Applications of Bioacoustics in Monitoring Forest Ecosystems

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Presentation

• Bioacoustic signals

• Applications in ecology and forest trees
  – Wood-boring insect detection
    • Pests, rare species
  – Automated species identification
    • Rapid biodiversity assessment
  – Tree health monitoring
    • Whole tree monitoring

• Future directions

• Conclusions
Bioacoustic Signals

• Any signal with a biological origin
  – Deliberate
    • Communications (birds, insects, etc), defense, echolocation (bats, cetaceans)
  – Incidental
    • Movement, feeding, flight sounds

• Signal transmission can be airborne, aquatic, substrate (vibration)
Applications of Bioacoustics for Trees

- Pest Detection
- Automated Identification
- Internal Sound Identification
- Tree Health

Impact on tree health
Rapid Biodiversity Assessment
Enabling Technology

• Advances in computing very rapid:
  – Processing now very powerful and low power
  – Ability to process large data in real-time
  – Ability to store large quantities of data
  – Ability to access data over large geographical areas (wireless networks)

• Allows new possibilities for ecological applications, e.g.
  – Rapid biodiversity assessment
  – Long term continuous monitoring
Detection of Wood-boring Species

• Coleoptera, Lepidoptera
• Pests
  – Native and non-native species
  – Alien invasive species
• Rare species
  – Saproxylic
  – Live wood including bark
• Detection of feeding/movement using vibration sensors
Coleopteran Pests

• Native Pests
  – *Hylobius abietis*
  – *Scolytus scolytus*
  – *Dendroctonus micans*
  – *Agrilus biguttatus*

• Non-native Pests
  – *Agrilus planipennis* (Emerald Ash Borer)
  – *A. glabripennis* and *A. chinensis* (Asian and Citrus Longhorn Beetles)

• Feeding sounds often characteristic
Recordings in Tree Stumps

- Recording work for BBC looking for Stag beetle larvae

Activity reduces over 2 minutes
A. glabripennis Activity, Norway Maple, 3 hours 28/9/2012

3 hours, 07:55 start

~5 minutes

Recorded at FERA for ANOPLORISK Project
Automated Recognition of Wood-boring Beetle Larvae

Uses artificial neural network trained on individual feeding sounds

<table>
<thead>
<tr>
<th></th>
<th>H. bajulus</th>
<th>P. corarius</th>
<th>R. bifasciatum</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. bajulus</td>
<td>86%</td>
<td></td>
<td>14%</td>
</tr>
<tr>
<td>P. corarius</td>
<td></td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>R. bifasciatum</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>
Rare Species

- Detection/identification of species in live and decaying wood
  - Stag beetle (*Lucanus cervus*) larvae produce species-specific stridulations
  - Other species also stridulate
  - Stridulations can be used to identify presence without damaging the wood and affecting the insects
## Species Recorded to Date

<table>
<thead>
<tr>
<th>Species</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cossus cossus</em></td>
<td>Cossidae (Lepidoptera)</td>
</tr>
<tr>
<td><em>Anoplohora glabripennis</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Anoplophora chinensis</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Trichoferus griseus</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Rhagium bifasciatum</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Prionius corarius</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Phymatodes testaceus</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Hylotrupes bajulus</em></td>
<td>Cerambycidae</td>
</tr>
<tr>
<td><em>Agrilus planipennis</em></td>
<td>Buprestidae</td>
</tr>
<tr>
<td><em>Lucanus cervus</em></td>
<td>Lucanidae</td>
</tr>
<tr>
<td><em>Dorcus parallelipipedus</em></td>
<td>Lucanidae</td>
</tr>
<tr>
<td><em>Cetonia aurata</em></td>
<td>Scarabaeidae</td>
</tr>
<tr>
<td><em>Hylobius abietis</em></td>
<td>Curculionidae</td>
</tr>
<tr>
<td><em>Pityogenes chalcographus</em></td>
<td>Curculionidae</td>
</tr>
<tr>
<td><em>Otiorhynchus sulcatus</em></td>
<td>Curculionidae</td>
</tr>
<tr>
<td><em>Anobium punctatum</em></td>
<td>Anobiidae</td>
</tr>
<tr>
<td><em>Hedobia imperialis</em></td>
<td>Ptinidae</td>
</tr>
</tbody>
</table>

* Stridulations recorded
Automated Species Identification (ASI)

Part of Computer-aided Taxonomy

- Interactive Keys
- Automated Species ID
- Genetic Techniques
  - Semi Automated
  - Fully Automated
Generic ASI System

Possible feedback paths

Sensors
- Microphone
- Vibration
- Camera
- SEM
- Radar
- Sonar

Preprocessing
- filter (LP, HP)
- filter (1-d, 2-d)
- amplification
- noise reduction

Features
- frequency components
- A-matrix
- shape
- colour
- correlation
- LPC coeff

Classification Algorithm
- statistical
- neural

Description Algorithm
- syntactic
- structural

Species ID
Example of Frequency Overlap in British Crickets

Mole and Tree crickets are separable on frequency only. Others are not.
Cricket Recognition using Cartesian Genetic Programming

Confusion between House and Wood cricket

Confusion between House and Wood cricket
Examples of Bioacoustic ASI

• Species specific
  – *Leptophytes punctatissima*
  – *Cicadetta montana*

• More general
  – Japanese cicadas (5 species of *Lyristes*)
  – British Orthoptera
  – European bats
  – US birds
Speckled Bush-cricket Datalogger (funded by NHM)

SBC activity

40kHz detection of SBC

S1 CLICKS
S1 BB CLICKS/50
S1 light/100
S1 TEMP(C)
S1 HUMID(%)
Example of Practical System – *Cicadetta montana*

Southampton University PhD

The New Forest Cicada Project

Welcome to the New Forest Cicada Project

*The New Forest Cicada (Cicadetta montana s. str.) is the only cicada native to the UK. During May to July it sings with a...

* iPhone and Android apps developed for optimal recognition of species + several Bush-crickets
ASI Issues

• Why not commercially available?
  – Many taxa
  – Overlapping features
  – Multiple simultaneous sounds
  – Low signal to noise ratio (quiet)
  – Wide dynamic range (very loud to very quiet)
  – Large quantities of data, especially for ultrasound
    • CD quality (16 bit) audio = 88kbytes/second
    • 200kHz US (16 bit) = 1Mbyte/s
Tree Health

• Current acoustic methods include
  – Cavitation detection (water stress) also related to disease progression (embolism)
  – Tomography for disease and cavity detection

• Additional possibilities
  – Insect damage
  – Disease progression via changes in sound characteristics
  – Mechanical damage, early detection of limb failure

• Concept of *Internal Tree Soundscape* (ITS)
Mechanical Damage

• Tree risk assessment is manually undertaken at infrequent intervals
• Visual inspection
• Danger of missing the problem
  – Horse Chestnut tree in Coppergate, York had a branch fall on a family in July 2013. It had been inspected 3 weeks earlier.
ITS of Trees in High Wind – lower traces are power in dB

Ash Tree
Power is a function of wind speed

Willow Tree
Simple unamplified sensor in dead part of tree. Input to Tascam DR-05 audio recorder.
Simple Example of Sound Classification – pitch contour

5 minutes recording at Skipwith – lower trace is pitch contour

Wind noise
More Complex Example

• Different methods tested to classify sounds, best is combination of MFCC, Kurtosis, ZC, local peaks and second derivative input to ANN

• Results for 5 minute recording:

<table>
<thead>
<tr>
<th>Confusion Matrix</th>
<th>Class</th>
<th>Total Confusion Success Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insect</td>
<td>Wind</td>
</tr>
<tr>
<td>Insect</td>
<td>137</td>
<td>6</td>
</tr>
<tr>
<td>Wind</td>
<td>5</td>
<td>133</td>
</tr>
<tr>
<td>Knock</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Success Percentage</td>
<td>90.7%</td>
<td>88.1%</td>
</tr>
</tbody>
</table>
Future Directions

• Pests and rare species
  – Expand acoustic database of signal from different species
  – Improve detection ability

• Automated species identification
  – Expand taxonomic groups
  – Requires major initiatives to achieve this

• Tree health
  – Extension to whole tree monitoring
Integrated system for monitoring at scales from individual trees to whole landscapes

Measures the Internal Tree Soundscape (ITS)

Potential for improving quantified tree risk assessment (QTRA)

Involves wireless networks on differing scales
  – Network on single tree
  – Network over number of trees (10’s-100’s)
  – Network over landscape scale
Forest/Woodland

sensor unit (acoustic, moisture, temperature, camera, IR, etc)

Wireless Network

Mobile Phone

Bluetooth

Sentinel Tree/Urban Tree/Veteran Tree

Base Station

Internet

Single Tree Network

Potential for citizen science?
Landscape scale monitoring

FOREST

WOODLAND

PARKLAND
Veteran trees
Ancient trees

Intermediate node

URBAN
Street trees
Amenity trees
Whole Tree Monitoring

- Multiple sensors placed at different heights on tree, coupled via WSN
  - Application specific, e.g. placed low for CLB, high for ALB
  - Develop a species specific model of the acoustic propagation inside the tree (modes); modes will change due to drying out, rot.
  - Inclusion of temperature, humidity, etc to develop models of tree microclimate
Conclusions

• Bioacoustics is becoming more widespread
  – Feasible to perform sound identification at high speed
  – Potential for whole tree health monitoring at low cost and large scale
  – Inclusion of environmental data is possible