Combining Towed Array and Visual Line Transect Data to Estimate Abundance and Availability Bias in a Bayesian Framework

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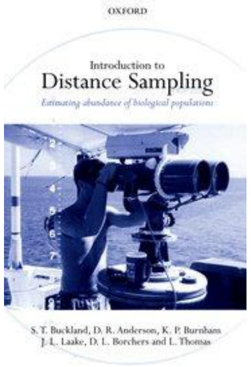
Visual Line Transects vs Towed Arrays
Why tow an array?

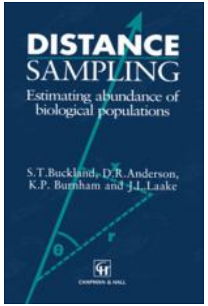
- **Visual line transect surveys**
  - Long history
  - Well developed statistical framework
    - (Distance sampling)

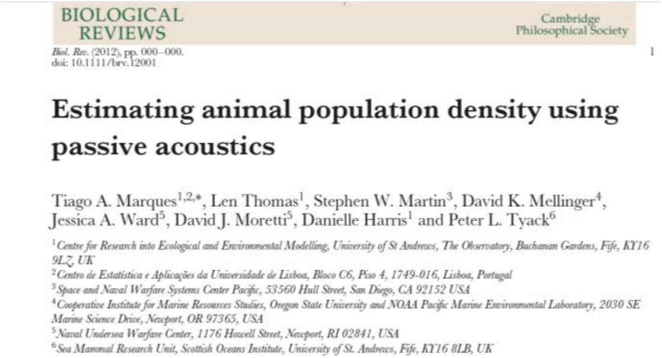
HOWEVER…
  - Sightings can be limited (cryptic species)
    - Often have to pool
  - Surface availability problem
    - Estimates from tagged data (if available) based on small sample sizes

- **Towed Array Data**
  - Opportunity to sample below surface

HOWEVER…
  - Animals need to be clicking
  - Statistical framework not well developed



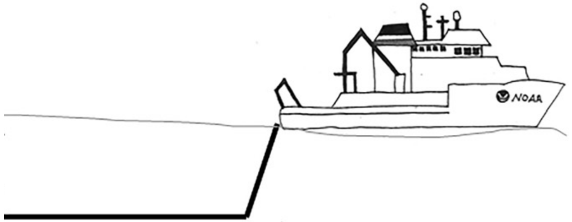


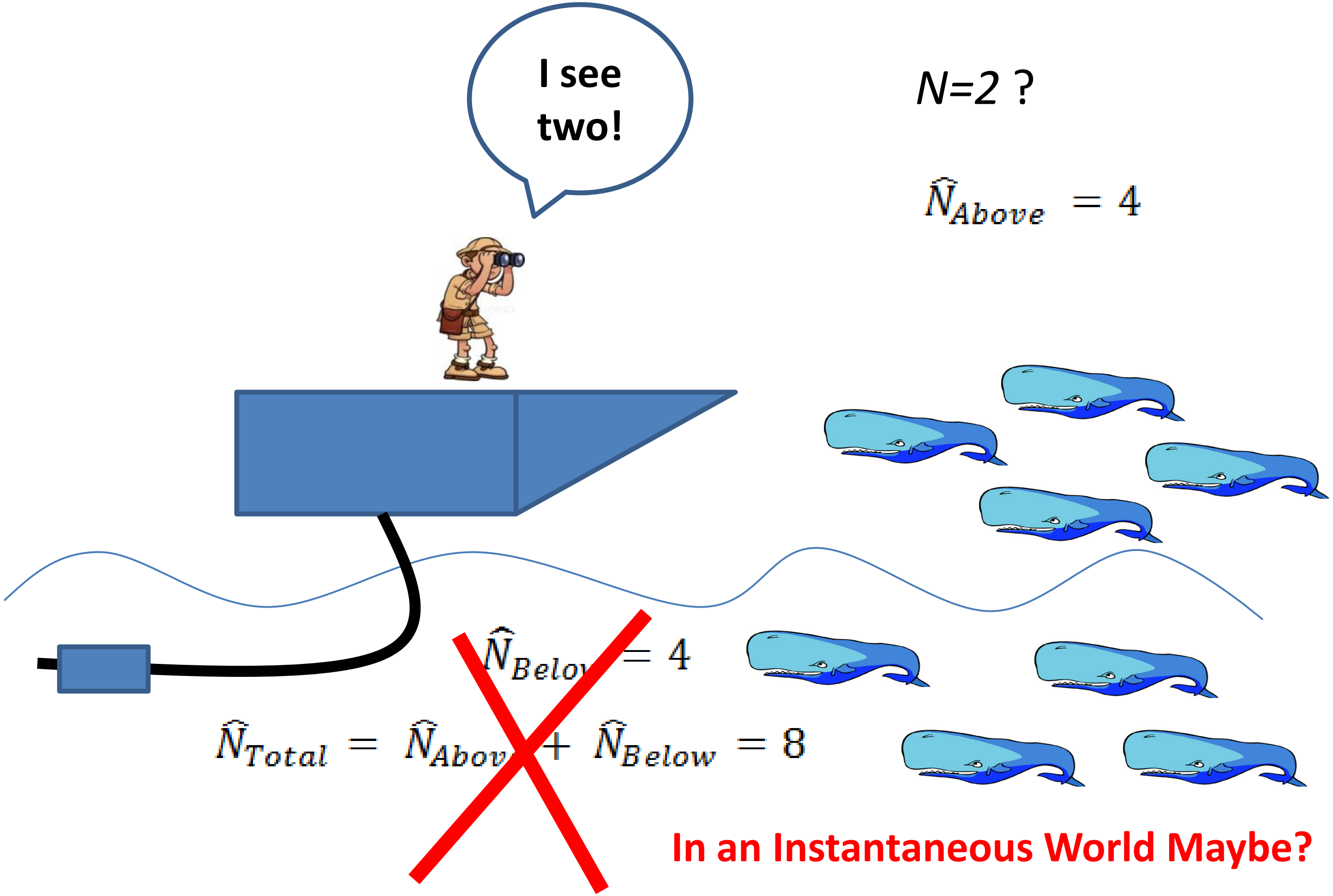


Goals and Challenges

- Goals
  - Integrate Towed Array and Visual Line Transect Data to…
    1. Estimate more precise estimates of abundance
    2. Directly estimate surface availability bias

- Challenges
  - How to analyze acoustic data
    - Use Conventional Distant Sampling for visual data
  - Combine information so estimates are unbiased
  - Make tool generally applicable




I see two!
N=2 ?
$\hat{N}_{Above} = 4$
$\hat{N}_{Below} = 4$
$\hat{N}_{Total} = \hat{N}_{Above} + \hat{N}_{Below} = 8$
In an Instantaneous World Maybe?

Motivation

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December 2015
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Double-Observer Line Transect Surveys with Markov-Modulated Poisson Process Models for Animal Availability

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Summary. We develop maximum likelihood methods for line transect surveys in which animals go undetected at distance zero, either because they are stochastically unavailable while within view or because they are missed when they are available. These incorporate a Markov-modulated Poisson process model for animal availability, allowing more clustered availability events than is possible with Poisson availability models. They include a mark-recapture component arising from the independent-observer survey, leading to more accurate estimation of detection probability given availability. We develop models for situations in which (a) multiple detections of the same individual are possible and (b) some or all of the availability process parameters are estimated from the line transect survey itself, rather than from independent data. We investigate estimator performance by simulation, and compare the multiple-detection estimators with estimators that use only initial detections of individuals, and with a single-observer estimator. Simultaneous estimation of detection function parameters and availability model parameters is shown to be feasible from the line transect survey alone with multiple detections and double-observer data but not with single-observer data. Recording multiple detections of individuals improves estimator precision substantially when estimating the availability model parameters from survey data, and we recommend that these data be gathered. We apply the methods to estimate detection probability from a double-observer survey of North Atlantic minke whales, and find that double-observer data greatly improve estimator precision here too.

Key words: Abundance estimation; Availability bias; Cox point process; Mark-recapture; Maximum likelihood.

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Markov-Modulated Nonhomogeneous Poisson Process for Modeling Detections in Surveys of Marine Mamma Abundance

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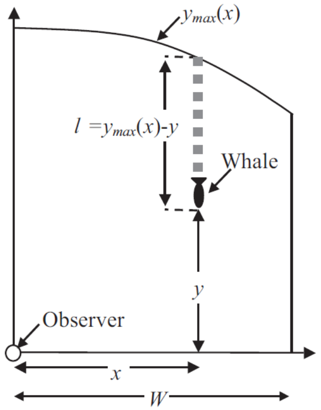
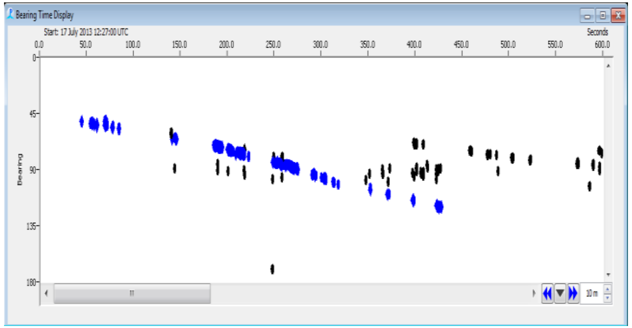
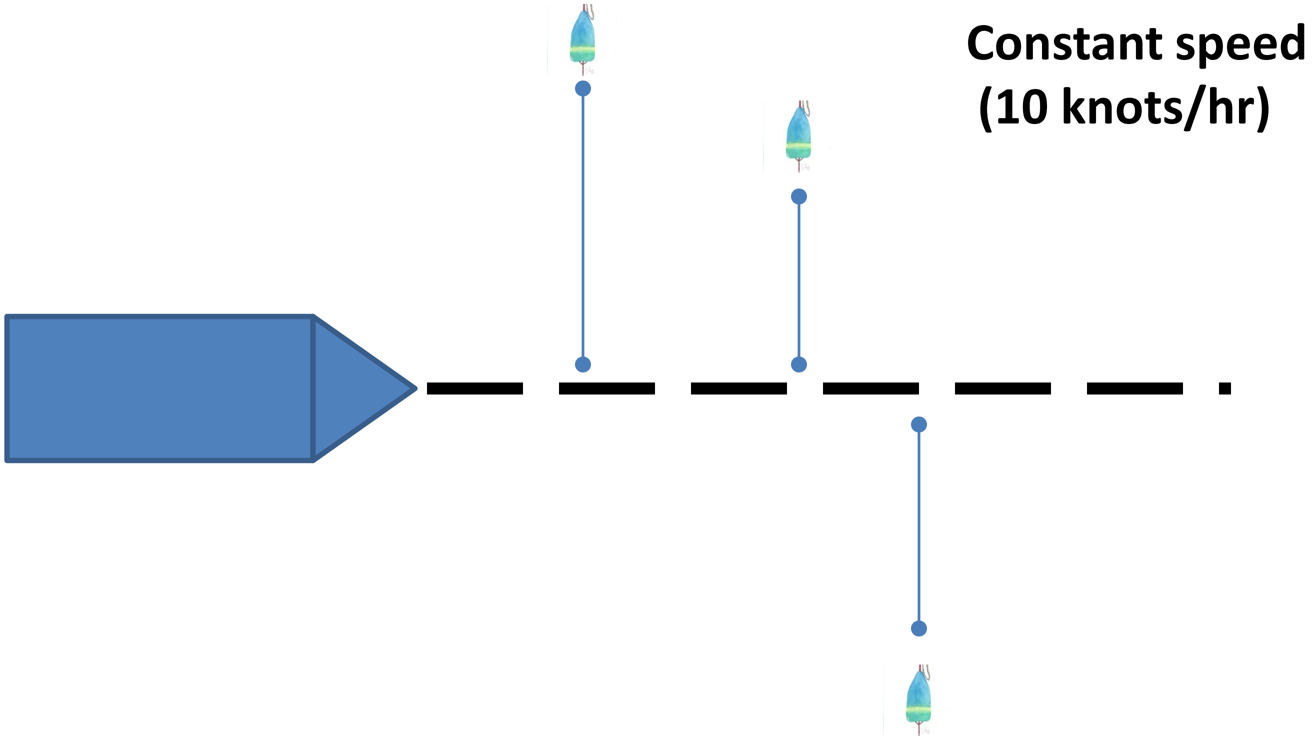
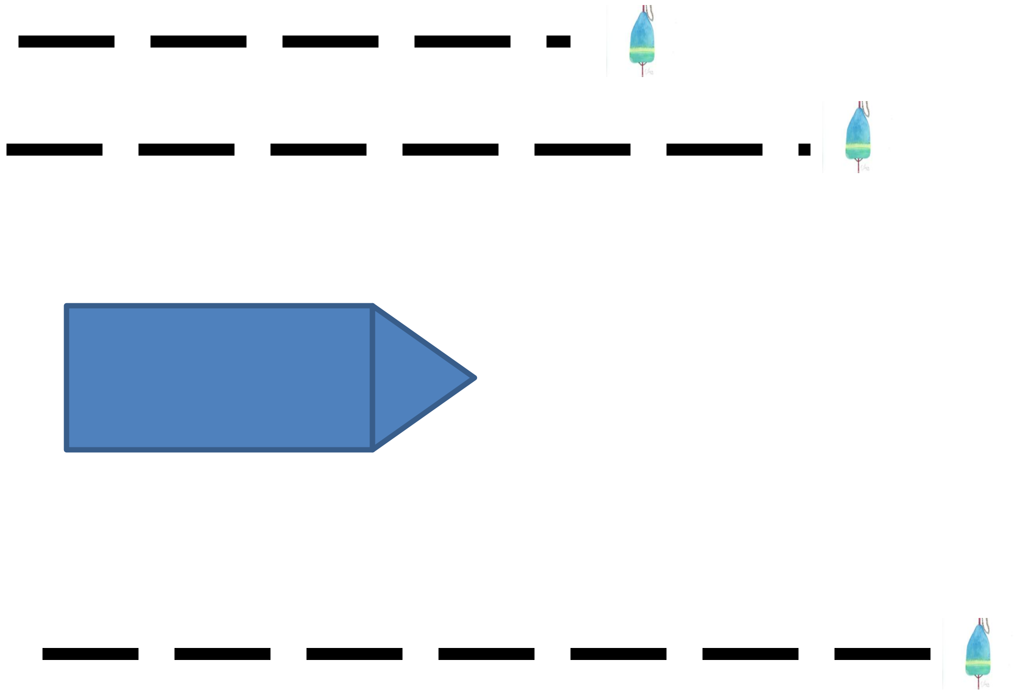




Conventional Distance Sampling



Conventional Distance Sampling



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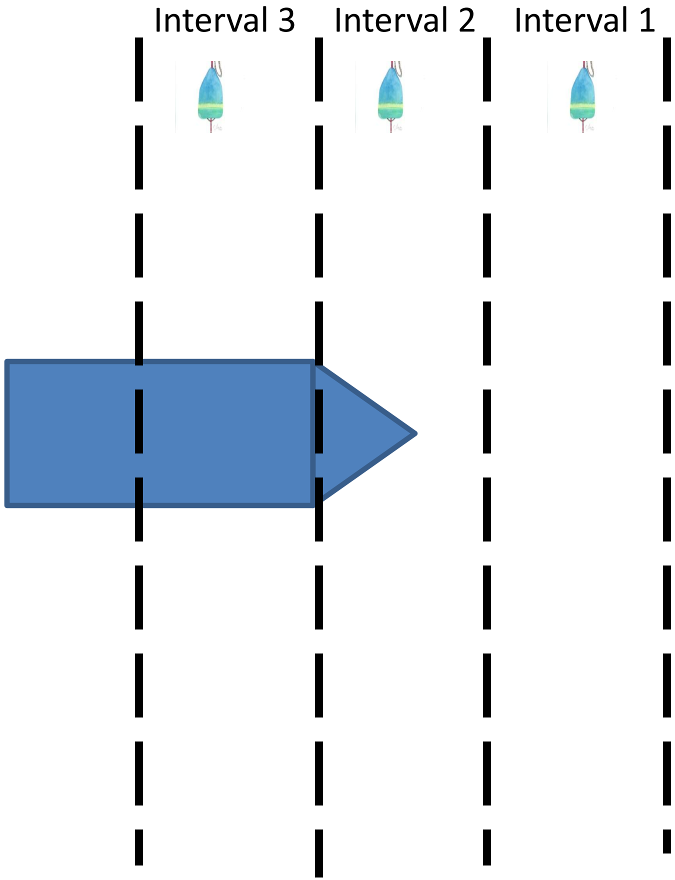
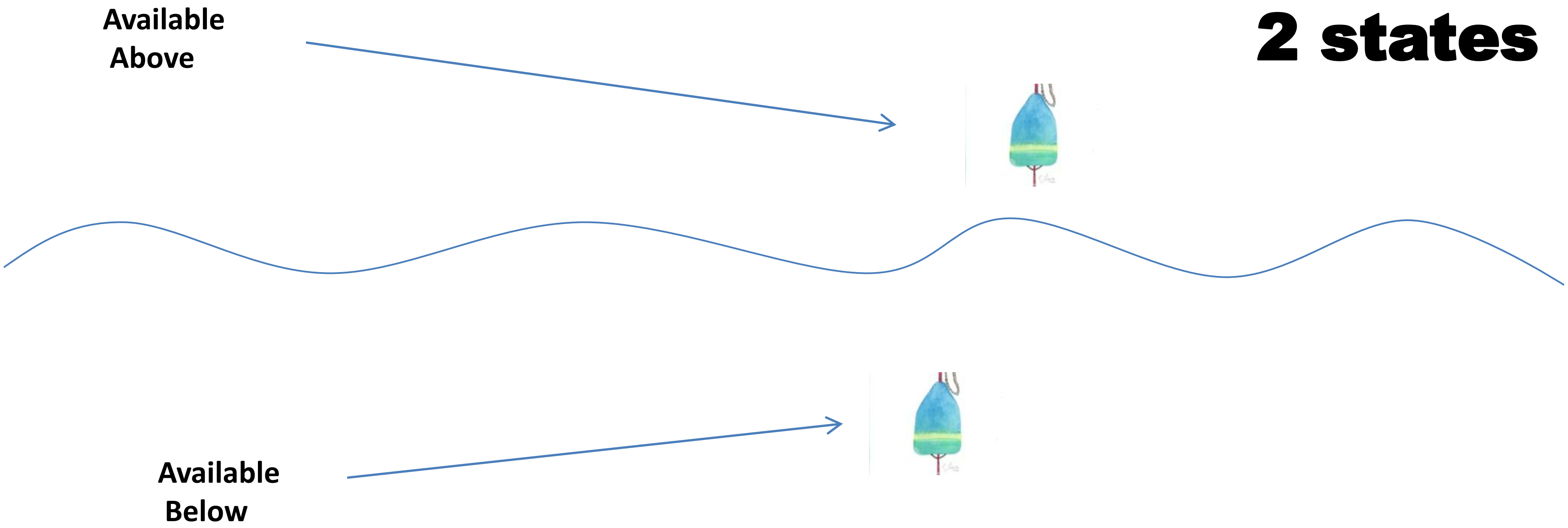
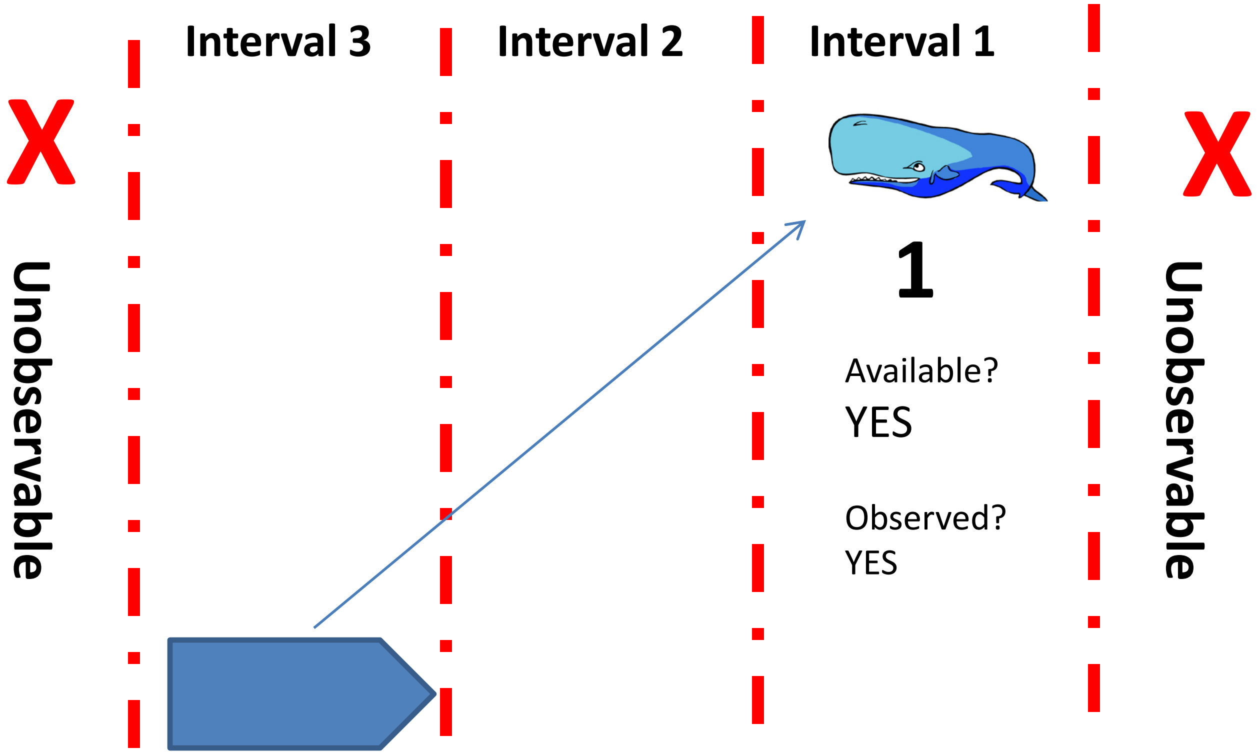


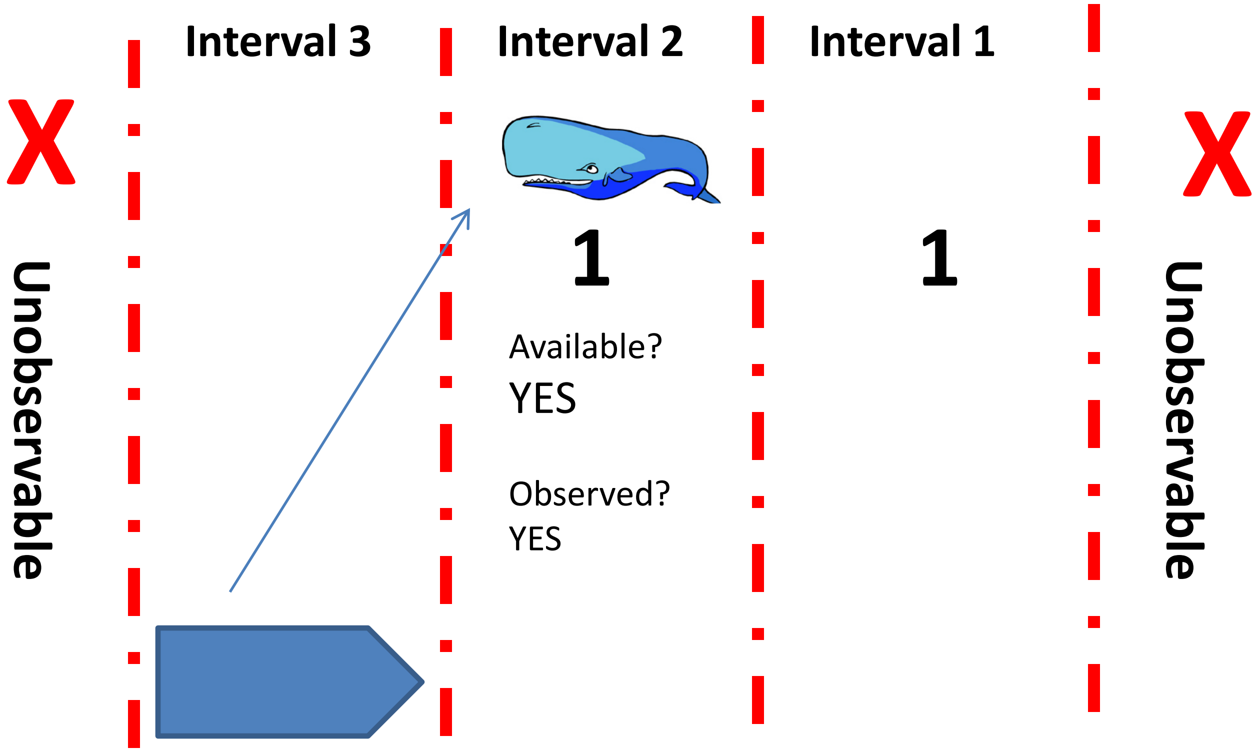
Whales as Buoys?



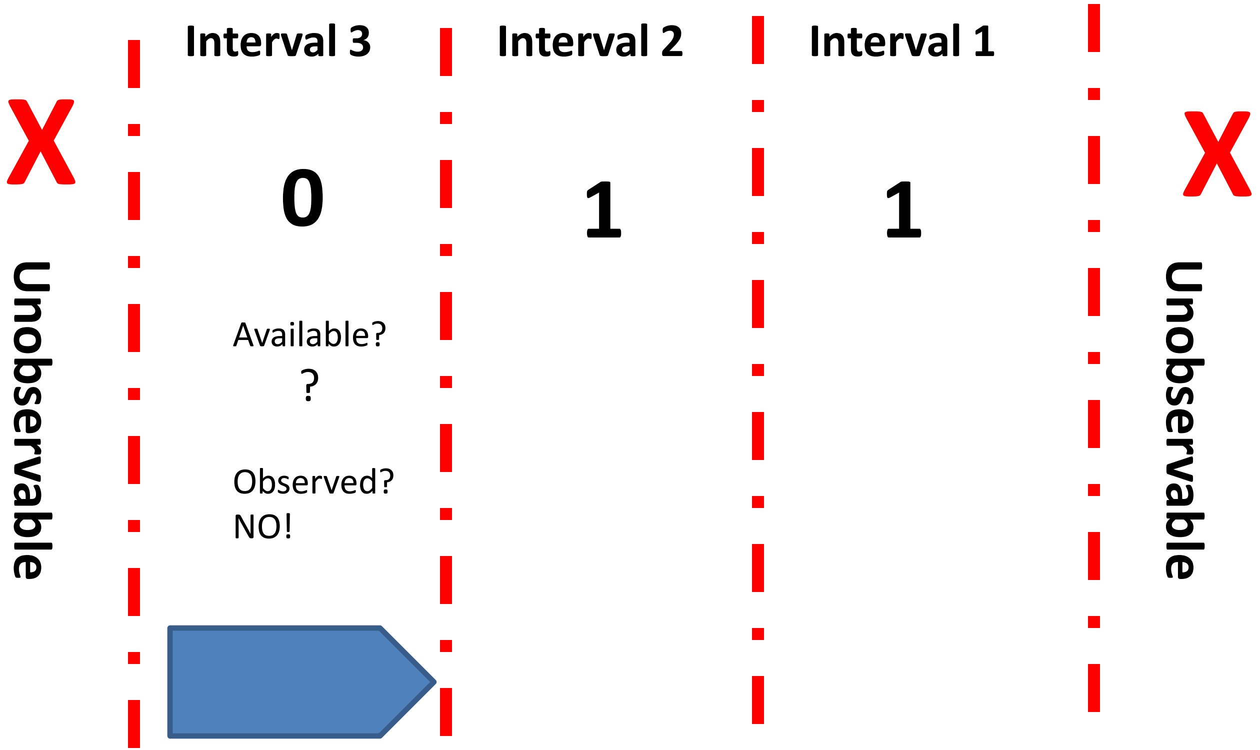
Towed Array Data



Towed Array Data



Towed Array Data



Capture history 1 1 0

Jolly-Seber Approach!

Parameters and Definitions

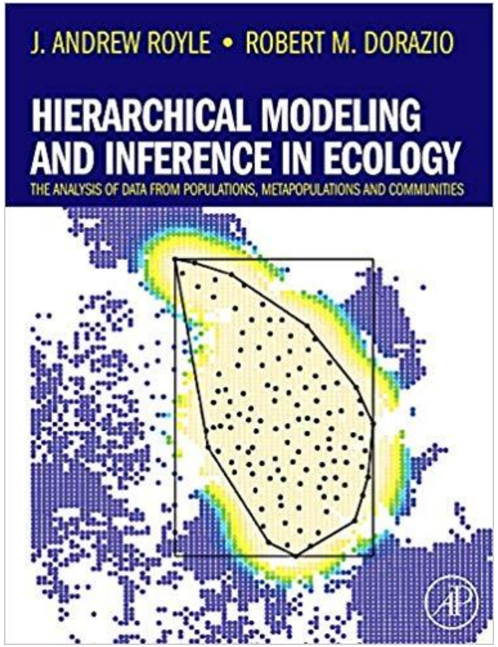
Parameter	Jolly-Seber
γ	Probability of recruiting into the population
ϕ_t	Probability of surviving from occasion t to t occasion t+1
P_t	Probability of detection at occasion t
B_t	Number of new recruits at occasion t
D_t	Number of individuals that die at occasion t
N_{Super}	Total number ever alive in the population

Parameters and Definitions

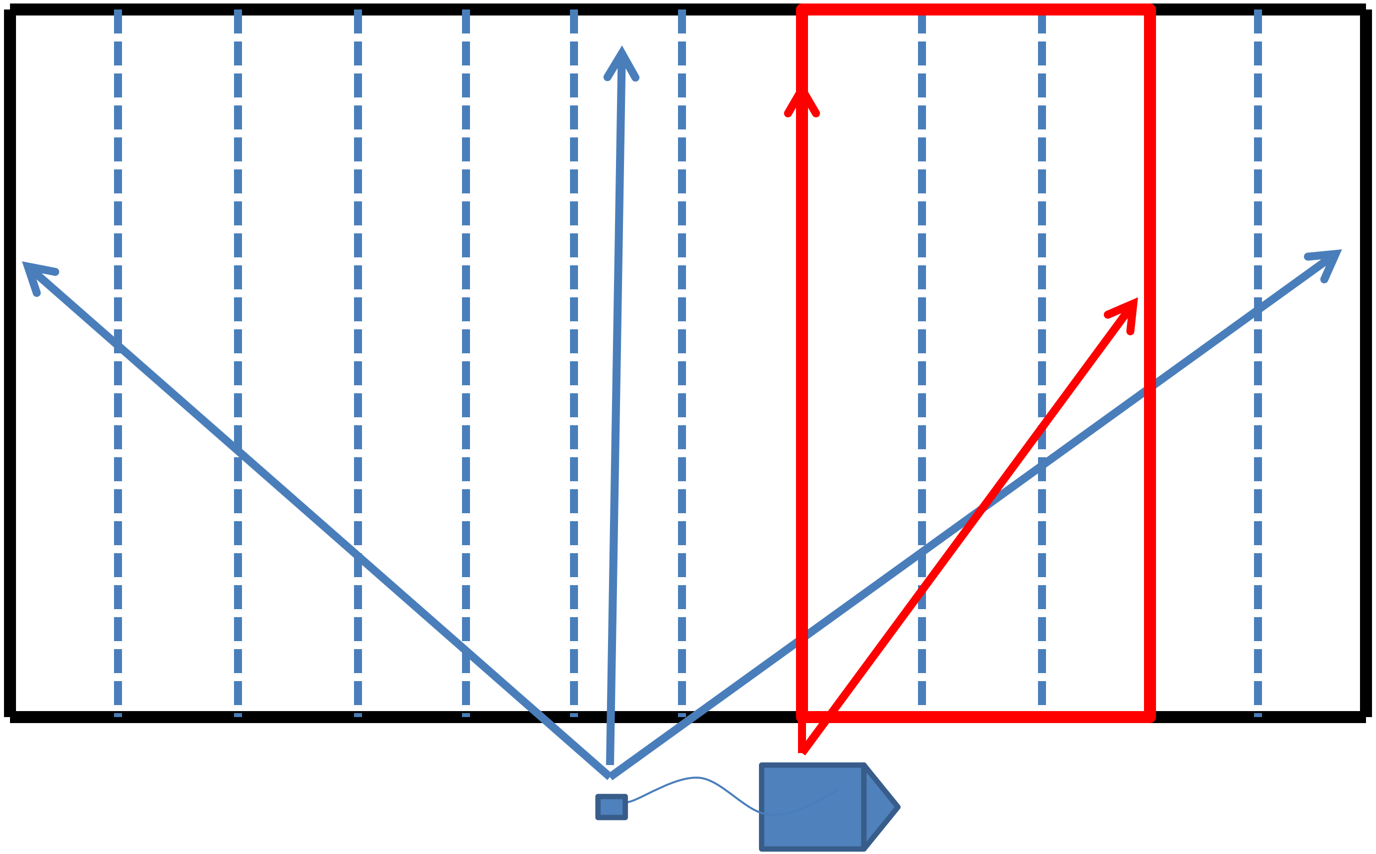
Parameter	Jolly-Seber	Acoustic Integration Model
γ	Probability of recruiting into the population	**Probability of transitioning from above the surface to below**
ϕ_t	Probability of surviving from occasion t to t occasion t+1	**Probability of remaining in the dive state**
P_t	Probability of detection at occasion t	**SAME**
B_t	Number of new recruits at occasion t	**Number transitioning from Above to Below at interval t**
D_t	Number of individuals that die at occasion t	**Number of individuals that surface at interval t**
N_{Super}	Total number ever alive in the population	**Total number ever below and in range of the acoustic array (i.e. N_{Below})**

Acoustic Integration Model

- N_{Above} (Conventional Distance Sampling)
- $N_{Below} = N_{Super}$
- $Duplicates_t = D_t + B_t$
- $Duplicates = \sum Duplicates_t$
- $N_{Total} = N_{Below} + N_{Above} - Duplicates$
- Availability Bias = N_{Above} / N_{Total}



Zone of Overlap

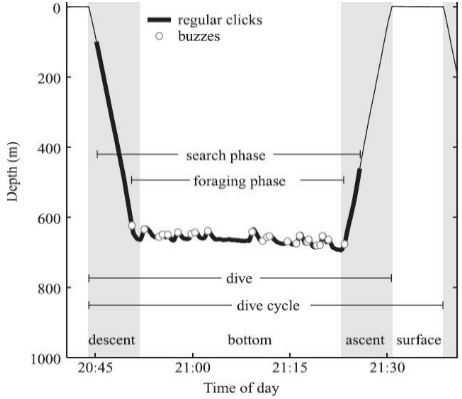


Assumptions vs Reality

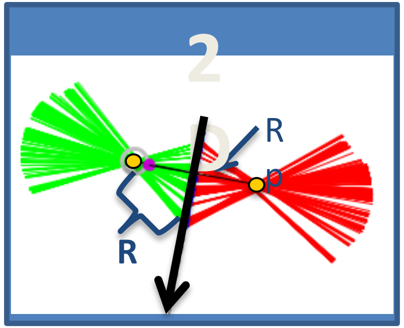
- Equal transition probability (ϕ)
  - Not true….probability changes
  - Try age effect (Observed age)

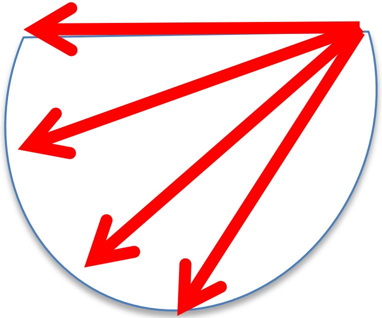
- Only 2 Observable states
  - Not true….Silent States

- Everything is in a 2 dimensional plane
  - Depth component ignored
  - Relative problem



PAMGUARD





Simulations

- Each individual whale started at a forward distance of 7 km
- Randomly assigned a perpendicular distance
- Assumed speed of ship was 10 knots/hr (0.31 km/minute)
- Detection probability below was based on current radial distance
- Detection above was based on perpendicular distance
- Used literature to simulate dive cycles with individual variation
- Ignored depth in the analysis!

Journal of Animal Ecology 2006
75, 814–825

Deep-diving foraging behaviour of sperm whales (*Physeter macrocephalus*)

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Simulation Results

- Relatively low bias in abundance (<3%)
- Relatively low bias in availability (<3%)
- Consistent negative age effect
  - The longer you’re observed the more likely to transition

Line Transect Surveys

- Visual Team
  - Two independent teams
  - Search directly in front to 90°

- Passive Acoustic Team
  - Single towed hydrophone array
  - 2 hydrophones
  - 300 meters behind
  - Data analyzed with PAMGUARD

- Limited communication between platforms

Species

- Sperm Whales
  - Data from 2013 and 2016
  - >200 events

- Beaked Whales
  - Data from 2013 and 2016
  - 4 species
  - >200 events

Gervais' beaked whale

Sowerby's beaked whale

Cuvier's beaked whale

True's beaked whale

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Gervais' beaked whale

Sowerby's beaked whale

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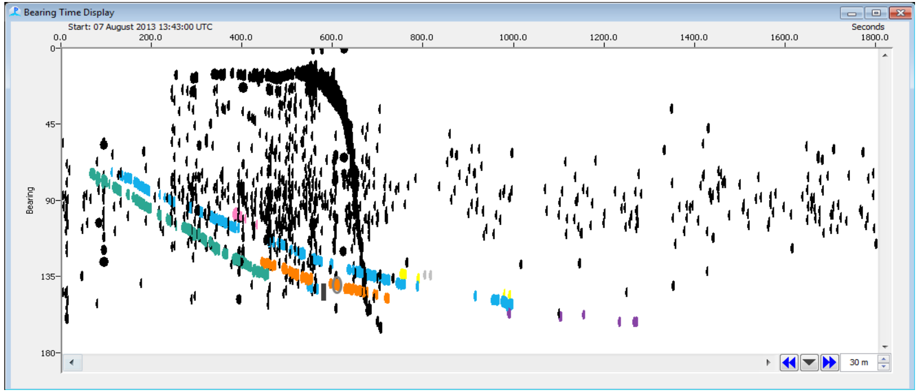
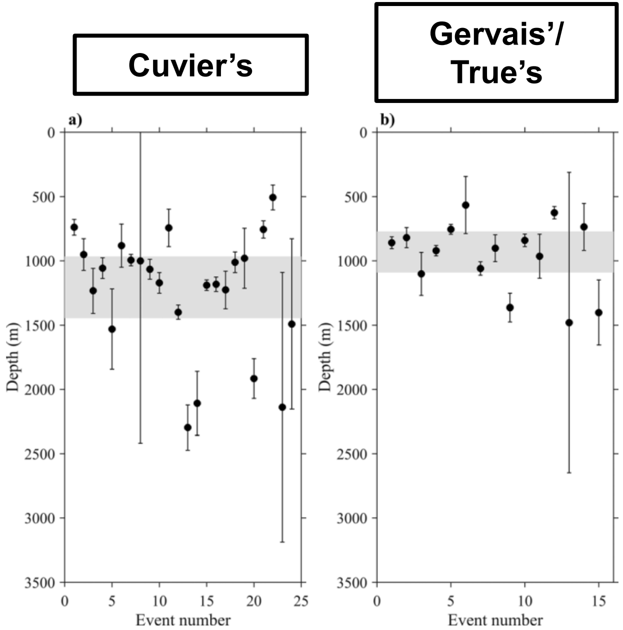
Beaked Whale Challenges

- Low detection range
- Accounting for dive depth
  - De Angelis et al. (2017)
- Difficult to separate individuals





Beaked Whales

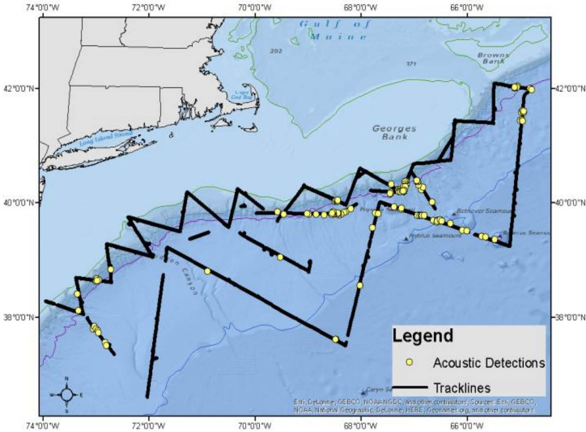
- Beaked Whales
  - 2013 Line Transect Surveys
  - 111 Acoustic Events

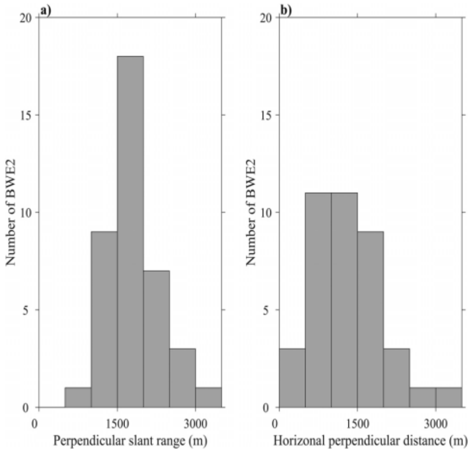
  - Rough adjustment for depth
    - Depth=1200 m

  - Pattern in perpendicular distances
    - Included a quadratic effect in detection probability

  - Truncation distance = 5 km

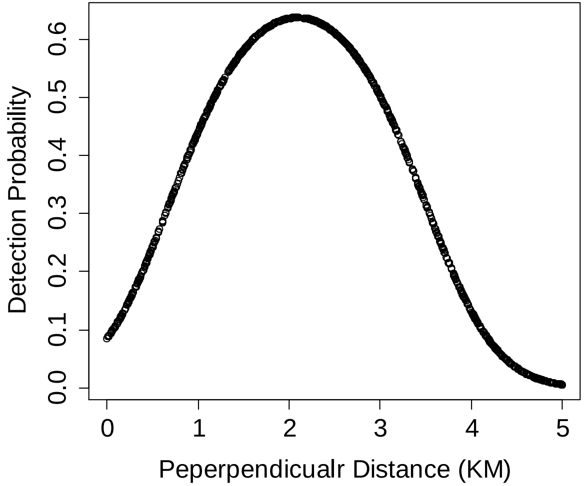
  - Combination of species
    - Cuviers
    - Trues/Gervais
    - Some Sowerbys ?





Beaked Whale Results

- Significant quadratic relationship between detection and distance
- Significant negative age effect
- Estimates comparable to other studies



Parameter	This Study	Palka et al. 2012
Abundance	6568	10462
	This Study	**Warden and Palka 2017**
Availability Bias	0.69	0.78

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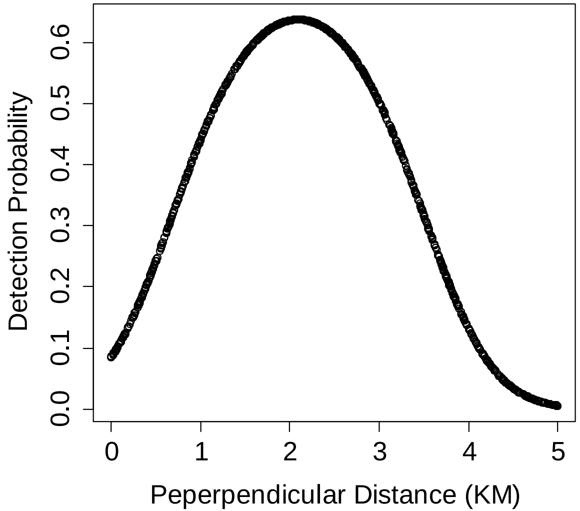


Parameter	This Study	Palka et al. 2012
Abundance	6568 **(0.21)**	10462 **(0.44)**
	This Study	**Warden and Palka 2017**
Availability Bias	0.69 **(0.08)**	0.78 **(0.23)**

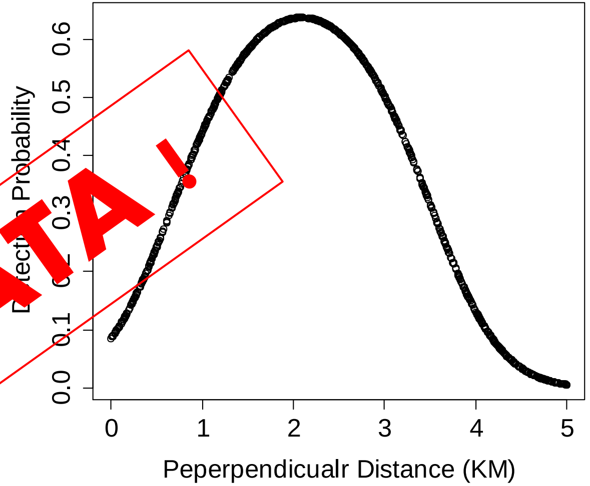
Higher Precision!

Beaked Whale Results

- Significant quadratic relationship between detection and distance

- Significant negative age effect

- Estimates comparable to other studies



PRELIMINARY DATA!

Parameter	This Study	Palka et al. 2012
Abundance	6568 **(0.21)**	10462 **(0.44)**
	This Study	**Warden and Palka 2017**
Availability Bias	0.69 **(0.08)**	0.78 **(0.23)**

Higher Precision!

Summary

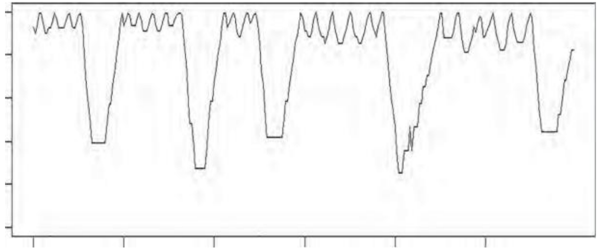
- Method combines two data types and two estimation methods in a Bayesian framework
  - CDS for visual data
  - J-S for acoustic data

- Simulations
  - Fairly robust to (some) assumptions
  - Able to pull out negative age effect
  - Relatively simple scenarios

- Beaked Whales
  - Estimated detection function
  - Negative age effect
  - Estimates comparable to other studies
  - Higher precision
  - **VERY PRELIMINARY!**

Stuff to still do and think about....

- Re-process sperm whale data and apply AIM
- Continue with simulations
  - More geared towards beaked whales
- Address group size
  - Potentially not an issue with sperm whales (mostly single animals)
  - Can do it with beaked whales in the future
- Think more about "silent" states
  - Bounce Dives (decrease availability to both platforms)
  - Could vary by environment or species



Stuff to still do and think about….

- Effects of pooling species
  - Different detection ranges (frequencies)

- Unlocalized events
  - Lots of unlocalized Beakers!

- Explore spatially-explict estimates of surface availability

- Integrate into a Species Distribution Model Framework

ACKNOWLEDGEMENTS

- NOAA-OST Protected Species Toolbox
- Atlantic Marine Assessment Program of Protected Species (AMAPPS)