PAPER

# Experiments with Broadband Sonar for the Detection and Identification of Endangered Shortnose Sturgeon

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ABSTRACT

Experiments were conducted in the tidal Delaware River to evaluate the use of broadband sonar to remotely detect and identify shortnose sturgeon, a federally listed endangered species. The objectives of this study were to determine if shortnose sturgeon could be detected by broadband sonar and, if so, to develop classifiers that could differentiate shortnose sturgeon from co-occurring fish species. Broadband acoustic echoes were collected from shortnose sturgeon, three non-sturgeon fish species, and the river bottom. Classifiers were developed using neural network analysis of the normalized frequency response spectra from each target class. Two independent classifiers were developed, one that distinguished "sturgeon" from the river "bottom" and a second that classified targets as "sturgeon," "non-sturgeon fish," and the "bottom." The training performance of the classifiers was 100% for each class. Testing of the two-class sturgeon vs. the bottom classifier resulted in correct classification of 96.6% of the shortnose sturgeon detections and incorrect classification of 3.4% of actual sturgeon echoes as bottom. None of the bottom detections were misclassified as sturgeon. Testing of the three-class classifier resulted in the correct classification of 89.0% of the actual sturgeon detections, and incorrect classification of 8.5% of actual sturgeon detections as non-sturgeon fish and 2.5% of actual sturgeon detections as bottom. Some 27.1% of the actual non-sturgeon fish echoes and 5.9% of actual bottom echoes were incorrectly identified as sturgeon, yielding a false-positive rate of 16.5%. Given that the "non-sturgeon fish" in this study typically occur in much higher abundance than shortnose sturgeon, incorrect classification of echoes from these fish would lead to overestimation of the abundance of shortnose sturgeon. Notwithstanding this potential problem, the results of this preliminary study were promising, and further investigations to improve classifier performance are warranted.

Keywords: broadband sonar, species identification, neural network, classification, remote sensing, shortnose sturgeon, Delaware River

## Introduction

The shortnose sturgeon (*Acipenser brevirostrum*) (Figure 1) is a relatively small (<1.2 m total length [TL]) sturgeon that historically inhabited the tidal and lower non-tidal reaches of large rivers and estuaries along the Atlantic coast from the St. Johns River, New Brunswick, Canada, to the St. Johns River, Florida, United States (Vladykov and Greely, 1963). Populations of shortnose sturgeon declined range-wide in the late 19th and early 20th centuries as a result of fishing mortality, water pollution, and habitat modification. The shortnose sturgeon was placed on the endangered species list in 1967 and is presently protected under the Endangered Species Act of 1973, as amended.

FIGURE 1

Shortnose sturgeon collected in the upper tidal Delaware River.

The endangered status of the shortnose sturgeon requires the assessment of the potential impact of activities such as dredging, waterfront/marine construction, and the construction/operation of electric-generating facilities. These assessments are often based on limited information regarding occurrence and distribution. Field sampling for shortnose sturgeon, primarily using gill nets or trawls (Moser et al, 2000), is performed for some projects. However, these field sampling programs are typically expensive, time consuming, spatially limited, and may result in fish injury and mortality. The use of a remote sensing technology

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to detect and identify shortnose sturgeon would be of obvious value in cost-effectively surveying large areas for the presence of shortnose sturgeon without the risk of injury to the target species.

The Environmental Research and Consulting, Inc. (ERC) has been investigating technologies that could be utilized to remotely detect and study the behavior of shortnose sturgeon. Earlier work on this project demonstrated that shortnose sturgeon could be detected close to the bottom using split-beam hydroacoustic techniques and identified several metrics that could potentially be used to differentiate shortnose sturgeon from other species (Nealson and Brundage, 2007). In this paper, we describe experiments to evaluate the use of broadband sonar for the remote detection and identification of shortnose sturgeon.

Broadband sonar differs from split-beam (narrowband) hydroacoustics in that sound is transmitted, and echo returns received, over a broad range of frequencies instead of a single frequency. The differential response of various sound-reflecting structures of a fish (e.g., swim bladder, muscle/viscera, scales, and scutes) to different frequencies maximizes the information content of the echo return. Digital signal processing and pattern classification techniques can then be applied to convert the detected echoes into sets of mathematical values that can be used to discriminate and classify fish, plants, and/or sediment type (Simpson and Denny, 1998a, 1998b; Jung et al., 2003; Kulinchenko et al., 2004).

## Methods

### Data Collection

This study was conducted in the tidal Delaware River near Bordentown, New Jersey. Shortnose sturgeon and three other fish species for hydroacoustic data collection were captured using anchored bottom-set gill nets fished parallel to the current at navigation channel depth (approximately 10–12 m). The nets were 100 m long by 1.8 m deep and consisted of either 12.7-cm or 15.2-cm stretched monofilament mesh. Hydroacoustic measurements were collected by passing over the netted fish with a downward-looking broadband transducer. Following acoustic data collection, the netted fish were recovered, identified, and measured for TL.

Acoustic data were collected using a SciFish 2100 broadband sonar system; the specifications of which are presented in Table 1. In the present study, data were collected over a frequency range of 110-220 kHz, using a pulse length of 1 m and an acoustic pulse repetition rate of 3 pings/s. The sonar system was calibrated in the laboratory prior to the study.

### Signal Processing and Classifier Development

All data sets collected during the study were saved in a SciFish 2100 database. Once data collection had been completed, the database was replayed for review, and selected echoes or groups of echoes were manually extracted to be saved as exemplar sets. Echoes were extracted from the raw data using a matched filter process, which recognized individual targets by correlating the waveform of the received signal with that of the transmitted signal. Matched filter processing optimizes the detection of a known signal in the presence of random noise. Matched filter processing of a broadband signal also improves range resolution, which is useful when studying a near-bottom dwelling species such as shortnose sturgeon. Range resolution is a function of the effective pulse length, which can be determined from the Time (T)-Bandwidth (B) product. Since a 1-m pulse (T = 0.667 ms) and a 110-220-kHz band (B = 110 kHz) were used in this study, the T-B product is 73.33, which means the effective pulse length is 73.33 times shorter and the range resolution is 73.33 times higher. The effective pulse length, therefore, became 1.36 cm instead of the original 1 m.

Each extracted echo had a range, target strength, correlation, and frequency response spectrum stored with it. The frequency response spectrum shows the strength of the received signal at each transmitted frequency. The time series signal of each detection was transformed into discrete frequency bins between 110 and 220 kHz by Fast Fourier Transform. Upon statistical comparison of all training samples, the majority of the behavior of spectral energy was observed between 120 and 190 kHz. Therefore, 62 spectral bins in this frequency zone from each echo were normalized and used as features for all classification processes.

**TABLE 1**

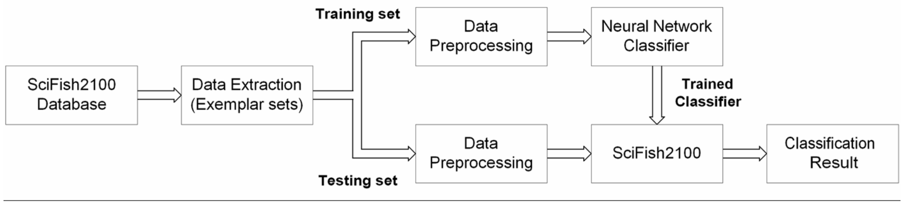
Specifications of the SciFish 2100 broadband sonar system.

| |
|---|
| • Split-beam transducer with 4 quadrants |
| • Beam angle: elliptical 4° × 9° |
| • Frequency: 110-220-kHz broadband signal |
| • Pulse length: 1 m |
| • Side lobes: <–30 dB |
| • Receiver gain: 20 dB–60 dB |
| • Operating system: Windows 2000 |
| • CPU: Pentium 4, 2.4 GHz |
| • A/D sampling: 16-bit, 500 kHz (4-channel simultaneous sampling) |
| • Network: TCP/IP 10/100 Mbps |

Extracted echoes were divided into three groups and labeled as "sturgeon," "non-sturgeon fish," and "bottom." The "sturgeon" class consisted of 236 echoes from shortnose sturgeon, the "non-sturgeon fish" class consisted of 236 echoes from the three non-sturgeon fish species with equal distribution, and the "bottom" class consisted of 236 reflections from the river bottom. One half of the echoes in each class were used for training a neural network classifier, and the other half was reserved for testing. A batch-mode back-propagation neural network with one hidden layer (62-5-3) was then trained with the training data set of 354 echoes using OwikNet 2.23. The trained classifier was imported by SciFish 2100 and used to classify the testing data set of echoes. Track-based averaging (3-ping running average) was used to improve the signal-to-noise ratio for both training and testing the classifiers. A flow chart of the signal processing and classifier development process is presented in Figure 2.

**FIGURE 2**

Flowchart showing the signal processing and classifier development process.



## Results

Acoustic data were collected from 12 shortnose sturgeon (663-928 mm TL), six channel catfish *Ictalurus punctatus* (322-540 mm TL), one white perch *Morone americana* (192 mm TL), and one American shad *Alosa sapidissima* (540 mm TL). Examples of the normalized frequency response spectra for each species and the river bottom are shown in Figure 3.

Two independent neural network classifiers were developed based on the normalized frequency response spectra, one that distinguished "sturgeon" from the river "bottom" and a second that classified targets as "sturgeon," "non-sturgeon fish," and the "bottom." The training performance of the classifiers was 100% for each class.

Testing of the two-class shortnose sturgeon vs. bottom classifier resulted in the correct classification of 114 (96.6%) of 118 actual sturgeon detections and incorrect classification of 4 (3.4%) actual sturgeon echoes as bottom. None of the actual bottom detections were misclassified as sturgeon (Table 2).

Testing of the three-class classifier resulted in the correct classification of 105 (89.0%) of 118 actual sturgeon detections, and incorrect classification of 10 (8.5%) actual sturgeon detections as non-sturgeon fish and 3 (2.5%) actual sturgeon detections as bottom. Thirty-two (27.1%) of the actual non-sturgeon fish echoes and 7 (5.9%) of actual bottom echoes were incorrectly identified as sturgeon, yielding a false-

**FIGURE 3**

Three-ping averaged frequency response spectra for shortnose sturgeon, channel catfish, white perch, American shad, and the river bottom.

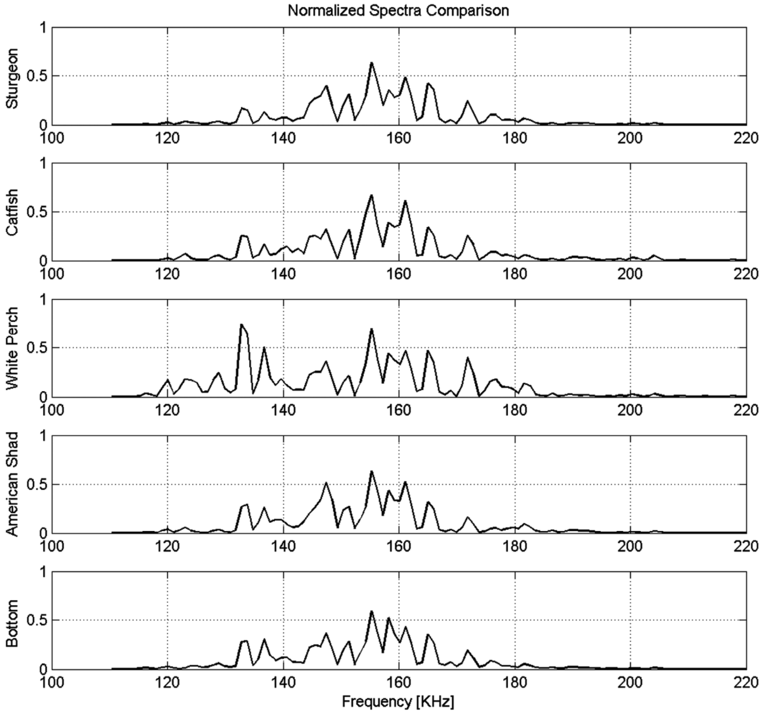


**TABLE 2**

Classification results for the two-class test: surgeon vs. river bottom.

| | Actual "Sturgeon" | Actual "Bottom" | Total |
|---|---|---|---|
| Echoes classified as "sturgeon" | 114 | 0 | 114 |
| Echoes classified as "bottom" | 4 | 118 | 122 |
| Total | 118 | 118 | 246 |
| True-positive | 96.6% | 100.0% | |
| False-positive | 0.0% | 3.4% | |
| True-negative | 100.0% | 96.6% | |
| False-negative | 3.4% | 0.0% | |

positive rate of 16.5% (32 + 7/236 echoes) (Table 3).

## Discussion

The two-class classifier showed excellent performance in its ability to differentiate between shortnose sturgeon and the river bottom, evidencing a true-positive rate of 96.6% and a false-positive rate of zero. The performance of the three-class classifier was lower, with a true-positive rate of 89.0% and a false-positive rate of 16.5%. The false-positive rate, which mostly reflects non-sturgeon fish echoes misidentified as shortnose sturgeon, is problematic. Given that the "non-sturgeon fish" in this study, particularly white perch and channel catfish, typically occur in much higher abundance than shortnose sturgeon, incorrect classification of echoes from these fish would lead to overestimation of the abundance of shortnose sturgeon.

Notwithstanding this potential problem, the results of this preliminary study were promising and further investigations with broadband sonar to detect and identify shortnose sturgeon are warranted. It is recommended that future studies include collection of data at a ping rate higher than that used in the present investigation, using both broadband and narrowband sonar. Recent advances in computing power now allow ping rates of over 30 pings/s alternating between broadband single-beam and narrowband split-beam signals. Narrowband split-beam processing allows locating a target with an accurate bearing angle, and the broadband spectrum can be adjusted according to transducer sensitivity and the beam plot across the band.

Consideration should be given to conducting future data collection in a more controlled environment such as a hatchery pond or raceway. In such a setting, an underwater video camera could be used to verify the position of the target during data collection. Burwin and Fleischman (1998) found that changes in the aspect angle of the target and, for large fish such as sturgeon, periodic ensonification of only part of the fish in the transducer beam increased the variability in hydroacoustic data. It may also be advantageous to collect data from fish tethered in a specially designed frame where the aspect angle can be controlled, such as that used by Jung et al. (2004) with salmon smolts. Because of the endangered status of the shortnose sturgeon, collection of data from tethered specimens would require a study-specific permit from the National Marine Fisheries Service (NMFS) and would best be performed using hatchery-reared specimens.

**TABLE 3**

Classification results for the three-class test: sturgeon, non-sturgeon fish, and river bottom.

| | Actual "Sturgeon" | Actual "Non-Sturgeon Fish" | Actual "Bottom" | Total |
|---|---|---|---|---|
| Echoes classified as "sturgeon" | 105 | 32 | 7 | 144 |
| Echoes classified as "non-sturgeon fish" | 10 | 86 | 7 | 103 |
| Echoes classified as "bottom" | 3 | 0 | 104 | 107 |
| Total | 118 | 118 | 118 | 354 |
| True-positive | 89.0% | 72.9% | 88.1% | |
| False-positive | 16.5% | 7.2% | 1.3% | |
| True-negative | 83.5% | 92.8% | 98.7% | |
| False-negative | 11.0% | 27.1% | 11.9% | |

Operationally, a broadband sonar-based system could be used to survey for shortnose sturgeon qualitatively or quantitatively. Qualitatively, the system could be used to detect probable sturgeon targets, either singly or in aggregations, the identity of which would then be verified by gill netting, underwater video, or perhaps, imaging sonar. Broadband sonar could also be used quantitatively to enumerate shortnose sturgeon. Enumeration would be performed at the level of tracks, where all echoes belonging to the same fish would be averaged to improve classification. The use of broadband sonar for enumeration would require that classifier performance be improved to reduce the false-positive rate to an acceptable level.

Many species of fish are today challenged by overexploitation, habitat destruction, climate change, and other anthropogenic impacts. Collection of data on occurrence, distribution, and abundance is critical for the protection and management of these species. Just as remote sensing has revolutionized meteorology and physical oceanography, remote data acquisition technologies need to be more broadly applied to fishery biology. Our experiments with shortnose sturgeon suggest that broadband sonar holds promise in this regard.

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