

**Integrating passive acoustic data with  
visual line transect surveys  
to refine population estimates and estimate  
availability bias  
for sperm whales (*Physeter macrocephalus*)**

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*In collaboration with:*

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**NEFSC-PSB**

# Population Estimation

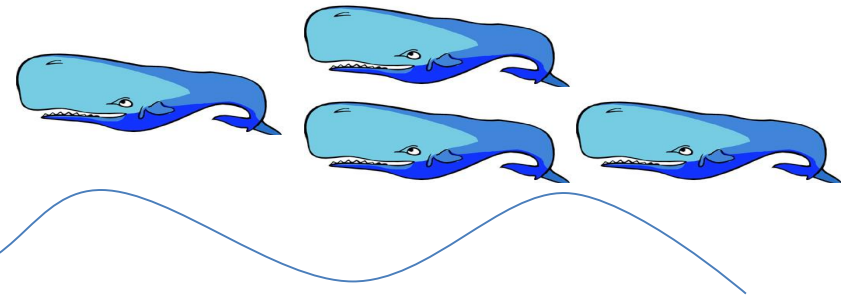
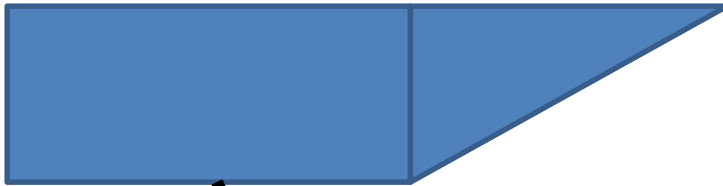
- If only we could just count everything!



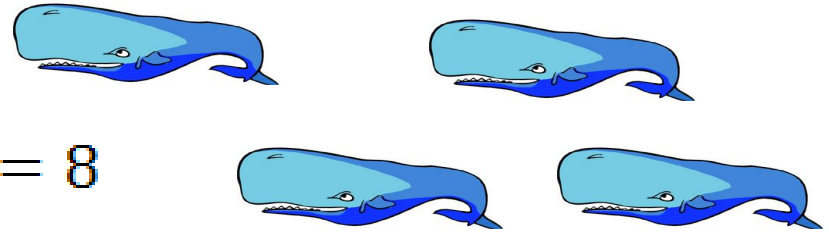
I see two!

$N=2?$

$$\hat{N}_{Above} = 4$$



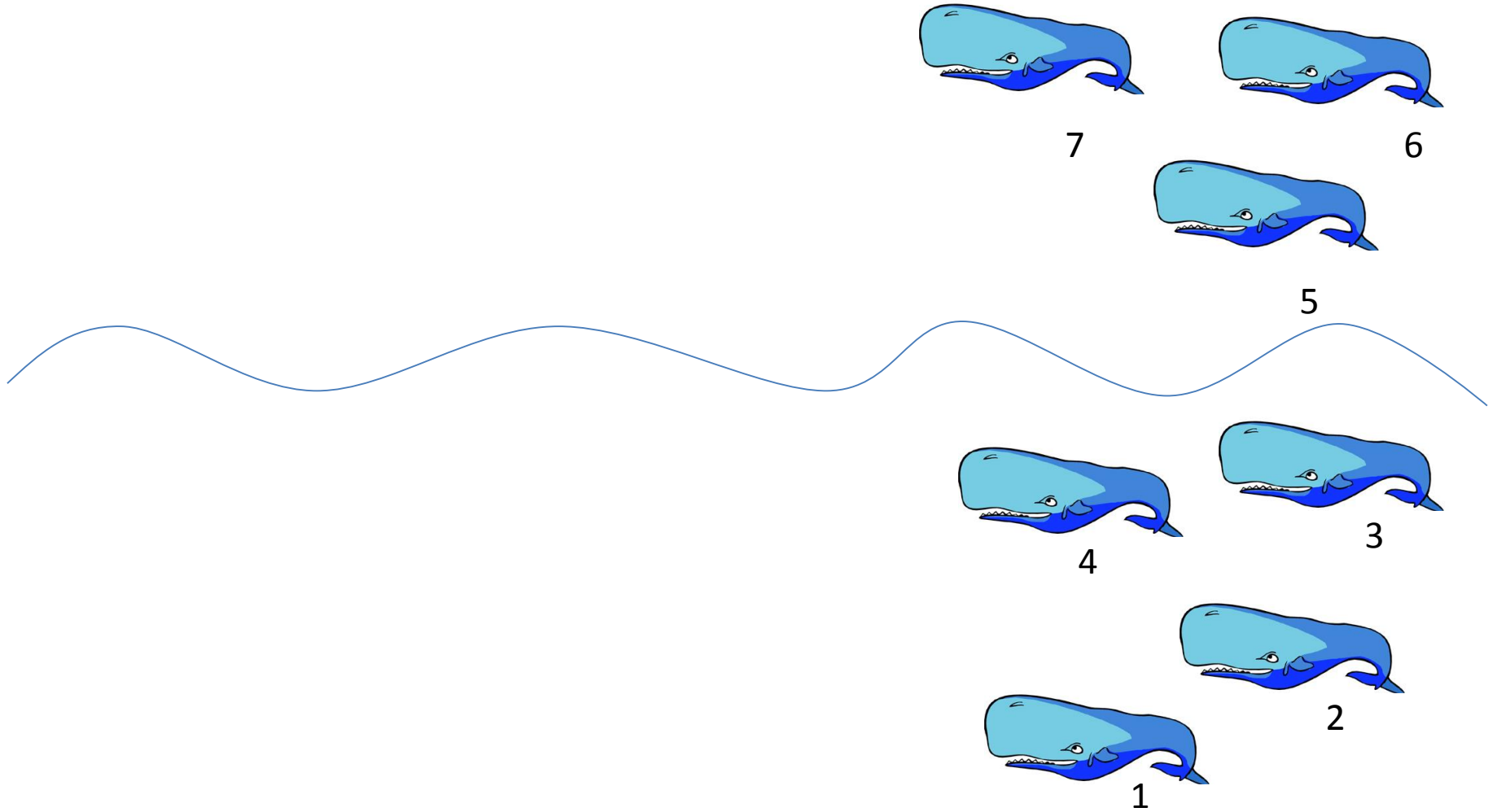
$$\hat{N}_{Below} = 4$$



$$\hat{N}_{Total} = \hat{N}_{Above} + \hat{N}_{Below} = 8$$

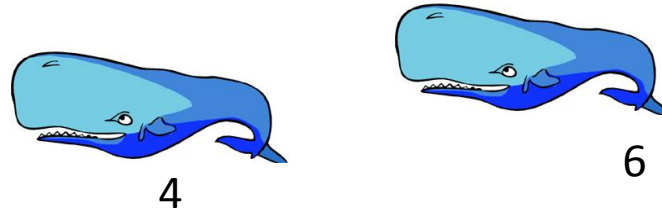
**In an Instantaneous World Maybe?**

# Continuous Time

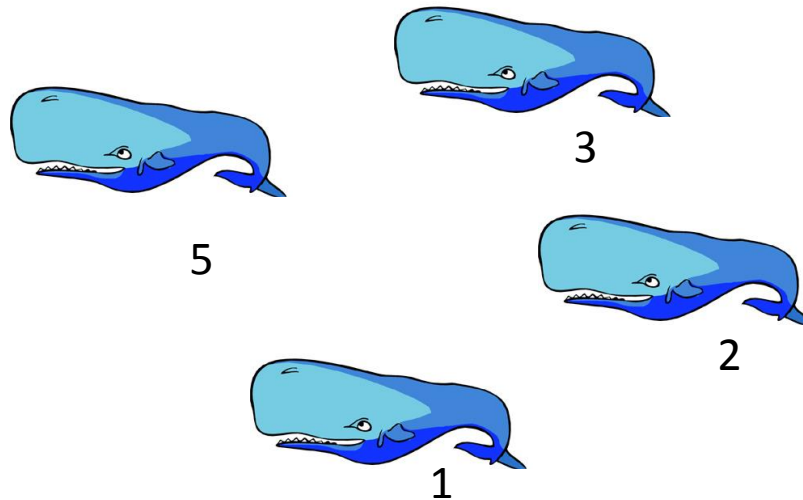
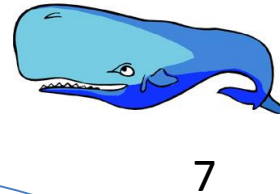


$$N_{\text{Total}} = N_{\text{Below}} + N_{\text{Above}} - \text{Duplicates}$$

**Double Counting**



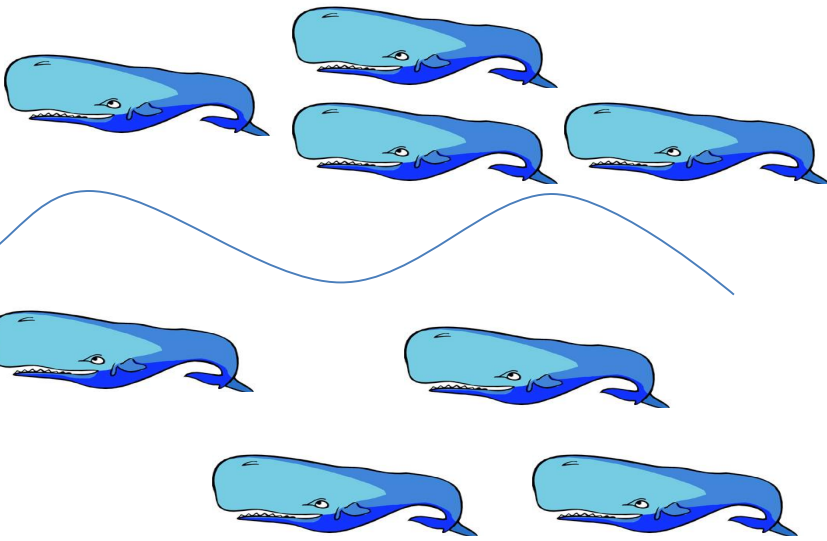
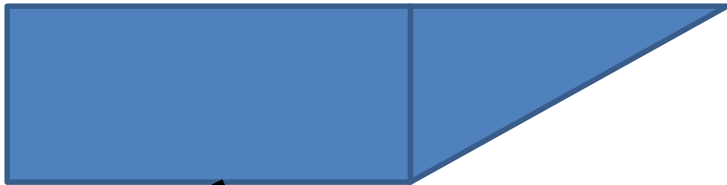
$$N_{\text{Above}} = 4$$



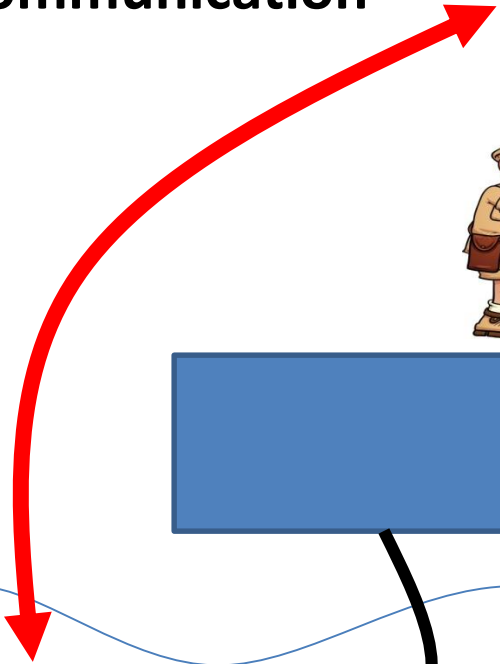
$$N_{\text{Below}} = 4$$

**No Communication**

I see two!



I can't hear you!

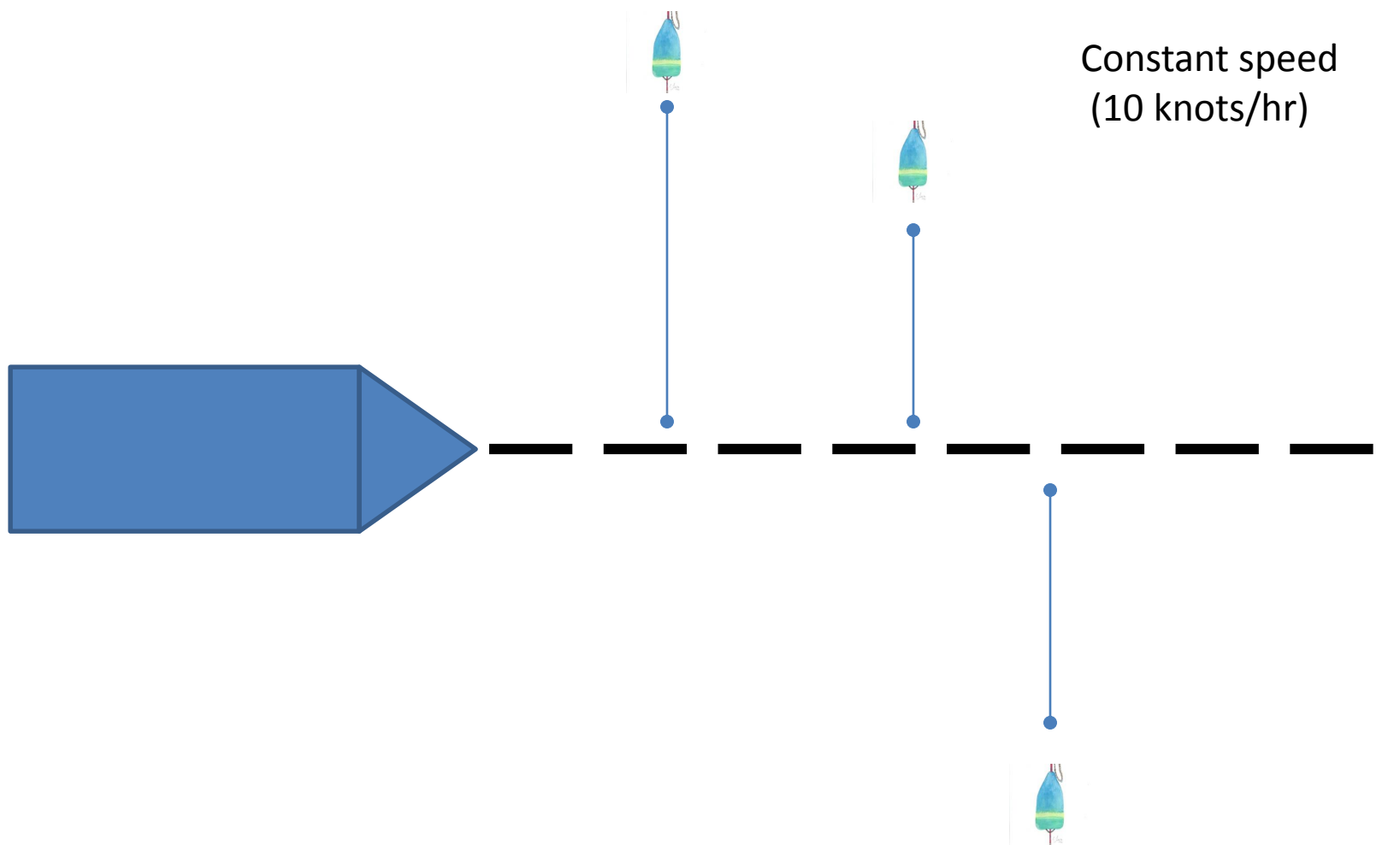


# Questions

- Can we combine visual and acoustic data to get an unbiased estimate of population size?
- Can we get an estimate of availability bias?

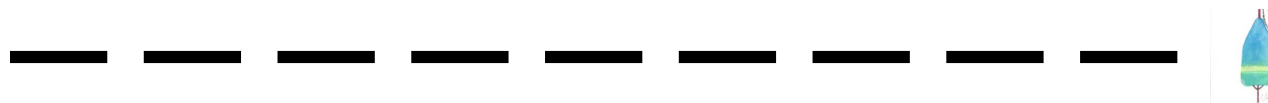
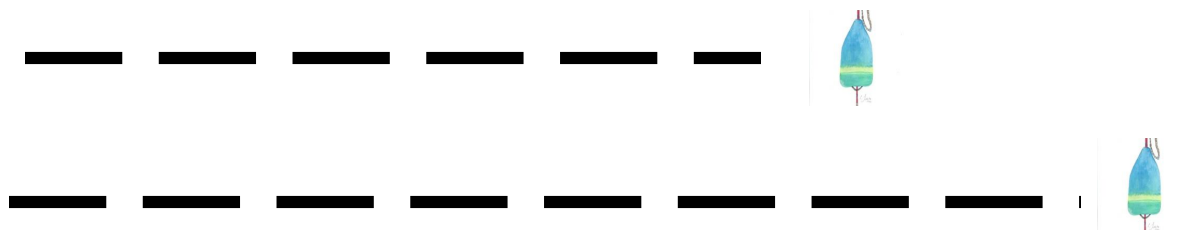


# Conventional Distance Sampling (CDS)

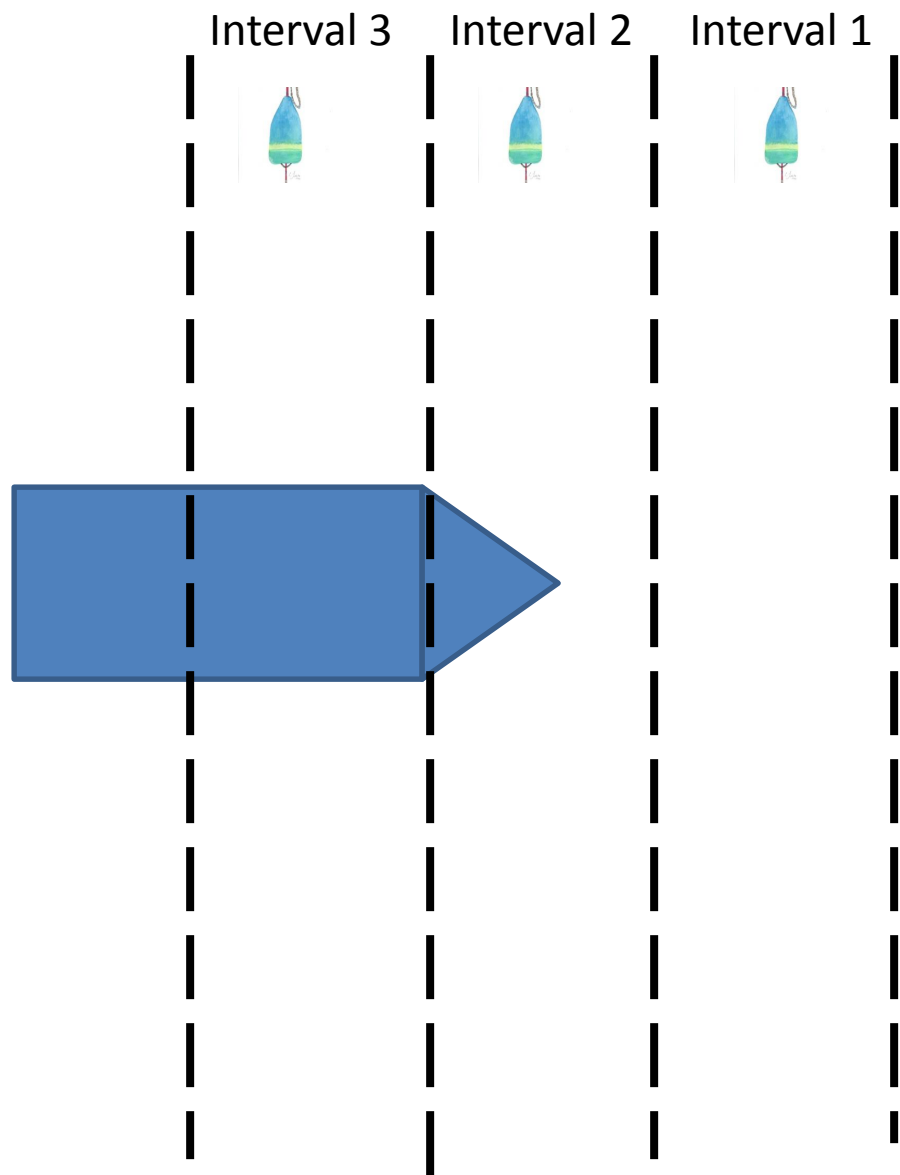




# Conventional Distance Sampling (CDS)



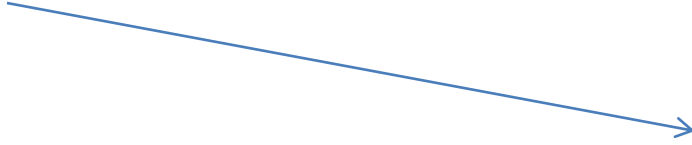
# Conventional Distance Sampling (CDS)



# Whales as Buoys?

**2 states**

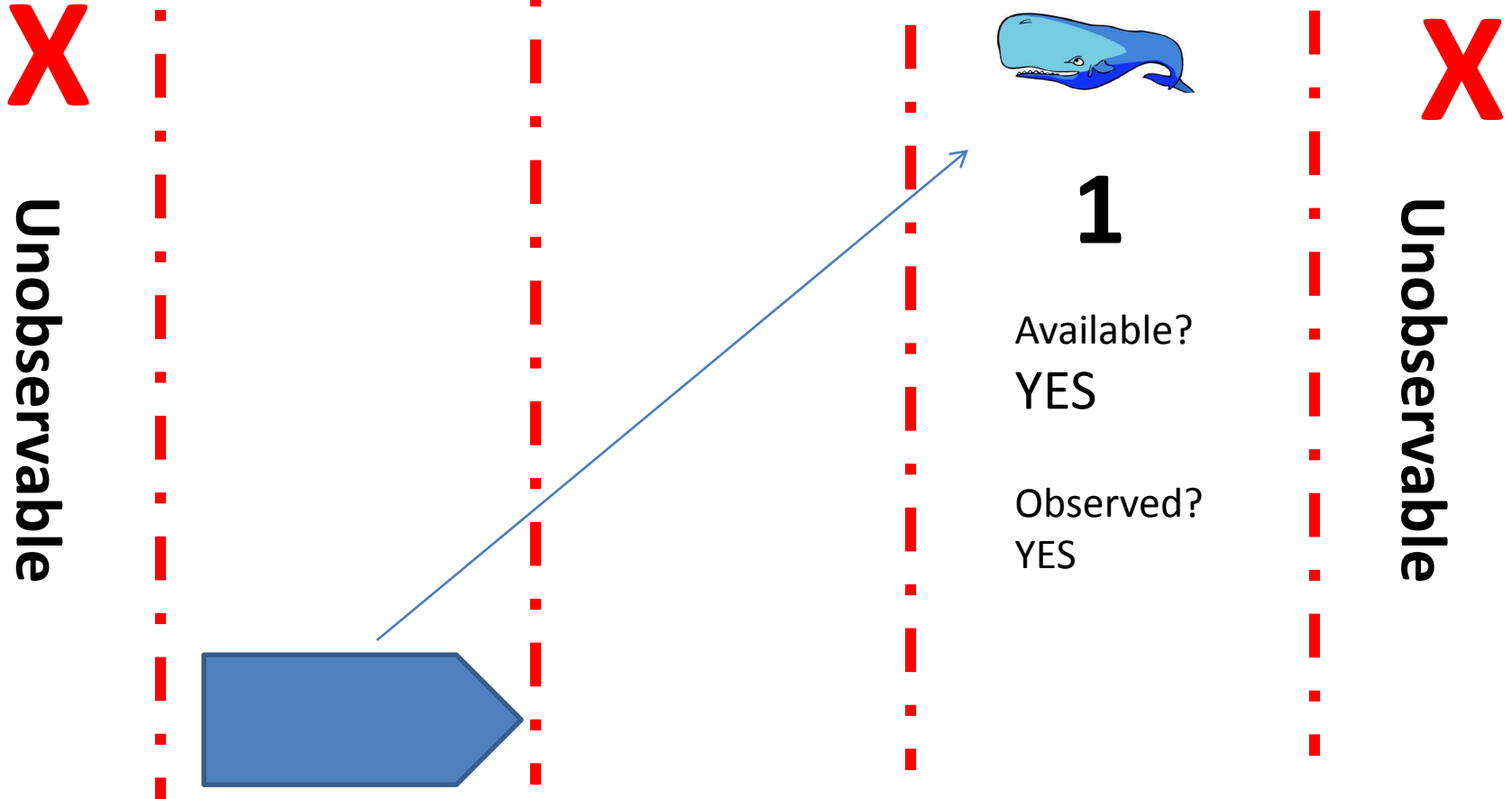
Available  
Above



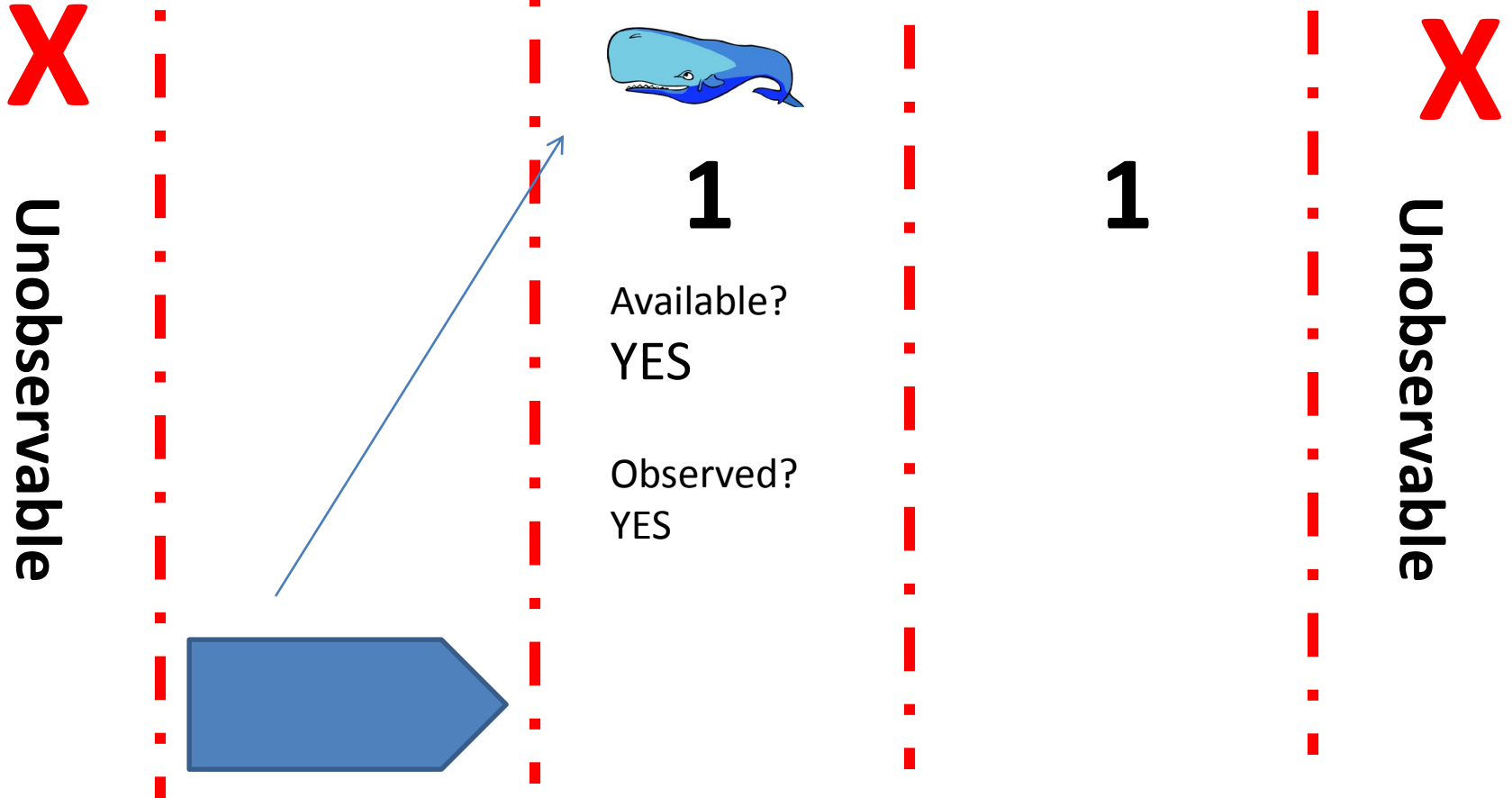
Available  
Below



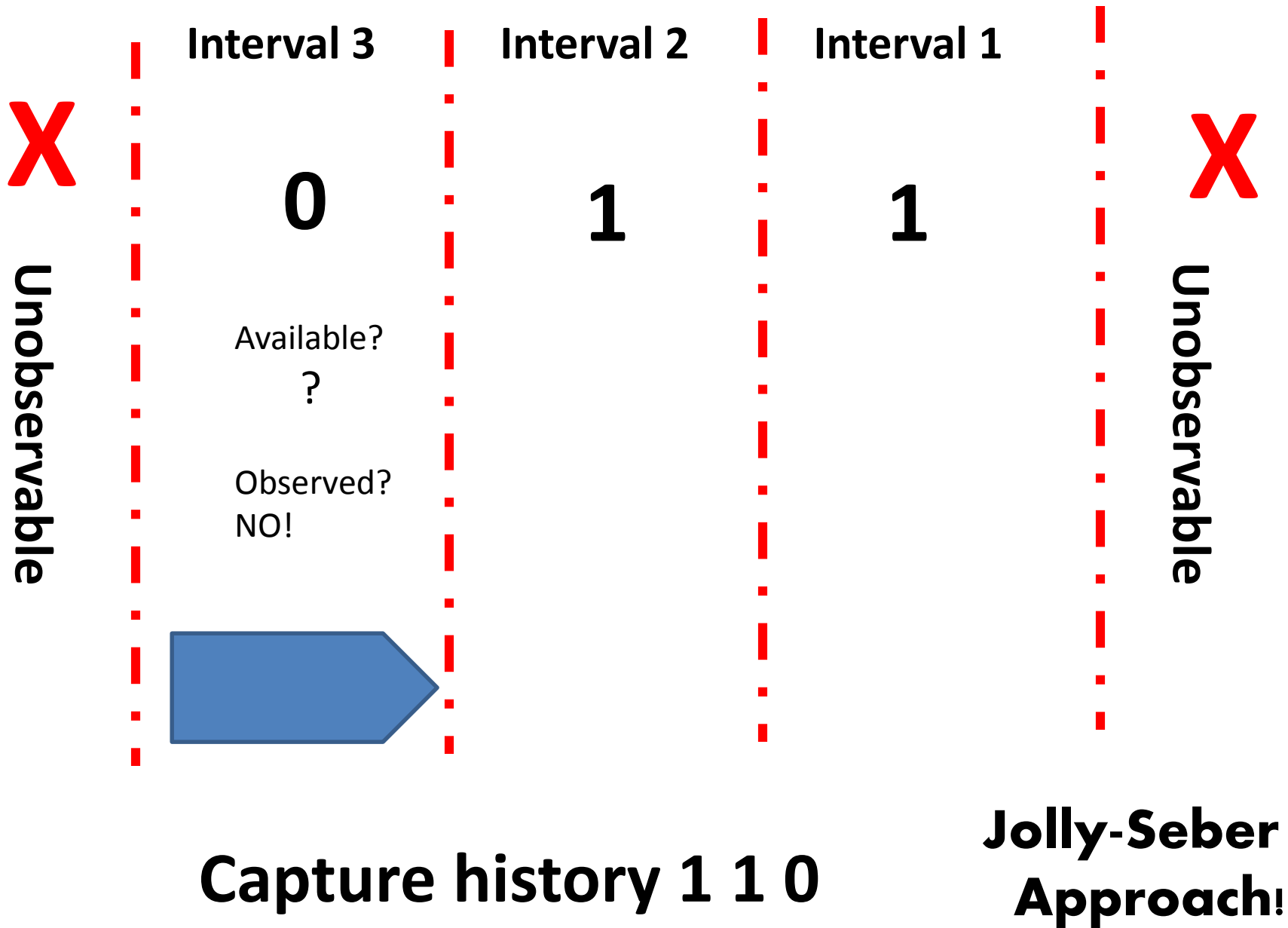
# Acoustic Data



# Acoustic Data



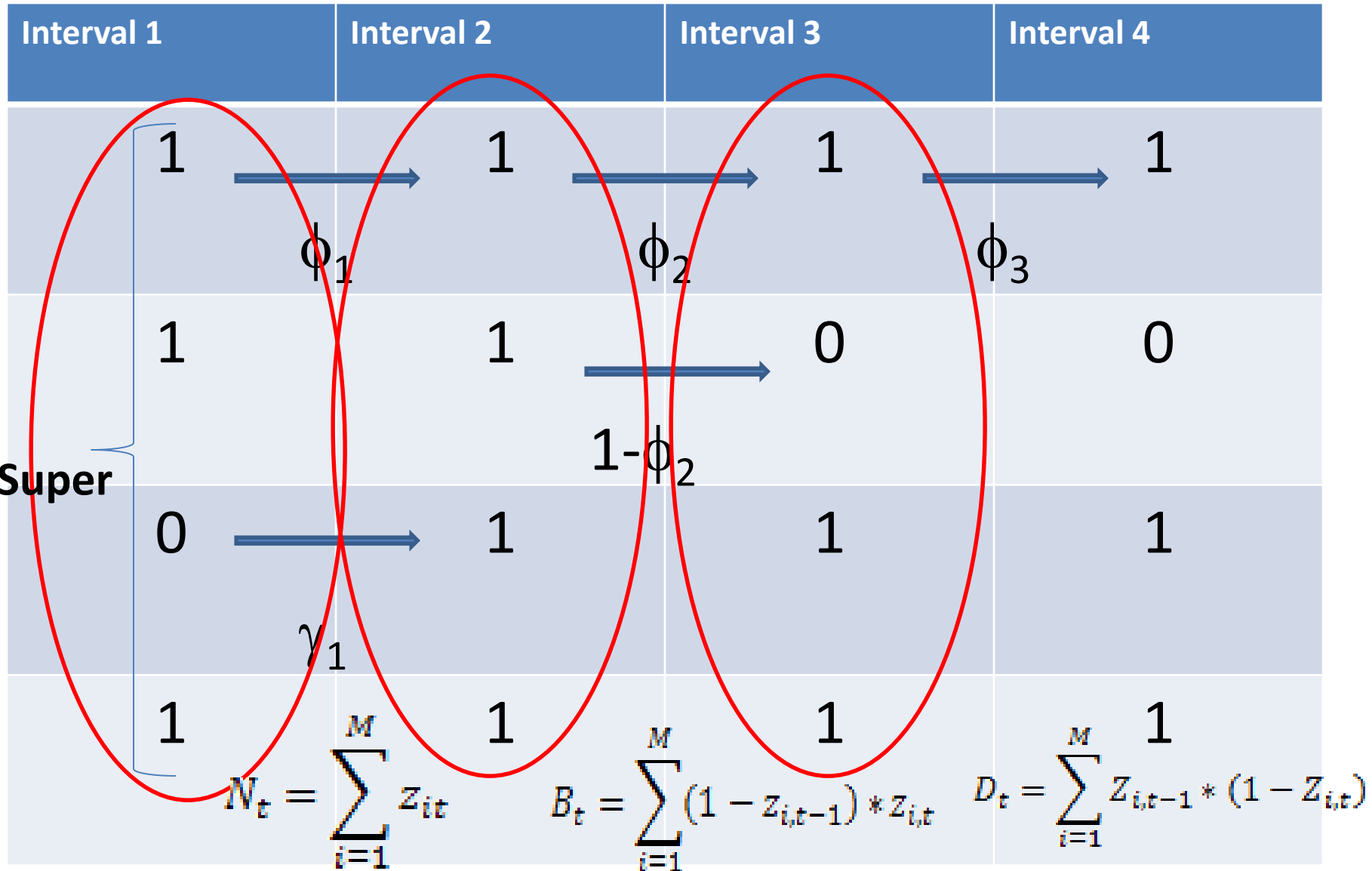
# Acoustic Data



# Jolly-Seber Parameters and Definitions

Parameter	Jolly-Seber Definition
$\gamma$	Probability of recruiting into the population
$\phi_t$	Probability of surviving from interval t to t interval t+1
$P_t$	Probability of detection at interval t
$B_t$	Number of new recruits at interval t
$D_t$	Number of individuals that die at interval t
$N_{\text{Super}}$	Total number ever alive in the population

# Jolly-Seber Example





# Jolly-Seber Example

Interval 1	Interval 2	Interval 3	Interval 4
1	1	1	1
1	1	0	0
0	1	1	1
1	1	1	1

# Jolly-Seber Example

Interval 1	Interval 2	Interval 3	Interval 4
1	0	0	1
1	1	0	0
0	1	0	1
1	0	1	1
$P_t$	$1-P_t$	$P_t$	

# Acoustic Integration Model Parameters and Definitions

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

# Acoustic Integration Model

- $N_{\text{Above}}$  estimated from conventional distance sampling
- $N_{\text{Below}} = N_{\text{Super}}$
- $\text{Duplicates}_t = D_t + B_t$
- $\text{Duplicates} = \sum \text{Duplicates}_t$
- $N_{\text{Total}} = N_{\text{Below}} + N_{\text{Above}} - \text{Duplicates}$
- Estimate in a Bayesian Framework



# 'Surface' Availability Bias

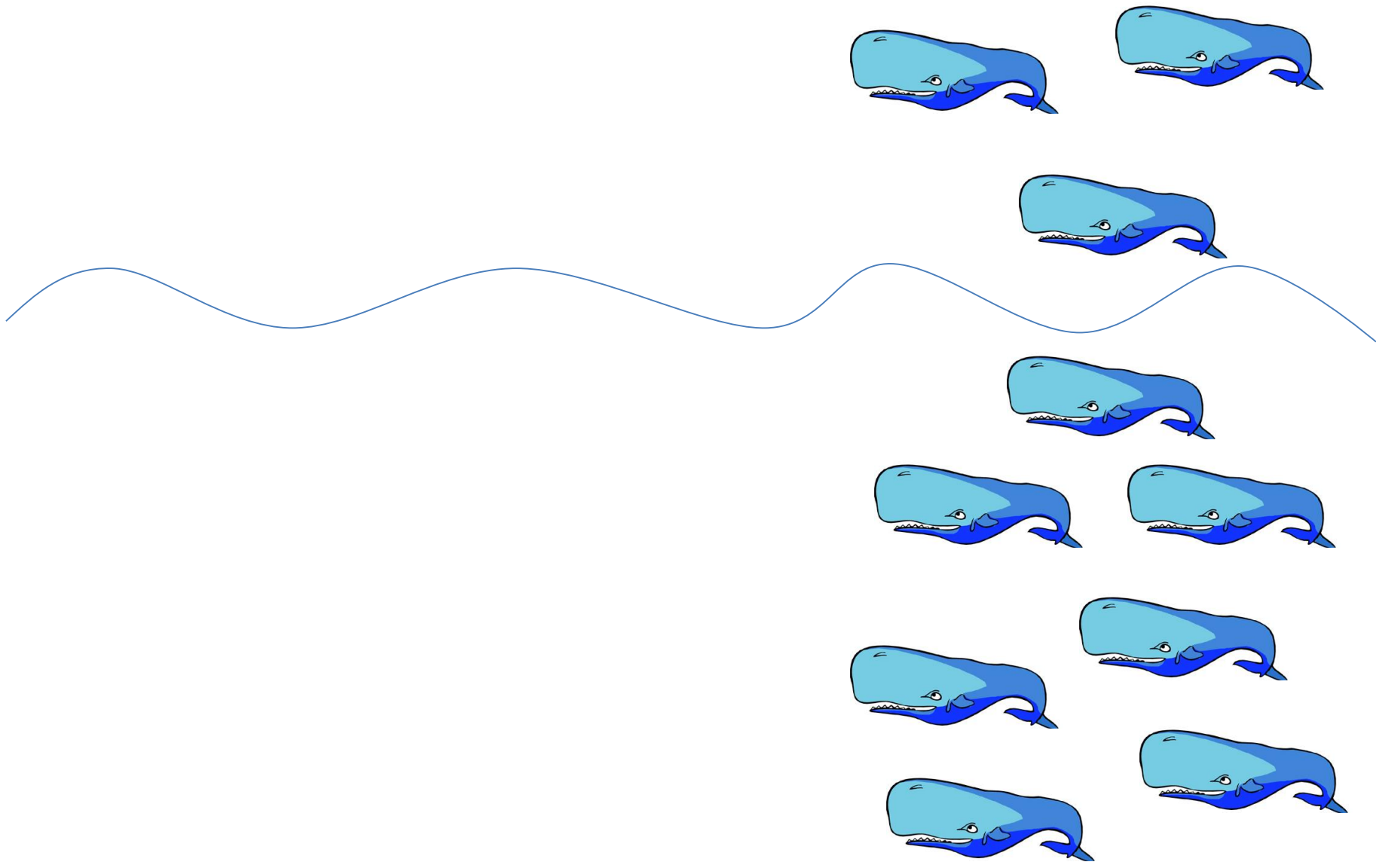
- Probability of being available (on the surface!) plus probability of becoming available over the viewing window
- Method of Laake et al. (1997)
  - Uses DTAG data

$$\frac{E(s)}{E(s) + E(d)} + \frac{w(x)}{E(s) + E(d)}$$



AIM Method True Availability =  $\frac{\hat{N}_{Above}}{\hat{N}_{Total}} = 4/10 = 0.4$

Instantaneous Availability =  $3/10 = 0.3$

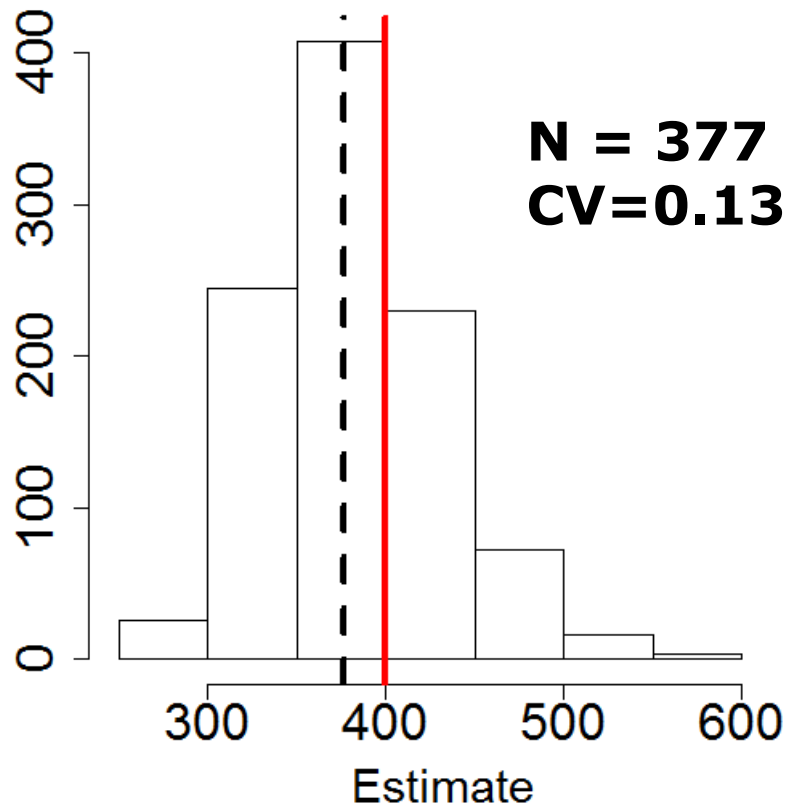


# Simulations

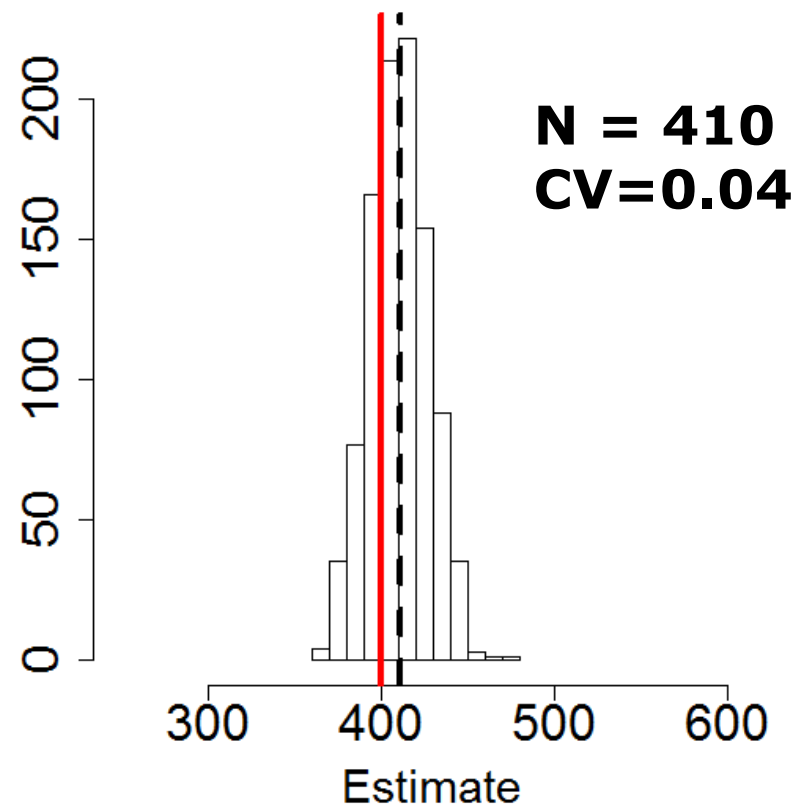
- Used literature to simulate dive cycles with individual variation
- Randomly assigned a perpendicular distance
- Assumed speed of ship was 10 knots/hr (0.31 km/minute)
- Each individual whale started at a forward distance of 10 km
- Detection probability below was based on current radial distance
- Detection above was based on perpendicular distance
- Compared AIM estimate to CDS estimate with availability bias correction factor

# Population Estimates from Simulated Data

## Population Estimate CDS

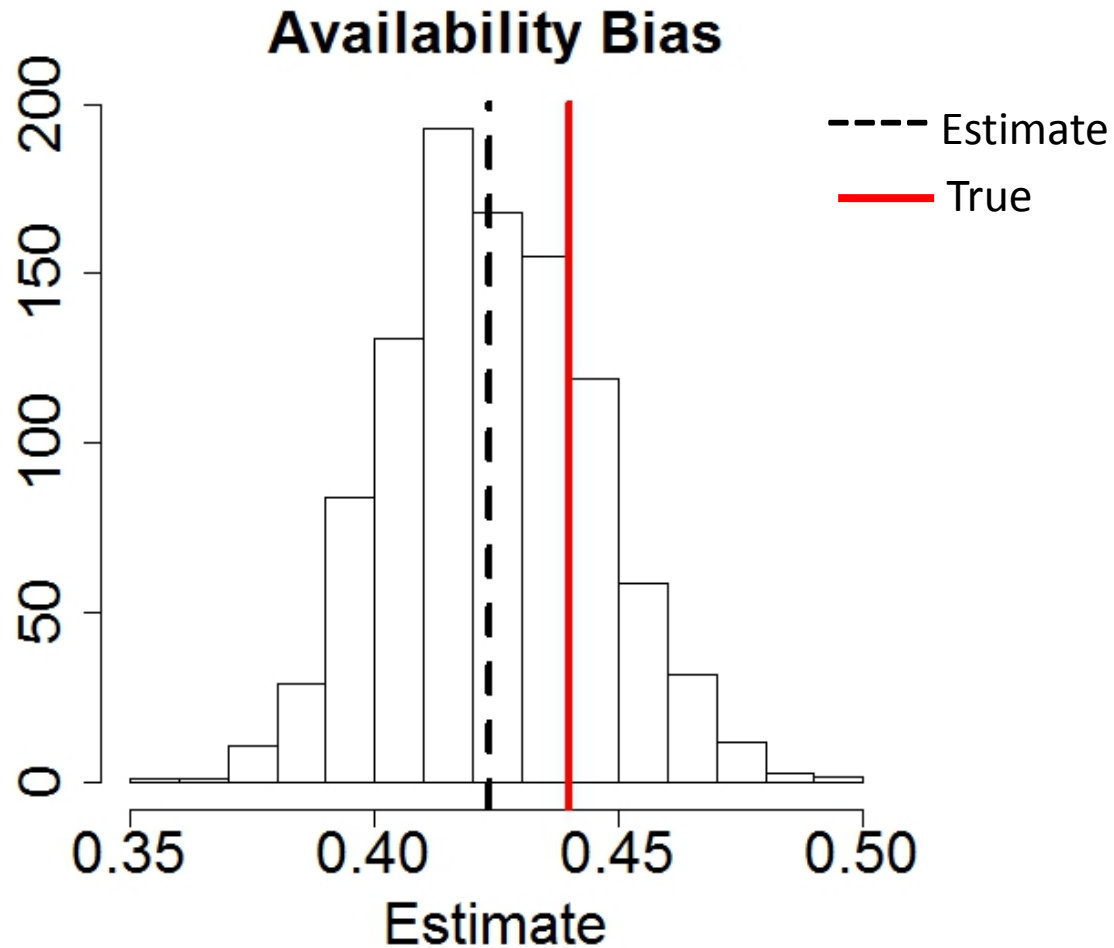


## Population Estimate AIM





# Availability Bias Estimate from Simulated Data



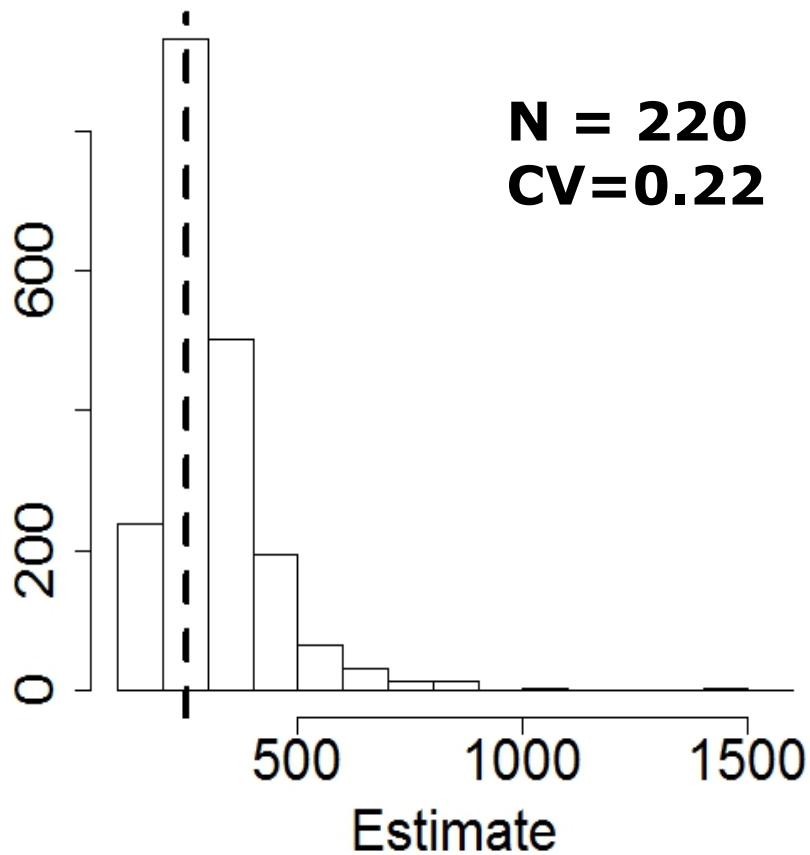
# Application to Sperm Whale Data

- Applied to 2013 shipboard surveys conducted by NEFSC
- 78 visual sightings
- 127 unique acoustic events
- Compared to CDS
  - Availability bias estimated using Lake et al. (1996) method

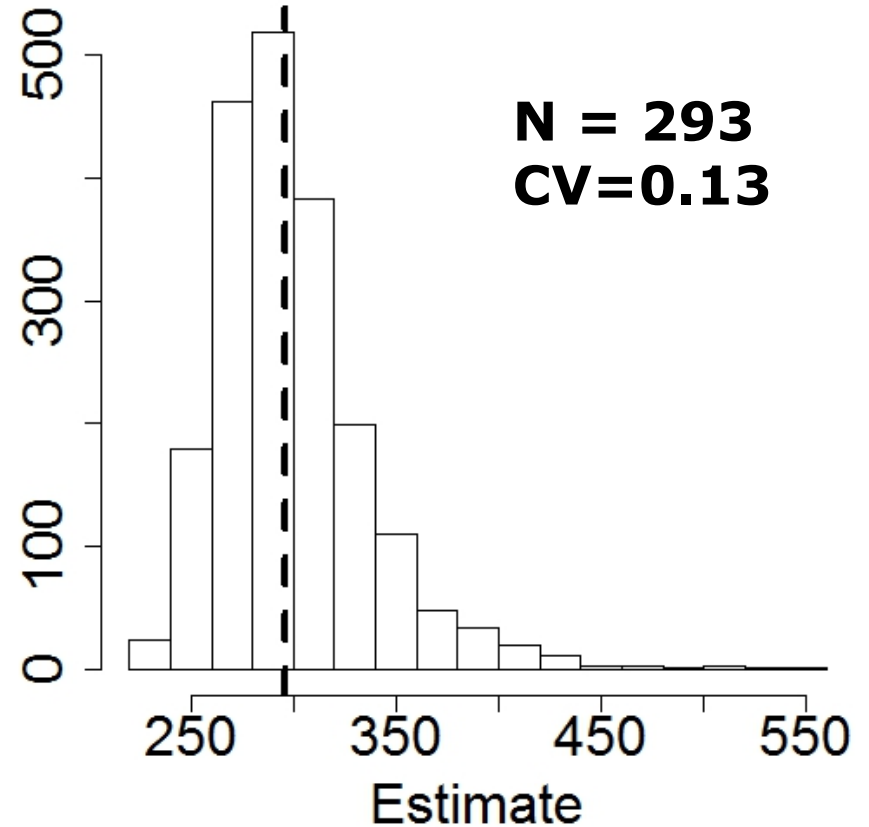


# Population Estimates from Sperm Whale Data

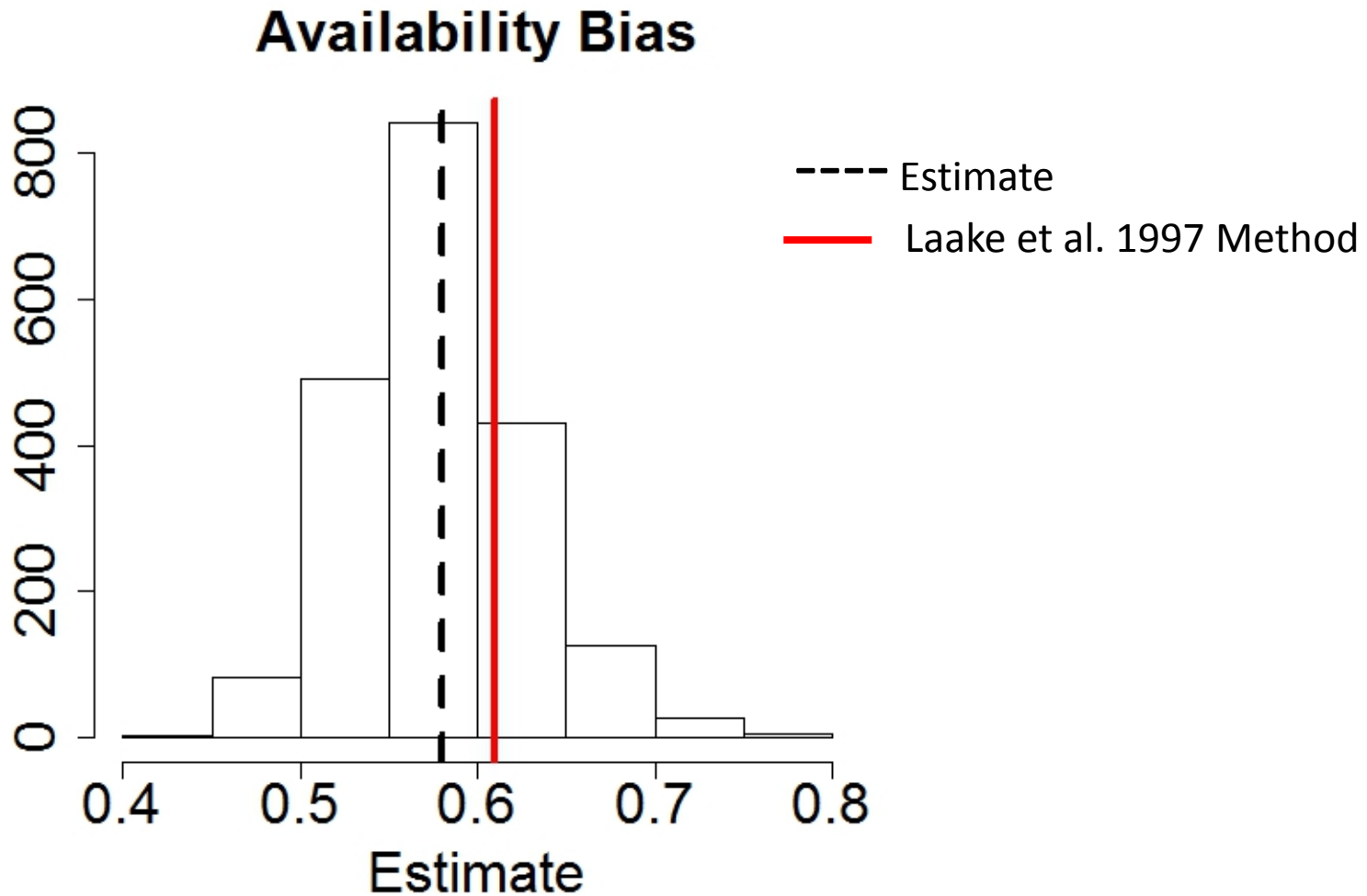
## Population Estimate CDS



## Population Estimate AIM



# Availability Bias Estimate from Sperm Whale Data



# Summary

- Combining two data types and two estimation methods in a Bayesian framework
  - CDS for visual data
  - J-S for acoustic data
- Method works on simple simulations
  - Comparable to CDS
  - Higher Precision
- Successfully applied to field data
  - Comparable to CDS
  - Higher Precision



# Future Work

- Continue to test model with more realistic simulations
  - Robust to assumptions?
- Test with more field data
  - Beaked whales?
- **Explore spatially-explicit estimates of availability bias**
- **Integrate framework into existing species distribution model**
- Develop user friendly application
  - R Shiny



# QUESTIONS SO FAR?



# Assumptions and Data Issues

- Assumptions of CDS
- Assumptions of Jolly-Seber
- Determining Zone of Overlap
- Ambiguous Click Trains
- Blind Spots
- Assumption of 2 states



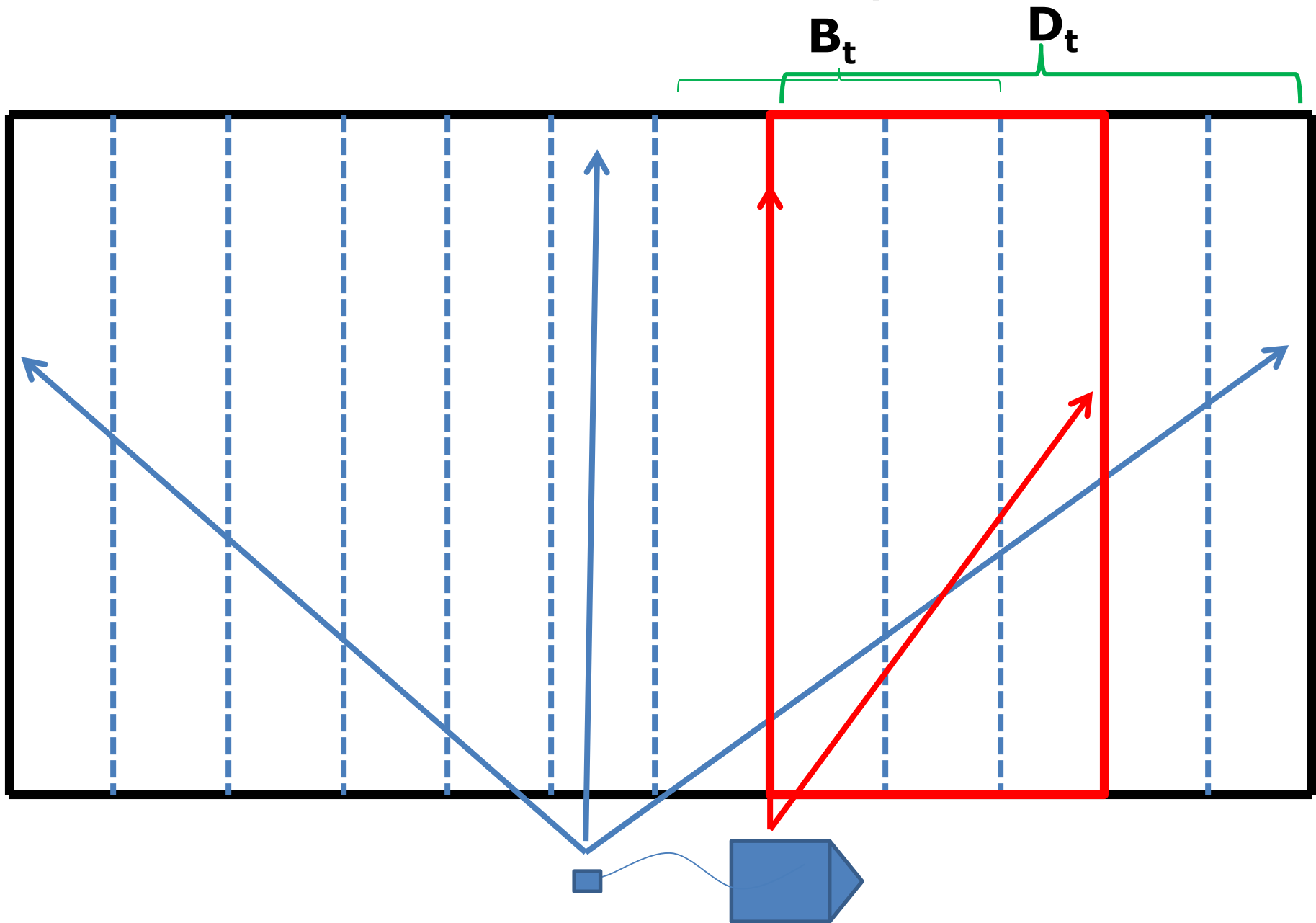
# Assumptions of CDS

- Objects randomly distributed perpendicular to the trackline
- Animals do not move relative to the trackline (i.e. perpendicular distances are fixed)
- Distances are measured accurately
- Do not need to assume all animals on trackline are detected
  - Two visual teams, can estimate  $g(0)$  directly for visual line transect data

# Assumptions of “Traditional” Jolly-Seber

- All individuals within an interval have the same capture probability
  - Can use individual level covariates (i.e. perpendicular distance)
  - Can include random effects
- All individuals within an interval have the same survival (transition probability)
  - Age model
    - probability of remaining changes the longer an individual has been observed below) (i.e. in the dive state)

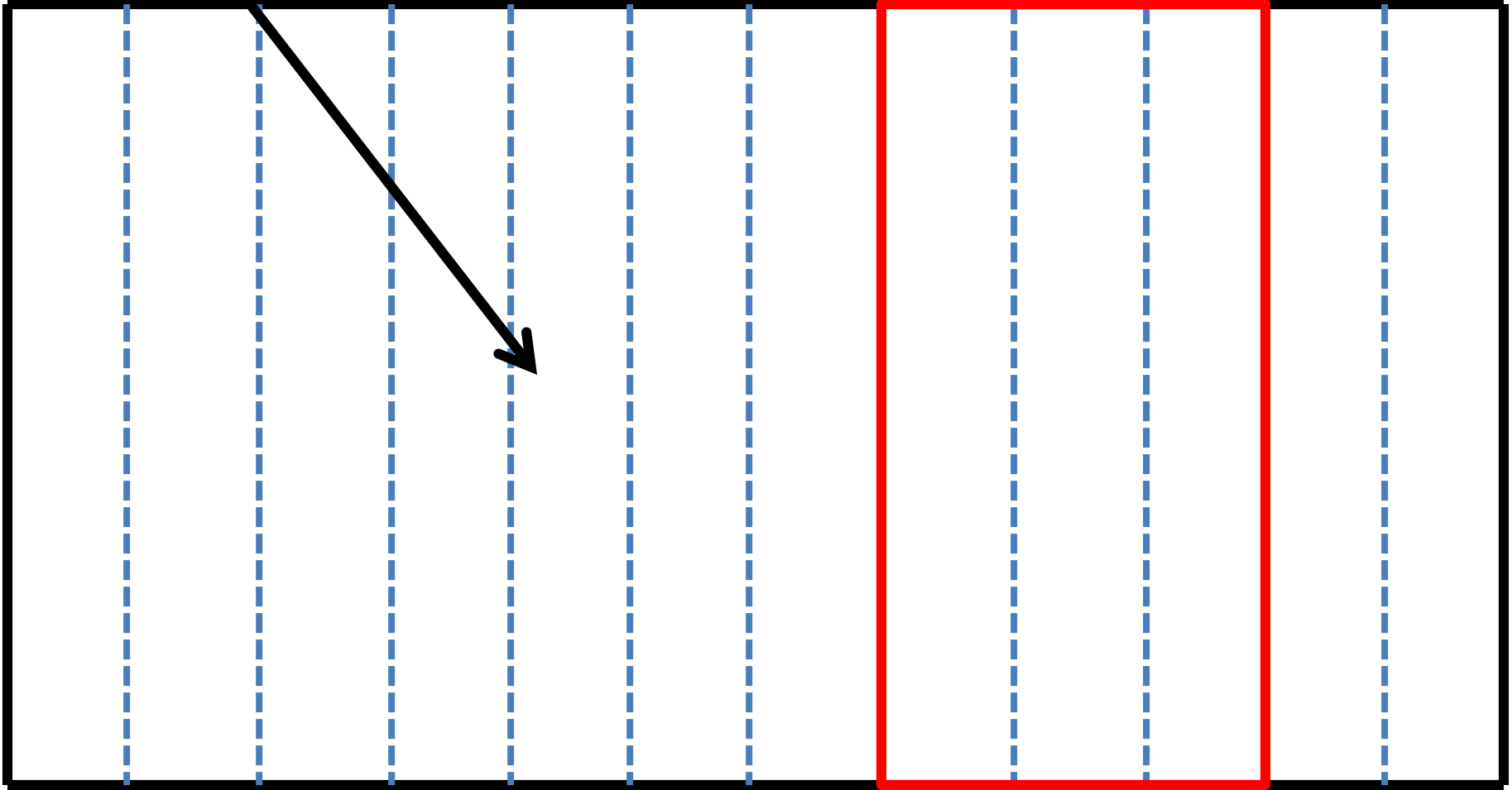
# Zone of Overlap



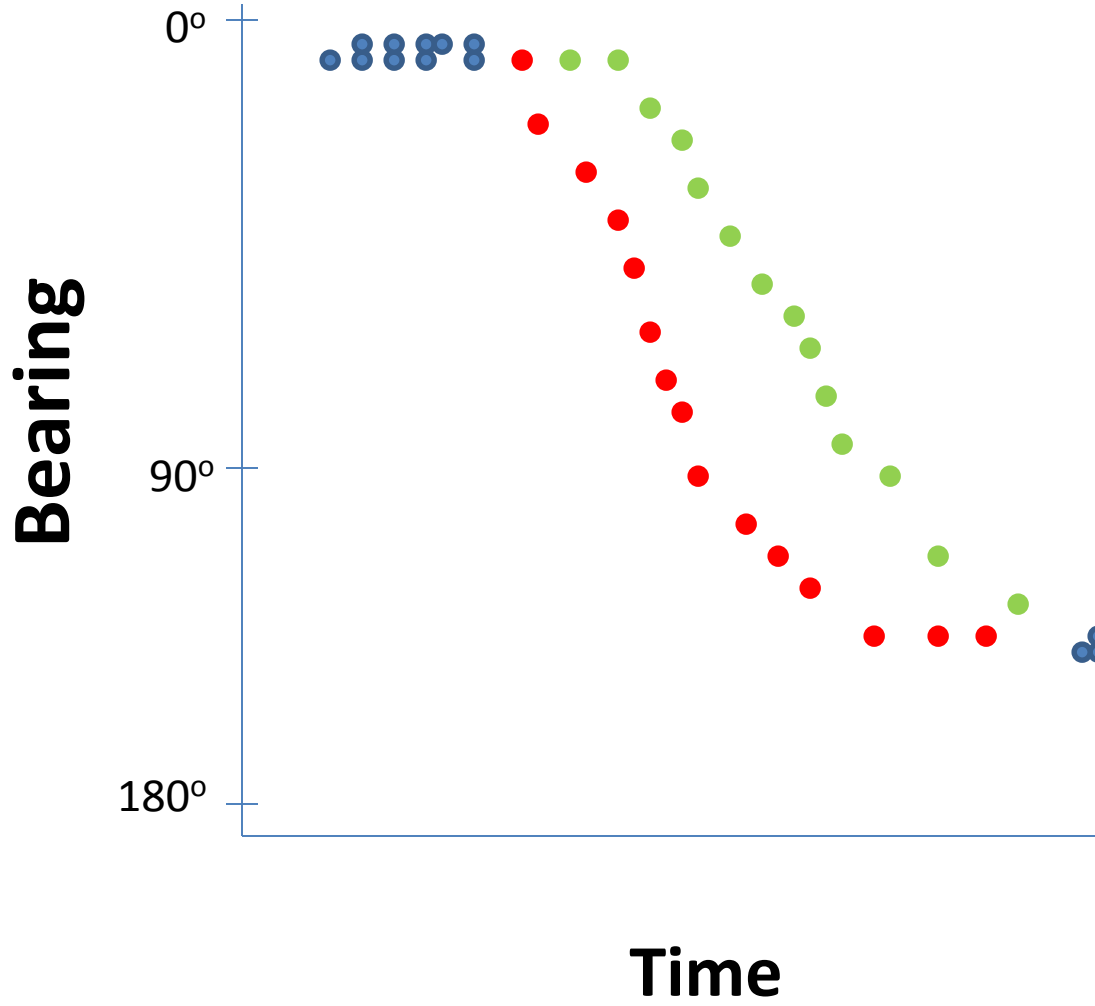
# Zone of Overlap

$N_{\text{Super}}$

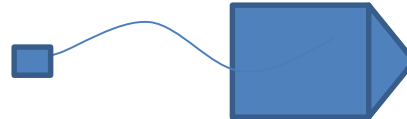
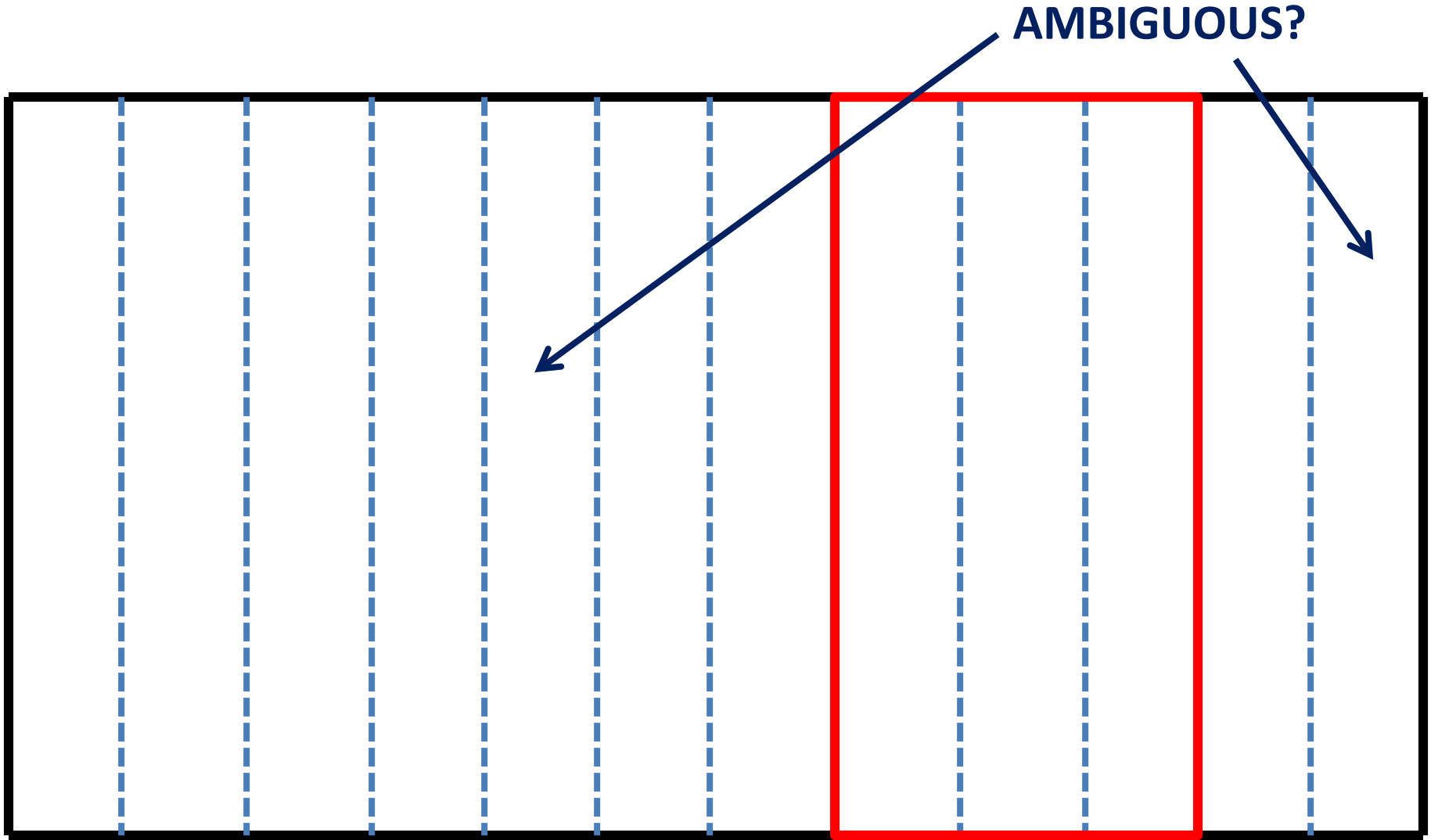
Double Divers?



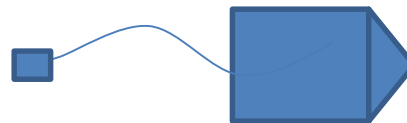
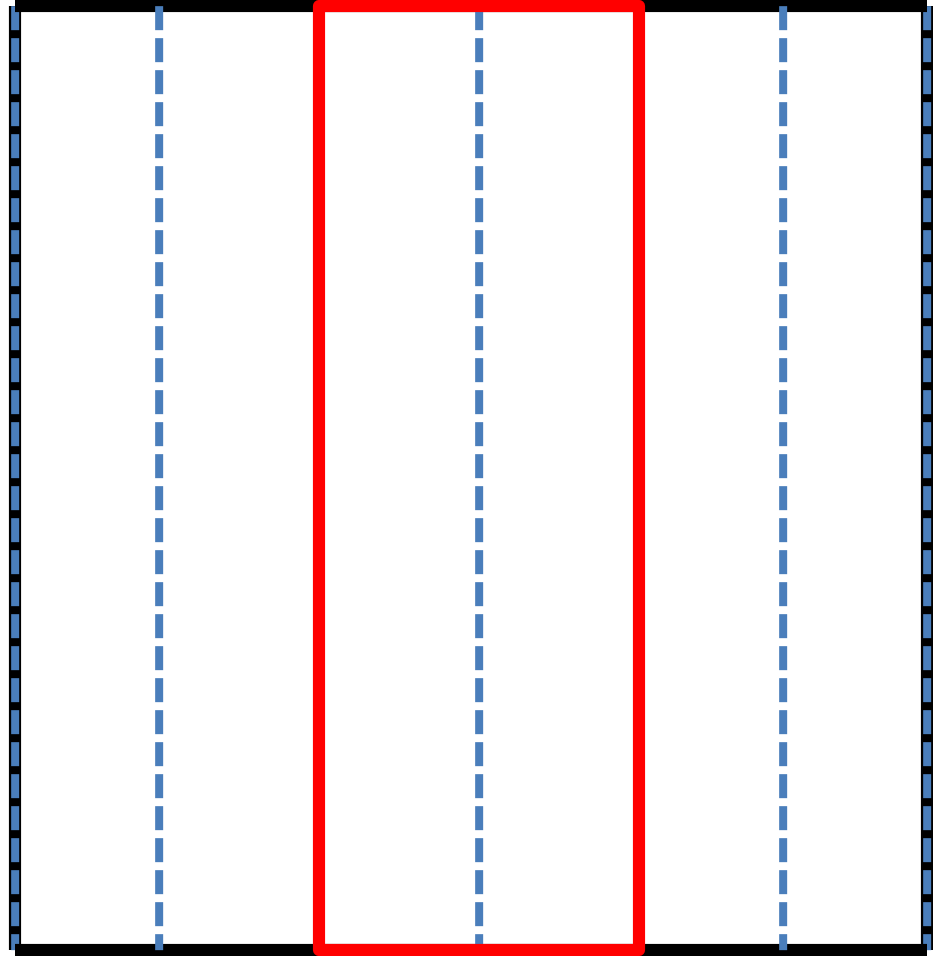
# Ambiguous Click Trains



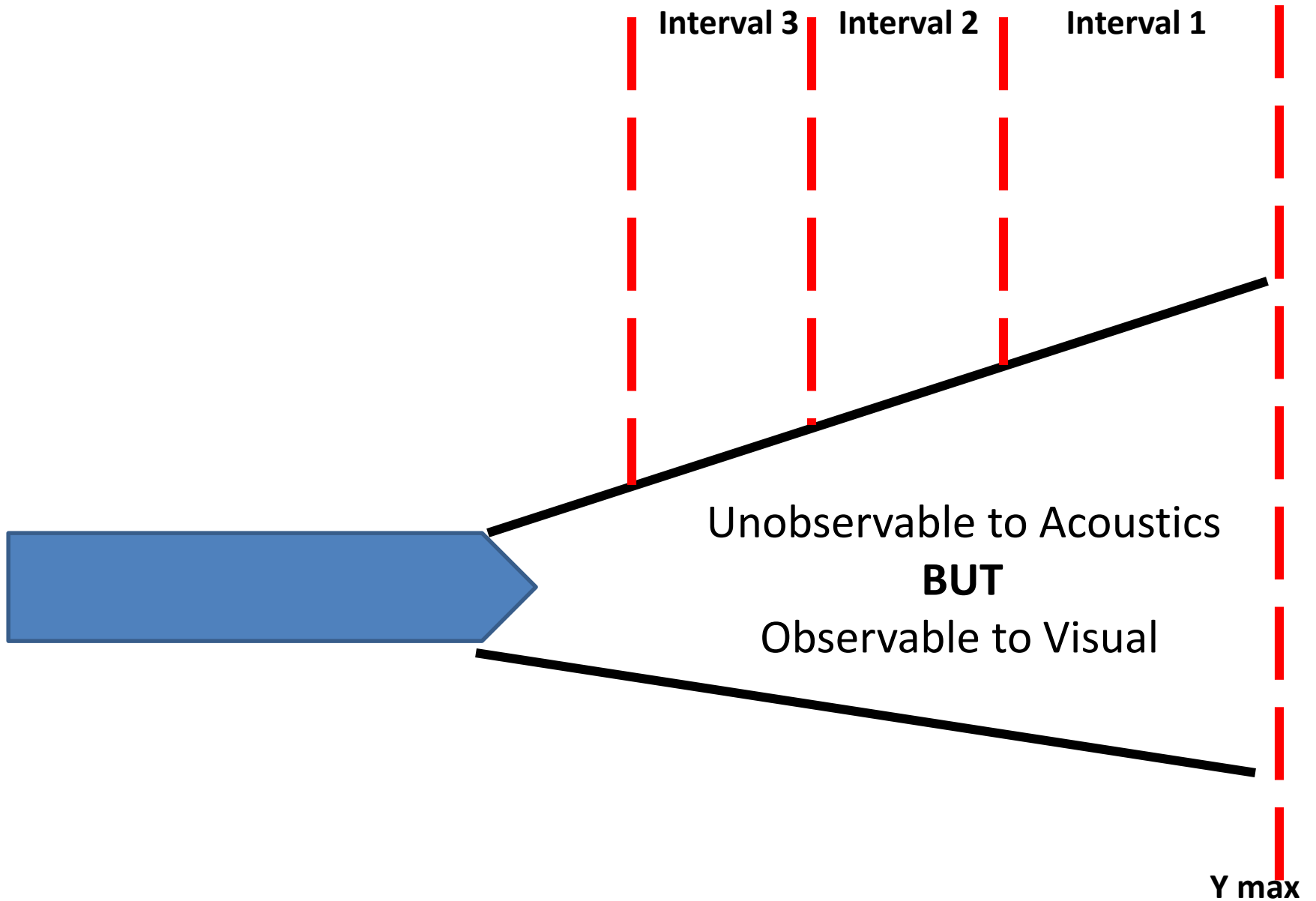
# Zone of Overlap



# Zone of Overlap



# Blind Spots

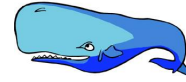




Interval 3

Interval 2

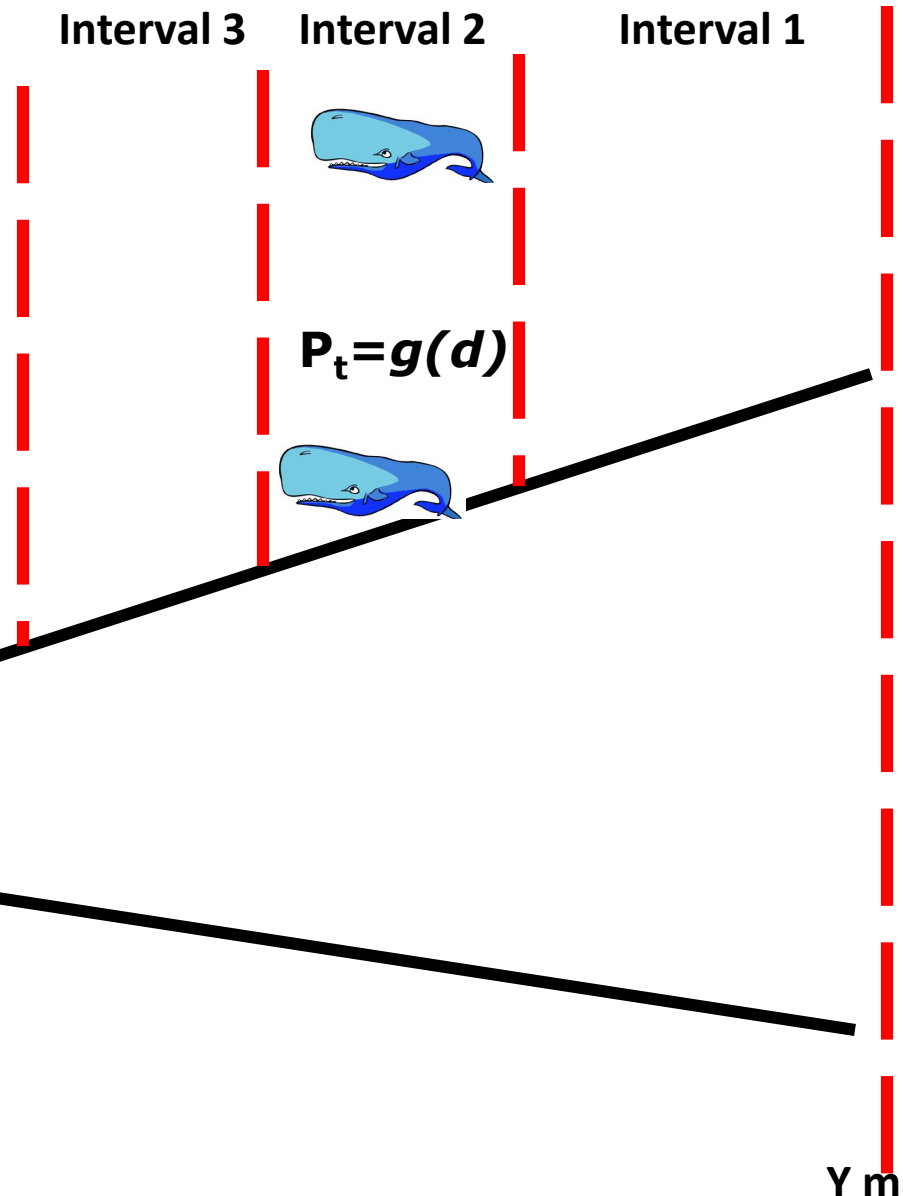
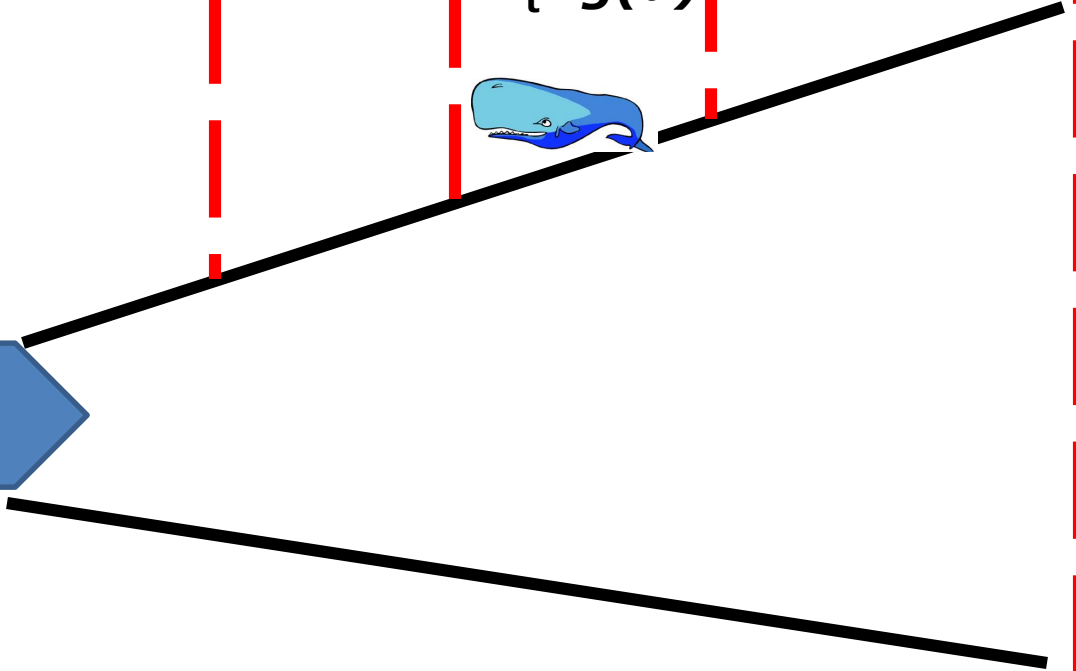
Interval 1

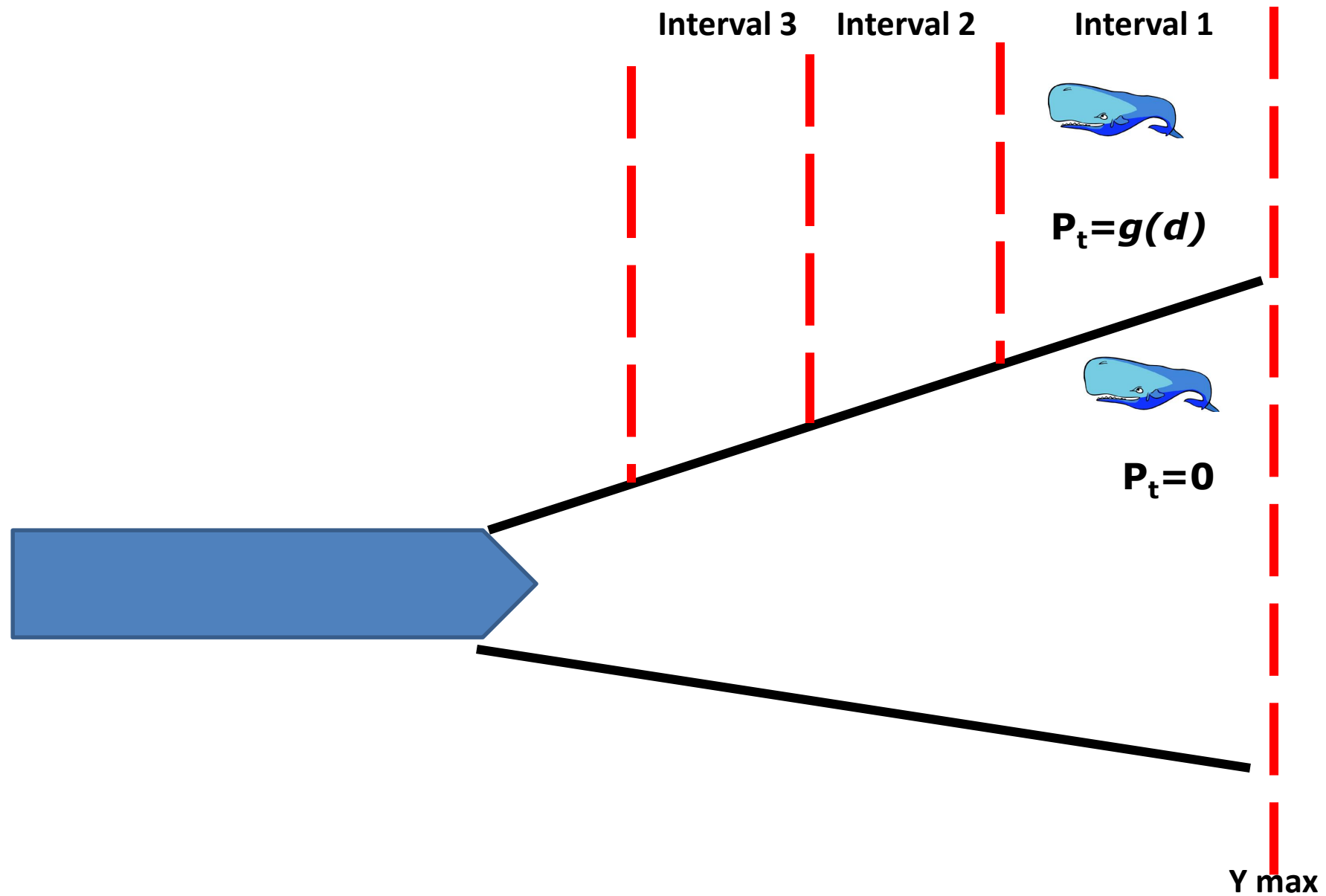


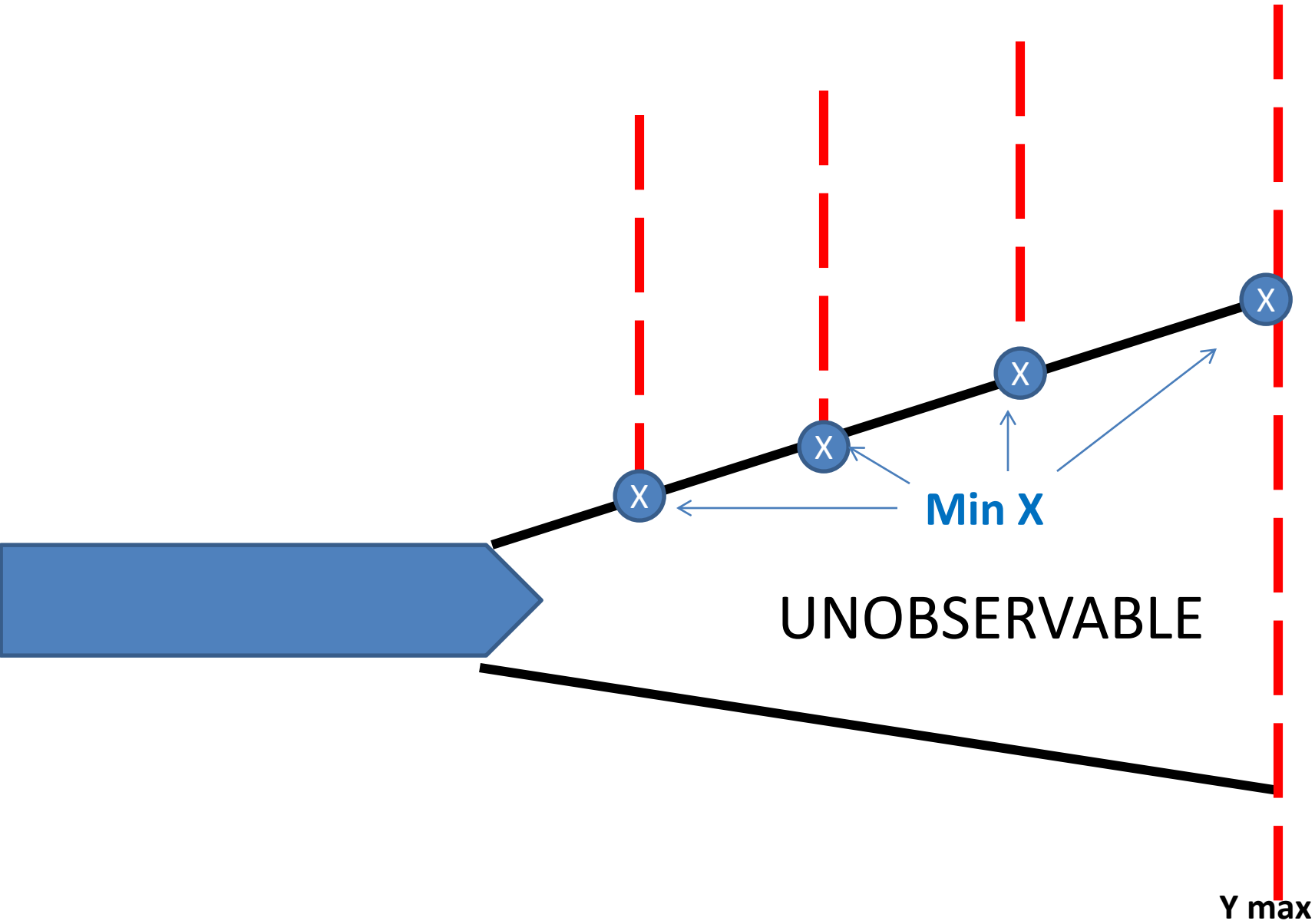
$$P_t = g(d)$$



Y max



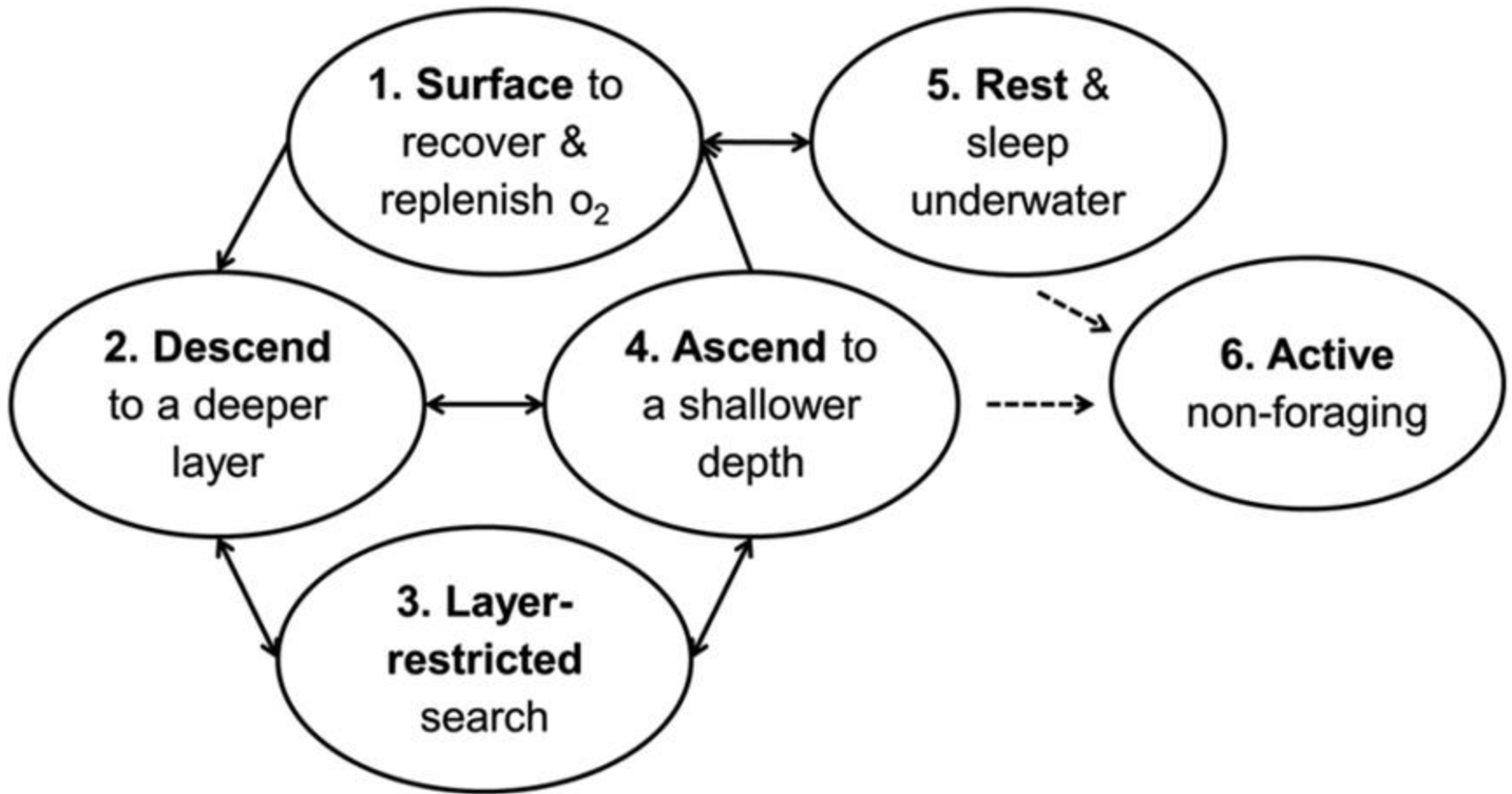




# 2 States?

- Multiple behavioral states
- Isojunno and Miller 2015

# Isojunno and Miller 2015



**ANY QUESTIONS NOW?**



**DEMO**



# Inputs

#Read in Acoustic Data

```
Acoustic_Data<read.csv("Full_Array_for_data_analysis.csv")
```

EventID	ClickNo	Time	Bearing. Deg	RadialD istM	Begi nnin g	End	X	Y
1	1	7/4/2013 18:07	61.456	1319N	N	1158	630	
1	2	7/4/2013 18:07	61.483	1319N	N	1159	629	
1	3	7/4/2013 18:07	61.531	1319N	N	1159	629	
1	4	7/4/2013 18:07	61.241	1319N	N	1156	634	
1	5	7/4/2013 18:07	61.137	1319N	N	1155	636	
1	6	7/4/2013 18:07	61.304	1319N	N	1157	633	



# Inputs

**#Enter Truncation Distance for Acoustic Data**

**W\_Below<-10000**

**#Enter Maximum and Minimum Forward Distance for Acoustic Data**

**Y.max<-10000**

**Y.min<--5000**

**# Enter Interval Width**

**Y.width<-250**

**#Enter Beginning and Ending Interval for Zone of Overlap**

**#Diving Intervals**

**start.interval\_B<-8**

**end.interval\_B<-34**

**#Surfacing Intervals**

**start.interval\_D<-6**

**end.interval\_D<-32**

# Inputs

```
#Format Data for Acoustic Integration Model  
source("Organize_Data_Demo.R")
```

<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
0	0	0	0	0	0
0	1	1	1	1	1
0	0	1	1	0	1
0	0	0	0	1	1
0	0	1	0	1	0

```
#Run Model (uses JAGS)  
source("Run_Model_Demo.R")
```

This PDF was later amended to make the document 508 compliant.