Eels III: Assessment of Three Sonars to Evaluate the Downstream Migration of American Eels in the St. Lawrence River

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BACKGROUND

- Electric Power Research Institute (EPRI) facilitated the collaboratively funded Eel Passage Research Center (EPRC)
- To provide effective downstream passage of out-migrating adult American eels at hydroelectric facilities on St. Lawrence R.
- EPRC strategy: trap-and-transport eels downstream
- Need a sampling technique to evaluate guidance systems and monitor abundance/distribution
- What about sonar? This Study
OBJECTIVES
Sonar Mount System on Iroquois Dam Pier Nose

• Can sonar be used to:
  1. Estimate relative abundance of out-migrating eels,
  2. Determine their distribution, and
  3. Describe their approach behavior?

• Test 3 Sonars
  - **EK60**: Simrad EK60 Split-beam Echosounder (120 kHz)
  - **ARIS**: Sound Metrics ARIS Explorer Multibeam Sonar (1100/1800 kHz)
  - **M3**: Mesotech M3 Multi-mode Multibeam Sonar (500 kHz)
MULTI-PHASE APPROACH
3 Phases of Sonar Evaluation

• **Phase 1** – Installation and testing multiple sampling configurations

• **Phase 2** – Sonar measurements of known number and size of live eels tethered to surface floats and released at known locations/depths.
  1. Develop tether-and-release methods
  2. Test detectability at multiple ranges
  3. Randomized, single-blind target classification test
  4. Test acoustic vs. batch release counts

• **Phase 3** – Continuous monitoring of “wild” out-migrating eels
PHASE 1 - SUMMARY
Optimal System Design & Sampling Configurations

- Absorption loss too high at 1800 kHz
- ARIS Spreader lens doubles sampling volume & eels still visible
- Eel targets seen in M3 & ARIS at expected sampling coverage
- Tracking > 20 m possible, but ID unlikely
- Near-surface deployment too noisy
- Near-bottom has blind zones & shadows
- Motion artifact of long, fast moving targets can mimic “anguilliform” echo patterns
Motion artifacts distort the image to resemble an anguilliform “squiggle” that makes interpretation difficult:

- Alters echo shape over time

A long, fast moving, rigid object mimics the changing shape of an eel in typical anguilliform swimming motion:

- Leads to false positives

Factors:

- Target speed within a single frame
- Target orientation relative to the trajectory
- Maximum range (affects cycle period, i.e. ping rate within a frame)
MOTION ARTIFACT EXAMPLE
Ping & Echo Pattern Within Frame from Fast-moving Oblong Target

Image Credit: A.M. Mueller, Aquacoustics
PHASE 2: EXPERIMENTATION WITH TEST EELS
Developed method to release live eels tethered with surface float

- 30 eels
- 70-91 cm TL
- 1.3-2.4 kg
PHASE 2: TARGET CLASSIFICATION TEST
Randomized, Single-Blind Classification of ARIS Data

<table>
<thead>
<tr>
<th>ARIS Setting</th>
<th>Total Valid Releases</th>
<th>Eel</th>
<th>Fish</th>
<th>Eel Lure</th>
<th>PVC Pipe</th>
<th>Stick</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 48 beams, r = 2-18 m, -13° Tilt</td>
<td>13</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2. 96 beams, r = 2-12 m, -13° Tilt</td>
<td>15</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3. 48 beams, r = 10-36 m, -32° Tilt</td>
<td>9</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
**Manual Eel Classification of ARIS Data**

**Visual Inspection & Quality Score for Eel Identification**

<table>
<thead>
<tr>
<th>Score</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Highly confident eel ID Eel shape &amp; anguilliform motion</td>
</tr>
<tr>
<td>Q2</td>
<td>Reasonably confident eel ID; shape and/or anguilliform motion ambiguity</td>
</tr>
<tr>
<td>Q3</td>
<td>Uncertain; ambiguity in shape/motion</td>
</tr>
<tr>
<td>Q4</td>
<td>Reasonably confident non-eel ID</td>
</tr>
<tr>
<td>Q5</td>
<td>Highly confident non-eel ID</td>
</tr>
</tbody>
</table>

*How accurate is Q1-Q2 vs Q1-Q3?*

- Balancing Missed Detections vs False Positives
- Classification Experiment with Known Targets
EEL ID SCORE = Q1
76-cm live eel (ID 901) released at 6 m
EEL ID SCORE = Q3
130-cm stick released at r=10 m
EEL ID SCORE = Q5
1-m PVC Pipe
### CLASSIFICATION TEST: EEL (Q1-Q3) ERROR RATE

Confusion Tables for Eel IDs Among Randomized Target Releases

#### Eel ID
- **Score**
  - Q1
  - Q2
  - Q3
  - Q4
  - Q5

#### Non-Eel ID
  - **Score**
    - Q1
    - Q2
    - Q3
    - Q4
    - Q5

#### Eel ID Confidence
- **HIGH**
- **LOW**

#### Non-Eel ID Confidence
- **HIGH**
- **LOW**

<table>
<thead>
<tr>
<th>Score</th>
<th>TRUE EEL</th>
<th>TRUE NON-EEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRUE (+)</td>
<td>FALSE (+)</td>
</tr>
<tr>
<td>Q1-Q3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>FALSE (-)</td>
<td>TRUE (-)</td>
</tr>
<tr>
<td>Q4-Q5</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>88%</td>
</tr>
</tbody>
</table>

**Setting 1**
- 48 beams/ 2-18 m range
- -13° Down

**Received “Ghost” Echo of Pier Nose 9 From Previous Ping**

**Setting 2**
- 96 beams/ 2-12 m range
- -13° Down

**Setting 3**
- 48 beams
- -32° Down

#### INITIAL CLASSIFICATION SCHEME:
- Q1+Q2+Q3= EEL, Q4-Q5, Missed = NOT EEL

---

**Score**
- Q1
- Q2
- Q3
- Q4
- Q5

**Confidence**
- **HIGH**
- **LOW**

**Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

**Non-Eel ID**
- **TRUE EEL**
- **TRUE NON-EEL**
- **FALSE (+)**
- **FALSE (-)**

**Score**
- Q1
- Q2
- Q3
- Q4
- Q5

**Confidence**
- **HIGH**
- **LOW**

**Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

**Non-Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

**Score**
- Q1
- Q2
- Q3
- Q4
- Q5

**Confidence**
- **HIGH**
- **LOW**

**Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

**Non-Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

**Score**
- Q1
- Q2
- Q3
- Q4
- Q5

**Confidence**
- **HIGH**
- **LOW**

**Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

**Non-Eel ID**
- **TRUE EEL**
- **FALSE (+)**
- **FALSE (-)**

---

**Normandeau Associates**

**Environmental Consultants**

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Aquacoustics
### Classification Test: EEL (Q1-Q2) Error Rate

Confusion Tables for Eel IDs Among Randomized Target Releases

<table>
<thead>
<tr>
<th>Eel ID</th>
<th>Score</th>
<th>TRUE EEL</th>
<th>TRUE NON-EEL</th>
<th>Score</th>
<th>TRUE EEL</th>
<th>TRUE NON-EEL</th>
<th>Score</th>
<th>TRUE EEL</th>
<th>TRUE NON-EEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TRUE (+)</td>
<td>FALSE (+)</td>
<td></td>
<td>TRUE (+)</td>
<td>FALSE (+)</td>
<td></td>
<td>TRUE (+)</td>
<td>FALSE (+)</td>
</tr>
<tr>
<td>Q1-Q2</td>
<td>EEL ID</td>
<td>4</td>
<td>0</td>
<td>Q3-Q5</td>
<td>NON-EEL</td>
<td>0</td>
<td>Q3-Q5</td>
<td>NON-EEL</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80%</td>
<td>0%</td>
<td></td>
<td></td>
<td>33%</td>
<td></td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20%</td>
<td>100%</td>
<td></td>
<td>67%</td>
<td>100%</td>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Preferred Classification Scheme:**

Q1+Q2 = EEL, Q3-Q5, Missed = NOT EEL

#### Image Descriptions:

- **Setting 1:** 48 beams/2-18 m range, -13° Down
  - 78-cm Eel

- **Setting 2:** 96 beams/2-12 m range, -13° Down
  - Received “Ghost” Echo of Pier Nose 9 From Previous Ping
  - 80-cm Eel

- **Setting 3:** 48 beams, -32° Down
  - Base of Pier Nose 9

**Notes:**

- Received "Ghost" Echo of Pier Nose 9 From Previous Ping
- 78-cm Eel
- 80-cm Eel
- Base of Pier Nose 9

**Environment:**

- Setting 1: 48 beams/2-18 m range, -13° Down
- Setting 2: 96 beams/2-12 m range, -13° Down
- Setting 3: 48 beams, -32° Down
M3 EXAMPLE OF AN EEL
83-cm Eel (ID 931) at 9 m on 18 Sep 2015 (~12:13)
EXAMPLE OF EK60 ECHOGRAMS
Matched to known range and time

1.9 seconds (8 frames on M3)
-3.2 m change in range

Eel SED
TS min

Eel Tracks
Mean TS range

Eel SED
TS max

Proportion

Mean Target Strength (dB)

Passive Tracks

Eel Tag ID# 930

Eel Tag ID# 931

PVC Pipe (1 m x 1.5 inch)

Northern Pike 670 mm
PHASE 2: RANGE TEST
Released live tethered eels into beams at 5 range intervals

- 80-cm eel released at 5 m
- Detected at 9 m in 3 sonars

NOTE: Eel TL = 70-89 cm, tether lengths = 3-7 m
PHASE 2: RANGE TEST SUMMARY

- Targets were detected by all sonars at multiple ranges
- ARIS sonar identified eels:
  - 30% at 5 m
  - 50% at 10 m
- Accepting more uncertainty eels, 25% at 25 m were identified as eels
- M3 and EK60 sonars detected targets, ID was only possible with the knowledge of the range and time of tethered eel release
PHASE 3: RESULTS OF SONAR MONITORING
Continuous Monitoring of Out-migrating Eels at Iroquois Dam

- No eels in 15-22 July 2015
- 2 eels in 17-19 September
  1. ID Quality Score 1: 18Sep 2015 01:06 (after midnight)
  2. ID Quality Score 2: 18Sep 2015 04:16 (pre-dawn)
- Estimated lengths of 95 cm & 64 cm
CONCLUSIONS

Sampling Limitations & Sonar Performance

• St. Lawrence River is challenging
  – 1.7 to 2 m/s flow
  – Orders of magnitude higher abundance of debris and fish
  – Potential impact of high false positive error

• Motion artifacts decreases eel ID certainty, especially at increasing ranges

• Important to classify targets conservatively to avoid false positives

• 15-22 July: no eels

• 17-19 September: 2 eels @ night

• EK60 can detect eels, but eel ID difficult

• ARIS can provide ID at range < 18-20 m

• M3 has merit for tracking behavior, but not ID
ACKNOWLEDGEMENTS

• Field staff
• Ecological Specialties for I-beam fabrication
• Hunt Underwater Specialties
• Ontario Power Generation
• New York Power Authority
• EPRC Members
• USFWS & NYSDEC
• Simrad, Kongsberg, & Sound Metrics
EXAMPLE OF M3 AND ARIS AT >20 M RANGE
Released 79-cm eel with 4-m tether at nominal 25-m interval

(detected 21 m range)
EEL ID SCORE = Q2
80-cm live eel (ID 930) released at 7 m
EEL ID SCORE = Q4
1-m PVC Pipe released, motion artifact present