frequency) broadband smart hydrophone, produced by Ocean Sonics Ltd., was able to process a wide frequency range of underwater sound (0.01 to 200 kHz) and store waveform and spectrum files. It was designed to be used in depths up to 200 m, ideal for use in the Minas Basin as the maximum depth is about 60 m.

Atlantic sturgeon

Atlantic sturgeon are large anadromous fish found along the eastern coast of North America, from Labrador to Florida (Scott and Scott, 1988). Being anadromous, they do the majority of their growth in the marine environment but once they reach sexual maturity, Atlantic sturgeon adults will cease feeding and migrate into freshwater rivers to spawn (Dadswell, 2006). Locally, these rivers include the Saint John, in New Brunswick, and possibly the Annapolis and Avon rivers, in Nova Scotia (Wehrell et al., 2008). Spawning occurs in June and July (Dadswell, 2006).

A large commercial fishery for Atlantic sturgeon existed in the U.S. from the 1950s to the mid-1990s, but due to overexploitation, a moratorium was implemented for the entire U.S. Atlantic coast in 1998 (NOAA, 2010). Since 1979, CITES has listed

Atlantic sturgeon under Appendix II, meaning they are not threatened with extinction but trade is controlled so as to ensure continued survival (CITES, 2013). Since the U.S. moratorium, few studies have been done to re-assess the abundance of Atlantic sturgeon (NOAA, 2010). In Canada, Atlantic sturgeon populations are relatively stable and the largest populations support managed commercial fisheries in the Saint Lawrence River and the Saint John estuary in New Brunswick (Dadswell, 2006).

Atlantic sturgeon are highly migratory and a great degree of stock mixing occurs at aggregation sites (Dadswell, 2006; Laney et al., 2007; Wirgin et al., 2012). In May and June, Atlantic sturgeon migrate into the Minas Basin along the northern shore and in the late summer, leave via the southern shore (Wehrell et al., 2008). In the summer, there may be aggregations of juveniles and adults in the Cumberland Basin and the inner Bay of Fundy (Dadswell, 2006). The Minas Basin is a rich foraging ground for juvenile and adult Atlantic sturgeon, feeding primarily on polychaete worms (McLean et al., 2013). DNA analysis of the Minas Basin summer aggregation determined that over 60% of the individuals present were natal to the Saint John River, New Brunswick, while 34 – 36% came from the Kennebec River, Maine, about 1 – 2% were from the Hudson River, New York, and less than 1% were from the James River, Virginia (Wirgin et al., 2012).

The main threats to Atlantic sturgeon survival include habitat degradation and loss, pollution, overexploitation of adults, negative impacts of coastal engineering projects such as tidal power turbines, and dam construction on spawning rivers (Dadswell, 2006). Although an increased awareness of these issues and action towards improvement has enabled recovery of most populations (Dadswell, 2006), long-term monitoring programs are still needed for most sub-populations in the U.S. in order to determine the overall status of the species (NOAA, 2010).

Atlantic sturgeon were chosen as the bioprobe species for this study because they are abundant in the Minas Basin and commonly captured by directed otter trawl. Sub-adults and adults are generally large enough to carry an *ic*Listen "backpack" without too much disturbance to their regular swimming pattern. Atlantic sturgeon are highly migratory, often travelling around the Minas Basin and occasionally through the Minas Passage. Thus a variety of locations may be sampled for ambient noise data by using an Atlantic sturgeon bioprobe.

Tidal power in the Bay of Fundy

Due to the migration of listed endangered (several U.S. populations) and assessed as endangered (Canadian Bay of Fundy populations) Atlantic sturgeon through the Minas Passage, tidal power development is of great concern. The Bay of Fundy is home to the highest tides in the world; the vertical tidal range can be over 16 m (FORCE, 2013). The Minas Passage is the gateway to the Minas Basin. On every rise and fall of the tide, 160 billion tonnes of seawater flow through this narrow entrance (FORCE, 2013), carrying with it marine mammals such as harbour porpoises (*Phocoena phocoena*) and large fish such as Atlantic sturgeon. The high flow rates of water through the Minas Passage make it an optimal site for the installation of in-stream tidal turbines. These devices use the kinetic energy of flowing water as a source of power (FORCE, 2013). The speed of water flow in the Minas Passage varies with location and depth therefore the turbines are designed to operate in speeds up to a maximum of ten knots (FORCE, 2013). The latest research suggests that over 7000 megawatts of power could be generated in the Minas Passage, 2500 megawatts of which could be extracted safely without changing the tidal range significantly (FORCE, 2013). In-stream devices are most popular for the Bay of Fundy because they are removable, can be scaled up gradually into an array or a farm, have lower potential costs and lower ecological impact when compared to barrages (FORCE, 2013).

The movement of the tides represents a reliable, predictable, clean and renewable source of energy (FORCE, 2013). However, the presence of an array of in-stream tidal turbines in the Minas Passage would make repeated movements with the tide, into and out of the Minas Basin, extremely risky for many fish species such as alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), Atlantic herring (*Clupea harengus*), Atlantic salmon, striped bass (*Morone saxatilis*), spiny dogfish (*Squalus acanthias*) and Atlantic sturgeon (Dadswell and Rulifson, 1994). Some shark species and marine mammals such as seals, porpoises and small whales that come into the Minas Basin may also be at risk, especially as larger organisms have a higher probability of experiencing a strike (Dadswell and Rulifson, 1994).

The development of tidal power in a narrow area experiencing frequent passage by many marine species introduces the possibility of continuous long-term mortality for those populations (Dadswell and Rulifson, 1994). Physical strikes by turbines would have a direct effect on marine animals. However secondary effects, such as sediment transport, extraction of energy from the tides (i.e. changing hydrodynamics), and production of noise is also of concern (Stokesbury, personnel communication). The reaction of marine animals to noise in the water column has not been investigated thoroughly. There are a number of methods that could be used in order to assess the noise in an area of interest. Hydrophones could be moored within a set location, they could be situated to float past a particular area, or they could be attached to a marine animal. The latter method would presumably allow the researcher to get a true sense of the noise the animal hears. This attachment methodology not only removes white noise, created by water flow moving past a moored hydrophone, but it also delivers data from areas that are important to the species, as represented by animals choosing to visit these locations.

Study objectives

An acoustic hydrophone (*ic*Listen) was deployed on an Atlantic sturgeon bioprobe to measure ambient noise from the Minas Basin, as well as signals from acoustic tags implanted within other fish, including other Atlantic sturgeon. This project aimed to answer two questions; first, as a proof of concept, can a broadband acoustic hydrophone (*ic*Listen) be successfully deployed on an Atlantic sturgeon for approximately eight hours, release properly, float to the surface, be tracked and retrieved? Second, to inform future on-board processing of acoustic data by the industrial partner, what ambient noise will be recorded by the *ic*Listen hydrophone during deployment on a large marine fish?

MATERIALS AND METHODS

Study site

The Minas Basin is the inner branch of the Bay of Fundy, made up of four distinct regions: the Minas Channel, Central Minas Basin, the Southern Bight, and Cobequid Bay. The Minas Basin is a megatidal estuary experiencing semi-diurnal tides and an average tidal range of about 13 m, with a maximum of about 16 m during spring tides (Percy, 2001). At low tide, the depth across most of the Minas Basin is less than 25 m (Percy, 2001). The water line may recede up to 5 km, exposing about 35 800 hectares of tidal flats (Percy, 2001). Several large rivers flow into the Minas Basin, including the Cornwallis, Gaspereau, Avon, Saint Croix, and Shubenacadie. The brackish water at the mouth of these rivers and throughout the Minas Basin has a salinity slightly lower than that of regular seawater. Because of the high turbidity of the water, light penetration is low (Percy, 2001). The water temperature of the Minas Basin ranges from around freezing in mid-winter to about 26°C over some tidal flats in the summer (Percy, 2001). The Southern Bight of the Minas Basin, off Kingsport, was chosen as the site for this study as it is known to be a feeding area for Atlantic sturgeon (McLean et al., 2013).

Atlantic sturgeon capture

Atlantic sturgeon were captured by directed otter trawl in the Southern Bight of the Minas Basin. The largest Atlantic sturgeon was selected and placed in a shallow holding tank at the rear of the boat with a few inches of water in it. The fish was then moved from the tank and placed, lying ventrally, on a table. During the attachment of the *ic*Listen backpack, the sturgeon's gills were kept aerated by pouring water from a bucket over them periodically. From the time of landing on the trawler to the time of release, the Atlantic sturgeon was out of the water for a maximum period of 30 minutes. Fishing was performed under the Department of Fisheries and Oceans Scientific License to Fish #322595. Handling procedures were performed under Acadia Animal Care Committee protocol #07-11.

A map of the Minas Basin is shown in Figure 1, with an inset of the study area off Kingsport, in the Southern Bight, where trawling took place. The deployment location of the Atlantic sturgeon bioprobe is shown as a green flag, while the retrieval location of the floating *ic*Listen is shown as a red flag. The locations at which acoustically tagged Atlantic sturgeon (circles) or striped bass (triangles) were first detected by the VR100 hydrophone are also shown, along with their Vemco tag ID numbers.

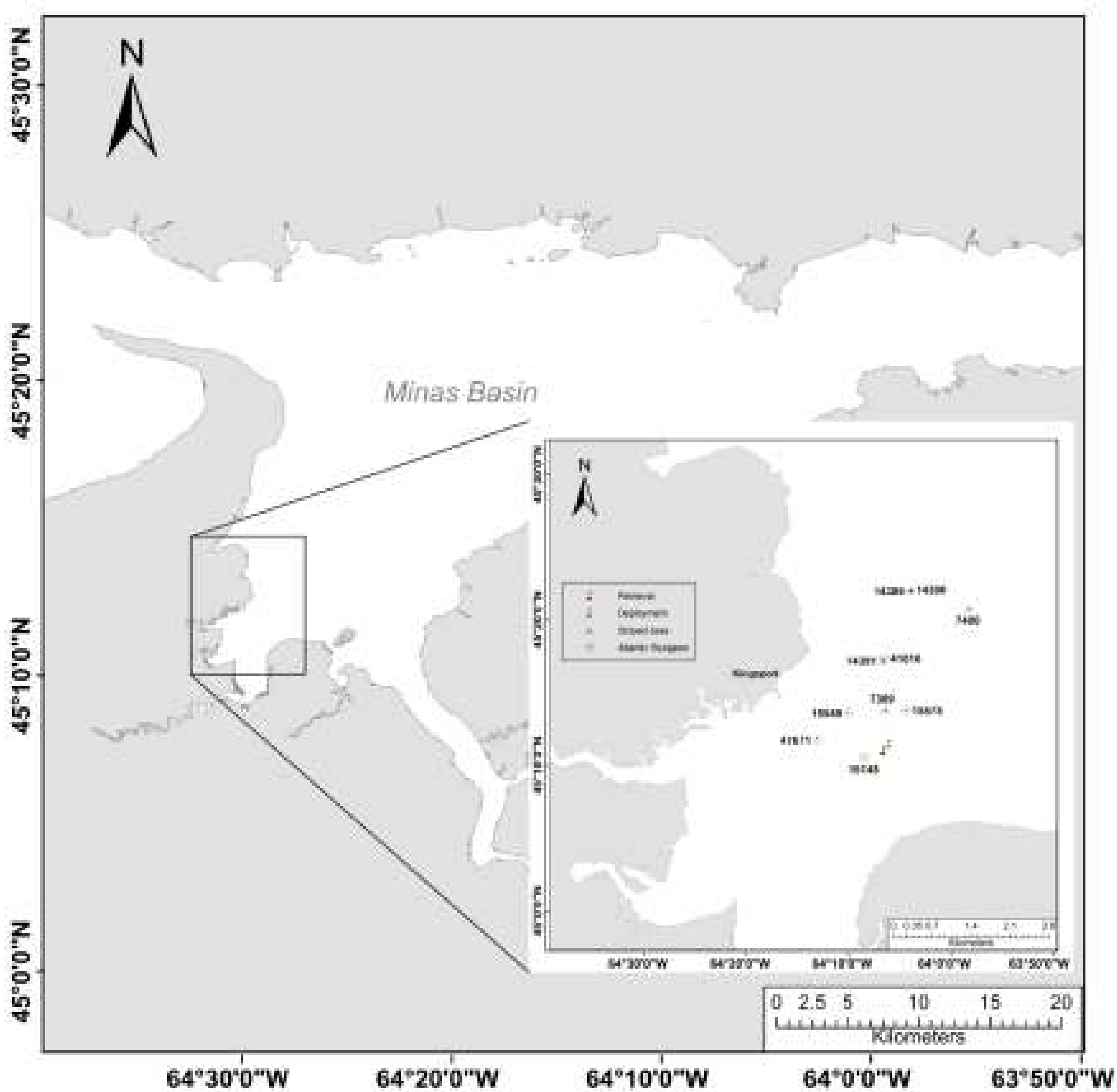

Figure 1. Map of the Minas Basin, Nova Scotia, showing the study site in the boxed area off Kingsport, in the Southern Bight. Labeled points on the inset identify the locations of *ic*Listen deployment and retrieval, as well as the locations at which other acoustically tagged Atlantic sturgeon or striped bass were first detected by the VR100 hydrophone, along with their Vemco tag ID numbers.

Hydrophone deployment

In designing the *ic*Listen hydrophone “backpack” to be deployed on the Atlantic sturgeon bioprobe, several issues had to be resolved. These included: secure attachment to the Atlantic sturgeon; tracking of the bioprobe; release of the *ic*Listen from the bioprobe; flotation of the *ic*Listen at the surface, and retrieval of the *ic*Listen.

Attachment

The forward facing (hydrophone) end of the *ic*Listen was secured to the Atlantic sturgeon through use of a Velcro belt that went snugly around its abdomen, just behind its pectoral fins. Velcro strips were glued (using epoxy) and sewn to a nylon strap. A strip of neoprene, 6 mm thick, was also glued and sewn to the inside of the belt which would press against the sturgeon's skin. On each end of the belt was an eyelet hole through which one end of an AA2 galvanic release was passed and then reclosed using a vice-grip. The same procedure was repeated for the other side. A looped piece of nylon with an eyelet hole on each side slid over the hydrophone end of the *ic*Listen and was secured with a zip tie. The two belt ends were attached to the *ic*Listen by sending the other end of each galvanic release through the eyelet hole on either side of the looped nylon piece and reclosing them with a vice-grip. Figure 2 shows the design. The back end of the hydrophone was secured to the Atlantic sturgeon by passing dissolving suture thread (polydioxanone) through a dorsal scute. The thread was knotted to one loop of an AA2 galvanic release while a zip tie passed through the other loop and was tightened around the exterior of the *ic*Listen.

Figure 2. Velcro belt similar in design to the one used for the deployment of the *ic*Listen hydrophone on the Atlantic sturgeon. The nylon strap had industrial strength Velcro glued and sewn to it, as well as a layer of neoprene on the inside. In this image, the belt is loosely attached to a dummy hydrophone for testing purposes.

Tracking

A Vemco V13P-1x acoustic transmitter (13 mm by 45 mm) with a pressure sensor (to a maximum 100 m depth) was glued to the exterior of the *ic*Listen (Figure 3). This tag sent out its unique acoustic signal (Vemco ID 5711) at 69 kHz every 45 – 95 seconds which allowed the sturgeon to be manually tracked using a VR100 acoustic receiver with an omnidirectional hydrophone (Figure 4).

Figure 3. The V13P acoustic tag, glued to the exterior of the *ic*Listen, used to track the Atlantic sturgeon bioprobe during the deployment.

Figure 4. The VR100 manual tracking unit used to follow the Atlantic sturgeon bioprobe by picking up the V13P acoustic tag signal (ID 5711). It also picked up acoustic tag signals (IDs) from other tagged fish and provided a time and GPS location for each detection.

Release

Galvanic timed releases contain two cathodes and one anode. When placed in seawater, the highly active metal alloy cylinder (anode) connecting the plated wire eyes (cathodes) begins to corrode, releasing hydrogen gas (International Fishing Devices, 2009). The time it takes the anode to corrode completely depends on how much of the metal alloy is present (more takes longer) as well as the salinity and temperature of the solution it is placed in.

Several types of galvanic releases were ordered and tested. The AA2 galvanic releases were used in the final backpack design for the deployment of the *ic*Listen on the Atlantic sturgeon (Figure 5). The AA2 releases were designed to corrode after about six hours in seawater with a temperature between 13 and 16°C. Before the deployment took place, the AA2 releases were tested for release time accuracy in a salt water tank in the Biology Department of Acadia University.

Figure 5. Three types of galvanic releases with different amounts of the metal alloy; the AA2 (6 hour) type, on the left, was used in the *ic*Listen hydrophone deployment.

Flotation

Syntactic foam, composed of tiny glass spheres embedded in an epoxy resin, was used as the flotation material for the *ic*Listen because it is very dense but light. The MZ (mesopelagic zone) grade we used was designed to withstand pressure up to 1000 m. Five pieces of syntactic foam were machined into cylinders with a hole through the center so that they could be stacked on the cable at the back end of the *ic*Listen (Figure 6). Each cylinder was about 4.6 cm wide and about 3.0 cm high. The two cylinders stacked first over the thicker base of the cable had a center hole that was about 2.3 cm in diameter, while the three cylinders stacked next had center holes that were about 1.3 cm in diameter. The five cylinders were glued together using a waterproof silicone. A neoprene sleeve fit over the column of syntactic foam and was zip-tied to the *ic*Listen to protect the cylinders from damage and keep them in place during the deployment.

Figure 6. Five cylinders of syntactic foam glued together using a waterproof silicone and stacked onto the back end of the *ic*Listen hydrophone for flotation.

Retrieval

The Wildlife Computers Ltd. Single Position Only Transmitter (SPOT-100), glued and zip-tied to the top of the neoprene sleeve holding the syntactic foam (Figure 7), was used to locate the *ic*Listen once it had released from the Atlantic sturgeon and was floating at the surface. Once the wet/dry sensor on the SPOT-100 indicated a dry setting, the transmitter began signaling its location to an ARGOS satellite. Position updates were obtained on shore through the online ARGOS system and were relayed to the boat crew. The latter then motored to that location and used an ARGOS AL-1 PTT (Platform Transmitter Terminal) Locator to guide movement towards the transmitting SPOT-100, attached to the *ic*Listen. The directional antenna of AL-1 PTT Locator was used to pick up signals from the SPOT-100 and the direction giving the highest signal strength was searched until the floating *ic*Listen was spotted visually and retrieved.

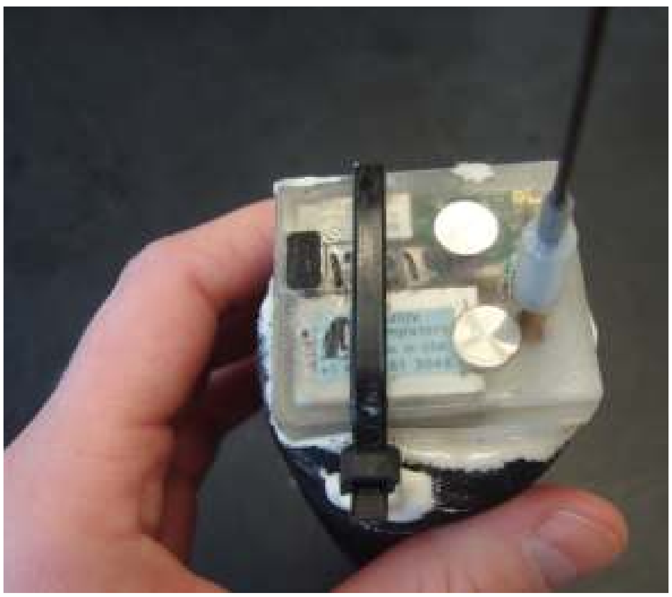

Figure 7. The SPOT-100 glued and zip-tied to the top of the neoprene sleeve on the back end of the *ic*Listen hydrophone. It was used to locate the *ic*Listen once it had released from the bioprobe and was floating at the surface.

Data analysis

The *ic*Listen hydrophone waveform files and spectrum files recorded throughout the deployment were examined using the Lucy™ version 3.4.3 software from Ocean Sonics Ltd. Tag data recorded by the VR100 hydrophone throughout the deployment was downloaded directly from the unit and examined in a Microsoft Excel file.

RESULTS

Atlantic sturgeon capture

The Atlantic sturgeon used as a bioprobe for the deployment of the *ic*Listen hydrophone was caught by directed otter trawl on September 17, 2012. The trawling tow speed was about 3 knots/hour, lasted approximately one hour and took place off Kingsport Beach, in the Southern Bight of the Minas Basin (Figure 1). Several Atlantic sturgeon were caught in the trawl net and brought on board the fishing vessel at approximately 01:30 AST. The largest Atlantic sturgeon (FL of 169 cm) was kept to be used as the bioprobe, while the others were immediately released overboard.

Figure 8 shows the final *ic*Listen hydrophone “backpack” design, attached to the Atlantic sturgeon and ready for deployment. In this image, the dissolving suture thread securing the back end of the *ic*Listen to the fish is hidden from view.

Figure 8. The complete *ic*Listen hydrophone "backpack" attached to the Atlantic sturgeon bioprobe and ready for deployment.

Proof of concept

The final design of the *ic*Listen hydrophone "backpack" (Figure 8) proved to be successful in all regards – attachment, release, flotation, and retrieval. The Velcro belt attachment kept the *ic*Listen securely in place on the Atlantic sturgeon and was not rubbed off before the scheduled release. The three AA2 galvanic releases built into the belt and suture attachment released the *ic*Listen from the Atlantic sturgeon after about seven hours when they had all fully corroded. The syntactic foam discs within the sleeve of neoprene enabled the *ic*Listen to float vertically at the surface once it was released from the fish. During this time, the hydrophone end, facing down, continued to collect ambient sound data from the water column. Once exposed at the surface, the SPOT-100 began signaling to ARGOS satellites and GPS positions for the *ic*Listen float path were obtained. The research vessel motored to the most recent GPS location and used the

ARGOS AL-1 PTT Locator to follow the direction of highest signal strength from the SPOT-100 until the floating *ic*Listen was spotted visually and retrieved at 10:25 AST.

Ambient noise data

The *ic*Listen was deployed on the Atlantic sturgeon bioprobe from approximately 02:06 to 10:25 AST on September 17, 2012. Over eight hours of acoustic data, recorded by the *ic*Listen in the form of waveform files (providing audio and Fast Fourier Transform or FFT data) and spectrum files (providing only FFT data without audio), were examined using Lucy™ v3.4.3. Spectrum charts displayed the frequency of the recorded sound waves in Hz (on the y-axis) through time (on the x-axis), usually set to span a one minute segment, although this could be increased. The frequency range displayed in the waveform files (0 to 12 800 Hz) was much smaller than the range displayed in the spectrum files (0 to 204 800 Hz), likely due to the audio component. The colours displayed in the spectrum charts represented the approximate dB level of the sound, set to range from 20 dB (blue) to 100 dB (red) in our files. The FFT chart, located above the spectrum chart, displayed the sound's amplitude or source level (in dB re 1 μPa) on the y-axis and the frequency (in Hz) on the x-axis. The brightest green line in the FFT chart corresponded to the most recent sound segment, continuously appearing on the far right side of the spectrum chart as the file played through.

A wide range of noise was recorded in the waveform files, including talking on the trawler while preparing for the deployment, a splash when the fish was released overboard (Figure 9), a crackling noise from snapping shrimp (Figure 10), boat engine noise (Figure 11), and wave noise (Figure 12). Figure 9 shows the point at which the

Atlantic sturgeon bioprobe was released over the side of the trawl boat. By listening to the audio of the waveform file while observing the spectrum chart FFT data, it was determined that the bright green column represents the splash of the fish hitting the surface of the water. The frequency of the splash noise ranged from 0 to about 200 kHz (well beyond the range displayed in Figure 9) and the source level was between about 80 and 140 dB re 1 μPa (obtained from the lines on the FFT chart). Previous to the splash, the vertical green lines, with a frequency range from 0 to about 4000 Hz, represent the crew talking on the trawl boat before the Atlantic sturgeon release. There is also some engine noise from the trawler in the lowest frequencies, up to about 1500 Hz. After the splash, the vertical green lines represent water flow and wave noise, again with some faint engine noise in the lowest frequencies.

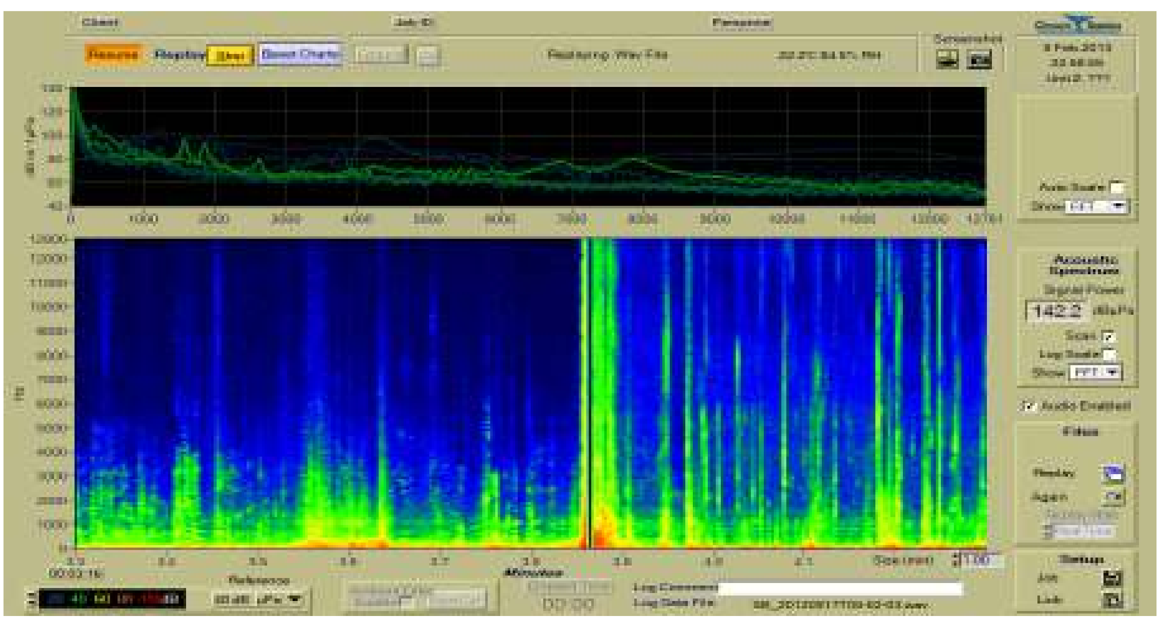

Figure 9. Waveform file spectrum chart displaying the variety of noise picked up by the *ic*Listen hydrophone before, during and after the Atlantic sturgeon was released over the side of the trawl boat.

The shrimp snapping noise, pictured in Figure 10, sounded like a faint crackling when played back in the waveform files. This ambient noise was present in most of the sound files from the *ic*Listen deployment, especially when the bioprobe was at some depth. The shrimp snapping noise was most intense within a frequency range of about 5000 to 8000 Hz, with a source level between about 60 and 80 dB re 1 μPa.

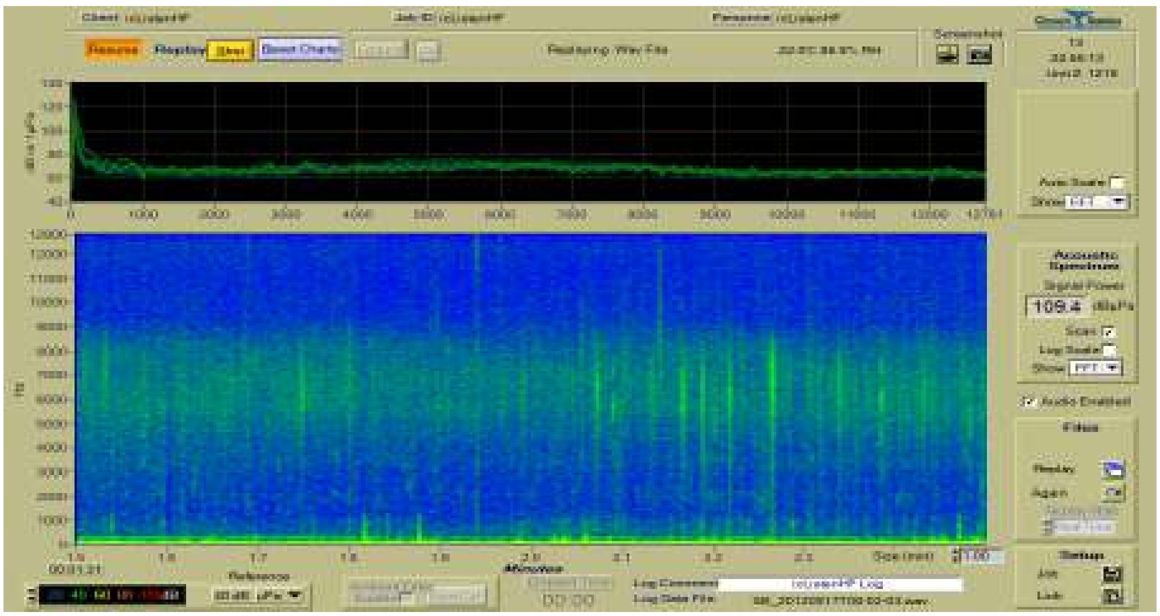

Figure 10. Waveform file spectrum chart showing the narrow frequency range of the snapping shrimp crackling noise that persisted throughout most of the sound files from the *ic*Listen deployment.

Engine noise from the research vessel's 50 hp Honda four-stroke outboard motor, pictured in Figure 11, appeared on the waveform file spectrum chart as bright green lines descending into a flattened yellow "U" shape as the boat approached the *ic*Listen, and extending upward again as the boat retreated into the distance. The corresponding spectrum file displayed the engine noise frequency between approximately 0 and 40 kHz as the research vessel approached or retreated from the *ic*Listen. When the research vessel was closest to the bioprobe, the frequency of the engine noise extended beyond

200 kHz. The source levels of the engine noise ranged between about 70 and 110 dB re 1 μPa. When the research vessel was more distant, the frequency of the engine noise generally fell below 20 kHz, with source levels ranging between about 60 and 80 dB re 1 μPa.

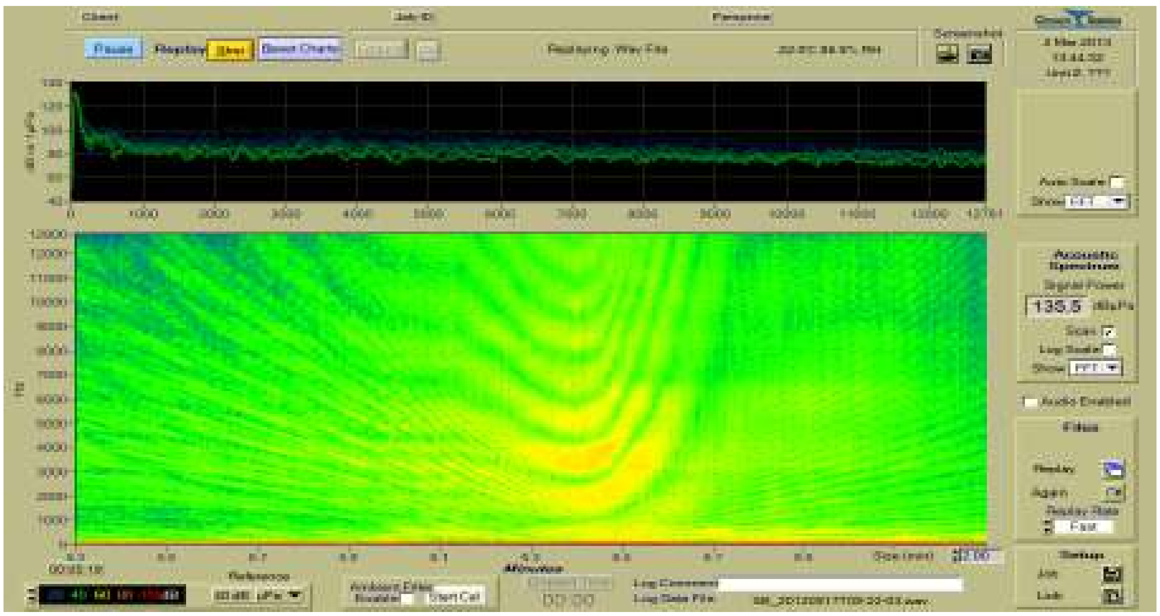

Figure 11. Waveform file spectrum chart showing a two minute segment of the wide frequency range of noise from the research vessel's outboard motor as it approached the *ic*Listen and then retreated again.

While the *ic*Listen was floating at the ocean surface before retrieval, the sound from individual waves was recorded. These appear in Figure 12 as bright green vertical lines with a wide frequency range from 0 to about 200 kHz (as displayed in the corresponding spectrum file) and a source level between about 60 and 80 dB re 1 μPa. Faint green horizontal lines are also visible in the waveform file spectrum chart and likely represent noise from the research vessel's outboard motor, in the distance.

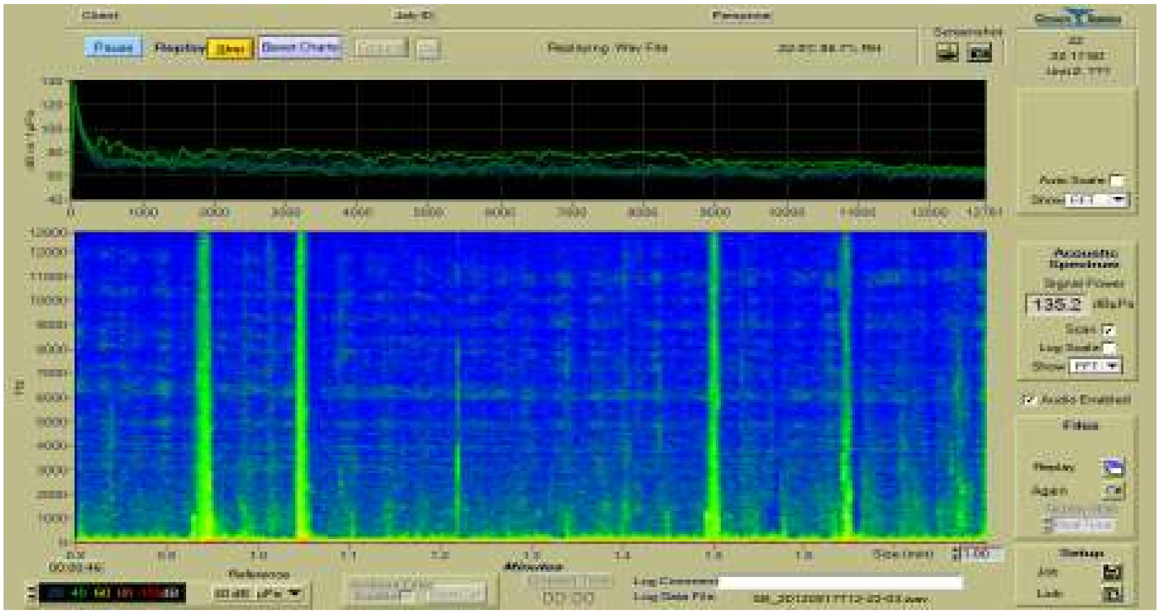

Figure 12. Waveform file spectrum chart showing the wide frequency range of wave noise picked up by the *ic*Listen while it was floating at the surface before retrieval.

The acoustic data from the spectrum files covered a wider frequency range (from 0 to 204 800 Hz) but without audio, as most of the sound was in the ultrasonic range, well above the limit for human hearing (about 20 kHz). In Figure 13, acoustic tag signals (all transmitting at a frequency of 69 kHz) appear as a series of ten dots or “pings” with vertical lines extending about 1000 Hz on either side. Peak source levels reached about 120 dB re 1 μPa. The echo from each series of acoustic “pings” can be seen on the spectrum chart at a frequency of about 140 kHz, as a series of green dots.

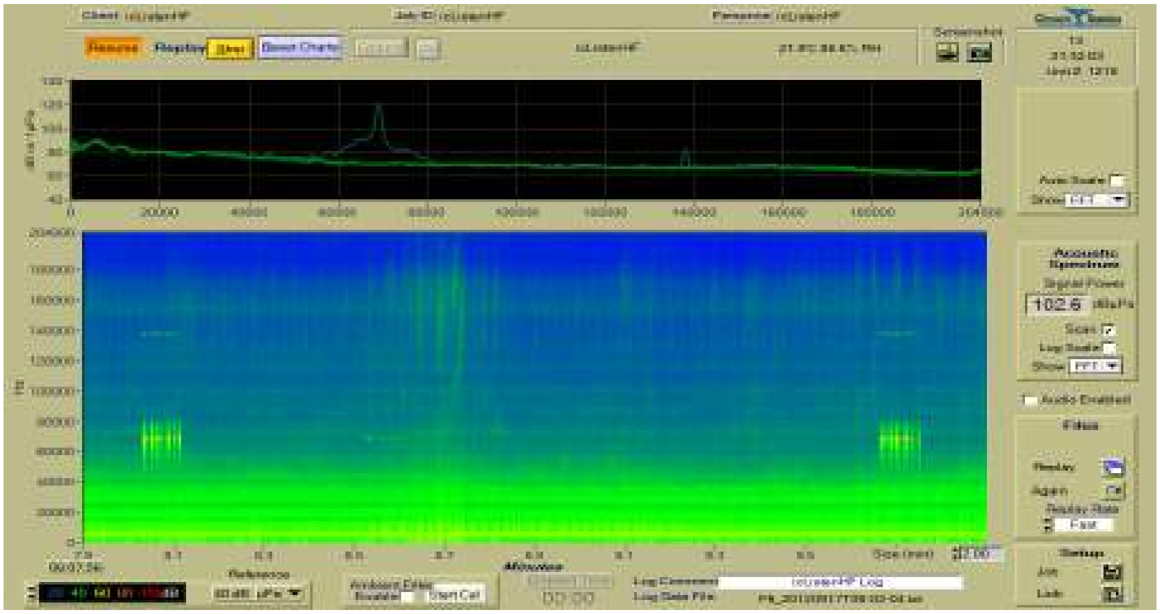

Figure 13. Spectrum chart showing a two minute segment of Vemco acoustic tags transmitting at 69 kHz, picked up the *ic*Listen.

An unexpected interaction with a harbour porpoise was also picked up by the *ic*Listen. After about 3.5 hours into the deployment, a harbour porpoise approached an acoustically tagged fish within range of the *ic*Listen. An apparent "conversation" took place, as the porpoise stopped clicking while the acoustic tag was transmitting its signal and then resumed when it was finished (Figure 14). The porpoise clicks were picked up by the *ic*Listen for about 30 minutes between 04:50 and 05:20 AST. The frequency of the clicks were concentrated between about 115 and 145 kHz, but ranged up to about 170 kHz, with a source level of approximately 70 dB re 1 μPa. Later in the deployment, when the *ic*Listen had just released from the Atlantic sturgeon and was floating at the surface, harbour porpoise clicks were picked up again for about 30 minutes between 09:10 and 09:40 AST. In this second interaction, the harbour porpoise was likely "talking" to the V13P acoustic tag glued to the exterior of the *ic*Listen. The clicks came in shorter bursts (Figure 15) but fell into a similar frequency range as in the first interaction. The harbour porpoise even clicked a response to the tag in between acoustic “pings” from the tag signal.

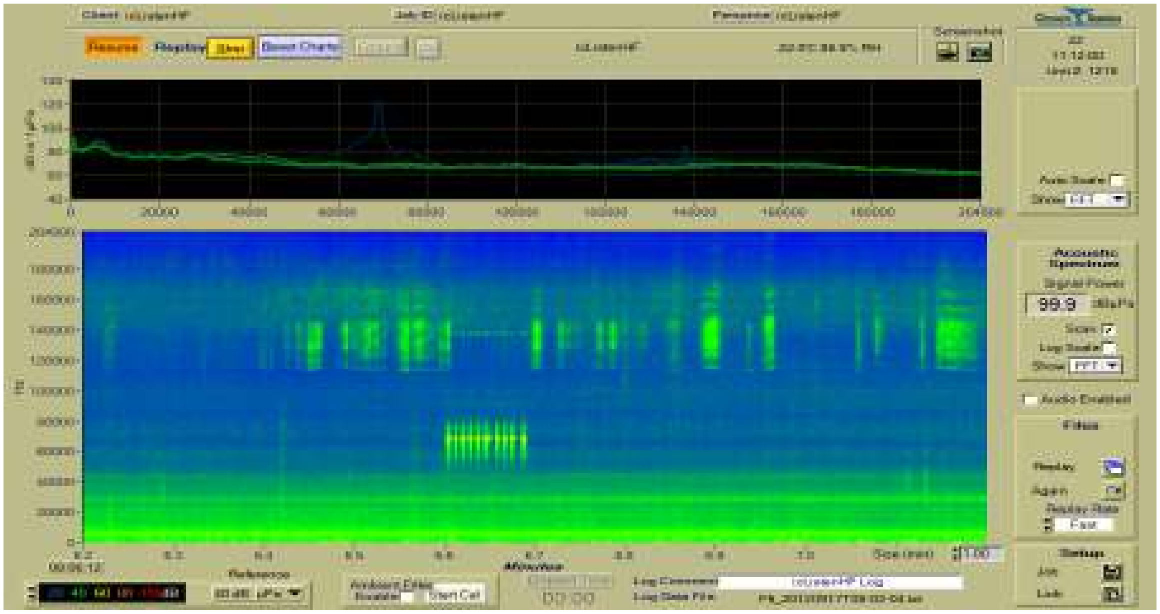

Figure 14. Spectrum chart depicting the first interaction between a harbour porpoise and an acoustic tag, picked up by the *ic*Listen.

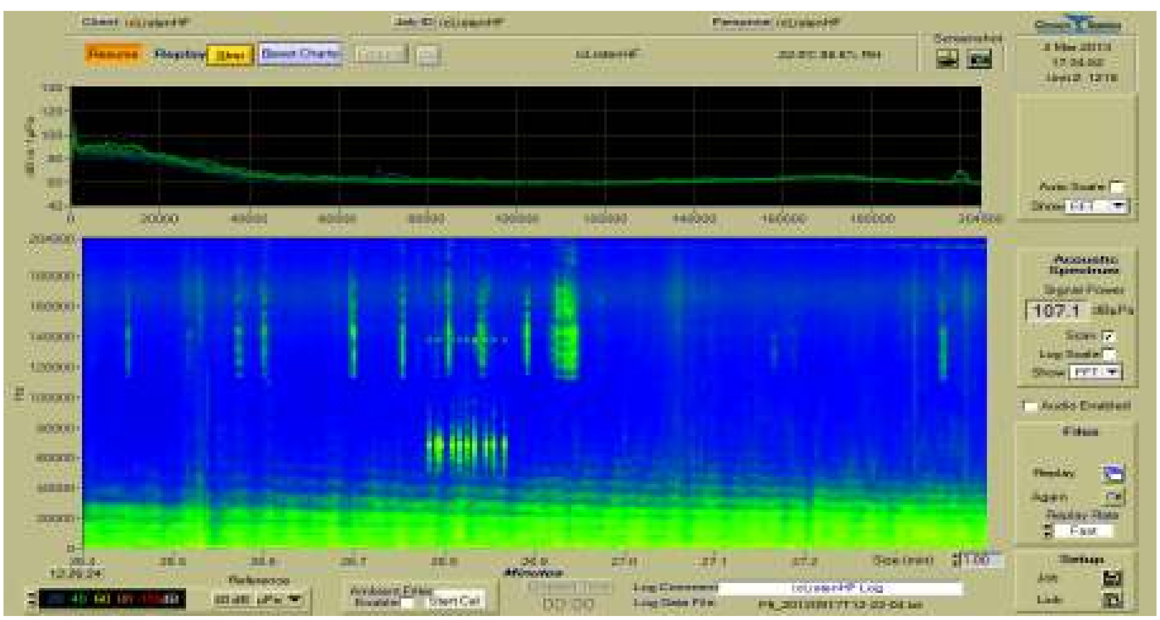

Figure 15. Spectrum chart depicting the second interaction between a harbour porpoise and an acoustic tag, likely the V13P, attached to the exterior of the *ic*Listen which was floating at the surface.

Tag data

While attempting to track the Atlantic sturgeon bioprobe during the *ic*Listen deployment (by following the V13P acoustic tag signals), the VR100 acoustic receiver (hydrophone) also picked up signals (IDs) from ten other acoustically tagged fish swimming within about 200 m of the research vessel. The VR100 recorded a time and GPS location for every acoustic tag detection.

The V13P acoustic tag attached to the exterior of the *ic*Listen had the Vemco ID number 5711. The Vemco ID numbers of the ten other fish picked up and identified by the VR100 were: 47671, 16148, 15549, 15575, 41616, 14391, 14389, 14386, 7400 and 7389. The first five tags were from Atlantic sturgeon, tagged between 2010 and 2012. The last five tags were from striped bass tagged in 2012 by students from the Acadia Center for Estuarine Research (ACER) under the direction of Dr. Anna Redden. Table 1 summarizes the tagging and detection details for the five Atlantic sturgeon picked up by the VR100.

Table 1. Tagging and detection details for the five Atlantic sturgeon picked up by the VR100 in the early morning of September 17, 2012, off Kingsport, Nova Scotia.

Vemco tag ID	FL (cm)	Deployment date	Deployment location	VR100 first detection time (AST)
16148	155	19/08/2010	SB	02:49:45
15549	101	04/07/2011	SB	03:20:05
41616	unknown	27/08/2012	SB	03:34:13
47671	119	19/08/2010	SB	04:15:58
15575	140	22/08/2012	SB	04:56.37

Note: SB refers to the Southern Bight of the Minas Basin, therefore these Atlantic sturgeon were captured by directed otter trawl and tagged on the boat.

The Atlantic sturgeon bioprobe was only detected five times by the VR100, but these detections provided some pressure (depth) data for this fish. The V13P acoustic tag, glued to the exterior of the *ic*Listen, indicated that the bioprobe was swimming at depths between 7.9 m and 10.1 m when detected by the VR100. Pressure (depth) data was also obtained for three of the five other acoustically tagged Atlantic sturgeon detected by the VR100 (Vemco tag IDs 16148, 15549 and 15575). These fish were tagged in 2010, 2011, and 2012, respectively, with V16P-6x acoustic transmitters (16 mm by 98 mm) programmed to send out their signal (ID) every 30 to 90 seconds, along with pressure data obtained to a maximum depth of 136 m. The two Atlantic sturgeon for which there was no recorded pressure data on the VR100 (Vemco tag IDs 41616 and 47671) were tagged with V16-6x acoustic transmitters (16 mm by 95 mm) that do not have pressure sensors.

The greatest number of detections recorded by the VR100 were from two Atlantic sturgeon with Vemco ID numbers 16148 and 15549, detected 15 times and 12 times respectively. Overall, there were 34 detections on the VR100 from the four Atlantic sturgeon equipped with pressure sensing tags (the bioprobe and three others). These detections were recorded at night, between 02:30 and 05:40 AST on September 17, 2012. The mean depth was calculated to be 20.14 m, with a standard deviation of 5.89 m.

Based on a population estimate of the number Atlantic sturgeon aggregating in the Minas Basin (Dadswell, unpublished data), the number of Atlantic sturgeon acoustically tagged between 2010 and 2012 (Stokesbury, unpublished data), and the number of tagged Atlantic sturgeon detected by the VR100 during the *ic*Listen deployment, a rough estimate of the number of untagged Atlantic sturgeon present in the area off Kingsport, on September 17, 2012, was calculated. A Schnabel (closed) population estimate, based on a total capture of 1242 Atlantic sturgeon between 2004 and 2012, of which 798 were externally tagged and 29 were recovered in subsequent years, indicates an average annual summer population of 10 283 (95% CF 6332-14154; Dadswell, unpublished data). Based on this estimate and the number of Atlantic sturgeon tagged with Vemco V16 acoustic transmitters between 2010 and 2012 (114 individuals), a ratio of tagged to untagged Atlantic sturgeon in the Minas Basin was calculated to be 1:89. Based on this ratio, and the number of Atlantic sturgeon detected by the VR100 during the *ic*Listen deployment (five individuals), the number of untagged Atlantic sturgeon likely present in the area of the boat search, off Kingsport, on September 17, 2012, was 445 individuals.

DISCUSSION

Proof of concept

The final *ic*Listen hydrophone "backpack" design was successful in that every element (attachment, tracking, release, flotation and retrieval) functioned as planned. This study serves as a proof of concept that a full-size *ic*Listen HF smart hydrophone can successfully be deployed on a marine animal bioprobe (Atlantic sturgeon) to gather ambient acoustic data. Our methodology serves as a baseline for future studies aiming to carry out a similar project, but perhaps with improvements to the "backpack" design. In hindsight, we speculated about using an additional strap to secure the back end of the *ic*Listen to the fish and further restrict side to side movement. However, a second strap would require more materials for every deployment, it would add more waste to the environment and it could limit or put stress on the Atlantic sturgeon's normal swimming movements. Dissolving suture thread was used to secure the back end of the *ic*Listen to the Atlantic sturgeon, through a dorsal scute, because it would disintegrate after a few weeks. Thus, the lasting impact of the *ic*Listen hydrophone deployment on the Atlantic sturgeon would likely be restricted to a single hole through a dorsal scute, which would eventually be covered over by skin again.

Another hypothetical improvement to the "backpack" design which would avoid losing the Velcro strap and adding waste to the environment would be to have only one galvanic release built into the strap design. Upon release, the Velcro strap would remain attached to the *ic*Listen and could be retrieved and re-used in another deployment (depending on its condition). However, some issues might arise from this change as well.

For example, while floating at the surface, a strap may rub against the hydrophone and affect the ambient noise data gathered; it may prevent the *ic*Listen from floating vertically and transmitting a signal through the SPOT-100 for retrieval; and finally, it may cause the *ic*Listen to be carried further by tides and currents, complicating retrieval. Thus, all changes to the *ic*Listen hydrophone "backpack" design would have to be tested and assessed for benefits and drawbacks.

The Atlantic sturgeon was on the trawl boat and out of the water for roughly thirty minutes, during which time final set-up and attachment details were taken care of before the *ic*Listen hydrophone "backpack" was secured around its abdomen and through a dorsal scute. Although the process was done as quickly as possible and the Atlantic sturgeon's gills were kept aerated with water, in subsequent deployments, improvements in planning and preparation could likely cut the time on board in half, thus decreasing the stress on the fish. This would likely speed up the recovery time of the Atlantic sturgeon as well, perhaps so that it could swim away immediately upon release. Although it took the Atlantic sturgeon several minutes of floating at the surface to recover, once it took off, it appeared to be swimming normally throughout the deployment and did not simply remain in one location, resting on the bottom. The hydrophone "backpack" likely had some impact on the Atlantic sturgeon's behaviour, however, this is difficult to quantify. In general, Atlantic sturgeon show a high level of survivorship from tagging and little behavioural change (Stokesbury et al., 2009). Based on our detections with the VR100, the Atlantic sturgeon bioprobe stayed in the same general area off Kingsport, which was not extensive movement but enough to confirm that it was alive and well.

Due to technical issues encountered in the set-up of the AA2 galvanic release tests in the saltwater tank, the number of hours after which the galvanic releases had fully corroded could not be narrowed down to anything more specific than under 24 hours. Based on the galvanic release Time/Temperature Chart from International Fishing Devices (2009), our prediction of six hours as the approximate amount of time the AA2 galvanic releases would last in the Minas Basin was relatively accurate. The three AA2 galvanic releases built into the "backpack" design had fully corroded and released the *ic*Listen from the Atlantic sturgeon after about seven hours in the Minas Basin. Therefore, based on the Time/Temperature Chart, we may suppose that the average water temperature in the area off Kingsport was closer to 8°C during the *ic*Listen deployment on September 17, 2012, rather than between 13 and 16°C as predicted.

Ambient noise data

Ambient or background noise in the ocean may be comprised of a multitude of sources, the two main categories being natural and anthropogenic noise (Hildebrand, 2009). The low frequency noise band (10 – 500 Hz) is dominated by anthropogenic noise from commercial ships and seismic sources (Hildebrand, 2009). Because of their low frequencies, these sounds experience little attenuation (scattering and absorption) and so may be heard at great distances from the source, even across ocean basins (Hildebrand, 2009). Noise in the medium frequency band (500 Hz – 25 kHz) is subject to significant attenuation and therefore may only propagate a few tens of kilometers (Hildebrand, 2009). Sea surface agitation noise (associated with wind) dominates this band but other sources of noise include small vessels, rainfall, breaking waves, spray, bubble formation and collapse, and various sonars (Hildebrand, 2009). Noise in the high frequency band (over 25 kHz), such as from thermal agitation, may only be heard within a few kilometers of the source as these sound waves experience extreme attenuation and so cannot not propagate far (Hildebrand, 2009).

The crackling sound from snapping shrimp has been documented as a widespread and significant source of ambient noise in the ocean since 1942 (Johnson et al., 1947). An individual shrimp produces a “snap” or “crack” only occasionally, but the combined snapping of all the individuals in a large population produces the continuous crackling noise heard underwater (Johnson et al., 1947). The “snap” sound occurs when, on the enlarged claw, the upper “finger” strikes the tip of the lower “thumb” (Johnson et al., 1947). The purpose of this mechanism is not to produce sound but a sudden water jet, by means of a plunger-socket arrangement, that may be used as a defensive strategy to scare off enemies and predators (Johnson et al., 1947).

Hildebrand (2009) noted that in the mid-frequency band, shrimp snapping by *Alpheus* spp. and *Synalpheus* spp. could increase ambient noise levels by 20 dB. Johnson et al. (1947) observed that the frequencies of shrimp snapping tended to override usual water noise above 2000 Hz. The shrimp snapping spectra observed in the *ic*Listen waveform files was most intense between 5000 and 8000 Hz, but extended beyond this frequency range as well (Figure 10). In some waveform files, louder and more distinctive clicks were also heard above the regular background crackling noise, showing up on the spectrum chart as bright green vertical lines.

Snapping shrimp range in size from about 2-8 cm and tend to be benthic animals, rarely swimming in the adult stage (Johnson et al., 1947). They conceal themselves in burrows, crevices and holes provided by corals, sponges, stones, shells, and calcareous algae; and commonly live among eelgrass roots and seaweed holdfasts (Johnson et al., 1947). Snapping shrimp tend to be more active at night when searching for food, thus the crackling noise may be 2-5 dB louder at night than during the day, with peak noise levels occurring before sunrise and after sunset (Johnson et al., 1947).

It was difficult to pinpoint a species for the snapping shrimp picked up by the *ic*Listen hydrophone in the Minas Basin. The range of most species seems to be governed by water temperature, thus they are limited to tropical and subtropical areas (Johnson et al., 1947). However, snapping shrimp noise was reported in temperate oceans off North Carolina and California (Johnson et al., 1947), so perhaps the range of some species extends further north than this. The tiny amphipod, *Corophium volutator*, abundant in the mud flats of the Bay of Fundy and the Minas Basin, has also been said to produce a crackling noise audible at low tide (Fisheries and Oceans Canada, 2012), however details regarding the mechanism of sound production, its source levels and frequency range were absent from the literature.

The Doppler effect caused the boat engine noise to appear in the spectrum charts as a flattened “U” shape, with the base of the “U” being the point at which the boat was closest to the *ic*Listen hydrophone and the source levels were highest (Figure 11). The left side of the “U” represented the approach of the boat towards the *ic*Listen, while the right side represented the retreat of the boat into the distance. Hildebrand (2009) reports small vessel noise as falling into the mid-frequency range, between about 500 Hz and 25 kHz. However, the *ic*Listen data files demonstrated that as the research vessel approached the hydrophone, the engine noise spectra increased into the high frequency range (over 25 kHz). In this case, the high frequency sound waves likely experienced less attenuation and were picked up by the hydrophone. Furthermore, the speed at which the research vessel was travelling also affected the engine noise spectra picked up by the *ic*Listen. In general, when the research vessel was travelling faster with the engine working harder, the noise displayed in the spectrum charts had a wider frequency range and higher source levels than when it was travelling at slower speeds or idling.

The ambient noise collected while the *ic*Listen was floating at the surface included waves along with the usual shrimp snapping. At this point, the *ic*Listen was no longer influenced by the Atlantic sturgeon's swimming movements but instead by tidal flow and wave action. According to Hildebrand (2009), noise from wind-generated breaking waves dominates frequencies between 500 Hz and 50 kHz. However, the *ic*Listen spectrum files showed a frequency range of wave noise from 0 to about 205 kHz and perhaps even beyond this upper limit.

The *ic*Listen hydrophone also picked up marine mammal noise from harbour porpoise clicks. Harbour porpoises are known to employ narrowband, high frequency sonar signals (Goodson and Sturtivant, 1996). The clicks displayed on the *ic*Listen spectrum files were concentrated between about 120 and 150 kHz, however overall they ranged from approximately 110 kHz to 180 kHz, at a source level between 60 and 80 dB re 1 μPa. According to Goodson and Sturtivant (1996), a typical power spectrum of a harbour porpoise click has most energy concentrated around 140 kHz. This corresponds well with the spectrum range (120 to 150 kHz) observed in the *ic*Listen data files. Goodson and Sturtivant (1996) measured spectra for two juvenile harbour porpoises at 2, 4 and 6 m ranges, showing that the spectrum with the most energy ranged between 140 to

160 kHz (Goodson and Sturtivant, 1996). They suggest that peak frequencies may relate to body size so that juvenile harbour porpoises would have higher peak frequencies than adults, which generally range between 125 and 140 kHz (Goodson and Sturtivant, 1996). Based on this data, the harbour porpoise clicks recorded by the *ic*Listen were likely from adults.

Based on the *ic*Listen spectrum files depicting apparent "conversations" between a harbour porpoise and an acoustic tag, it seems evident that harbour porpoises can hear Vemco acoustic tags transmitting at 69 kHz. Furthermore, these mammals were interested enough to come and investigate the source of the acoustic signal, as seen by the increasing source levels of the clicks over time. In the first interaction, the harbour porpoise stopped clicking to hear the acoustic tag response before it resumed clicking again (Figure 14). In the second interaction, the harbour porpoise seemed to be clicking a response in between the acoustic "pings" emitted by the tag (Figure 15). This demonstrates the harbour porpoise's superior echolocation abilities.

Acoustic tags were developed to transmit at ultrasonic frequencies (50 kHz to 100 kHz) that exceeded the upper limit of human hearing, approximately 20 kHz, as well as fish hearing, approximately 1000 Hz (Bowles et al., 2010). However, these tags may not be ultrasonic to marine mammals such as seals, dolphins, porpoises and whales, which may readily hear the tags. Bowles et al. (2010) predicted that harbour porpoises could hear both Vemco Ltd. acoustic tags transmitting at 69 kHz as well as Sonotronics Ltd. acoustic tags transmitting at 83 kHz, at distances of several hundred meters from the source. Therefore, harbour porpoises could use ultrasonic coded transmitter (UCT) signals as cues to the presence of predators or prey (Bowles et al., 2010). This could have serious implications for tracking studies involving the prey of harbour porpoises and other marine mammals, as intense predation would result in biased tag data (Bowles et al., 2010).

However, because harbour porpoises could likely detect acoustic “pings” at such great distances from the tagged prey, the latter may not be in danger of direct predation unless they are nearer the predator. Furthermore, young harbour porpoises have a natural instinct to avoid unfamiliar, high-frequency tonal sounds due to their association with predators such as killer whales (*Orcinus orca*), thus juveniles may be slow to associate “pings” with prey (Bowles et al., 2010). However, over the long-term, natural instincts may not be enough to keep harbour porpoises away from tagged prey, especially if they learn to associate them with food (Bowles et al., 2010). The signal frequency of acoustic tags would have to be increased above 150 kHz in order to avoid being heard by harbour porpoises (Bowles et al., 2010).

The steady increase in anthropogenic noise in the ocean could have deleterious effects on the behaviour of marine mammals and fish that rely greatly on sound for navigation, communication, feeding, mating, and more (Hildebrand, 2009). Therefore, it is important to understand the characteristics of both natural and anthropogenic sounds in the sea, in order to evaluate their potential impacts on local marine species. The ambient noise data gathered by the *ic*Listen hydrophone during its deployment on the Atlantic sturgeon bioprobe provides a baseline for future studies in the Minas Basin. For example, the noise created by hydropower tidal turbines in the Minas Passage, measured from the perspective of a marine animal bioprobe like an Atlantic sturgeon, should be investigated along with the animal’s reaction to the noise. The potential effects of increased anthropogenic noise levels from industrial projects on local migratory species that travel in and out of the Minas Basin via the Minas Passage requires examination.

Tag data

The *ic*Listen hydrophone deployed on the Atlantic sturgeon bioprobe picked up signals from Vemco acoustic tags, all transmitting at 69 kHz, which could be visualized on spectrum charts. However, in order to identify different tags based on their Vemco ID numbers, the VR100 data was used. The bioprobe was "lost" by the VR100 relatively early on in the deployment and was only detected again briefly several hours later. Therefore, there was little data available on the movement of the Atlantic sturgeon bioprobe during the *ic*Listen deployment. While the bioprobe was "lost", the *ic*Listen likely picked up acoustic tag signals from fish that could not be identified because the VR100 was not within range to record their tag IDs. However, considering the research vessel only covered a relatively small area of the Minas Basin, it was impressive that the VR100 detected ten acoustically tagged fish, five of which were Atlantic sturgeon.

For every tagged Atlantic sturgeon in the Minas Basin, it was calculated that there are likely about 89 untagged Atlantic sturgeon also present. Based on this ratio, there were likely about 445 untagged Atlantic sturgeon in the vicinity of the research vessel and VR100 that went undetected. Although these calculations only provide rough estimates, they give a general idea of the huge numbers of Atlantic sturgeon that may be present in the area off Kingsport and elsewhere in the Minas Basin.

Two of the Atlantic sturgeon detected by the VR100 were originally tagged with V16 acoustic transmitters in August 2010, which provides evidence that their acoustic tags were not ejected and may last well over two years. The battery life of a V16 acoustic tag generally ranges from one month to several years depending on the battery size, the power output level, the delay between transmissions, and the types of sensors included in the tag (temperature and/or pressure). Based on the set-up of the V16P acoustic tags implanted in three of the Atlantic sturgeon detected by the VR100, the estimated tag life span was approximately 1287 days or about 3.5 years. The other two Atlantic sturgeon detected by the VR100 did not provide any pressure (depth) data as they were originally tagged with V16 transmitters without pressure sensors. However, the V16 tags have a longer estimated life span of approximately 1633 days or nearly 4.5 years. Acoustically tagged Atlantic sturgeon may provide valuable long-term movement data to researchers, along with temperature and/or pressure readings from year to year.

Only five detection readings were obtained by the VR100 for the Atlantic sturgeon bioprobe making it difficult to get an overall idea of the depths at which it was swimming throughout the *ic*Listen deployment. However, sufficient overall depth data was obtained by the VR100 from the four Atlantic sturgeon equipped with pressure sensing tags (the bioprobe and three others). The water level of the Minas Basin would have been slowly dropping from about 60 m to less than 25 m, as the tide receded between 01:47 (high tide) and 07:54 AST (low tide). The average depth of these four fish during the night, from about 02:30 to 05:40 AST, was 20.14 m, with a standard deviation of 5.89 m. As the tide receded, these Atlantic sturgeon likely adjusted their position in the water column in order to remain at a comfortable depth below the surface.

The deployment of an *ic*Listen high frequency hydrophone on an Atlantic sturgeon bioprobe was done, first and foremost, as a proof of concept. All elements functioned as planned and over eight hours of acoustic data was recorded by the *ic*Listen. A variety of ambient noise data was examined from the deployment, including noise from natural oceanic processes (waves), marine animal noise (shrimp snapping and harbour porpoise clicks), and anthropogenic noise (boat engine noise and acoustic tag signals). Two separate interactions between a harbour porpoise and a Vemco acoustic tag were recorded, providing further evidence that these mammals can likely hear the acoustic "pings". This may result in biased data from some fish tracking studies. The VR100 hydrophone and manual tracking unit detected the Vemco tag IDs from five Atlantic sturgeon in the area off Kingsport, along with a time and location for each detection. Pressure (depth) data was also recorded for most of the Atlantic sturgeon detected, from which an average depth was calculated. An estimate of the number of untagged Atlantic sturgeon in the area off Kingsport was calculated and yielded a large number. This study serves as a launching pad for further research involving the use of marine animal bioprobes in the collection of underwater acoustic data.

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