Estimating spatial densities of vocalizing animals using bearings of signals detected with a directional acoustic recorder

Ildar Urazghiidiiev, Bruce Martin, Art Cole, John Moloney, Harald Yurk, and Xavier Mouy

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Introduction

Animal population density is defined as

\[ D = \frac{M}{S} \]

where \( M \) is the number of animals presented in an observation area of size \( S \) over a certain observation interval.

The goal of this work is to estimate the number of vocalizing animals, \( M \).
Canonical Density Estimator

The most popular density estimators are based on a fundamental assumption that “in passive acoustic surveys, it is often not possible to count the number of animals directly” (Marques et al., 2013).

The canonical density estimator:

\[ D = \frac{N \downarrow c (1 - c)}{p \, Tr \, S} \]

where

- \( N \downarrow c \) is the total number of the detections (or detected cues)
- \( c \) is the probability of false positives estimate
- \( p \) is the detection probability estimate
- \( r \) is the call rate estimate

Canonical Density Estimator

The canonical density estimator provides acceptable accuracy if the following assumptions hold true:

A1: The call rate, \( r \), is a stationary ergodic random process.

A2: The mean call rates are equal for all sources, \( r_m = r, \ m=1...M \).

A3: For all sources, all detection probabilities are equal, \( p(d_m) = p, \ m=1...M \).

A4: The average probability of false positives, \( c \), is constant.

A5: The estimates \( c, p \) and \( r \) are unbiased and have small mean square error and coefficient of variation (CV).

A6: Over the observation interval, the number of animals presented in the observation area is constant.
Canonical Density Estimator

The assumptions A1-A6, are rarely met in practice because of

• Animals travel across the habitat, such that the number of animals in an area and source-to-sensor distances change with time;

• For many animals, changes in their calling rates may be significant, such that no call rate estimates with low CVs available;

• The proportion of false positives may change significantly over a long observation interval due to changes in ambient noise conditions;

• The CV for the probability of false positives, $c$, may be high.

The parameters $p$, $r$, and $c$ requires manual counts of the automatic detections. Manual analysis is a very time consuming and expensive task.
Bearing-based Density Estimator

Sources S1 and S2 simulated the behavior of Blainville’s beaked whale.

The speeds of sources $S_1$ and $S_2$ were 1.2 and 2.5 m/s. Call rates were $r_1=3.3$ and $r_2=2.5$ calls per second, respectively.

The source S3 simulated a ship travelling with a speed of 8 m/s.

Fig. 1. Trajectories of three moving sources.
Fig. 2. (Left) Trajectories of three moving sources, (right) source bearings
Bearing-based Density Estimator

Fig. 3. The number of detectable sources
Bearing-based Density Estimator

To estimate the number of sources, $M(t)$, the short-time bearing distribution (STBD), $W(\alpha,t)$, is proposed.

**Fig. 4. The short-time bearing distribution**
Bearing-based Density Estimator

In practice, the short-time bearing distribution (STBD) can be computed using bearings estimates provided by the directional sensor.

Fig. 5. Output of the directional sensor. Top: data spectrogram. Bottom: bearing estimates of the detected signals.
Bearing-based Density Estimator

Using the empirical STBD, the following estimators of the number of sources are proposed:

**Instantaneous estimator:**
$M_{\downarrow I}(t)$ is the number of peaks of the empirical STBD that exceed some threshold, $W(\alpha,t) > c_{\downarrow 0}$

**Smoothed estimator:**
$M_{\downarrow S}(t) = smooth\{M_{\downarrow I}(t_{\downarrow j}),L\}$ is the smoothed estimate of $M_{\downarrow I}(t)$

**Track-based estimator:**
$M_{\downarrow T}(t)$ is the number of bearing tracks created automatically or manually by visually analyzing the empirical STBD
Simulations

**Instantaneous estimator:**

$M \downarrow I(t)$ is the number of peaks of the empirical STBD that exceed some threshold, $W(\alpha, t) > \omega_0$

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**Fig. 6.** Top: empirical STBD of the detected signals. Bottom: *instantaneous* estimates of the number of sources.
Simulations

Smoothed estimator:

\[ M \downarrow S(t) = \text{smooth}\{M \downarrow I(t \downarrow j), L\} \]

is the smoothed estimate of \( M \downarrow I(t) \)

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**Fig. 7.** Top: empirical STBD of the detected signals. Bottom: smoothed estimates of the number of sources.
Simulations

**Track-based estimator:**

\( M \downarrow T(t) \) is the number of bearing tracks created manually by visually analyzing the empirical STBD.

*Fig. 8. Top: empirical STBD of the detected signals. Bottom: Track-based estimates of the number of sources.*
Simulations

Canonical estimator:

\[ M = N \downarrow c \frac{(1 - c)}{p \, Tr} \]

\[ r = 2.9 \quad (r \downarrow 1 = 3.3; \quad r \downarrow 2 = 2.5) \]
\[ N \downarrow d = N \downarrow c (1 - c) = 8871 \]
\[ p = \{0.2, 0.45, 0.72\} \quad (p \downarrow 1 = 0.4; \quad p \downarrow 2 = 0.47) \]

Fig. 9. Top: empirical STBD of the detected signals. Bottom: Canonical estimates of the average number of sources.
Simulations

Comparison of the canonical and bearing-based estimators.

Fig. 10. Top: empirical STBD of the detected signals. Bottom: Bearing-based and canonical estimates of the number of sources.
In Situ Tests Using the Directional Sensor

Directional sensor:
• Tetrahedral frame
• 4 hydrophones
• 64 kHz sampling rate:
• 1° bearing estimation accuracy

Deployment:
• VENUS ocean observatories operated by Ocean Network Canada:
  – East node (172 m)
  – DDL node (144 m)
• Near BC ferry routes, Vancouver vessel traffic lanes and active area for Marine Mammals
In Situ Tests Using the Directional Sensor

Fig. 11. Empirical STBD computed using TDOA-based maximum likelihood localization algorithm (Urazghildiiev and Clark, 2013).

**In Situ Tests Using the Directional Sensor**

Fig. 12.
*(Top)* Empirical STBD computed for the data collected on June 17, 2014;
*(Bottom)* Bearing-based estimates of the number of sources (Killer whales).
**In Situ** Tests Using the Directional Sensor

Near-real time automatic DCLT and DE of marine mammals:
- VENUS ocean observatory;
- DDL node;
Conclusions

• Bearing measurements of detected signals can be used as an important feature to solve the problem of DE for a variety of vocalizing animals and anthropogenic noise sources.

• The number of sources can be directly counted as a number of different bearings or as a number of bearing tracks extracted from empirical short-time bearing distributions.

• The bearing-based estimators provide accurate estimation of the number of sources if the directional acoustic sensor produces bearing estimates with accuracy of about 1 degree.

• No prior information about the detection probability as a function of source to sensor range, false alarm probability, or calling rate is required
Questions?
Ildar.urazghildiiev@jasco.com