From Clicks to Counts: Using passive acoustic monitoring to estimate the density and abundance of Cuvier's beaked whales in the Gulf of Alaska (GoA)

Tina M. Yack[1*], Shannon Coates[1], Danielle Harris[2], Len Thomas[2], Thomas Norris[1], Elizabeth Ferguson[1], and Brenda K. Rone[3]

1. Bio-Waves, Inc. – 364 2nd Street, Suite #3, Encinitas, CA 92024
2. Centre for Research into Ecological and Environmental Modelling, The Observatory, Buchanan Gardens, University of St. Andrews, St. Andrews, Fife, KY16 9LZ, United Kingdom.
3. *National Marine Mammal Laboratory, Alaska Fisheries Science Center – 7600 Sand Point Way N.E., Seattle, WA 98115-6349 & Cascadia Research Collective, 218 1/2 W 4th Ave., Olympia, WA 98501*

Objectives

- Detect and localize beaked whales and obtain ***'perpendicular'*** distances to **individual** animals (e.g. acoustic localization).

- Compare **2 distance sampling analytical methods**; (1) conventional distance sampling (**cds**) and (2) distance sampling using a depth distribution model (**dsddm**) to estimate density and abundance of Cuvier's beaked whales.

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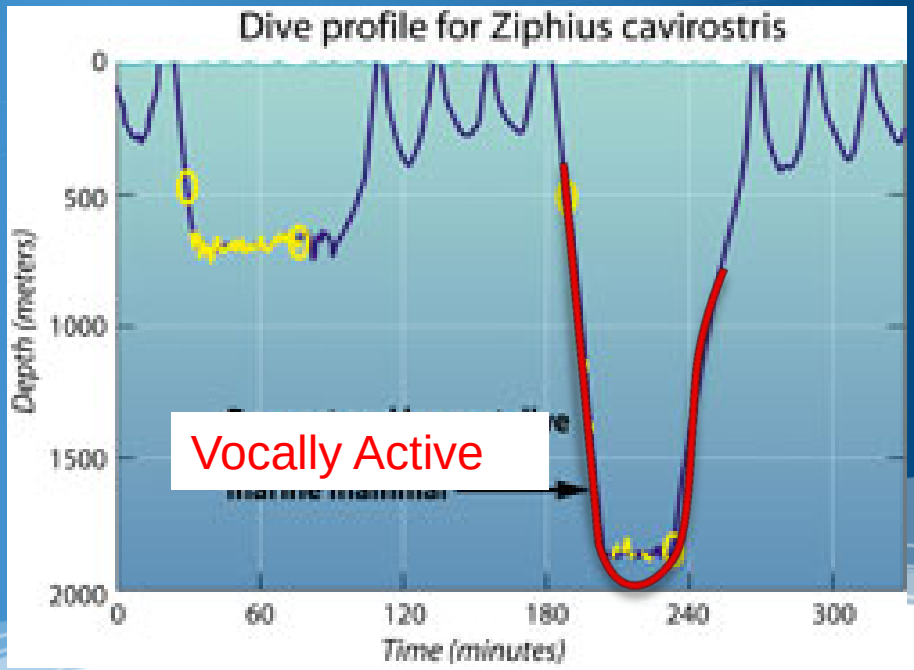
Beaked Whale Ecology

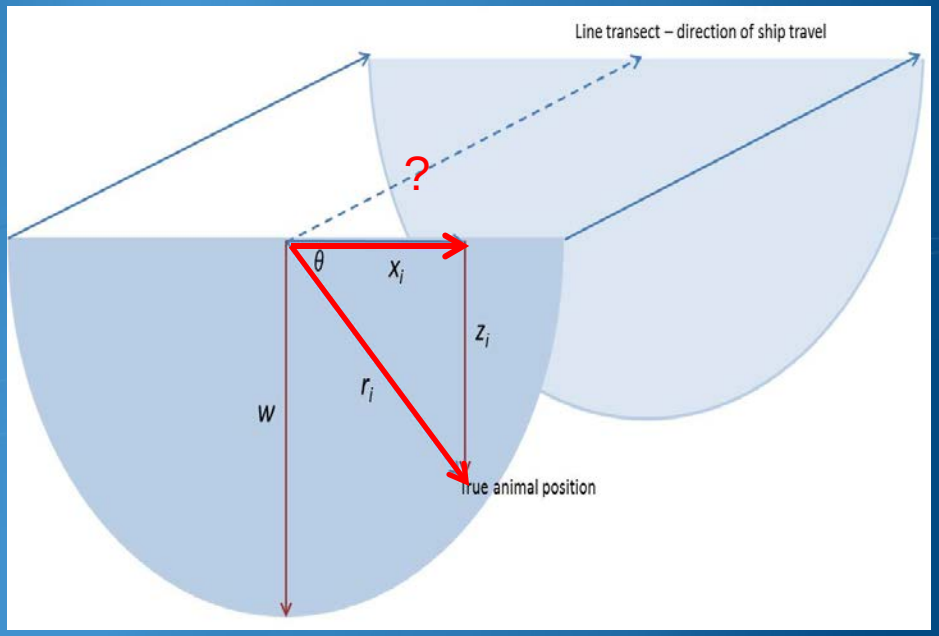
- 3 species of beaked whales occur in GoA
  - Cuvier's beaked whale (*Ziphius cavirostris*), Baird's beaked whale (*Berardius bairdi*), Stejneger's beaked whale (*Mesoplodon stejnegeri*).
- Feed on squid & benthic fish
- Deep-diving: Foraging dive durations > 1 hr @~2000 m
- Often occur in small groups
- Cryptic surface behavior
- Vocally active during foraging dives



Tyack et al. 2012
http://www.whoi.edu/main/newsreleases/2006?tid=3622&cid=16726

The Problem with Deep Divers

- Unknown animal depth = unknown **horizontal** distance.
- Problem for any species where **dive depths are similar to the detection range.**
- Ignoring the problem overestimates distances and **underestimates** density.



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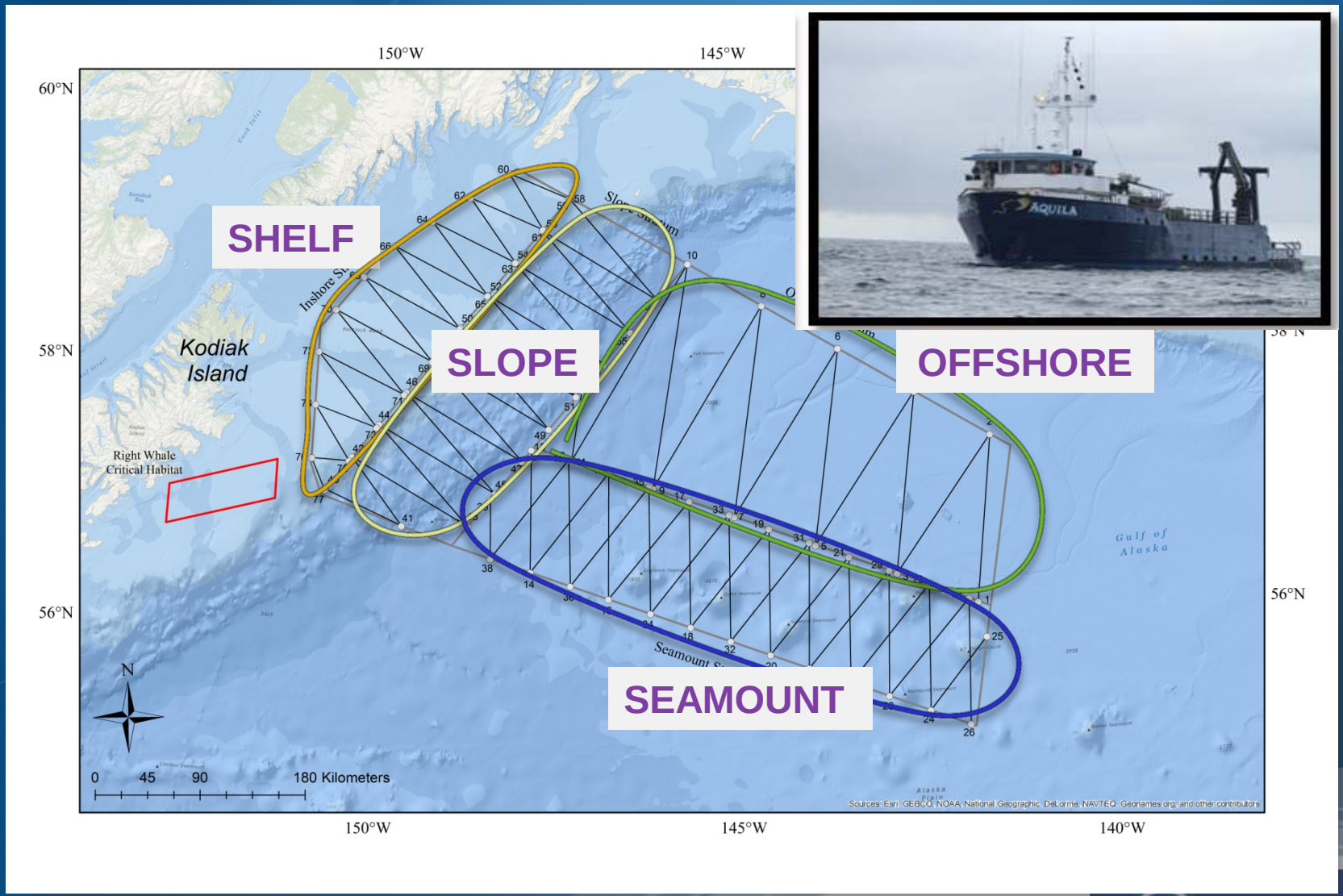
Study Area & Survey Design



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Methods

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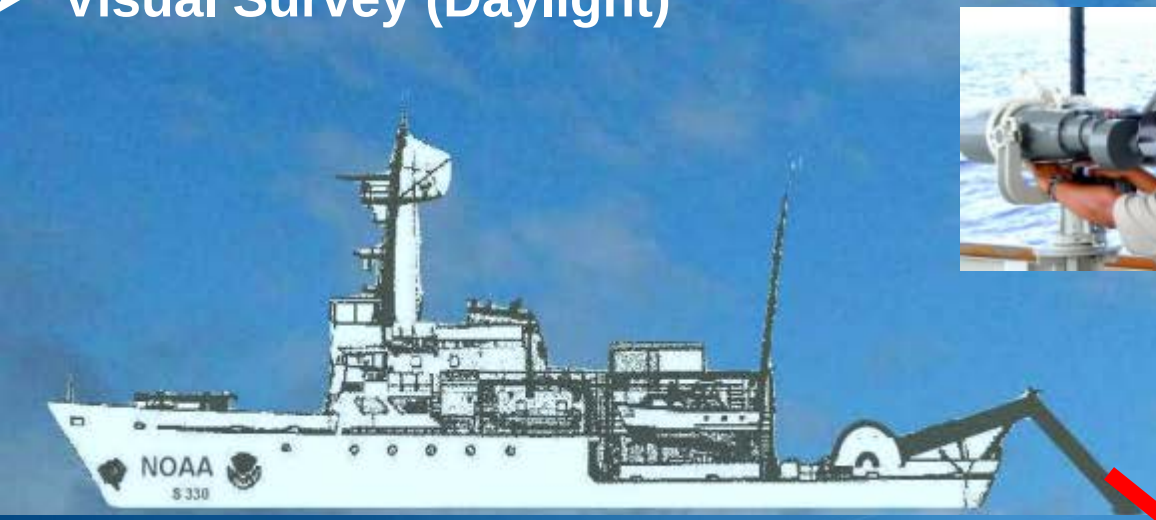
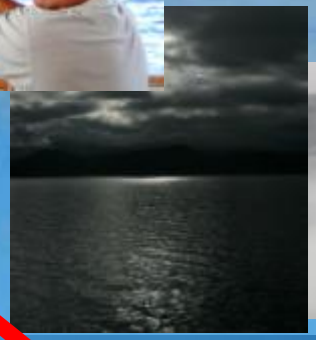
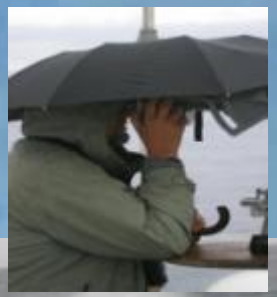
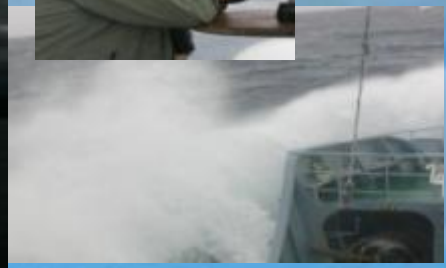
Survey Methods

- **Visual Survey (Daylight)**

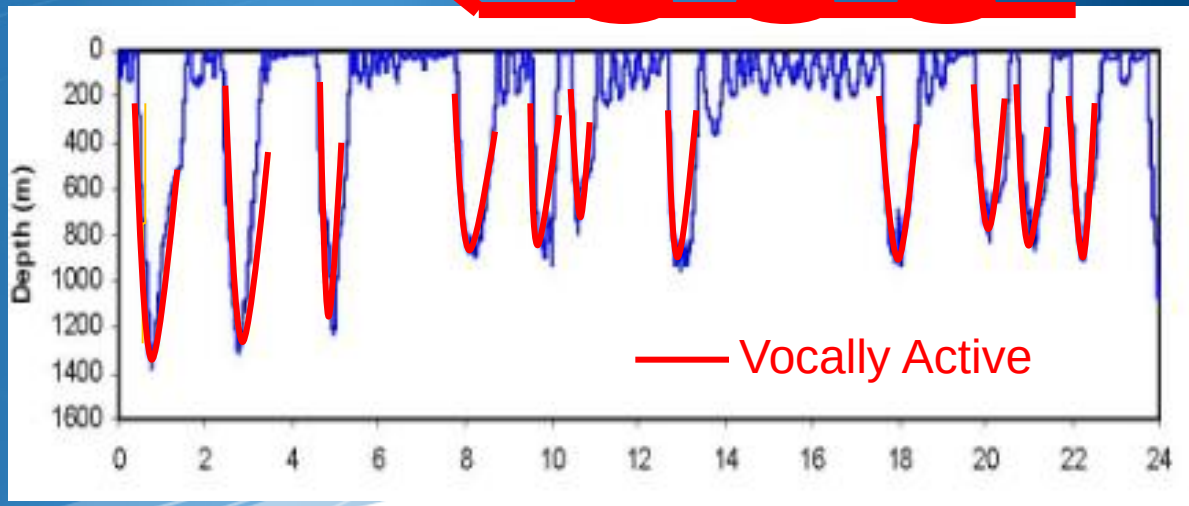






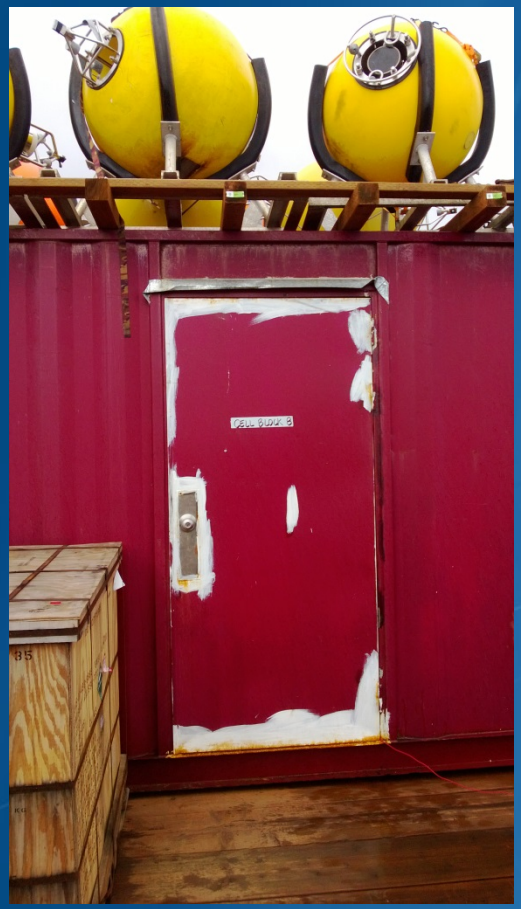


- Acoustic Survey: (24 hrs)



Baird, et al. 2005.

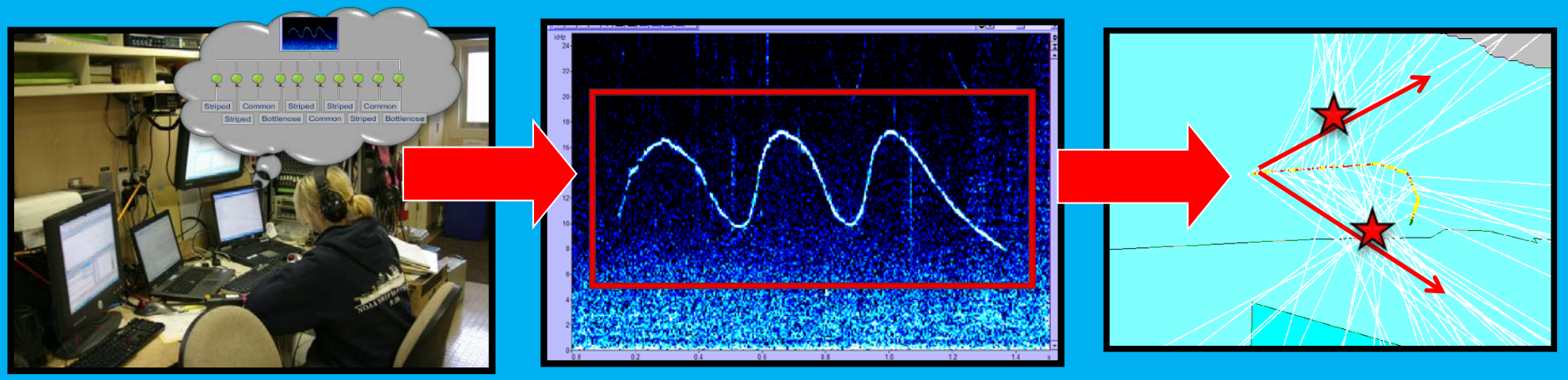
Our Home In the Acoustics Lab



Manual Detection/Tracking

Ishmael

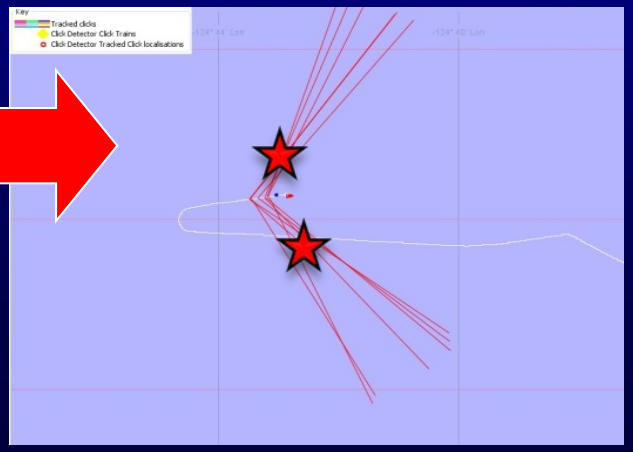
WhalTrak II



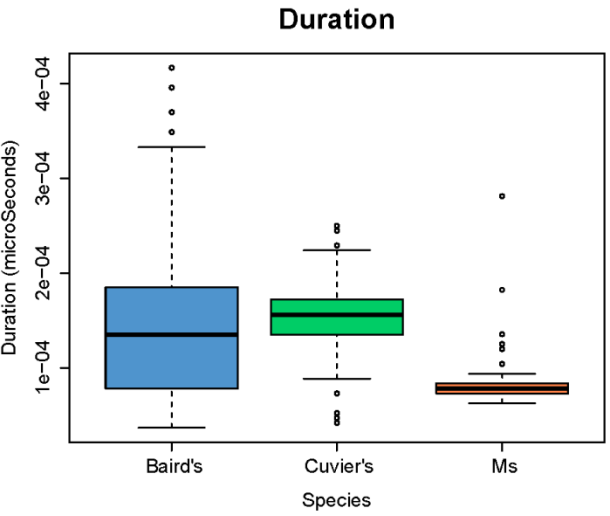
Semi-Automated Detection/Tracking

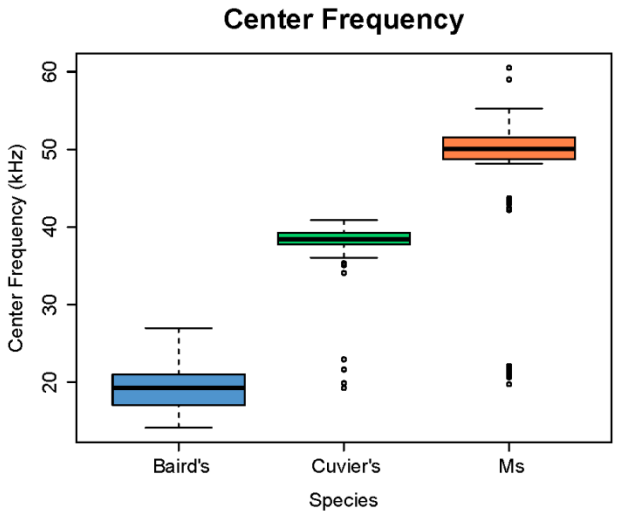
PAMGuard Bearing Time Display

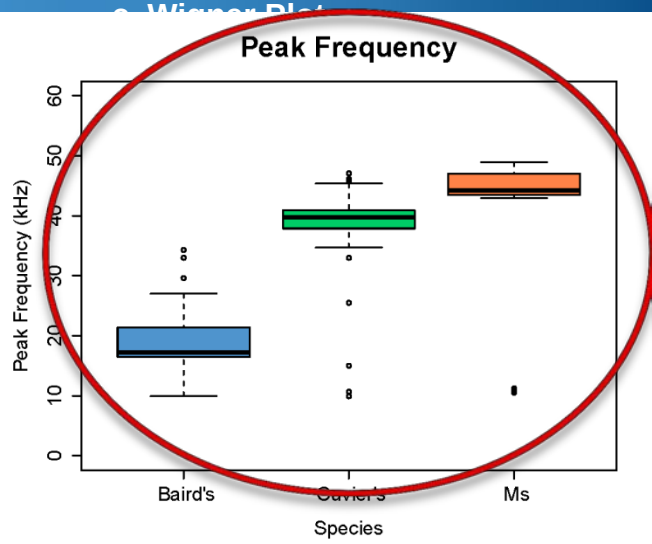
PAMGuard Map Display

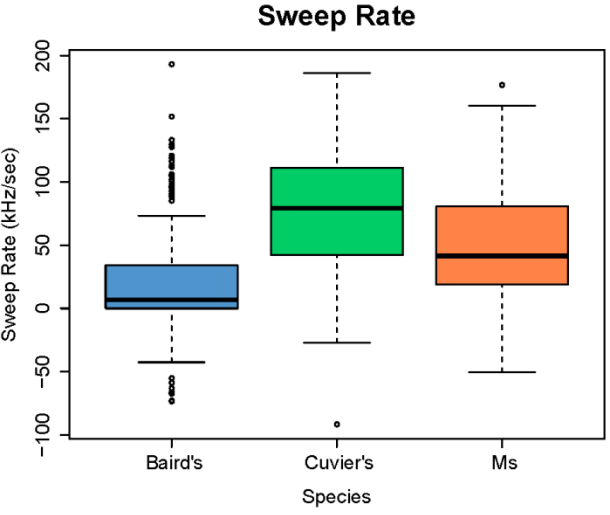


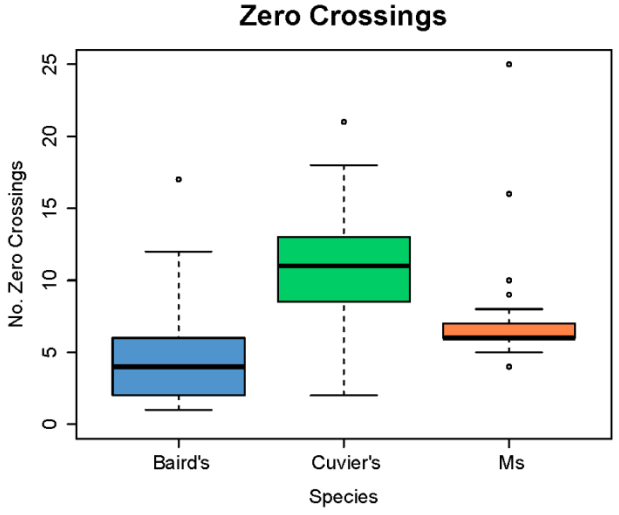
GOA Beaked Whale Species

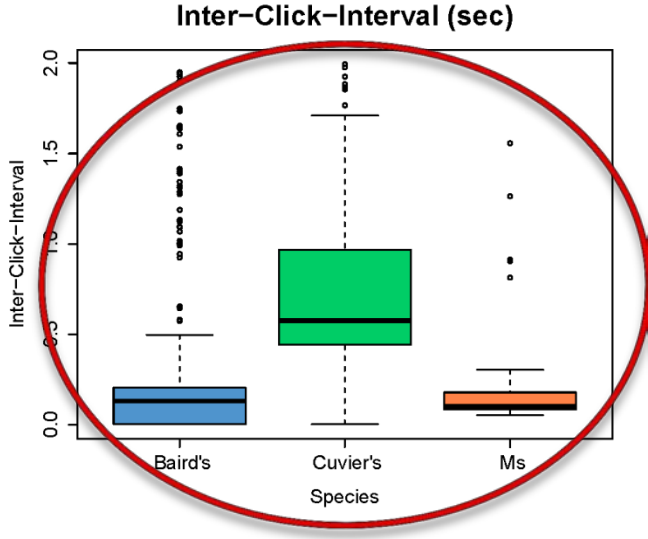






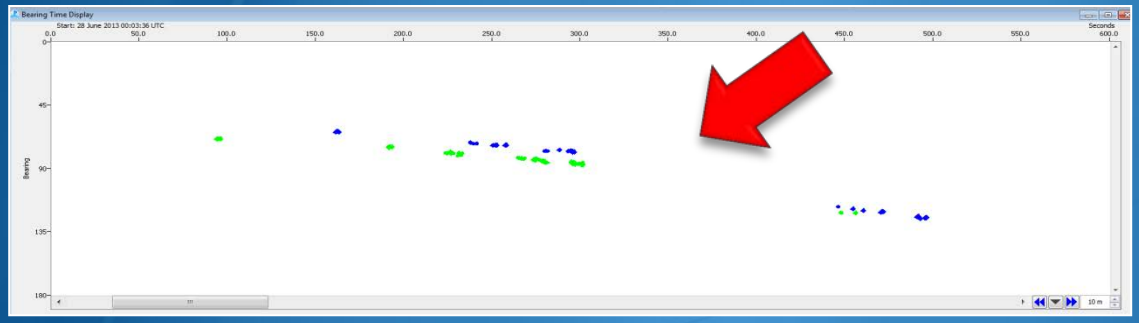




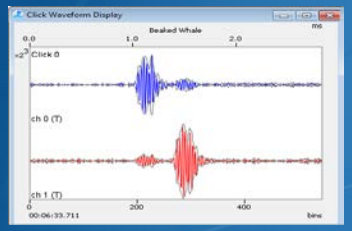


PAMGuard's 'ViewerMode'

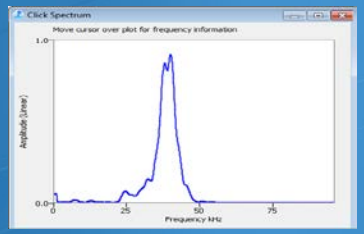
I. Time/Bearing Display



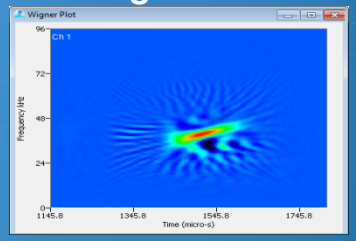
II. Waveform



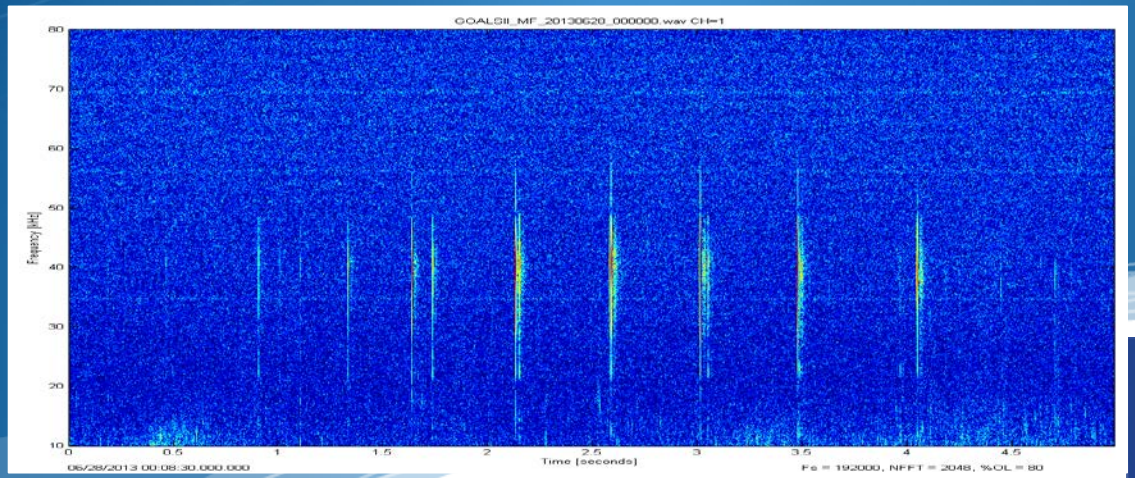
III. Click Spectrum



IV. Wigner Plot



V. Spectrogram



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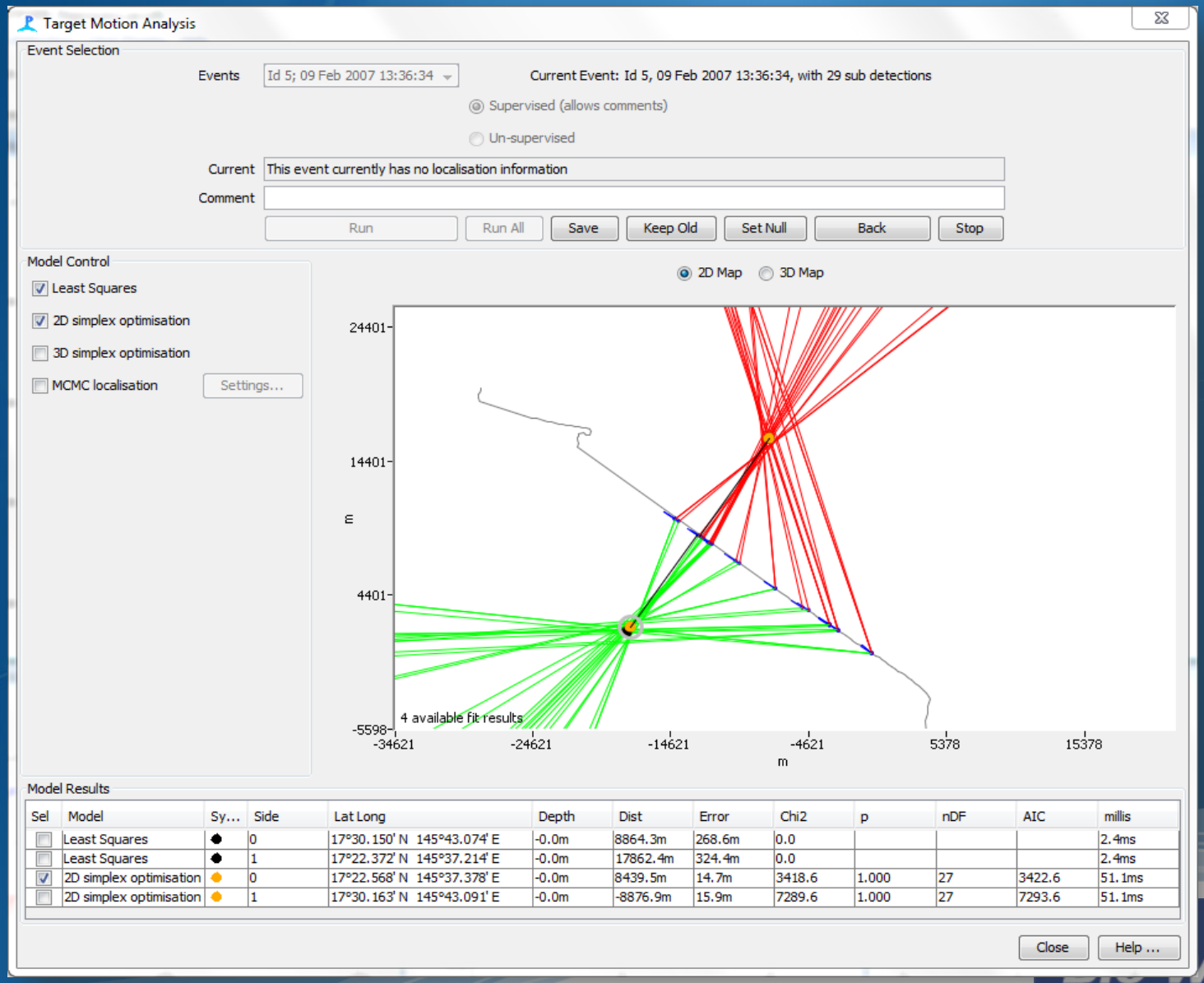
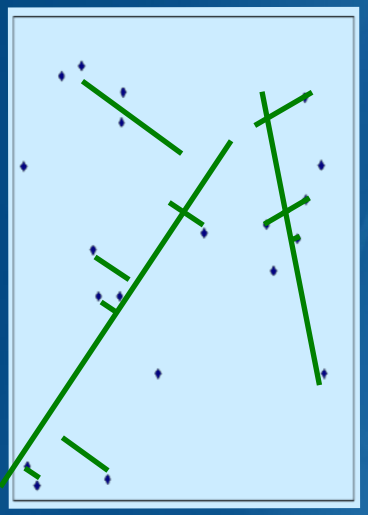
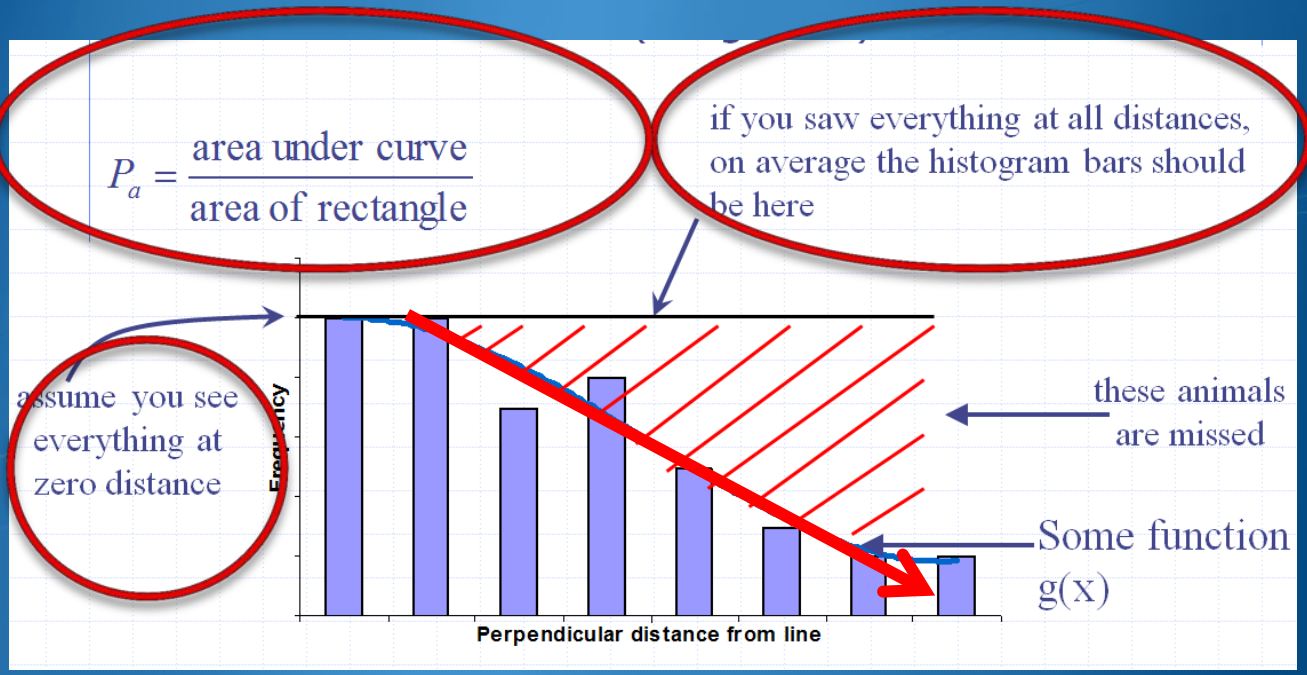
Target Motion Analysis in 'ViewerMode'



Distance Sampling



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



Slide images courtesy of: http://warnercnr.colostate.edu/~gwhite/fw663/DistanceSampling.ppt and Danielle Harris

Distance Sampling

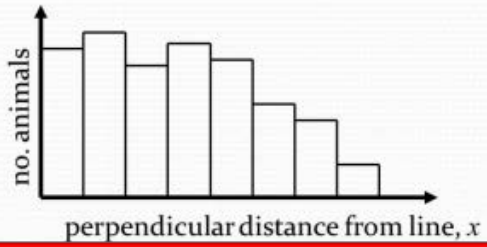
Distance sampling (with acoustic data)

Distances, x – perpendicular (lines)

Fit a detection function, $g(x)$, with parameters, ϕ, using maximum likelihood. Assume $\pi_x(x)$ is known

Given an estimator for $g(x)$ i.e., $\hat{g}(x)$, estimate the average probability of detection

Correct n for missed detections using P and estimate density, D



$$L(\phi) = \prod_{i=1}^{n} \frac{g(x_i)\pi_x(x_i)}{\int_0^w g(x)\pi_x(x)\,dx}$$

$$\hat{P}_a = \int_0^w \hat{g}(x)\pi_x(x)\,dx$$

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

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Slide images courtesy of: Danielle Harris

Methods

- Conventional Distance Sampling
  - Distance 6.2 software
- DSDDM Distance 6.2 software
  - Custom R code: *Developed by Danielle Harris*

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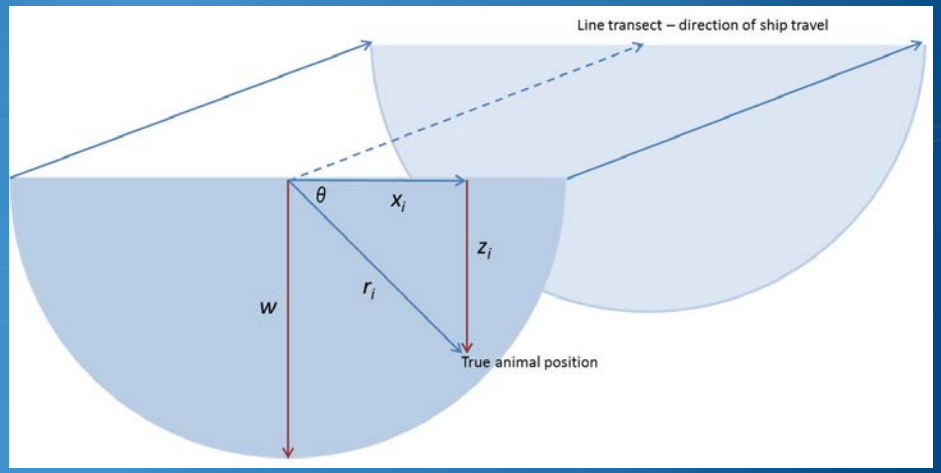
The Problem with Deep Divers

- Unknown depth = **unknown horizontal** distance.
- Problem for any species where dive depths are similar to the detection range.
- Ignoring the problem overestimates distances and **underestimates** density.



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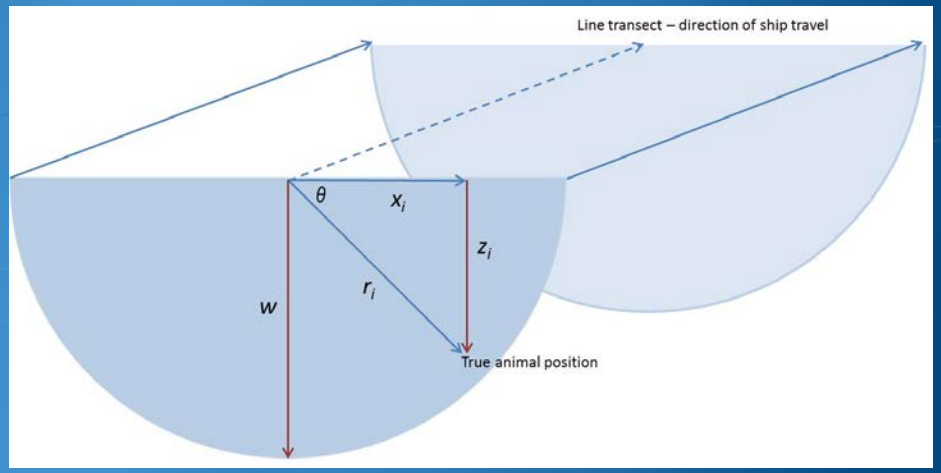
The Solution

- Use DSDDM
  - Issue can be addressed by incorporating a **depth distribution** into the algorithm to estimate probability of detection.
  - Algorithm then works with the **slant ranges** to animals.
  - Still expect **horizontal distribution** of animals from the transect line is **uniform**.



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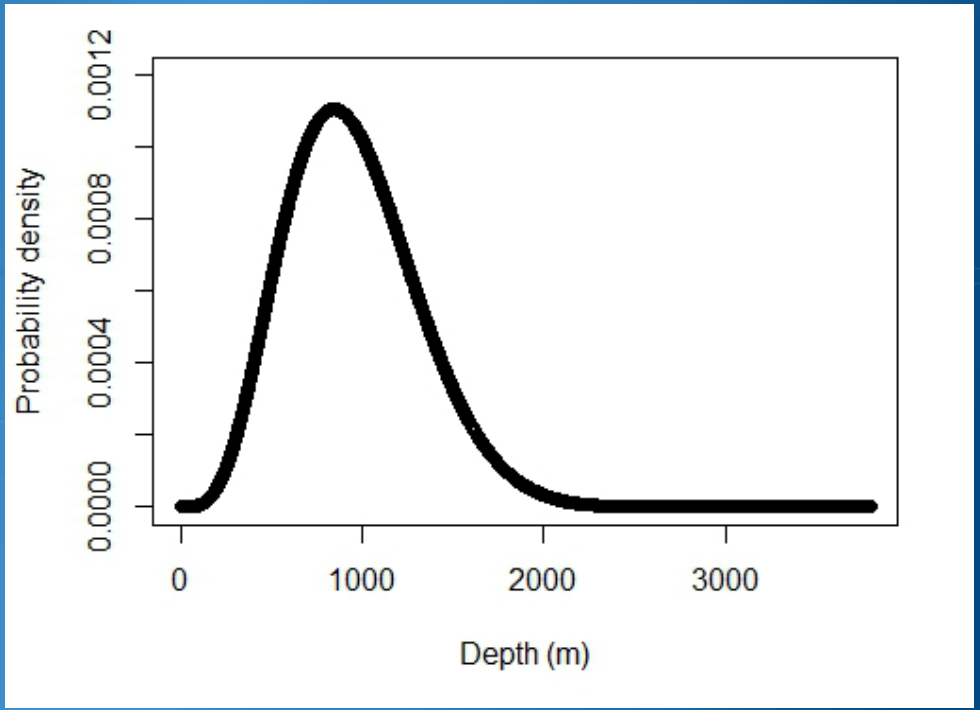
Methods

- DSDDM Methods
  - A scaled beta distribution used to describe depth distribution of **vocalizing animals**
  - Based on data from Tyack *et al*. (2006)
  - **Half normal** detection function fitted.
  - Model requires **constant** survey area **depth** input.



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Results

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Survey Results

- Survey Effort included:
  - Acoustic Effort: 6,304 km, 426 hours
  - Visual Effort: 4,155 km
- Cuvier's beaked whale encounters included:
  - Acoustic Encounters: 47 (40 localized individuals)
  - Visual Encounters: 1 (1 individual)

Species Encountered	No. Encounters	No. Localized Encounters	No. Encounters On Effort Available for Distance Sampling
Stejneger's beaked whale	14	10	10
Baird's beaked whale	32	29	18
Cuvier's beaked whale	47	43	40*

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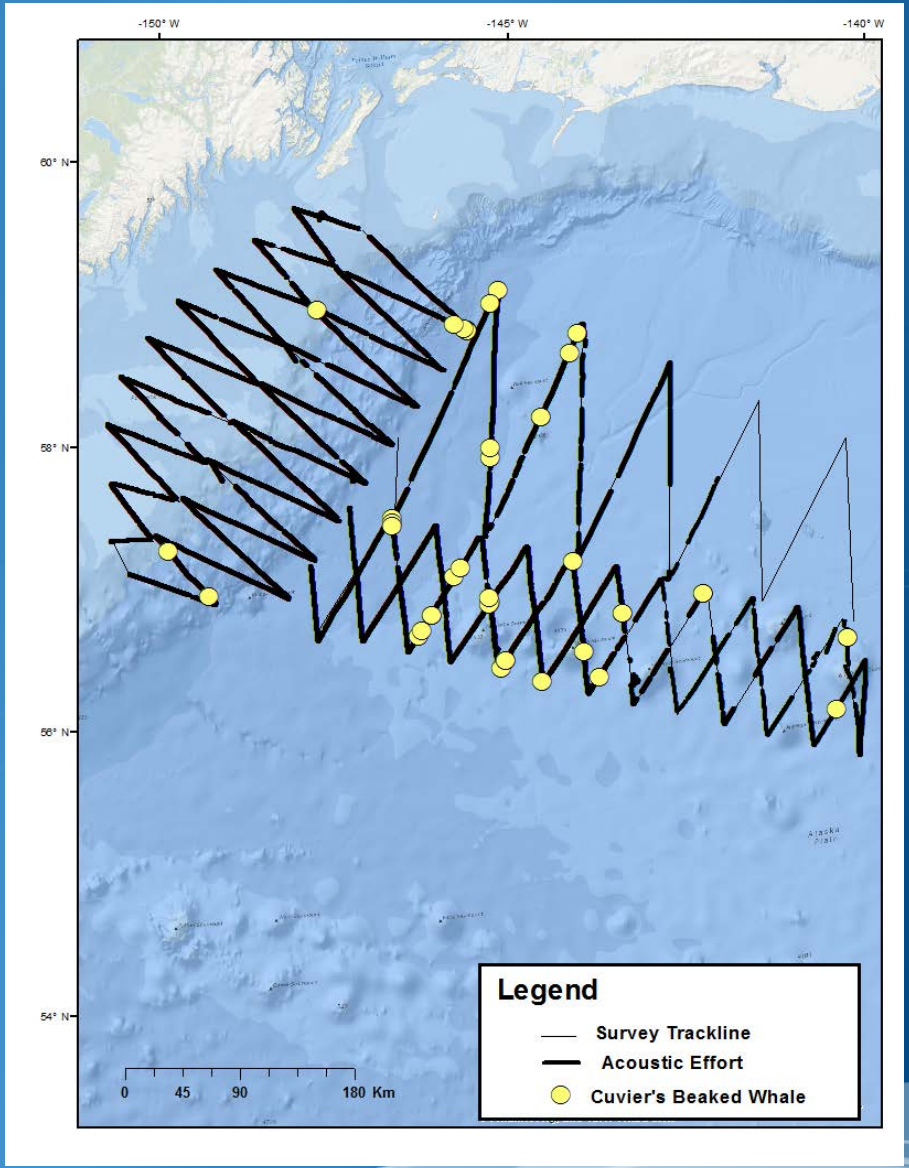
Results

- Encounter rates varied by strata
  - Seamount strata contained majority of encounters
- Samples by strata
  - Offshore = 8
  - Seamount = 26
  - Slope = 6



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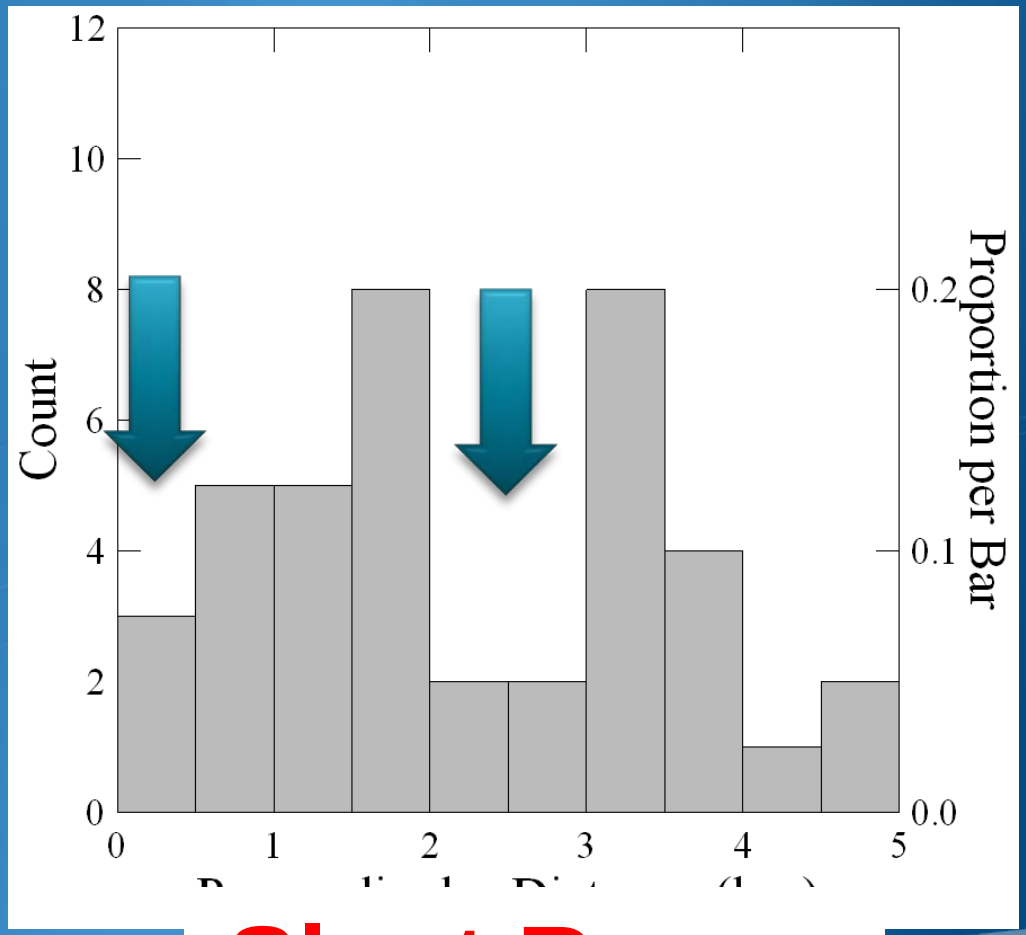
Results

- Localizations = 40 total used in analysis



Slant Range

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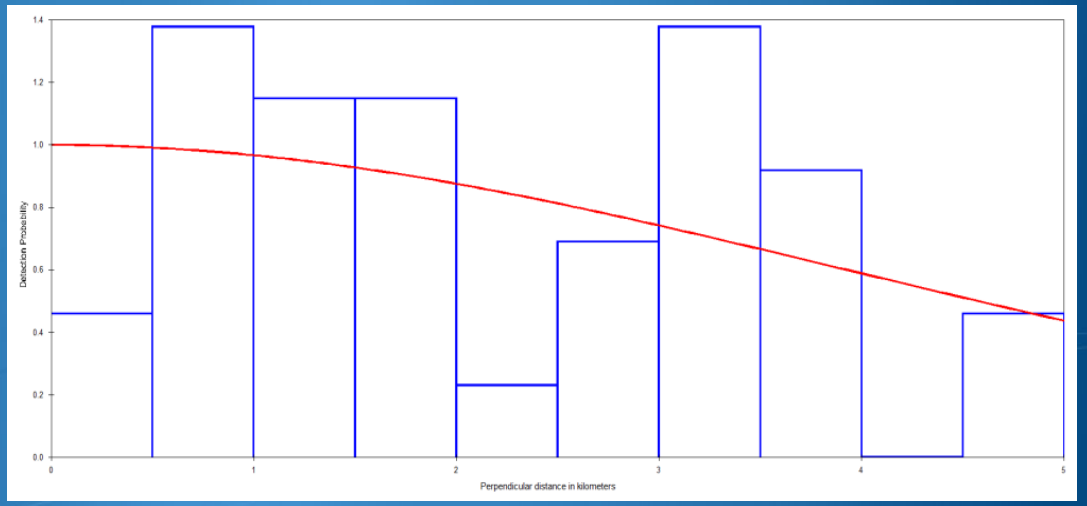
Distance Model Results - Comparison

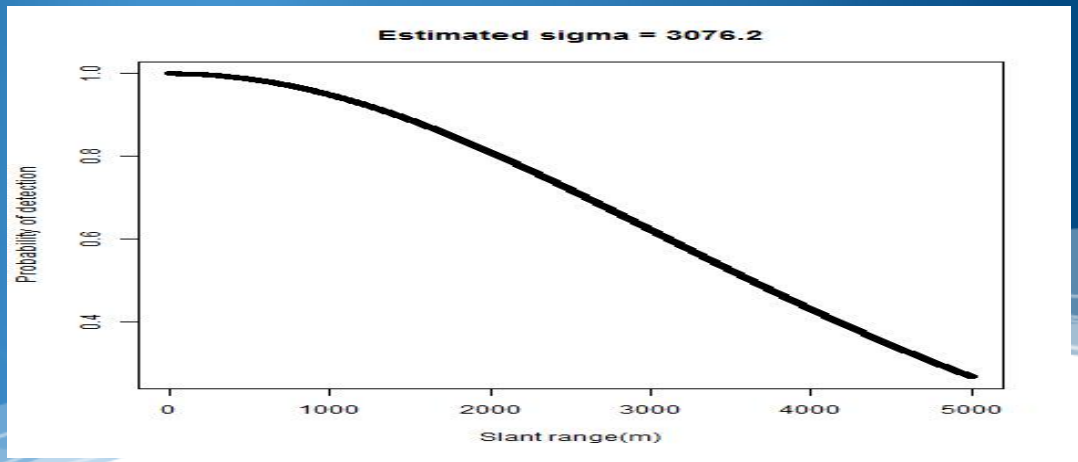
Half Normal - No Slope Stratum

obs	N	D (1000 km²)	CVb	Pa
34	121	1.1	29.6%	0.78



Half Normal - DSDDM

obs	N	D (1000 km²)	CVb	Pa
34	145	1.4	31%	0.65*



* Density/Abundance estimates shown are not corrected for g(0) ≠ 1 (Barlow et al. 2013; Cuvier's acoustic g(0) = 0.28)

Results – Model Comparison

CDS resulted in 20% 'underestimate' of abundance compared to DSDDM

	CDS Offshore	DSDDM Offshore	CDS Seamount	DSDDM Seamount	CDS Pooled	DSDDM Pooled
Obs	8	**8**	26	**26**	34	**34**
N	57	**68**	64	**77**	121	**145**
N 95% CI	(7-115)	**(0-130)**	(30-120)	**(38-150)**	(57-200)	**(68-265)**
CVb	48.1%	**55%**	33.3%	**34%**	29.6%	**31%**

* Density/Abundance estimates shown are not corrected for g(0) ≠ 1 (Barlow et al. 2013; Cuvier's acoustic g(0) = 0.28)

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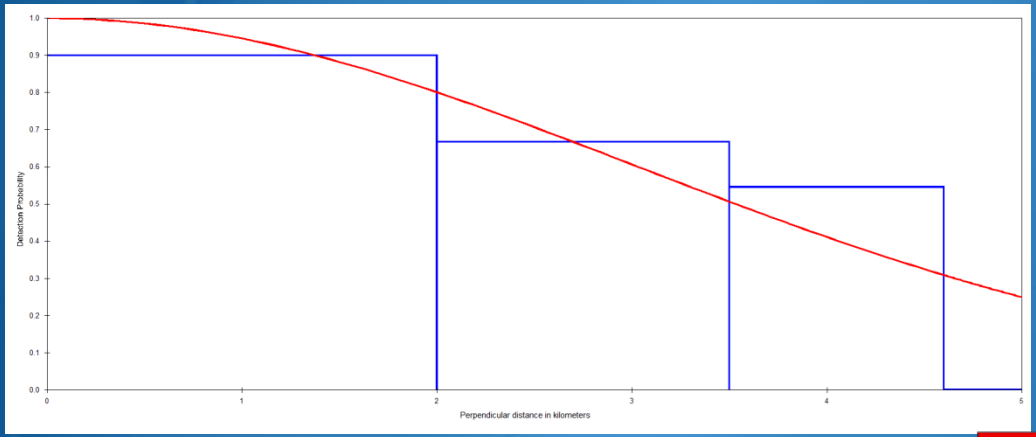
Can we account for slant range by binning data??



	CDS-BIN Offshore	DSDDM Offshore	CDS-BIN Seamount	DSDDM Seamount	CDS-BIN Pooled	DSDDM Pooled
N	65	**68**	74	**77**	139	**145**
N 95% CI	(20-208)	**(60-105)**	(40-136)	**(60-105)**	(72-267)	**(119-204)**
CVb	53%	**52%**	31%	**30%**	32%	**27%**

* Density/Abundance estimates shown are not corrected for $g(0) \neq 1$ (Barlow et al. 2013; Cuvier's acoustic $g(0) = 0.28$)

Discussion

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Model Comparison/Selection

- GOALS II – Density

Binning Data can be used address slant range issue until more comprehensive and flexible DSDDM methods are readily available: Resulted in only ~4% 'underestimation' vs. ~20% when data was not binned

n^2

n^2

m^2

- G

* Density/Abundance estimates shown are not corrected for g(0) ≠ 1 (Barlow et al. 2013; Cuvier's acoustic g(0) = 0.28)

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Conclusions

- Acoustic monitoring methods are a valuable resource for estimating abundance of deep-diving, continuously clicking species.
- Will provide the first line-transect acoustic density estimates for Cuvier's and the first estimates in the GoA.
- DSDDM enabled us to characterize 'underestimation bias' and will be a valuable tool to use in future effort.
- Applicable to other species
  - Baird's acoustic encounters on effort: 18
  - Stejneger's acoustic encounters on effort: 10

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Future Work Needs

- Correct estimates for $g(0) \neq 1$ (Barlow et al. 2013; $g(0) = 0.28$ for Cuvier's).
- Tagging of beaked whales in the GoA to provide ground truth of DSDDM depth distribution and proportion of time spent clicking for GoA.
- Continued development of the DSDDM methods to extend to other model types, account for variable depth and allow for multi-covariate distance sampling etc.
- Habitat modeling

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Thank you!

Sponsors: We would like to acknowledge the **U.S. Navy Fleet Forces Command** and **NAVFAC-Atlantic** for sponsoring the survey and analysis effort, and **HDR, Inc**.(*especially Kristen Ampela*) for support and coordination of all project logistics.

Advice & Support: Douglas Gillespie and Jay Barlow

A special thank you to the tireless and dedicated efforts of the survey acousticians;, Jessica Crance, and Dawn Grebner. A special thank you to John Calambokidis and Cascadia Research Collective for survey planning, coordination, and support. We would also like to thank all of the participants of the survey; Jeff Foster, Annie Douglas, Michael Richlen, Jennifer Gatzke, Ernesto Vasquez and Bridget Watts, and the Captains and crew of the R/V Aquila.

Questions?

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