The Passive Aquatic Listener (PAL): An Adaptive Sampling Passive Acoustic Recorder

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Passive Acoustic Monitoring

• Popular in monitoring and mitigation of vocalizing animals (marine mammals)

• Advantages
  – Non-invasive
  – Large spatial coverage
  – Data collection is not labor intensive

• Limitations/challenges
  – Only detects vocalizing animals
  – Tradeoffs: size vs deployment duration, power vs storage, storage vs bandwidth
  – Post-processing is labor intensive
Passive Aquatic Listener (PAL)

- 100 kHz sampling rate
- 20 Hz-50 kHz usable frequency range
- Adaptive, sub-sampling protocol (onboard processing)
- Year deployments
- Stored data
  - Spectra
  - 4.5 sec time series, “soundbites”
Passive Aquatic Listener (PAL)

- Passive acoustic time series of spectra and sound bites
  - Marine mammal detections
  - Environmental sound levels
  - Ocean wind and precipitation
  - Sea Ice dynamics
  - Detections of human activity
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Passive Aquatic Listener (PAL)

- Passive acoustic time series of spectra and sound bites
PAL Operation

Default Sampling Strategy
PAL Operation

Alternate Sampling Strategy

- Triggers (user specified)
  - Exceeding a defined dB threshold level between sequential sub-samples indicating a **transient source**
  - Matching of spectrum characteristics to known spectra (rain, vocalizations, etc)
  - Matching of predefined peaks (e.g. 300 Hz- 3 kHz) indicating possible tonal or click vocalization
PAL Operation

Triggered Soundbite
PAL Operation

Alternate Sampling Strategy

- Wake up
- Record 4.5 sec time series (100 kHz)
- Sub-sample time series (Eight 40 ms samples)
- Fourier transform (0-50 kHz)
- Identify sound source characteristics
- Quantify source
- Store individual spectra AND time series
- Reduce time in “deep sleep” mode before next sampling period

Trigger identified
PAL Operation

Duty Cycle Example

• Default (Low Duty Cycle)
  – 10 minute sampling interval
  – 0.75% duty cycle
  – Average spectrum saved

• Triggered (High Duty Cycle)
  – 30 second sampling interval
  – 15% duty cycle
  – Time series saved
  – NOTE: only a limited number of time series can be saved each day. User specified
PAL Performance

Bering Sea Case Study

• Two mooring locations
  – M2: SE Bering Sea
  – M5: Central Bering Sea

• Sampling Parameters
  – Default: 10 min interval
  – Trigger: 2 min interval
  – 16-20 soundbites/day
PAL Performance

- Spectral data: full coverage at 10 min intervals
- Soundbites: Variable coverage by month
## M5 soundbite triggers

<table>
<thead>
<tr>
<th></th>
<th>Oct 2007 (n=73)</th>
<th>Jan 2008 (n=239)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echolocation</td>
<td>28%</td>
<td>Bowhead</td>
</tr>
<tr>
<td>Wind</td>
<td>20%</td>
<td>Echolocation</td>
</tr>
<tr>
<td>Humpback</td>
<td>20%</td>
<td>Unknown</td>
</tr>
<tr>
<td>Gray whale</td>
<td>8%</td>
<td>Beluga</td>
</tr>
<tr>
<td>Mooring</td>
<td>7%</td>
<td>Wind</td>
</tr>
<tr>
<td>Precipitation</td>
<td>7%</td>
<td>Precipitation</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Apr 2008 (n=240)</th>
<th>Jul 2008 (n=133)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearded seal</td>
<td>70%</td>
<td>Wind</td>
</tr>
<tr>
<td>Ribbon seal</td>
<td>8%</td>
<td>Echolocation</td>
</tr>
<tr>
<td>Bowhead</td>
<td>5%</td>
<td>Low clicks</td>
</tr>
<tr>
<td>Walrus</td>
<td>5%</td>
<td>Mooring</td>
</tr>
<tr>
<td>Precipitation</td>
<td>4%</td>
<td>Ship</td>
</tr>
<tr>
<td>Low clicks</td>
<td>2%</td>
<td>Precipitation</td>
</tr>
<tr>
<td>Echolocation</td>
<td></td>
<td>Gray whale</td>
</tr>
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</table>
## M5 soundbite triggers and incidental detections

### Oct 2007 (n=73)

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Oct 2007</th>
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</thead>
<tbody>
<tr>
<td>Echolocation</td>
<td>28%</td>
<td>5%</td>
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<tr>
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<td>20%</td>
<td></td>
</tr>
<tr>
<td>Humpback</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Gray whale</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td>Mooring</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>Precipitation</td>
<td>7%</td>
<td>7%</td>
</tr>
</tbody>
</table>

### Jan 2008 (n=239)

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Oct 2007</th>
<th>Jan 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowhead</td>
<td>89%</td>
<td>5%</td>
</tr>
<tr>
<td>Echolocation</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td>Beluga</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>7%</td>
<td>25%</td>
</tr>
</tbody>
</table>

### Apr 2008 (n=240)

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Oct 2007</th>
<th>Jan 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearded seal</td>
<td>70%</td>
<td>29%</td>
</tr>
<tr>
<td>Ribbon seal</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Bowhead</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Walrus</td>
<td>5%</td>
<td>19%</td>
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<tr>
<td>Precipitation</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Low clicks</td>
<td>2%</td>
<td>20%</td>
</tr>
<tr>
<td>Echolocation</td>
<td>20%</td>
<td></td>
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### Jul 2008 (n=133)

<table>
<thead>
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<th>Jan 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td></td>
<td>26%</td>
</tr>
<tr>
<td>Echolocation</td>
<td>21%</td>
<td>9%</td>
</tr>
<tr>
<td>Low clicks</td>
<td>14%</td>
<td>4%</td>
</tr>
<tr>
<td>Mooring</td>
<td>11%</td>
<td>8%</td>
</tr>
<tr>
<td>Ship</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
<td>6%</td>
</tr>
<tr>
<td>Gray whale</td>
<td>2%</td>
<td>1%</td>
</tr>
</tbody>
</table>
M5 Example
April 25, 2008

[Graph showing frequency and time with labels for Walrus knocks, Bearded seal, and Ribbon seal]
M2 soundbite triggers and incidental detections

Oct 2008 (n=215)

<table>
<thead>
<tr>
<th>Event</th>
<th>Incidental</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echolocation</td>
<td>36%</td>
<td>3%</td>
</tr>
<tr>
<td>Right whale</td>
<td>26%</td>
<td>1%</td>
</tr>
<tr>
<td>Ship</td>
<td>14%</td>
<td>12%</td>
</tr>
<tr>
<td>Mooring</td>
<td>12%</td>
<td>10%</td>
</tr>
<tr>
<td>Humpback</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Killer whale</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Precipitation</td>
<td>2%</td>
<td>8%</td>
</tr>
<tr>
<td>Wind</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Fin whale</td>
<td></td>
<td>60%</td>
</tr>
</tbody>
</table>

Fin whale
Oct. 15, 2008
Applications of PAL Data

Summary Spectra

Sound Pressure Level (dB) rel 1μ Pa²/Hz

Frequency (kHz)

- wind 7m/s
- wind 5m/s
- wind 3m/s
- rain < 2 mm/hr
- 2 < rain < 5 mm/hr
- 5 < rain < 10 mm/hr
- 10 < rain < 20 mm/hr
- rain > 20 mm/hr
- fishing vessel
- cargo
- Oil Tanker
Visual Representation of Sound Level and Variability

- Regional soundscapes generated from spectral patterns
Visual Representation of Sound Level and Variability

- Regional soundscapes generated from spectral patterns
Visual Representation of Sound Level and Variability

- Regional soundscapes generated from spectral patterns

Quieter overall levels, but greater variability due to ice sounds and mammal vocalizations
Visual Representation of Sound Level and Variability

M5 - October 2007

M5 - January 2008

M5 - April 2008

M5 - July 2008

8 vs 20 kHz
8 vs 1 kHz
M2 vs M5

- Greater sound level (note difference in axes) and variability at M2 due to vessels and vocalizations from large whales

Soundscapes

Sea ice onset - January 2009

Sound intensity (dB re 1 µPa² Hz⁻¹)

Date - Year Day 2009

2 kHz vs 20 kHz - Sea ice onset

Sound intensity at 20 kHz (dB re 1 µPa² Hz⁻¹)

- open water
- Day 5
- Day 15
- Day 20
- Day 25

Bowheads

Sound intensity at 2 kHz (dB re 1 µPa² Hz⁻¹)
Conclusions

• Adaptive sub-sampling with PALs provides wide bandwidth (20Hz-50 kHz) acoustic data for year long deployments
  – Spectral data: soundscapes, source identification
  – Limited time series (soundbites): confirmation of source identification
    • Primary triggers
    • Incidental detections

• The PAL is appropriate for specific applications
  – Remote or hazardous areas with limited access
  – Questions related to species richness and co-occurring species
  – Questions related to temporal distribution
Future Goals

• Building representative spectra for different species
• Automated classification of spectral data
• Address ecosystem questions
  – Species richness
  – Temporal distribution/co-occurring species
  – Effects of background noise on signal detection
  – Population/regional response to environmental change
Acknowledgements

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