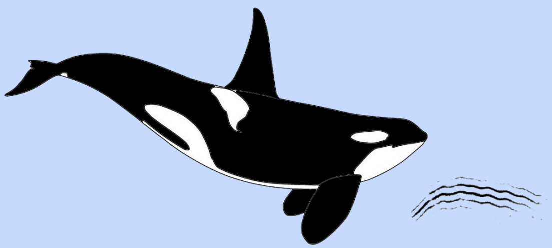
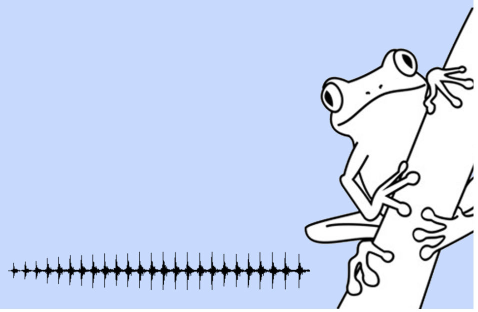
Animal monitoring using acoustic data

Advanced Distance Sampling research talk

30th Aug 2019

Danielle Harris





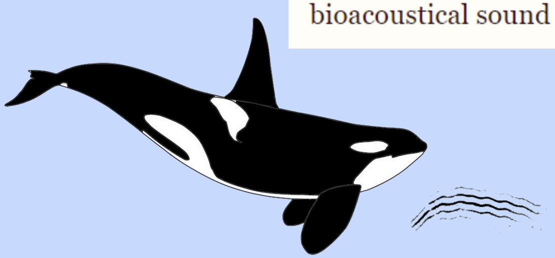
Acoustics is a current hot topic
for ecological research
(just like drones, camera traps, environmental DNA, biologging or citizen science – not exhaustive list)

Bioacoustics

Bioacoustics - the International Journal of Animal Sound and its Recording

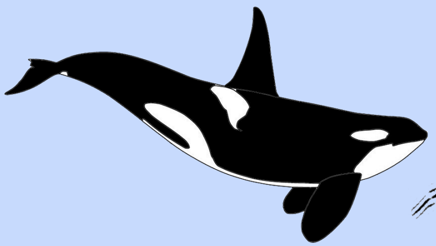
Bioacoustics is the only international peer-reviewed journal devoted to the scientific study, recording and analysis of animal sounds.

Bioacoustics primarily publishes high-quality original research papers and reviews on sound communication in birds, mammals, amphibians, reptiles, fish, insects and other invertebrates, on the following topics: communication and related behaviour; sound production, hearing, ontogeny and learning; bioacoustics in taxonomy and systematics; impacts of noise; bioacoustics in environmental monitoring; identification techniques and applications; recording and analysis equipment and techniques; ultrasound, infrasound, underwater sound; bioacoustical sound structures, patterns, variation and repertoires. *Bioacoustics* is published by Taylor and Francis.



Several key advantages of acoustics

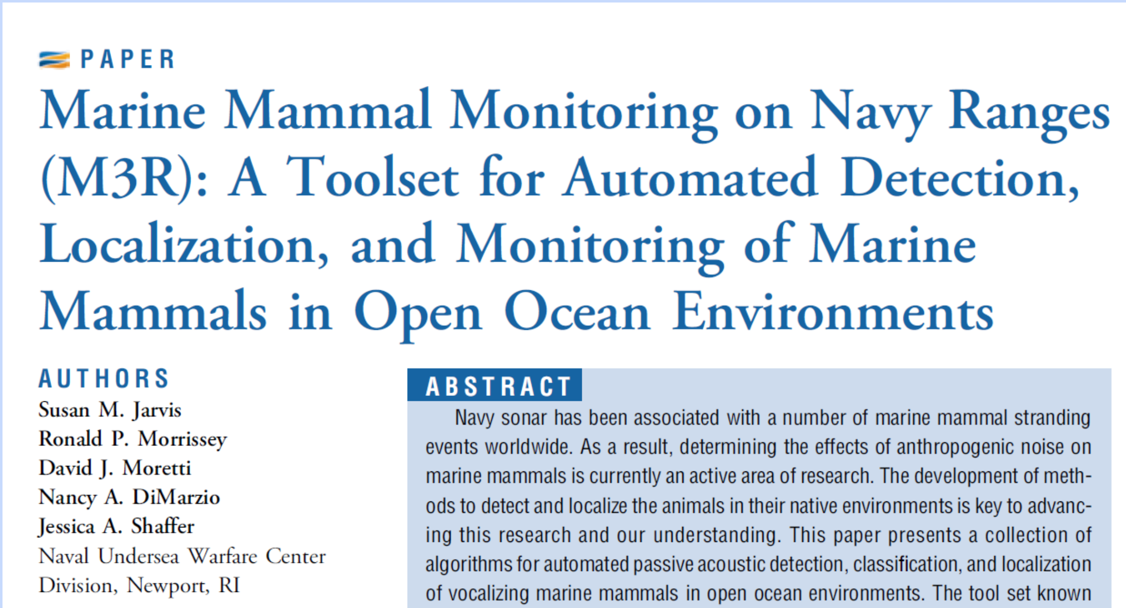
1. Animals that produce loud or frequent sounds may be detectable at greater ranges acoustically than by other means.
2. Unlike (most) visual surveys, passive acoustic surveys can operate under any light conditions (e.g. both day and night, or in fog), being less affected by weather conditions
3. Passive acoustics is highly amenable to automated data collection and processing, so large amounts of data can readily be analyzed
4. Automated data collection means that information can be gathered in environments where it is not easy for human observers to work (e.g. deep or polar oceans). Acoustic monitoring is a popular choice for marine environments, though terrestrial monitoring is increasing rapidly.



Marques *et al.* 2013 Estimating animal population density using passive acoustics *Biological Reviews* **88**: 287-309

Basics of DCLDE

- There are a number of tasks involved prior to density estimation: DCL
- Detection
- Classification
- Localization



PAPER

Marine Mammal Monitoring on Navy Ranges (M3R): A Toolset for Automated Detection, Localization, and Monitoring of Marine Mammals in Open Ocean Environments

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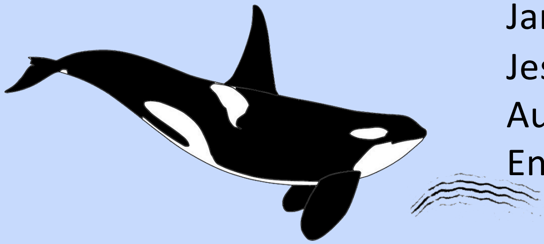
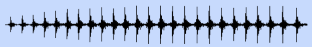
ABSTRACT
Navy sonar has been associated with a number of marine mammal stranding events worldwide. As a result, determining the effects of anthropogenic noise on marine mammals is currently an active area of research. The development of methods to detect and localize the animals in their native environments is key to advancing this research and our understanding. This paper presents a collection of algorithms for automated passive acoustic detection, classification, and localization of vocalizing marine mammals in open ocean environments. The tool set known



Jarvis, Susan & P. Morrissey, Ronald & Moretti, David & A. DiMarzio, Nancy & A. Shaffer, Jessica. (2014). Marine Mammal Monitoring on Navy Ranges (M3R): A Toolset for Automated Detection, Localization, and Monitoring of Marine Mammals in Open Ocean Environments. Marine Technology Society Journal. 48. 10.4031/MTSJ.48.1.1.

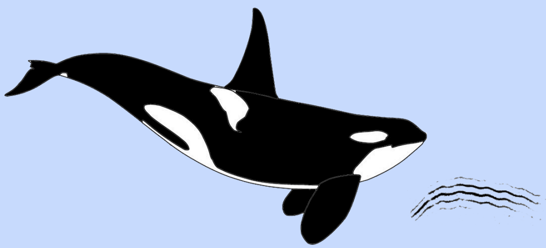


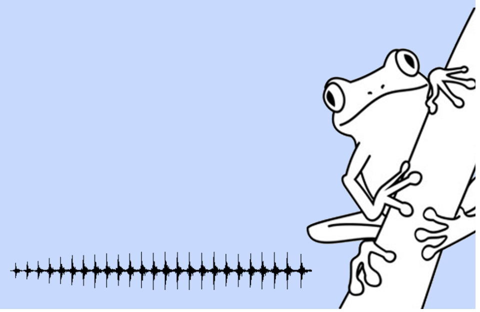
Passive Acoustic Density Estimation is…

…just another way of doing density estimation

…so the usual methods will apply, often with tweaks

- Total counts/plot sampling
- Distance Sampling
- Capture Recapture
- Spatial Capture Recapture
- Methods using auxiliary data





Canonical density estimator

- Object of interest:
  - animals
  - groups
  - cues

$$\hat{D} = \frac{n}{a}$$

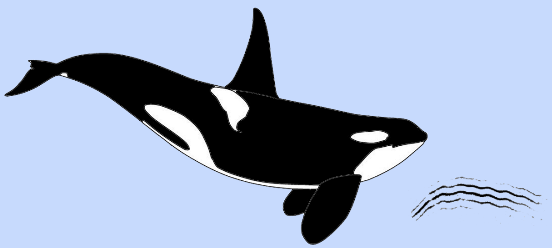
$$\hat{D} = \frac{n}{\hat{p}a}$$

$$\hat{D} = \frac{n\left(1 - \hat{f}\right)}{\hat{p}a\hat{r}}$$

False positives

Detection probability

multiplier(s) that converts object density to animal density (e.g. cue rate, time)



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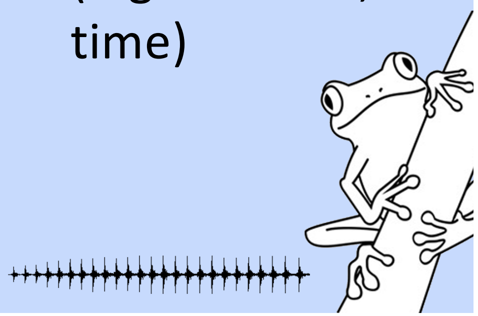
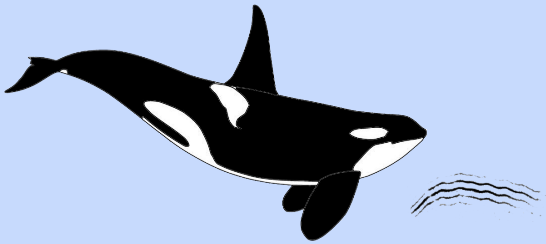
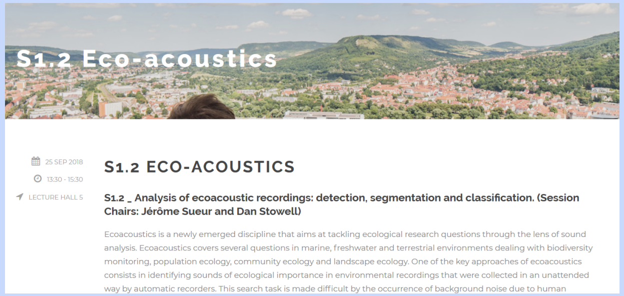


How do we deal with large volumes of data?

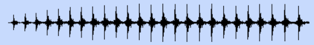
Detection and **Classification**

http://sabiod.univ-tln.fr/DCLDE/

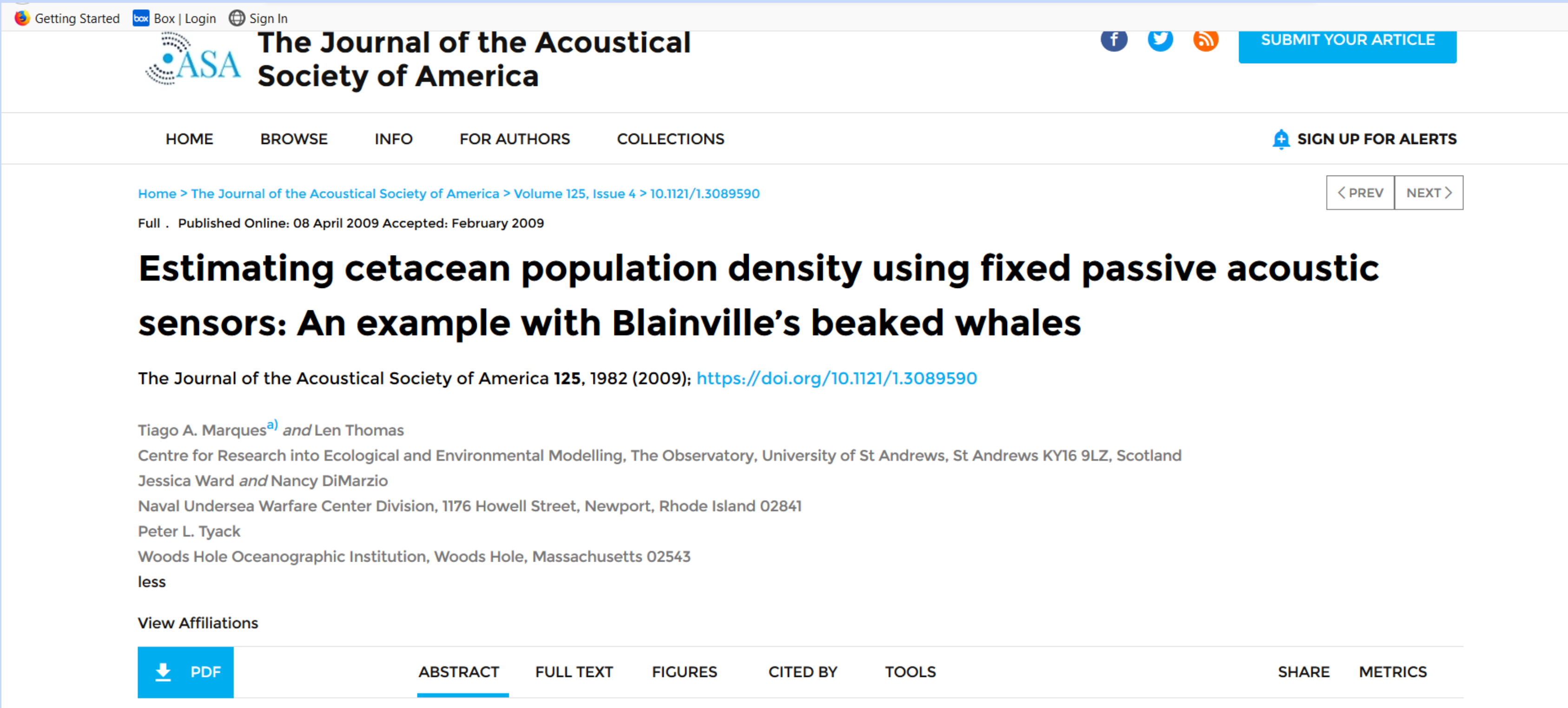




https://icei2018.uni-jena.de/



The need to check automated methods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Full . Published Online: 08 April 2009 Accepted: February 2009

Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville's beaked whales

The Journal of the Acoustical Society of America **125**, 1982 (2009); https://doi.org/10.1121/1.3089590

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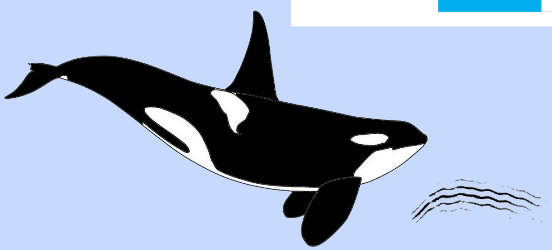
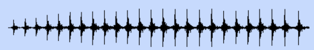
PDF ABSTRACT FULL TEXT FIGURES CITED BY TOOLS SHARE METRICS



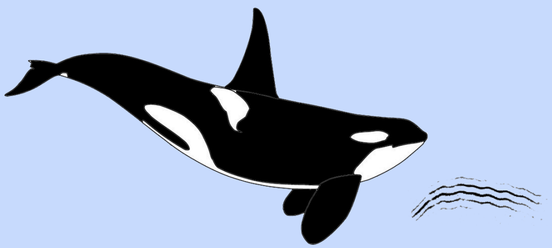


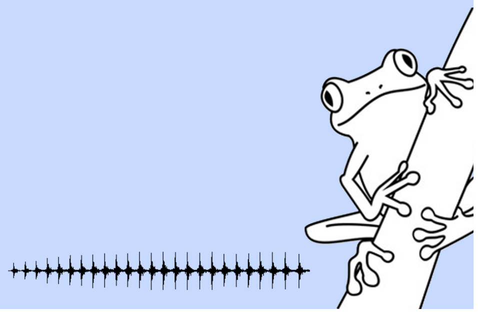
The need to check automated methods

6 days of data
82 hydrophones
2.9 million detections
Low CV for encounter rate (5.5%)

False positive rate checked
160,300 detections
(1 – f) = 0.5
Low CV = 2%

$$\hat{D} = \frac{n\left(1 - \hat{f}\right)}{\hat{p}a\hat{r}}$$





The need to check automated methods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Open . Published Online: 31 December 2018 Accepted: December 2018

Two unit analysis of Sri Lankan pygmy blue whale song over a decade

The Journal of the Acoustical Society of America **144**, 3618 (2018); https://doi.org/10.1121/1.5084269

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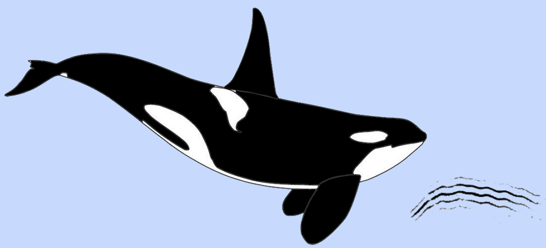

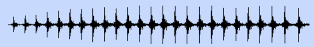

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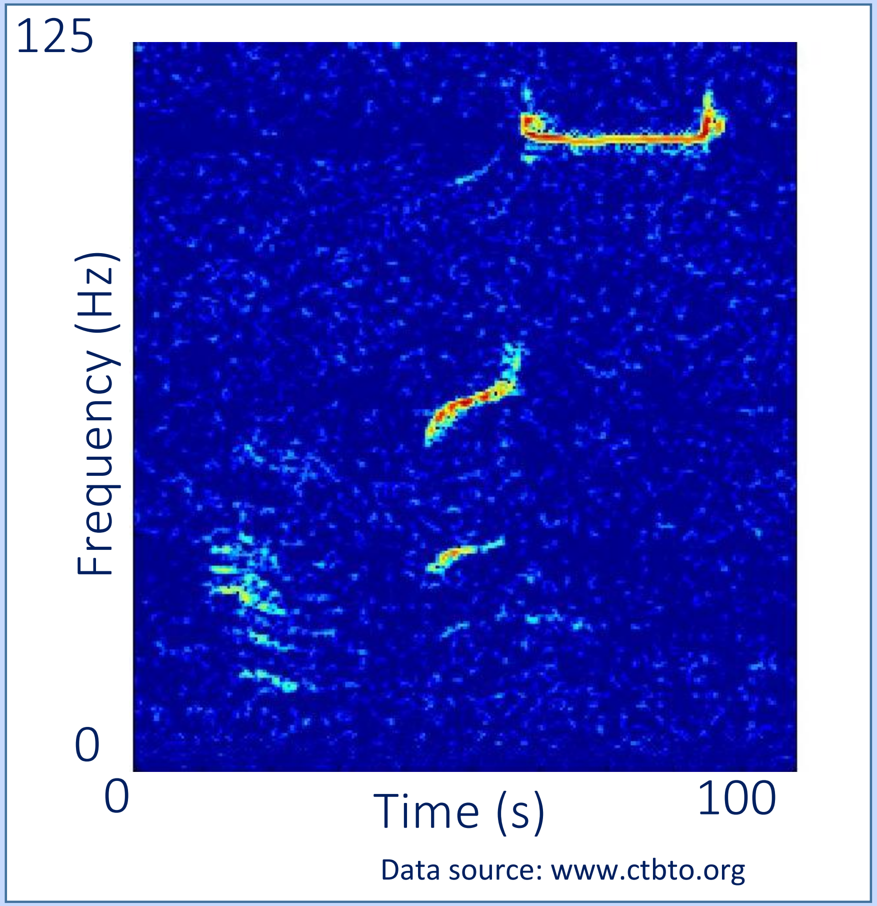

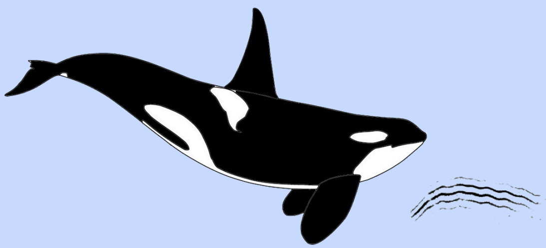

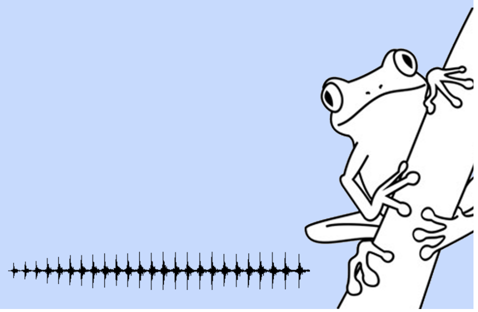

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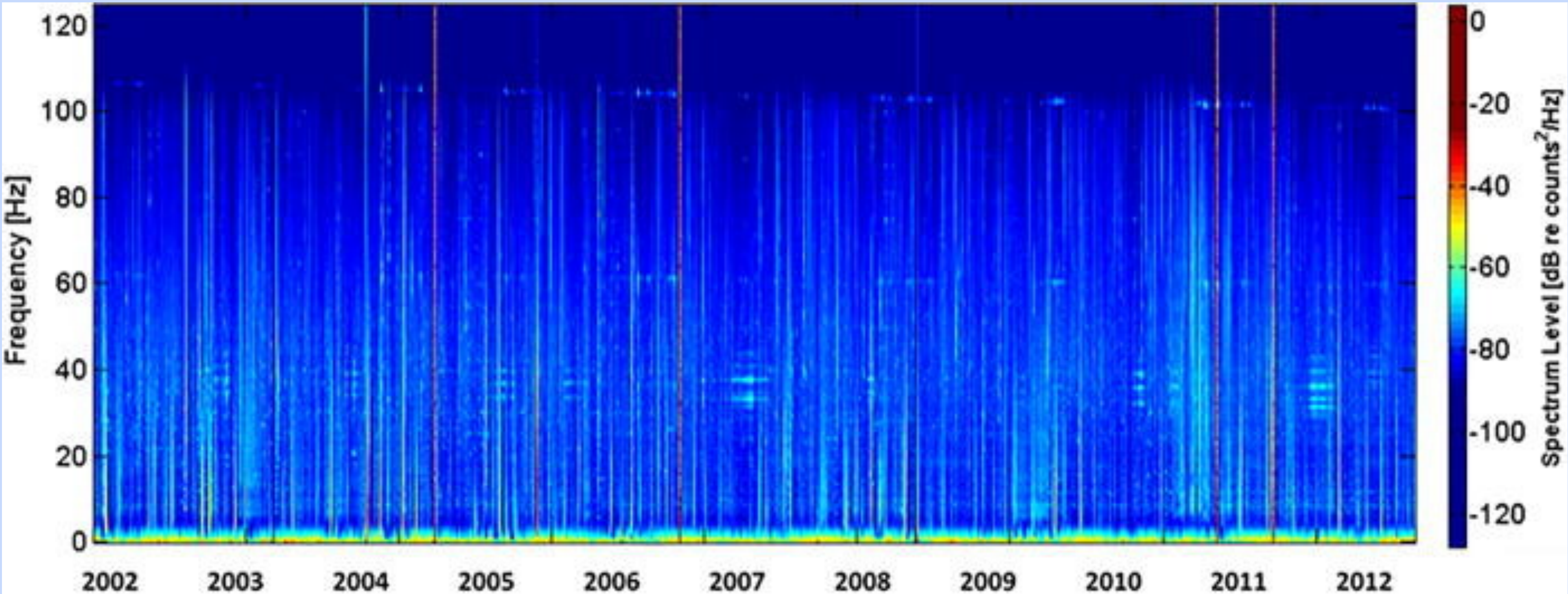
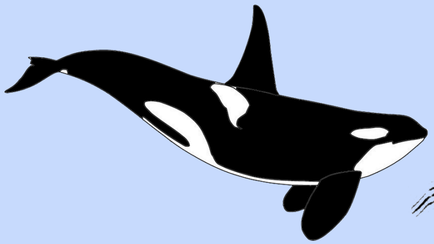
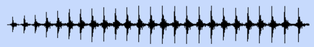





Published in: Jennifer L. Miksis-Olds; Sharon L. Nieukirk; Danielle V. Harris; *The Journal of the Acoustical Society of America* **144,** 3618-3626 (2018)
DOI: 10.1121/1.5084269

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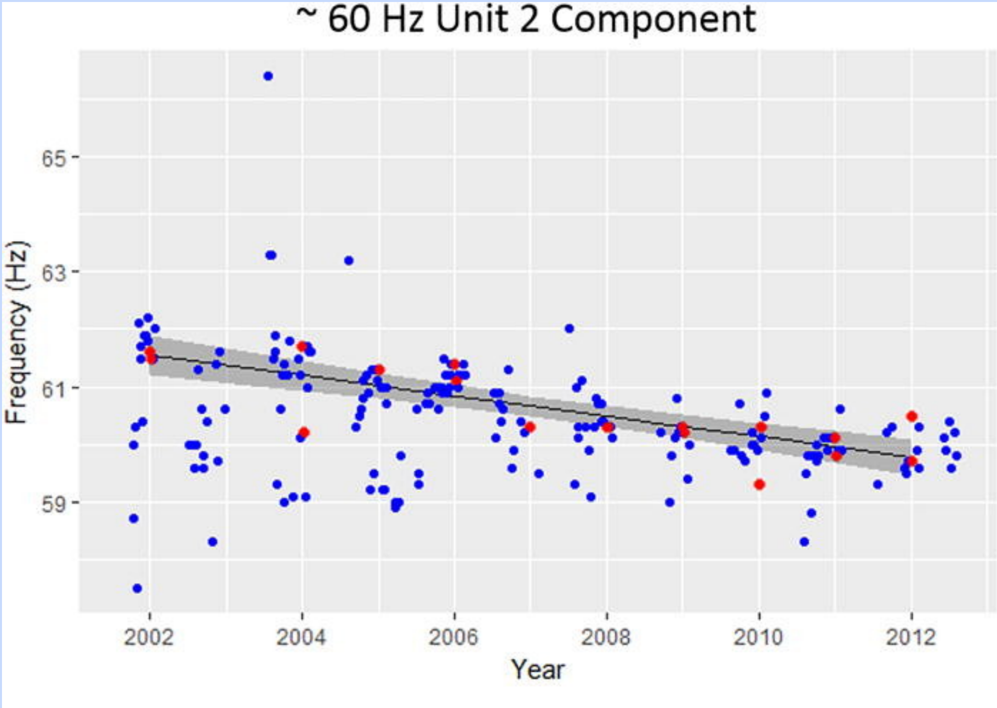

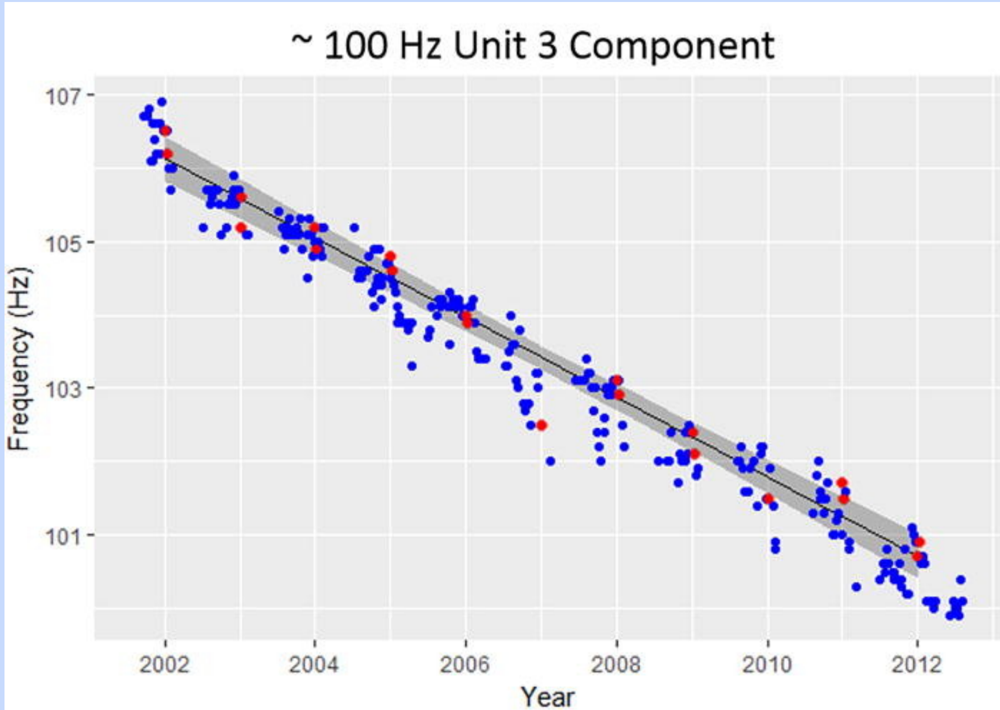

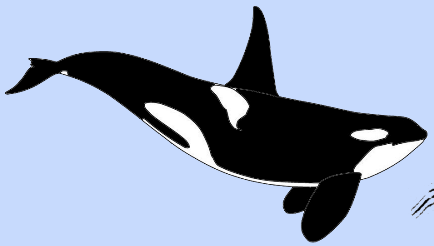

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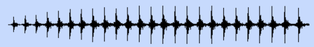
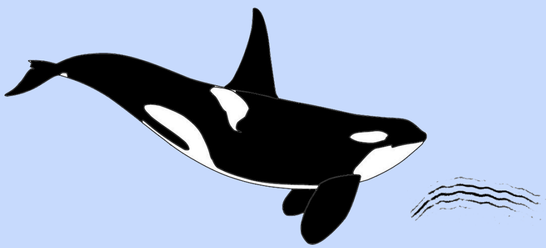
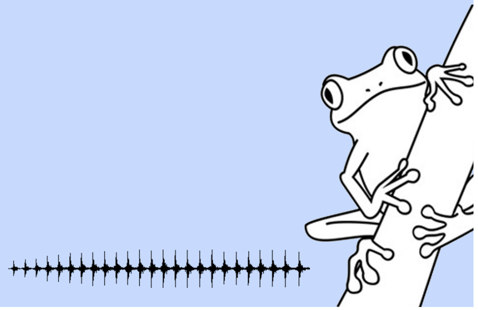


Lessons learned

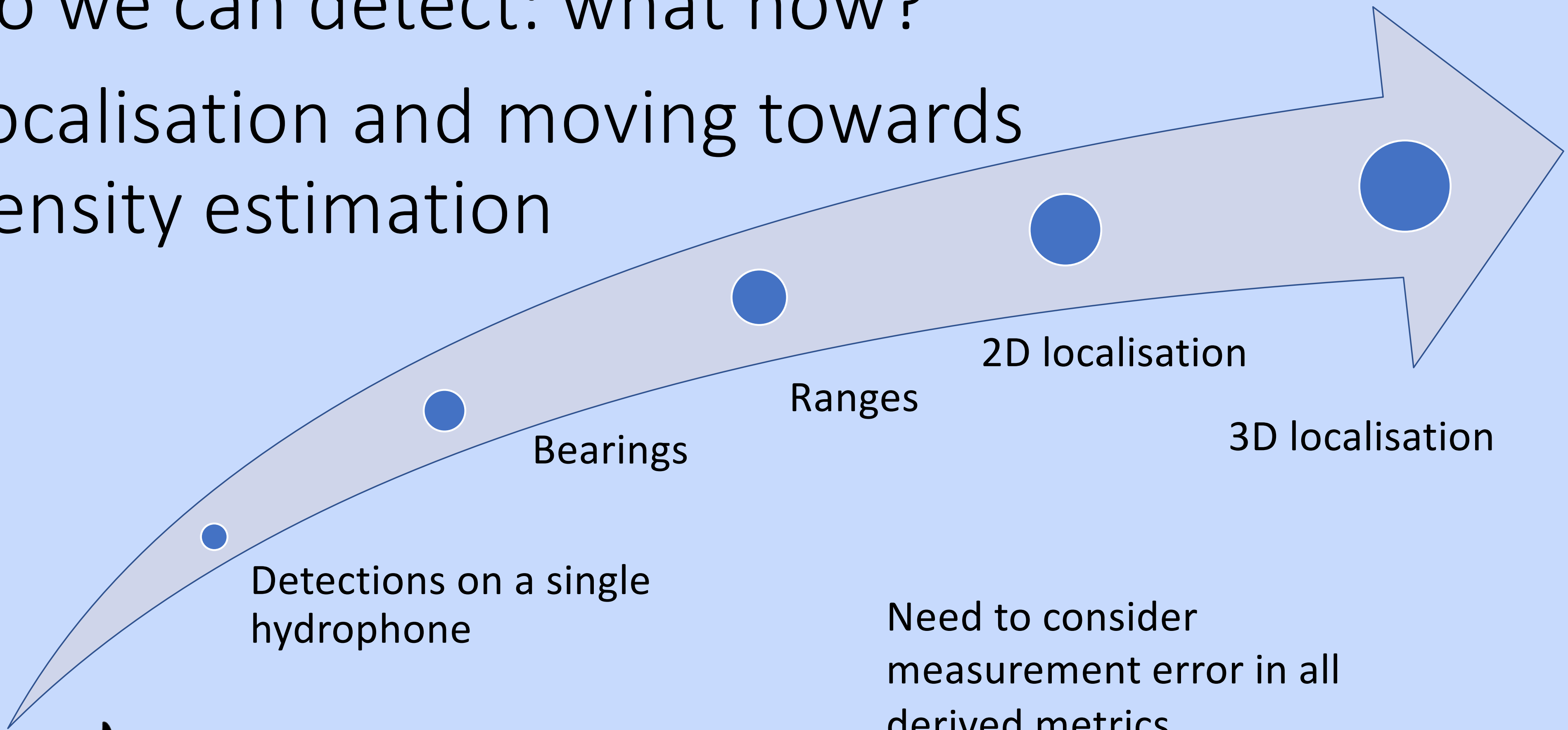
- Detection and classification are their own fields.
- Important to be aware of how detection and classification problems can evolve over time, even for the same target signal.
- Multidisciplinary teams are vital to cover the different fields.



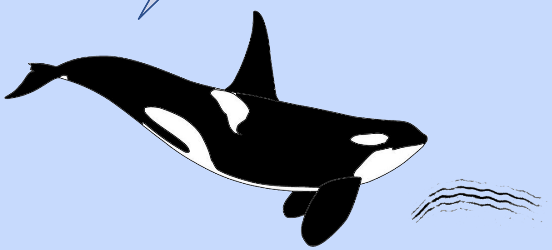


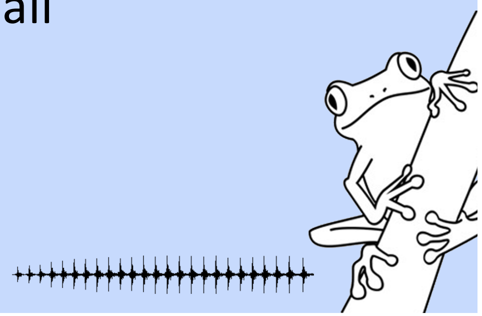
So we can detect: what now?

Localisation and moving towards density estimation



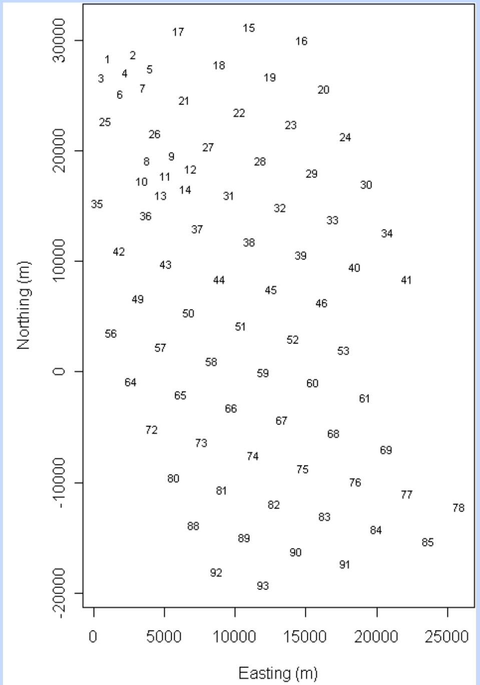
Need to consider measurement error in all derived metrics





Plot sampling examples

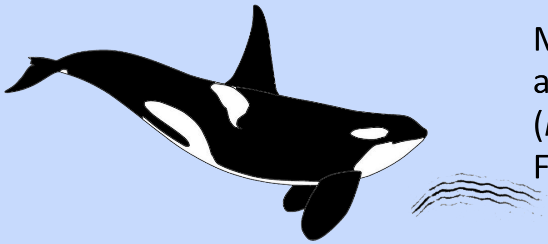
Image: Diane Claridge



$$\hat{D} = \frac{n}{a} \times \frac{\hat{s}}{T\hat{r}}$$

- n: number of dive starts
- a: area monitored
- $\hat{s}$: mean group size from separate visual surveys
- T: time spent monitoring
- $\hat{r}$: mean dive rate taken from a sample of tagged whales

Moretti et al. (2010)
Monitoring period:
10 days around time of a Navy exercise

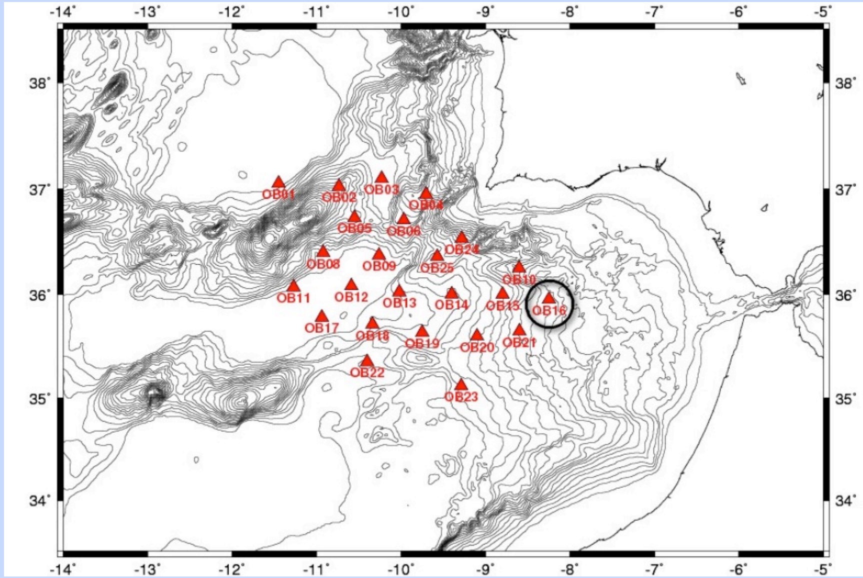


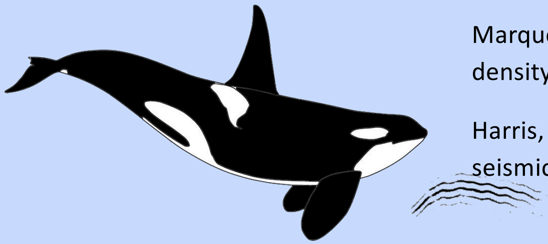
Moretti, D., T.A. Marques, L. Thomas, N. DiMarzio, A. Dilley, R. Morrissey, E. McCarthy, J. Ward and S. Jarvis. 2010. A dive counting density estimation method for Blainville's beaked whale (*Mesoplodon densirostris*) using a bottom-mounted hydrophone field as applied to a Mid-Frequency Active (MFA) sonar operation. Applied Acoustics 71: 1036-1042.

Distance sampling examples

Image: http://www.afsc.noaa.gov

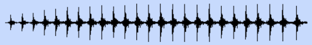
- North Pacific right whales: Marques et al. (2011)
- Fin whales: Harris et al. (2013)
- Examples of point transect cue counting methods
- Also good examples of making use of existing instrumentation.





Marques, T.A., L. Thomas, L. Munger, S. Wiggins and J.A. Hildebrand. 2011. Estimating North Pacific right whale (*Eubalaena japonica*) density using passive acoustic cue counting. Endangered Species Research 13: 163-172.

Harris, D., L. Matias, L. Thomas, J. Harwood & W. Geissler. 2013. Applying distance sampling to fin whale calls recorded by single seismic instruments in the northeast Atlantic. The Journal of the Acoustical Society of America 134: 3522-3535.



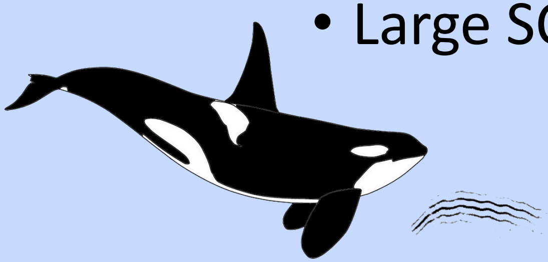
Spatial capture recapture examples

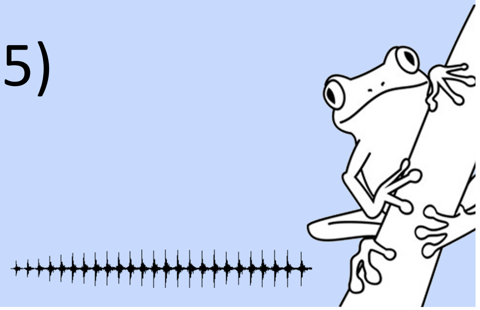
- 16 hydrophones at the Pacific Missile Range Facility (PMRF), off Kauaii, Hawaii
- Minke whale “boings” detected
- See: Marques et al. (2012); Martin et al. (2013)
- Large SCR developments since: Stevenson et al. (2015)

Marques, T. A., Thomas, L., Martin, S. W., Mellinger, D. K., Jarvis, S., Morrissey, R. P., Ciminello, C. and DiMarzio, N. 2012 Spatially explicit capture recapture methods to estimate minke whale abundance from data collected at bottom mounted hydrophones. Journal of Ornithology 152 (Suppl 2):S445–S455.

Martin, S.W., T.A. Marques, L. Thomas, R.P. Morrissey, S. Jarvis, N. DiMarzio, D. Moretti and D. K. Mellinger. 2013 Estimating minke whale (*Balaenoptera acutorostrata*) boing sound density using passive acoustic sensors. Marine Mammal Science 29: 142-158.

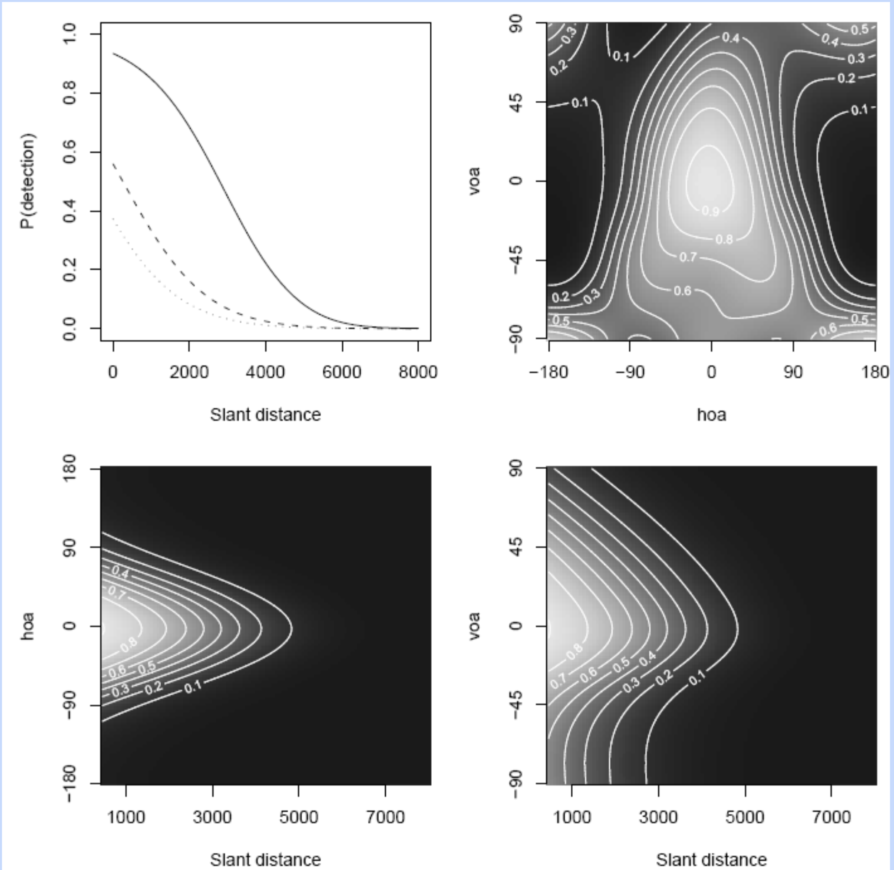
Stevenson, B.C., Borchers, D.L., Altwegg, R., Swift, R.J., Gillespie, D.M., and Measey, G.J. (2015) A general framework for animal density estimation from acoustic detections across a fixed microphone array. *Methods in Ecology and Evolution*, 6 38-48.



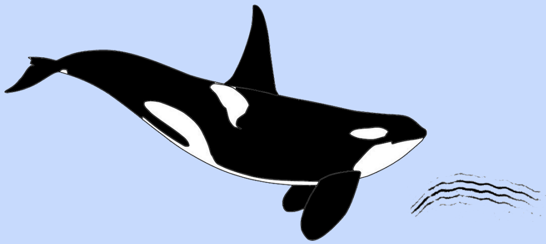


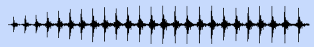
Auxiliary data-driven examples

- Using tag data e.g., Marques et al. (2009)



Marques, T.A., L. Thomas, J. Ward, N. DiMarzio and P. L. Tyack. 2009. Estimating cetacean population density using fixed passive acoustic sensors: an example with beaked whales. Journal of the Acoustical Society of America 125: 1982-1994.





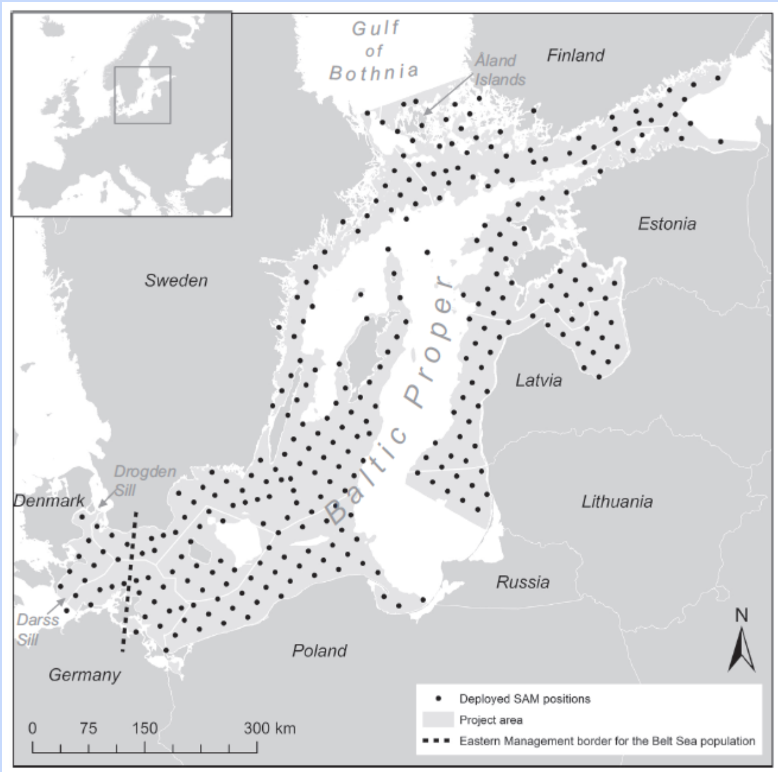
Auxiliary data-driven examples

- Use of logistic regression in a trial e.g., Kyhn et al. (2012)

SAMBAH
Focus: Baltic Sea harbour porpoise.

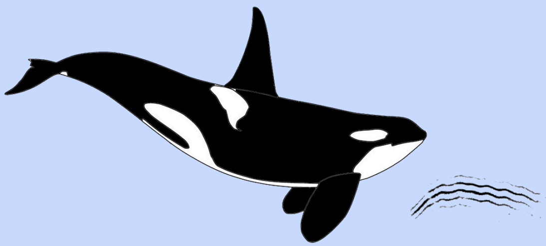
+- 300 instruments

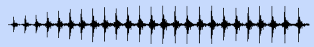
450 years of acoustic data!



Kyhn L.A., J. Tougaard, L. Thomas, L.R. Duve, J. Steinback, M. Amundin, G. Desportes and J. Teilmann. 2012. From echolocation clicks to animal density - acoustic sampling of harbour porpoises with static dataloggers. Journal of the Acoustical Society of America 131: 550-560.

Carlén et al. 2018 Basin-scale distribution of harbour porpoises in the Baltic Sea provides basis
for effective conservation actions *Biological Conservation* **226**: 42-53





Spatial modelling possible using data from acoustic monitoring.

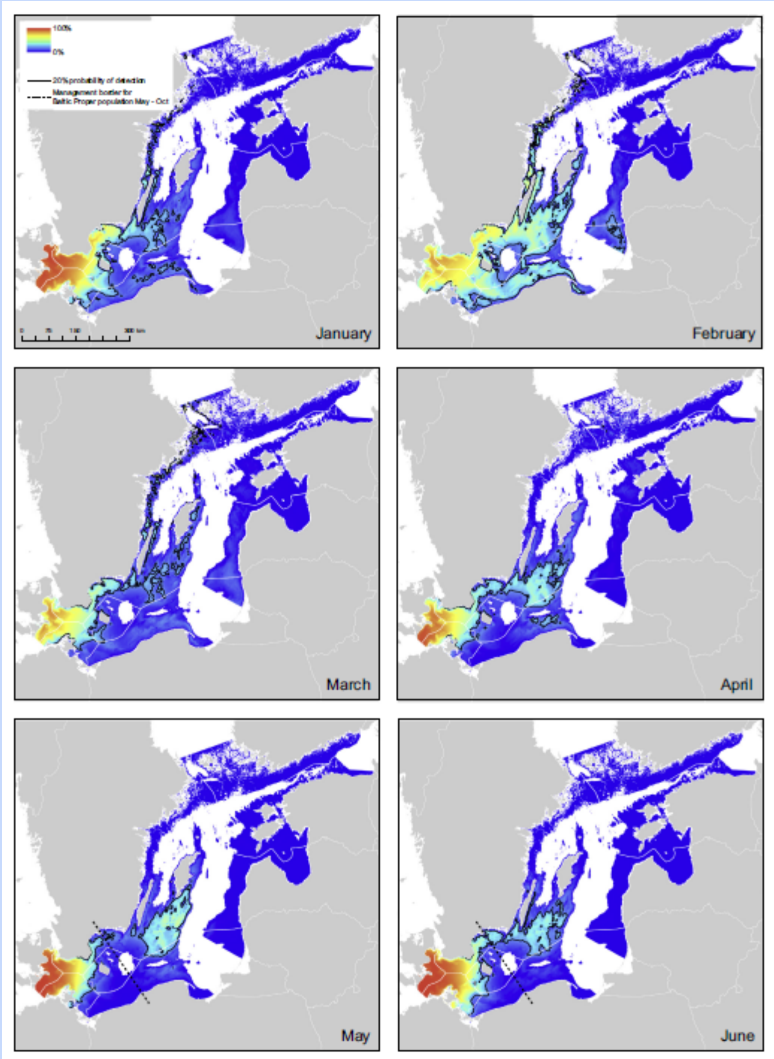
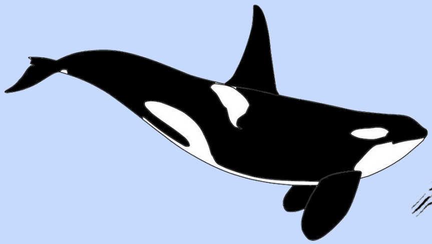
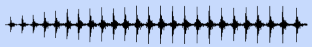


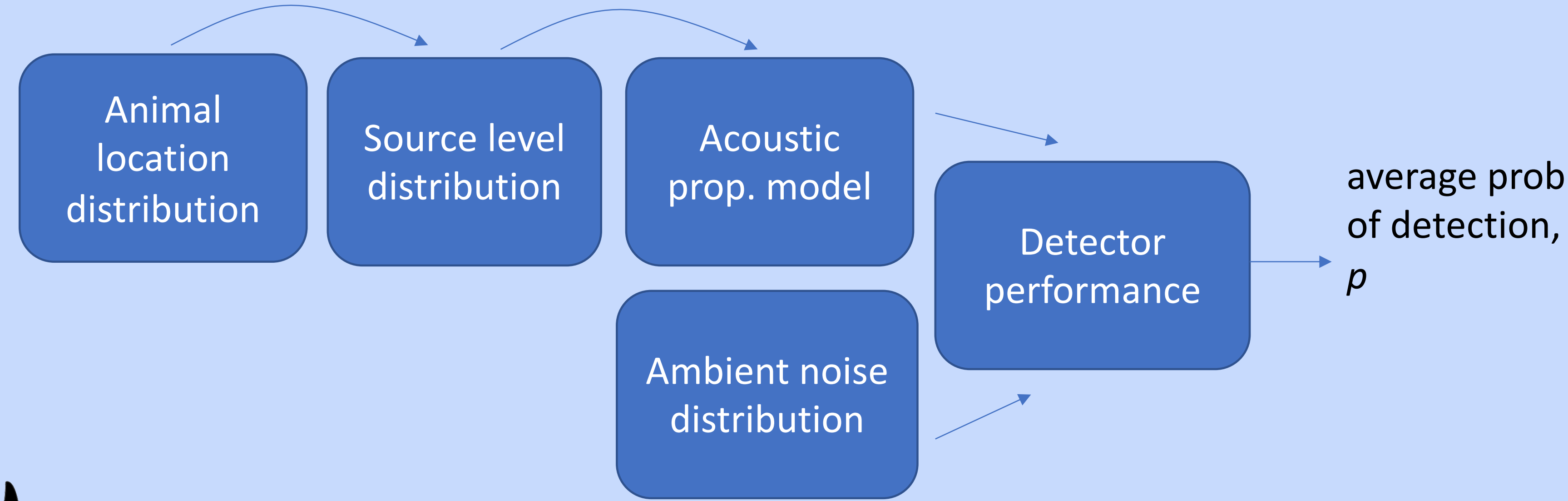
Figure taken from: Carlén et al. 2018 Basin-scale distribution of harbour porpoises in the Baltic Sea provides basis for effective conservation actions *Biological Conservation* **226**: 42-53

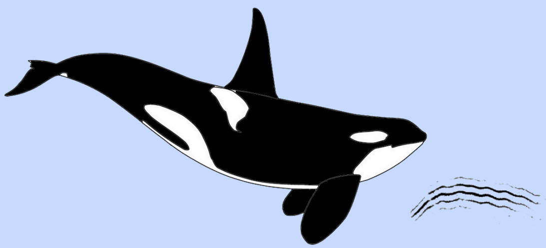




Auxiliary data-driven examples

- Using simulation e.g., Küsel et al. (2009)
- Extended to include bearing e.g., Harris et al. (2018)



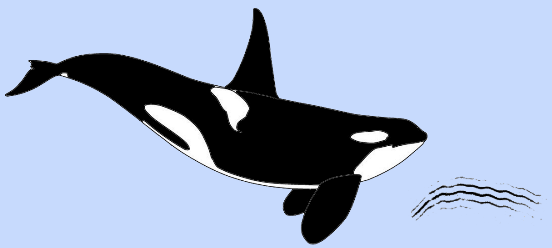


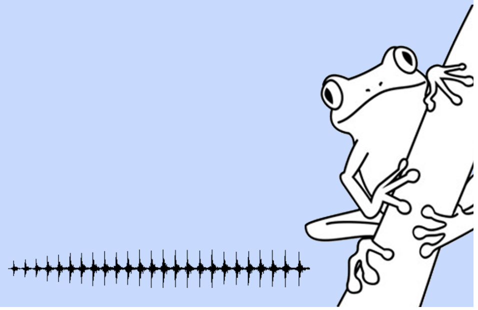
Küsel, E.T., D.K. Mellinger, L. Thomas, T.A. Marques, D.J. Moretti, and J. Ward. 2011. Cetacean population density from single fixed sensors using passive acoustics. Journal of the Acoustical Society of America 129: 3610-3622.

Harris, D V, Miksis-Olds, J L, Vernon, J A & Thomas, L 2018, 'Fin whale density and distribution estimation using acoustic bearings derived from sparse arrays' *Journal of the Acoustical Society of America*, vol. 143, no. 5, pp. 2980-2993. https://doi.org/10.1121/1.5031111

Lessons learned

- Large variety of species and surveys: need variety of methods
- More to be developed, in both terrestrial and marine environments.
- Sound propagation can be highly variable in the ocean
- Need to consider large ranges in some cases.

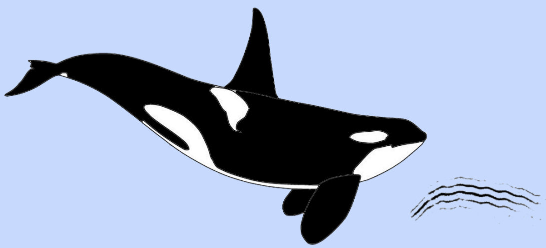




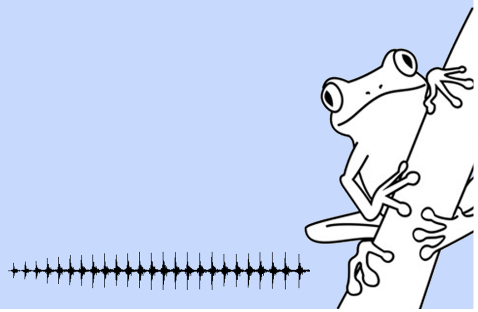
Cue rates

"… cue rates should be obtained under actual survey conditions. Otherwise, survey results are always subject to the potential issue that the multiplier depends on unmeasured covariates that may differ between the time and place where the multiplier and survey data were collected, leading to bias."

- Largely unknown for most species
- Not easy to estimate
- Very dependent on multiple factors:
  - Sex
  - Behavioral state
  - Season
  - Time of day
  - Weather
  - Density!



Marques *et al.* 2013 Estimating animal population density using passive acoustics *Biological Reviews* **88**: 287-309



- Animal behaviour is key for cue rates

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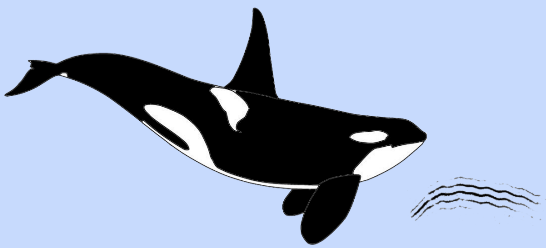
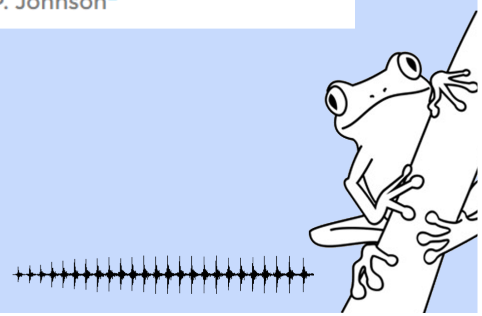
Published Online: 21 March 2017 Accepted: February 2017

Spatio-temporal variation in click production rates of beaked whales: Implications for passive acoustic density estimation

The Journal of the Acoustical Society of America **141**, 1962 (2017); https://doi.org/10.1121/1.4978439

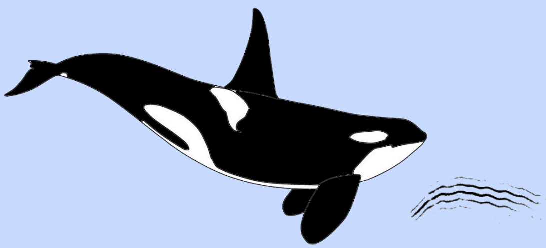
Victoria E. Warren[1,a)], Tiago A. Marques[1,b)], Danielle Harris[1], Len Thomas[1], Peter L. Tyack[2], Natacha Aguilar de Soto[1,c)], Leigh S. Hickmott[2], *and* Mark P. Johnson[2]





Lessons learned

- There is still a lot to learn about bioacoustics.
- Still need to understand the basic repertoire of species.
- For density estimation, we then need to understand call production rate.
- Need to continue behavioural studies.
- Can use biological knowledge to choose which signal is best for monitoring.



IBAC International Bioacoustics Council

International Bioacoustics Council (IBAC)

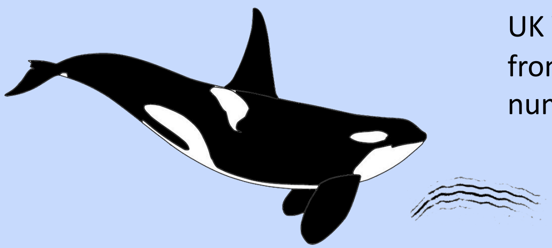
http://www.ibac.info/meetings.html

Survey design and trend detection: AVADECAF tool

Simulation tool:

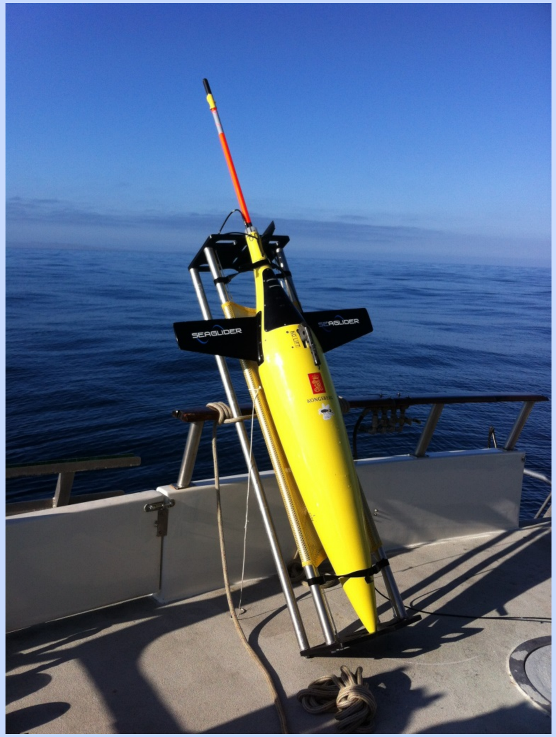
- Assess the power to detect a change in animal densities over a number of survey years for a given scenario
- Will a certain design give me sufficient data to monitor a certain species, i.e. will we be able to detect a potential decline in the population?
- How can we collect better data to improve the power to detect a change?

Booth CG, CS Oedekoven, D Gillespie, J Macaulay, R Plunkett, R Joy, D Harris, J Wood, TA Marques, L Marshall, UK Verfuss, P Tyack, M Johnson & L Thomas 2017. Assessing the Viability of Density Estimation for Cetaceans from Passive Acoustic Fixed Sensors throughout the Life Cycle of an Offshore E&P Field Development. Report number: SMRUC-OGP-2017-001.



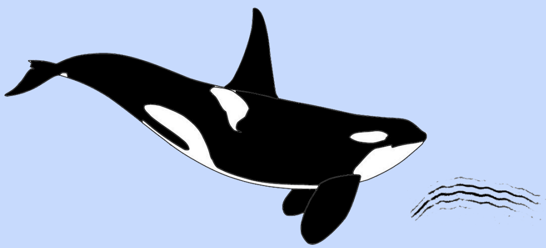
Noisy statistical challenges – plenty to work on!

- Survey design: how many sensors do I need and where do I put them?
- Automatic detection and classification
- Localisation
    - measurement error
- Estimating cue rates
- Estimating detectability
    - comparison/validation of methods
- False positives
- Multi-object tracking
- New technologies
- Dealing with continuous processes



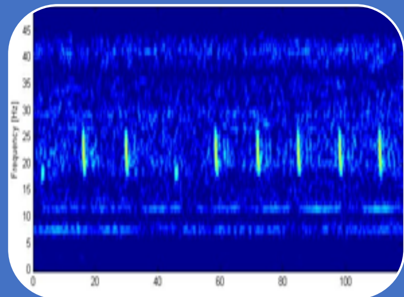
SEAGLIDER

KONGSBERG

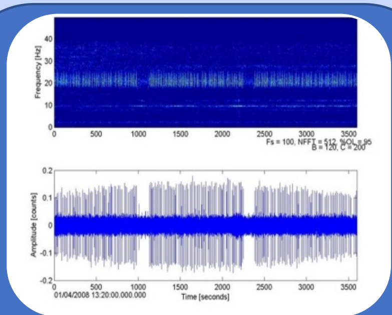


Cost effective abundance estimation

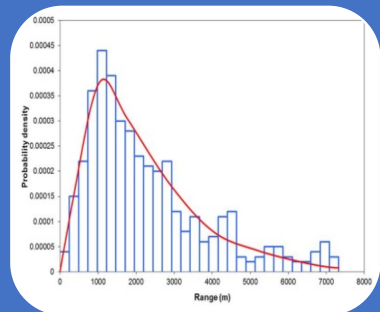
Survey design



Behavioural data



Data collection & processing



Data analysis