Estimating population density from fixed passive acoustic detectors

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International Statistical Ecology Conference  
6th June 2010
Motivation

• Many statistical methods for estimating density/abundance require you to see the animals…

E.g., for cetaceans:
  visual line transects / mark-recapture photo ID
Motivation

• ... but some species are **hard to see**, and **easy to hear** ...

Examples:

– many marine animals
  • echolocation
  • intraspecific communication

– many forest animals
  • elephants
  • gibbons
  • songbirds
Motivation

• … making passive acoustic methods attractive

  passive – listen only
  active  – playback then listen
          (attract animals, or echolocate them)

• Some “standard” passive acoustic methods…
1. Point transects for forest birds

\[ D = \frac{n}{ap} \]

- **number of individuals heard**
- **surveyed area**
- **average probability of detection**
Estimating $p$

True distribution of animals, $\pi(x)$

Detection function, $g(x)$

Observed distribution, $f(x)$

\[ \hat{p} = \int_{0}^{w} \pi(x) \hat{g}(x) \, dx \]

Note:
- you need two of these things to get the third
- you need to know $\pi(x)$ to get average $p$
Cue counts

- Sometimes easier to count calls (cues) than count birds

\[ D = \frac{n}{aTpr} \]

- number of cues heard
- surveyed area
- time spent listening
- probability of detection of cue
- cue rate
2. Towed acoustic line transects for cetaceans

Survey vessel

2D acoustic array

True distribution of animals $\pi(x)$

$$D = \frac{n}{ap}$$

Detection function, $g(x)$

$$\hat{p} = \int_0^w \pi(x)\hat{g}(x)dx$$

Observed distribution, $f(x)$

Some surveys break off to visually estimate group size (e.g., Barlow + Taylor 2005)
but wait, they are interesting!

- Complications:
  - 2 element array gives range, not perpendicular distance
    - with assumed depth distribution, have a measurement error problem
  - species mis-identification – particularly with automated detection and classification algorithms
    - estimate mis-classification rate – another multiplier …
    - … but a false positive for one species may be a false negative for another – see Marjolaine Caillat poster
The potential of fixed passive acoustics

• Potential for highly cost-effective monitoring for some species
• Can deploy fixed sensors for long periods (in all weathers)
  – record to hard drives
• Can automate processing
  – use recent (and ongoing) advances in DCL
• Can make use of existing sensors ("platforms of opportunity")
DECAF
Density Estimation for Cetaceans from passive Acoustic Fixed sensors

- 3-year project: 2007-2010; 14 people, 4 institutes
- Objectives:
  1. Develop methods for estimating the density of cetaceans from fixed passive acoustic devices. Methods should be applicable to a wide range of scenarios.
  2. Demonstrate methods by implementing on a set of case studies
  3. Promote adoption of methods in the marine mammal research community.
Density Estimation for Cetaceans from passive Acoustic Fixed sensors

www.creem.st-and.ac.uk/decaf/

Project Outputs

Outputs from the DECAF project:

Journal Articles (submitted)

- Baggenstos, P.M. Separation of Sperm Whale Click Trains for Multipath Rejection.
- Baggenstosse, P.M. An Algorithm for the Localization of Multiple Interfering Sperm Whales Using Multi-Sensor Time Difference of Arrival.
- Ward, J., Janaki, S., Moretti, D., Morrissey, R., D'Marco, N., Thomas, L. and Marques, T. Beaked whale (Mesoplodon densirostris) passive acoustic detection with increasing ambient noise.

Related work by project members:

Journal Articles (in press or published)

  - Full text (pdf)
  - The final publication is available at www.springerlink.com. DOI: 10.1007/10538.015-0537-7
  - Abstract (pdf)
  - Full text (pdf)

News

- Sperm whale click-train separation tech report available
  - Jun 22, 2010
- Project extended until Feb 011
  - Mar 31, 2010
- Data files uploaded
  - May 30, 2010

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Methods that can be used depend upon…

- Information available from sensor(s)
  - detections
  - “raw sound data”
  - association between sensors
  - range and/or bearing
- What is known about the species
  - vocal behaviour (e.g., rate, who makes the sounds, source levels, …)
  - spatial distribution around sensors
  - group size
- Other auxiliary information
  - tagged animals
Early thoughts on possible methods

Poster presented at ISEC 2008 conference

Our first case study
Update

+ many more case studies
What can you identify acoustically?

Cues (e.g. whale clicks, dive starts)

Can you get cue rate?

No

Can you get mean group size?

Yes¹

Groups of animals

Individual animals
Certain detection

Is detection certain within some defined area, and can you exclude all detections from outside that area?

Yes

No

Plot sample methods
Examples:
1. strip transect (animal based)
2. dive counting (cue based)
Plot sample example: Dive counting for beaked whales at AUTEC

Plot sample example: Dive counting for beaked whales at AUTEC

\[ D = \frac{ns}{aTr} \]

- Problems:
  - false positives
  - hard to automate
  - groups close together in space and time
Strip transect example II: Snapshots for sperm whales at AUTEC

Sperm whale clicks are classified into “trains”…

… direct path trains are localized to distinguish individuals…

… number of animals present at a set of snapshot times is calculated

\[ D = \frac{n}{\text{surveyed area} \cdot \text{number of snapshots} \cdot \text{proportion of time spent vocalizing}} \]

Ward et al. Submitted
Uncertain detection

Can you estimate distance to sound source? Yes

Do you know (relative) density gradient? Yes

Is $g(0)$ known? Yes

Is $\pi(r)$ a triangular distribution? Yes

Standard point transect snapshot methods or cue counting

Can you estimate distance to sound source?
North pacific right whales in the Bering Sea: single sensor cue counting with distances

Marques, Thomas, Munger, Wiggings, Hildebrand. Submitted.

Truncation <15km and >75km

Standard cue counting methods:

\[
D = \frac{n}{aTpr}
\]

\[
\hat{D} = 0.21 \text{ whales/10,000km}^2
\]

\[
\hat{N} = 20 (95\% \text{ CI 14 – 29})
\]
Fin whales in the Gulf of Cadiz: sparse array point transect with distances

Collaboration with Luis Matias, University of Lisbon, and Danielle Harris
Known, but non-triangular density gradients

Is $\pi(r)$ a triangular distribution?

Yes

Standard point transect snapshot methods or cue counting

No

Horvitz Thomson type estimator

$$\hat{D} = \frac{1}{k} \sum_{i=1}^{k} \frac{n_i}{\pi r_i^2}$$
Unknown $g(0)$

Is $g(0)$ known?

- No

Can you associate sounds across hydrophones?

- No

- Yes

Mark-recapture distance sampling (a.k.a. SECR with known distances/locations)
Unknown density gradients

Do you know (relative) density gradient?

No

Can you get bearing (or assume density same in all directions)?

No

Is sound propagation modeling possible?

Yes

Horvitz Thomson type estimator

\[ \hat{D} = \sum_{i=1}^{k} \frac{1}{A_{(p>0)} p_i} \]

where \( A_{(p>0)} \) is a defined area where \( g(r)>0 \)
Unknown density gradients, no sound propagation

Is sound propagation modeling possible?

No

Is $g(0)$ known?

Yes

Simultaneous spatial density surface and detection function modeling
Potential example of simultaneous density surface and detection modelling: SOSUS

Source: Charif, Clapham & Clark. 2001. MMS 17:751-68.
No distances, association

Can you estimate distance to sound source?

No

Can you associate sounds across hydrophones?

Yes

Spatially-explicit capture recapture (SECR)
Minke whales at PMRF: dense array spatially-explicit capture recapture (SECR)

Marques et al. (In press) Journal of Ornithology (EURING proceedings)
Model selection
Likelihood and Bayes

- Martin et al (In prep) – longer term encounter rate dataset; habitat mask, ...
- Joint use of localization and association data
No distances, no association

Can you associate sounds across hydrophones?

No

Do you know (relative) density gradient? 

No

Yes

Can you estimate $g(r)$ any other way?

Yes

No

Horvitz Thomson type estimator

$$
\hat{D} = \frac{1}{k} \sum_{k=1}^{k} \frac{n_k}{\pi r_k^2}
$$
Beaked whales at AUTEC via sparse array cue counting with: (1) auxiliary tag data

- Analysis of beaked whale clicks

\[ D = \frac{n(1-c)}{aTpr} \]

- Proportion of false positive detections – from manual analysis of a sample of clicks
- Prob of detection – estimated by associating clicks recorded on tags with those on range hydrophones
- Cue rate – from tags

Marques et al. (2009)
J. Acoust. Soc. Am
Beaked whales at AUTEC via sparse array cue counting with: (2) propagation modelling

• Same as previous example, except:
  • Probability of detection estimated from models of source level characteristics, sound propagation and detector characteristics (Küsel et al. in prep)

• For details of approach, see talk on blue whales by Danielle Harris tomorrow
Other methods

• Occupancy data: Sperm whales (Whitehead 2009 Journal of Wildlife Management)

• Regression of sound intensity on density: Jez monster (Mellinger + al in prep)

• Gibbons – direction-only data (Kidney, 2009)
Conclusions

• Estimation of animal density from passive acoustics is a rapidly developing and expanding field
  – Increasing knowledge of vocal biology
  – Advances in signal processing
  – Better hardware
  – New statistical methods
• In practice, estimation often hampered by lack of auxiliary data, e.g., vocalization rates, information about detectability
• Future emphasis on optimal survey design
• University of St Andrews (UStAnd) - Len Thomas; Tiago Marques; David Borchers; Catriona Harris
• Naval Undersea Warfare Center (NUWC) - Dave Moretti; Jessica Ward; Nancy DiMarzio; Ron Morrissey; Susan Jarvis; Paul Baggenstoss.
• Space and Naval Warfare Systems Command (SPAWAR) - Steve Martin
• Oregon State University (OSU) - Dave Mellinger; Elizabeth Kusel
• Woods Hole Oceanographic Institution (WHOI) - Peter Tyack
• Steering group: Steve Buckland, Jay Barlow and Walter Zimmer.