All together now: understanding at depth group behavior of beaked whales at AUTEC

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aka

GROUPAM: What it is and what is the current state-of-the-art?

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Disclaimer

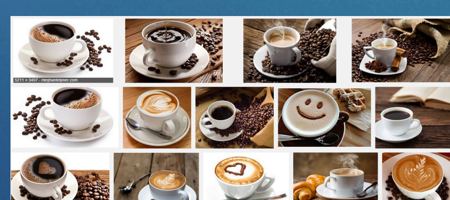
- GROUPAM just starting

PRELIMINARY WORK IN PROGRESS

CLASSIFICATION DILEMA

BREW
DECAF
LATTE
MOCHA
MACHIATO
DECAF-TEA
CHEAP DECAF
AFFOGATO

← GROUPAM → ?



Layout

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5. Model for within group movement & behaviour
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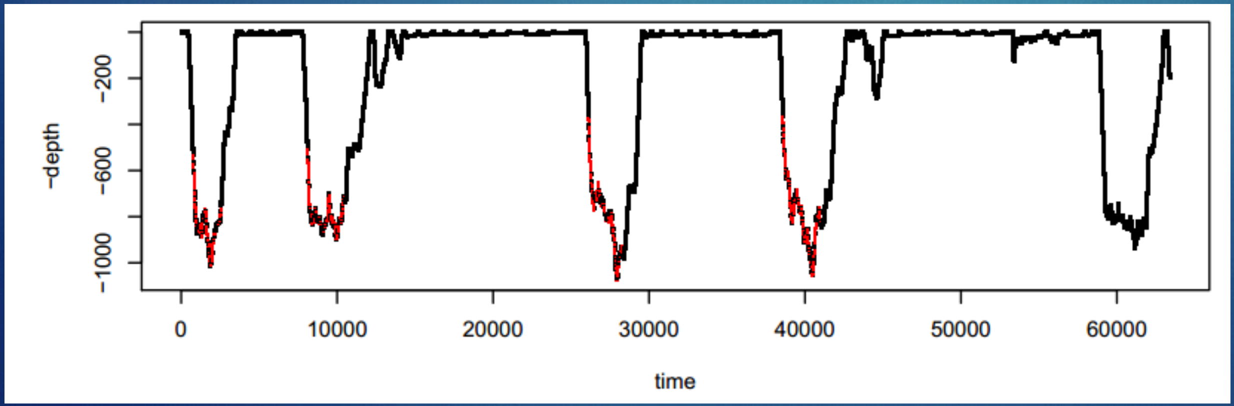
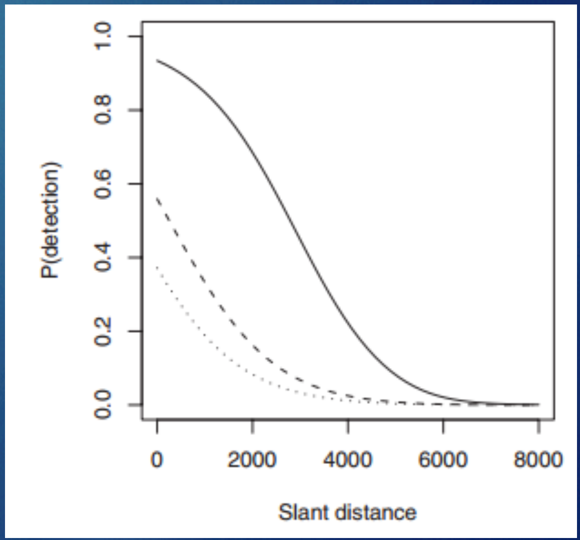
Background

- We have learned a lot about beaked whales in the last few years
- Navy ranges like the Atlantic Undersea Test and Evaluation Center (AUTEC) have provided a unique window for observation
- DTAG data have been instrumental in providing fine-scale data
- Density estimation methods have been developed and successfully applied





Motivation

- Although much is now known about individual animal movement and cue production rate, the way groups of animals behave at depth and how they coordinate their movements is still a mystery
- There are very few cases of simultaneously tagged beaked whales
- But anecdotally the data hint at some (intuitively expected) degree of coordination

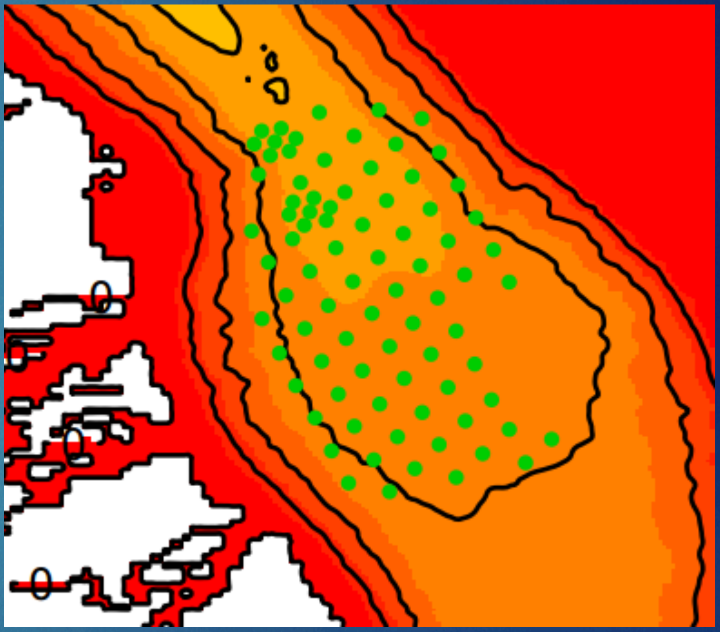
GROUPAM Objectives

- To develop a post-processing detection, classification and localization method capable of utilizing passive acoustic data from the hydrophone array at AUTEC to track individual clicking beaked whales within group deep dives
- To relate acoustic footprint of groups to group sizes (opening the door to routine density estimation at AUTEC via group counting[1])
- To develop and fit to data a mathematical model describing animals-within-group behavior at depth

[1] Moretti et al (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

AUTEC

Atlantic Ocean
AUTEC
Grand Bahama
NW Providence Channel
Great Bahama Canyon
Berry Islands
NE Providence Channel
Eleuthera Island
New Providence Island
Tongue of the Ocean
Cul de Sac
Great Bahama Bank
25km



GROUPAM DCL details

- Species specific matched filter detector
- Time difference of arrival (TDOA) correlation in the frequency domain
- Multi-hypothesis tracker uses "low quality" position estimates to bridge the gap between high-quality solutions.
    - Simultaneously track thousands of potential track association hypotheses, called "particles"
    - Use the estimated solution ambiguity ellipse in the individual "particle" Kalman filters
- High-quality tracks are maintained, with estimation variance shrinking during times of high-quality solutions and widening during times of low-quality solutions.
- For details see
    - Baggenstoss, P. M. 2015. A multi-hypothesis tracker for clicking whales. JASA 137(5): 2552-2562

Dive counting

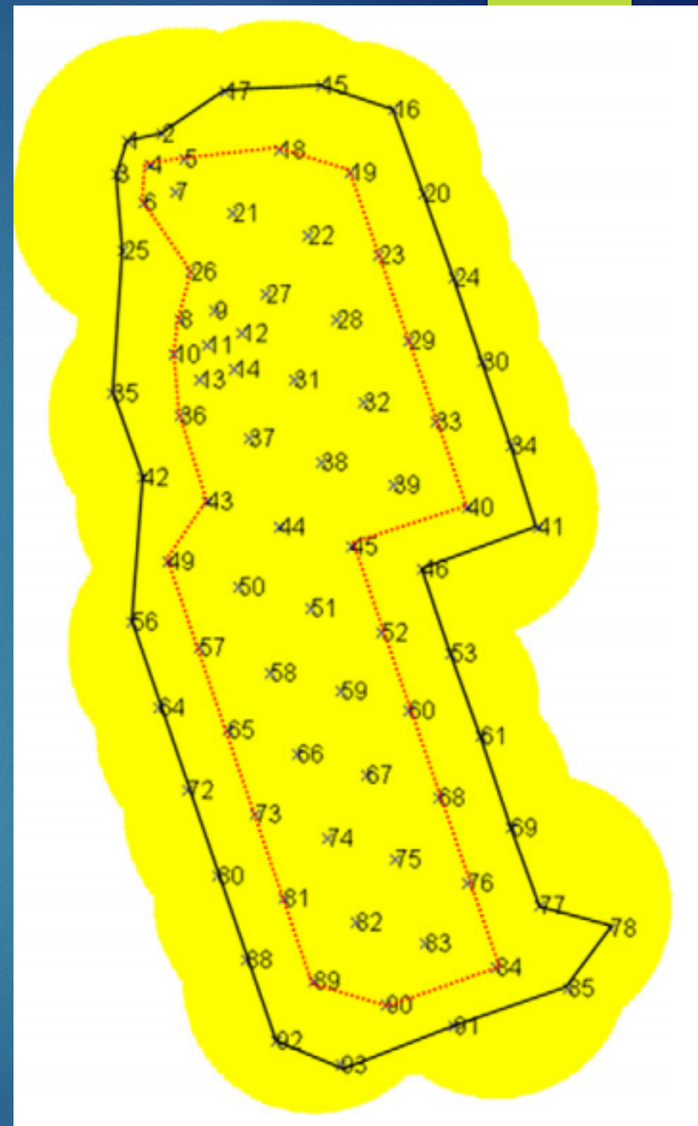
- All dives occurring within AUTEC assumed to be detected
- Abundance/Density then estimated simply as

$$N = \frac{n_d s}{r_d T}$$

where n_d = total number of dive starts; s = average group size; r_d = dive rate (dives/unit time); T = time period over which the measurement was made

$$D = \frac{n_d s}{r_d T A}$$

A = measurement area



$$\mathrm{var}(\hat{D}) \approx \hat{D}^2 \left(CV(\hat{s})^2 + CV(\hat{r}_d)^2 \right)$$

Relating Group Size to Acoustic Footprint

- Data set with 43 instances where a group of (visually verified) known size was reliably detected on AUTEC hydrophones

Group size = 3, typically very loud

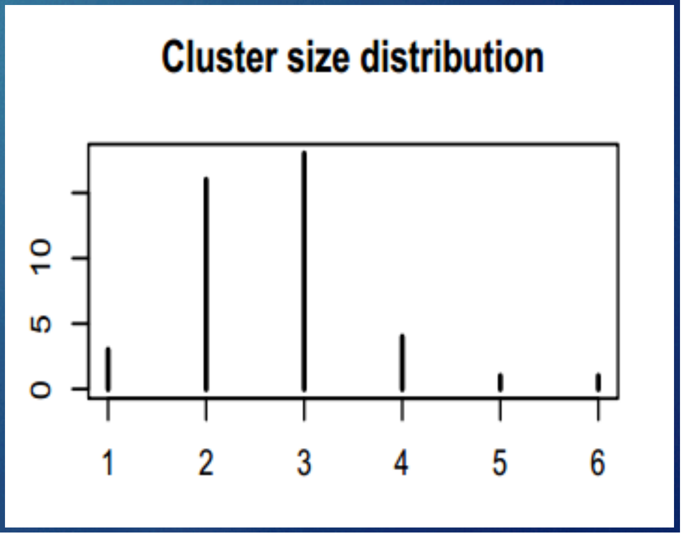
Group size = 2 or 3 **?**

Relating Group Size to Acoustic Footprint

- Used the output of an automated routine that associates clicks into click trains and then trains across hydrophones into group dives
- From this output derived a number of covariates which would be a priori related to group size, e.g.:
  - Number of hydrophones group was detected at
  - Total number of clicks detected
  - Length of vocal period
  - Clicks per second during vocal period
  - Mean number of clicks per hydrophone
  - Maximum number of clicks per hydrophone
- Used a regression model to predict

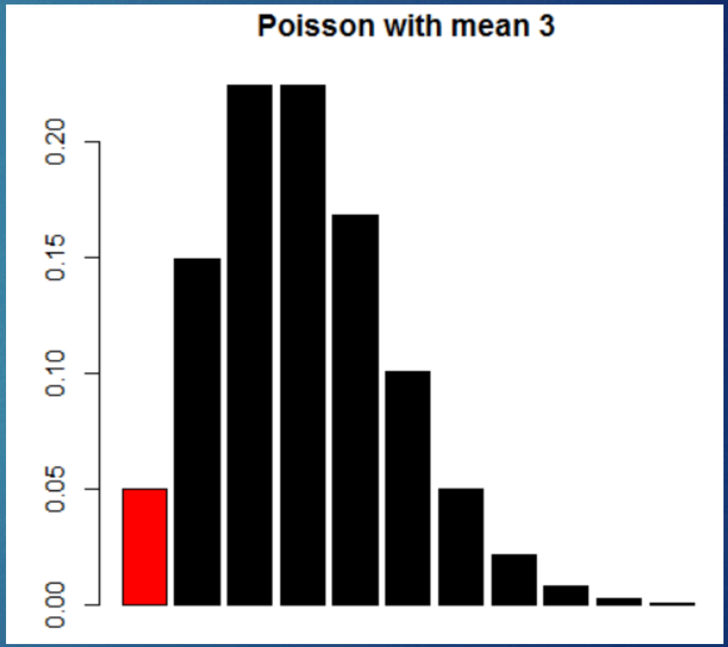
  group size as a function

  of these covariates

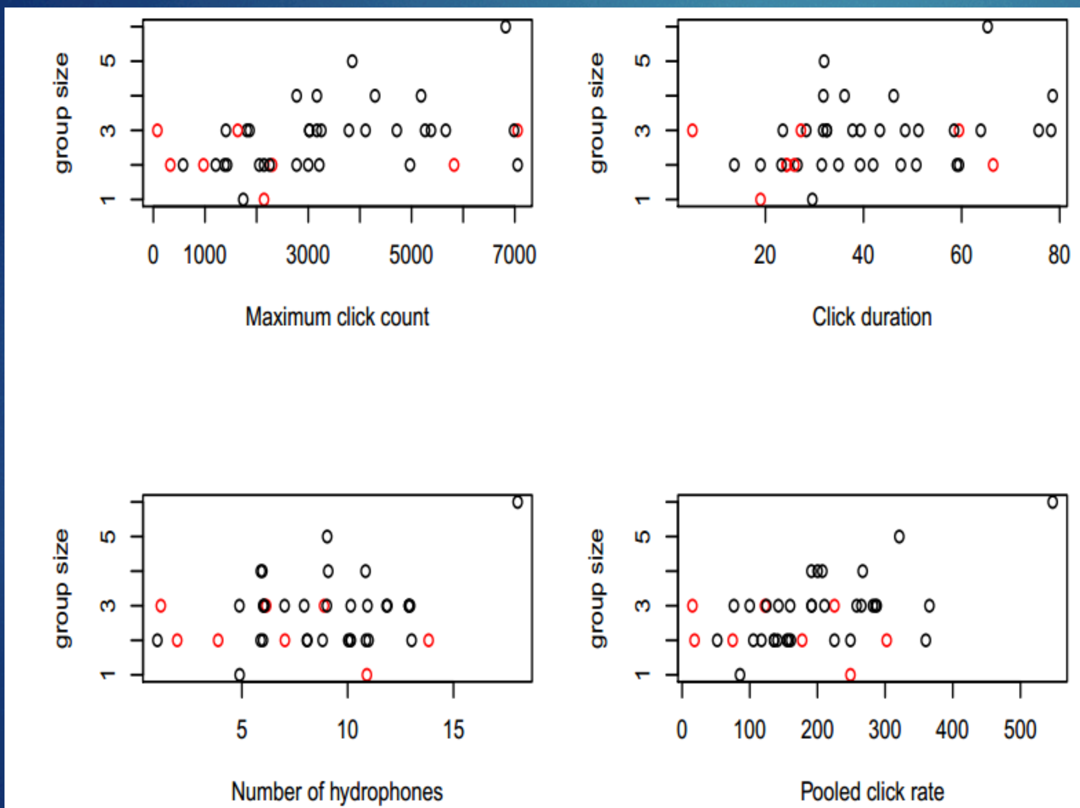


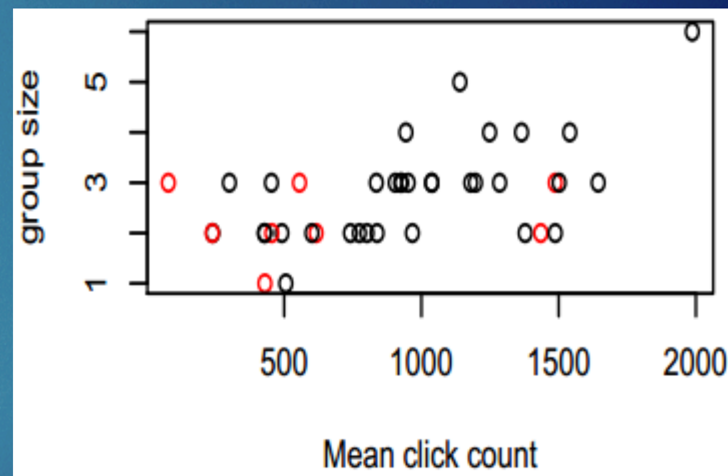
Minor tweak re modelling group sizes

- Consider X to be the group size
- When modelling counts, Poisson or negative binomial are typical distributions used
- However such count distributions imply the existence of 0's, while by definition a group size is larger than zero
- We model Y=X-1, requiring a back transformation in the end
- Alternative would be to use a truncated count model



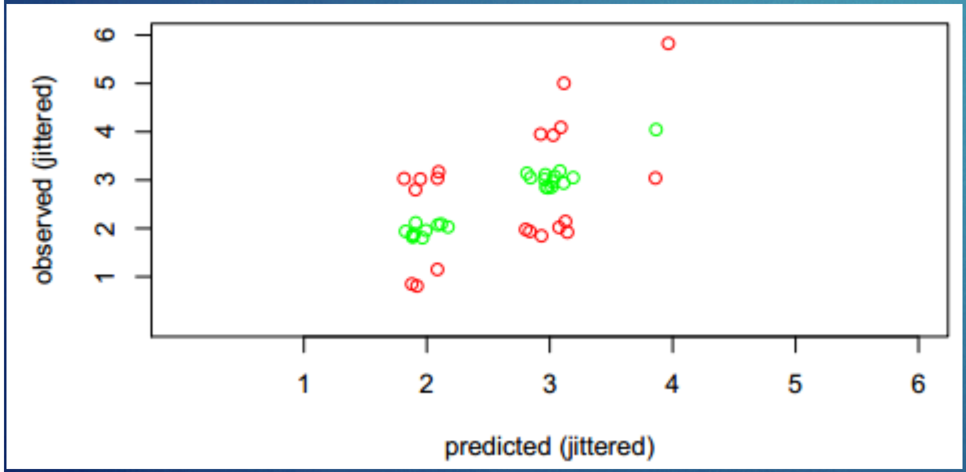
Exploratory data analysis

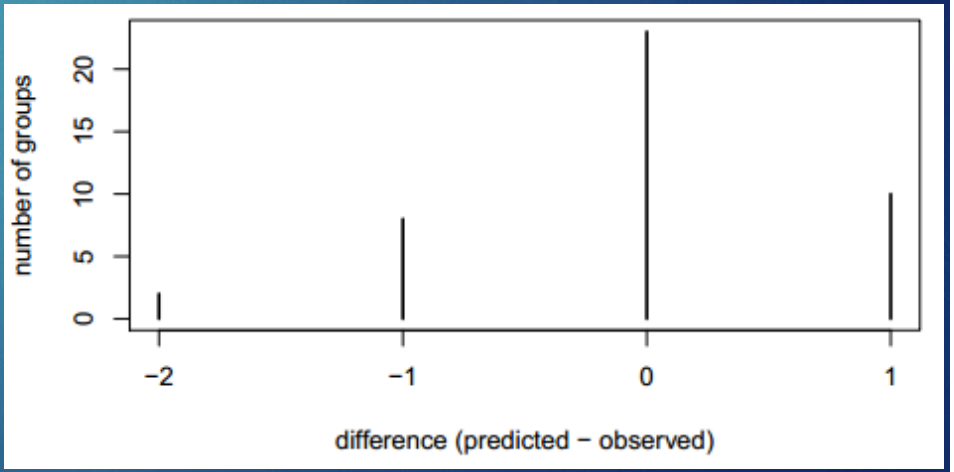




Model predictions

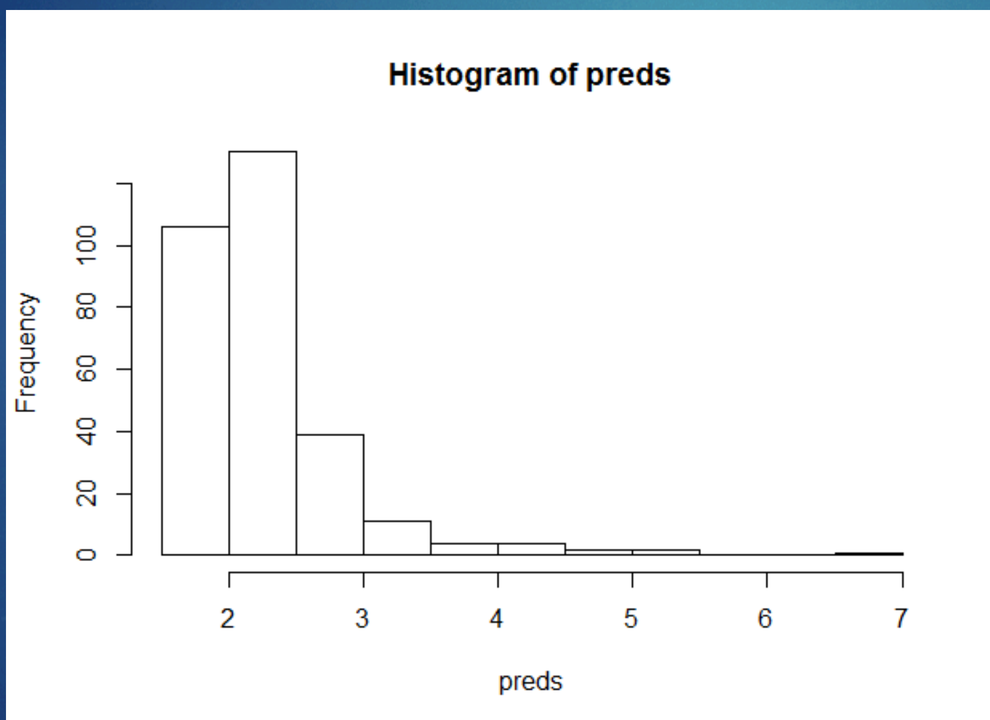
- Best model (by lowest AIC) is a simple linear model just including mean number of clicks per hydrophone
- While this model can only explain 28 % of the deviance, ~95% of the group size estimates were within one animal of the actual group size.





Incorporate variability in group size estimate

- Non-parametric bootstrap over the 43 group sizes



$$\mathrm{var}(\hat{D}) \approx \hat{D}^2 \left(CV(\hat{s})^2 + CV(\hat{r}_d)^2 \right)$$

resample

Fit model

repeat

Predict

Estimate mean cluster size

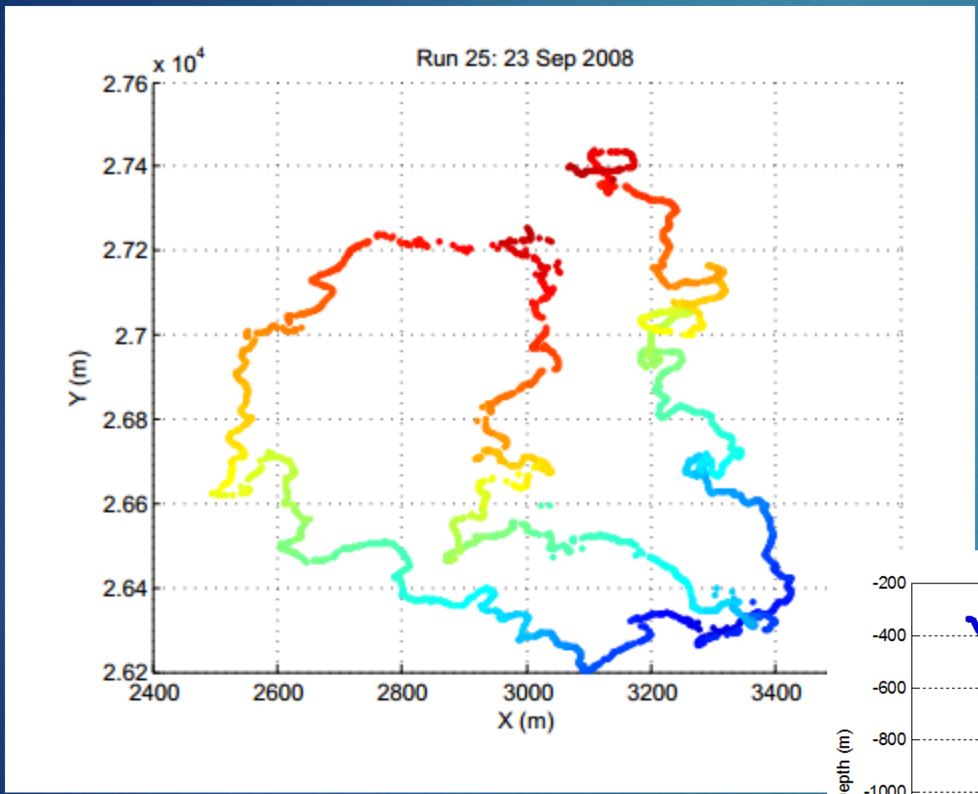
Estimating density over a small example time period

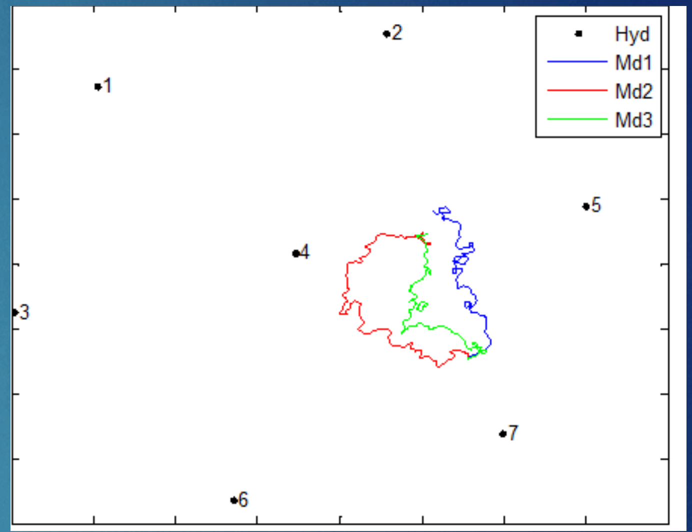
- Survey area 1291 km^2
- 299 groups detected over 3.95 days
- Dive rate = 0.36 dives per hour (weighted standard error of 0.04 and CV of 10.6%)

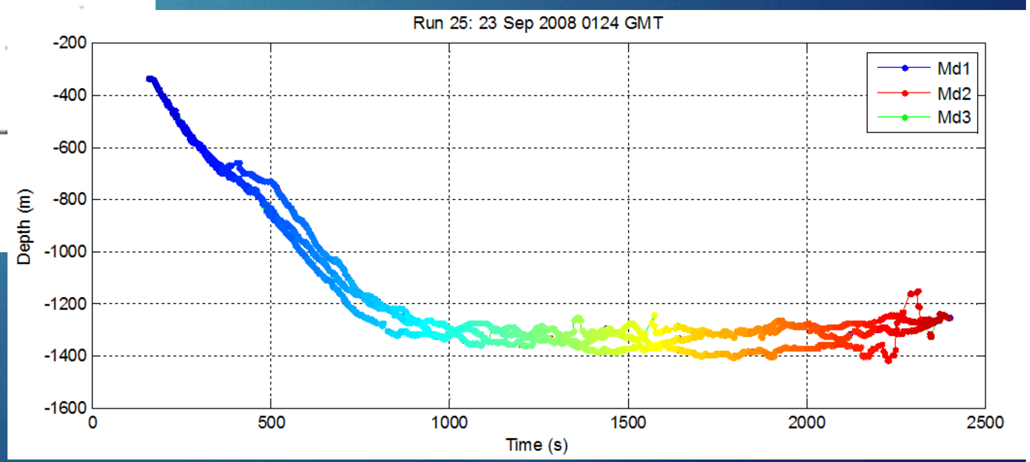
- Mean group size from literature = 2.62 animals/group (n = 73, CV = 5.46%)
- D= 1000*(299*2.62)/(3.95*24*0.36*1291)=17.78 animals / 1000km^2 (CV=11.89%)

- Regression model based mean group size = 2.31 animals/group (n=43, CV=7.22%)
- D= 1000*(299*2.31)/(3.95*24*0.36*1291)=15.68 animals / 1000km^2 (CV=12.83%)

Animal Coordination at Depth – Just a Teaser



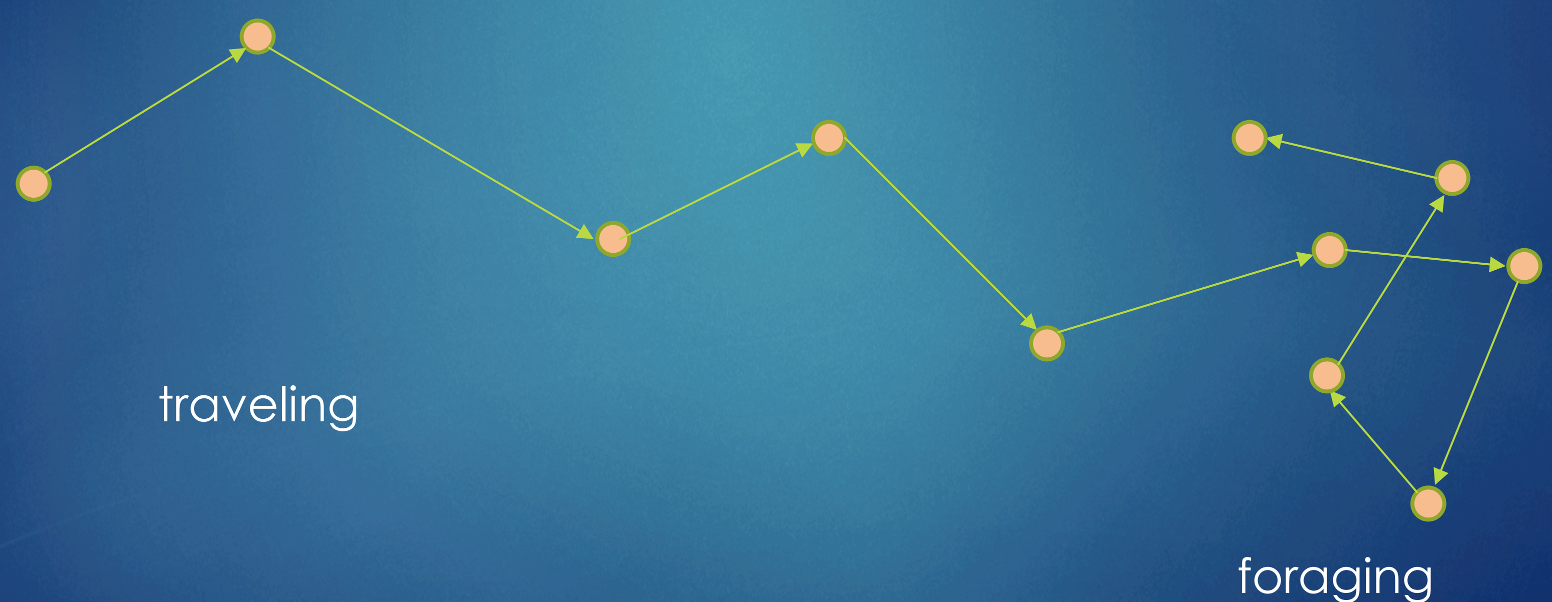




Color indicates progression in time

A Model for within Group Animal Behavior

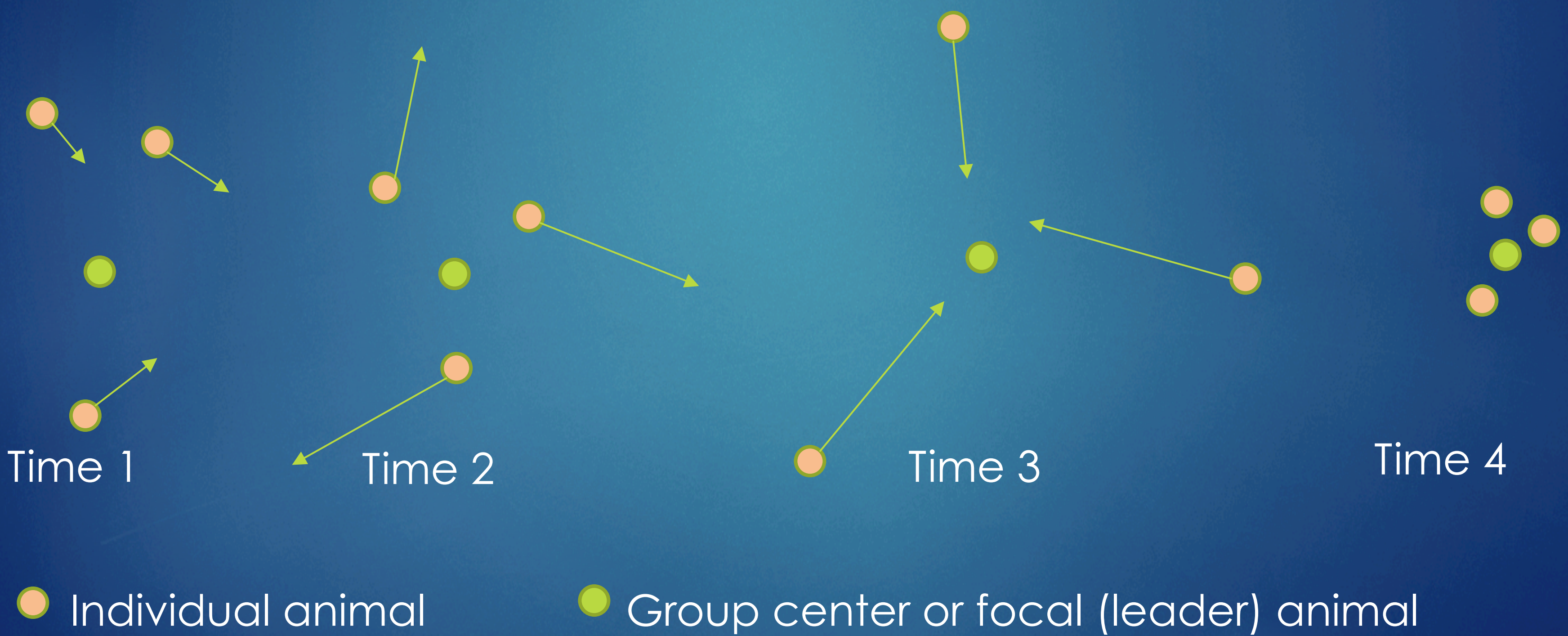
- Animal movement (2D): step lengths and turning angles
- 3D : add change in depth (or 3D angle)
- Include behaviour states



Langrock et al. 2014 A model for group dynamic animal movement *Methods in Ecology & Evolution* **5**: 190-199

A Model for within Group Animal Behavior

- Movement model for the individual animals + movement model for the group center



Langrock et al. 2014 A model for group dynamic animal movement *Methods in Ecology & Evolution* **5**: 190-199 synchronous

Discussion

- GROUPAM is just starting, but it seems like a promising project
- Routine on-the-fly density estimation possible at AUTEC using dive counting methods (but what is a reasonable time step to produce a density estimate over?)
- Replaced generic multiplier with value valid for the time and place of the survey
- Obtain additional visually verified data to refine model
- An unprecedented window of observation into animal behaviour at depth
- Questions about animal coordination and synchrony

Acknowledgments

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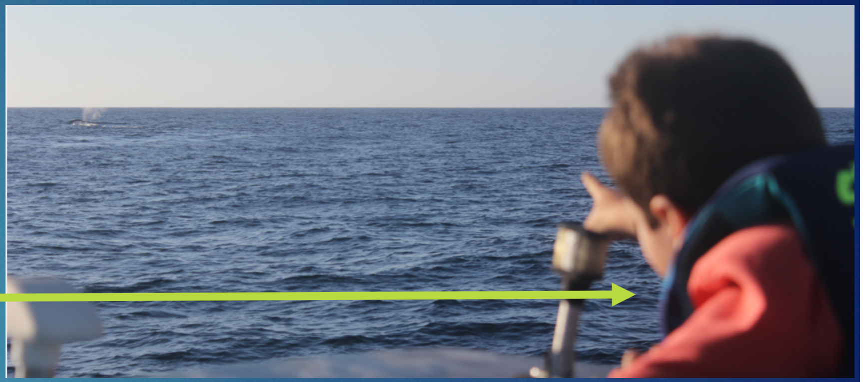
- Other key GROUPAM members: Diane Claridge and Charlotte Dunn

Acknowledgments



- Baumann-Pickering Foundation
  - Accomodation & subsistence
  - Childcare
  - Mindblowing blue whale sightings

www.baumannpickering.org