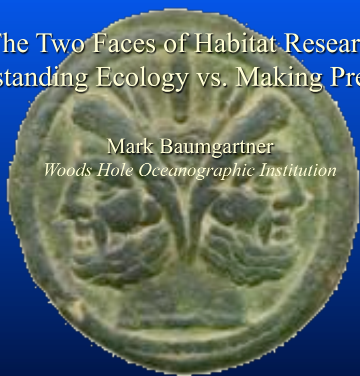
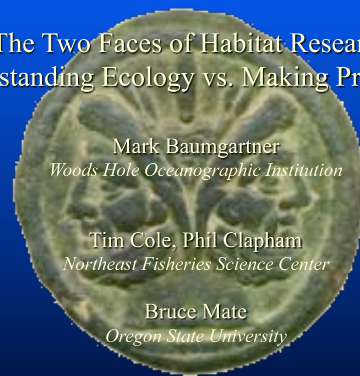


The Two Faces of Habitat Research: Understanding Ecology vs. Making Predictions

Mark Baumgartner
Woods Hole Oceanographic Institution



The Two Faces of Habitat Research: Understanding Ecology vs. Making Predictions

Mark Baumgartner
Woods Hole Oceanographic Institution

Tim Cole, Phil Clapham
Northeast Fisheries Science Center

Bruce Mate
Oregon State University

Outline

- Prediction models
- Understanding ecology with models
- Case study: North Atlantic right whales

Ideal Prediction Model

- Provides estimates of occurrence, abundance or community composition

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- Predicts spatial distribution over multiple spatial scales

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- Predicts temporal distribution

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- Provides estimates of occurrence, abundance or community composition
- Predicts spatial distribution over multiple spatial scales
- Predicts temporal distribution
- Has known (and hopefully high) accuracy

Ideal Prediction Model

- Provides estimates of occurrence, abundance or community composition
- Predicts spatial distribution over multiple spatial scales
- Predicts temporal distribution
- Has known (and hopefully high) accuracy
- Robust over time and environmental change (can explain anomalous years)

Ideal Prediction Model

To achieve high accuracy and robust results...

- Models **must** be based on a fundamental understanding of ecology
  - → Where do they go?
  - → Why do they go there?
  - → What are they doing when they're there?
- Our understanding of these issues for many marine mammals is quite poor
- Prediction? We're not there yet!

Using Models to Understand Ecology

Basic questions of habitat research:

- Is there an association between the spatial distribution of Marine Mammal Y and Environmental Variable X?
- If so, why?

Using Models to Understand Ecology

Environmental Variables
Depth
Sea surface temperature
Surface salinity
Surface chlorophyll
etc.

Sighting Data
Abundance

Black Box

The "BEST" Model

Abundance = 0.350 + (0.0123 × Depth) + (0.000456 × Depth^2) + (0.589 × Salinity) + (0.0458 × Salinity^2) + (0.000450 × Chlorophyll) + (0.00221 × Depth × Salinity^2) + (0.00845 × Temperature × Chlorophyll)

Using Models to Understand Ecology

Environmental Variables
Depth
Sea surface temperature
Surface salinity
Surface chlorophyll
etc.

Detectability Variables
Sea state
Visibility

Sighting Data
Abundance

Not-so Black Box

Testing Hypothesis

Abundance = 0.350 + (–0.490 × Sea State) + (0.0123 × Depth)

SE = 0.00298, z-statistic = 3.67, p = 0.0002

Using Models to Understand Ecology

Develop hypotheses!

- Go to the literature
  - → Regional biological and physical oceanography
  - → Factors affecting prey abundance and distribution
  - → What motivates marine mammal distribution?
- Talk with oceanographers, scientists who study prey, marine mammalogists
- Conduct studies

Using Models to Understand Ecology

Choose environmental variables

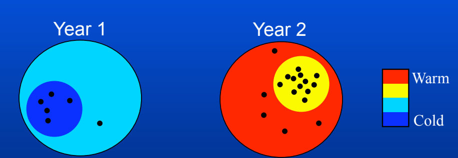
- Represent (or proxy) relevant oceanographic processes or features
- Found to be important in other studies
- To test specific hypotheses
- To snoop or explore

Using Models to Understand Ecology

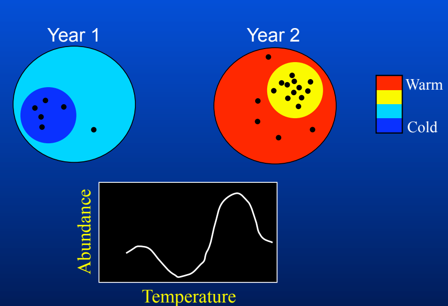
Account for confounding factors

- Detectability
- Variation that is spatially "independent"
  - → Regional
  - → Seasonal
  - → Annual

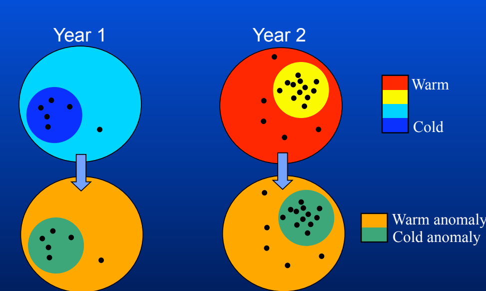
Using Models to Understand Ecology



Using Models to Understand Ecology

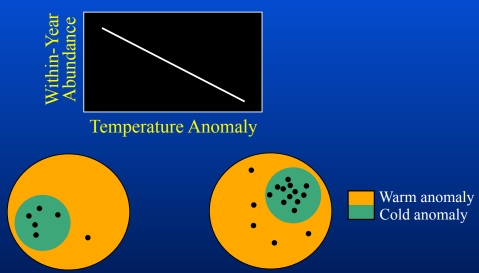


Using Models to Understand Ecology



- Subtract seasonal mean from temperatures
- Account for seasonal variability in abundance

Using Models to Understand Ecology



Using Models to Understand Ecology

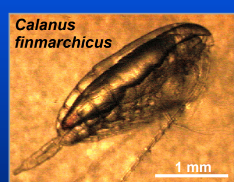
Use model to test hypotheses about *individual* environmental variables

Abundance = 0.350 + (–0.490 × Sea State) + (0.0123 × Year) + (–0.208 × Annual Temperature Anomaly)

SE = 0.0994, z-statistic = 3.67, p = 0.0002

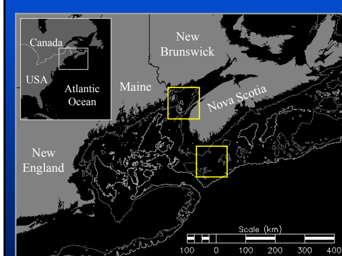
Conclusion: There is a negative association between abundance and water temperature after accounting for the effects of sea state and year

Case Study: North Atlantic Right Whales

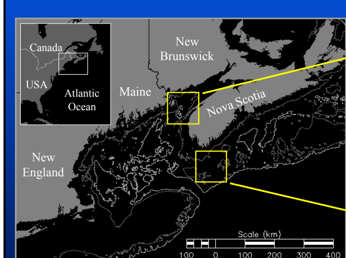


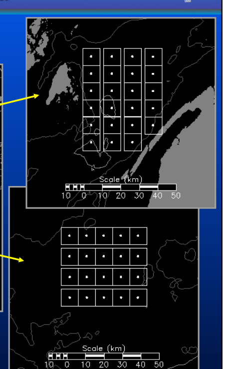
Baumgartner, M.F., T.V.N. Cole, P.J. Clapham and B.R. Mate. 2003. North Atlantic right whale habitat in the lower Bay of Fundy and on the southwestern Scotian Shelf during 1999–2001. *Marine Ecology Progress Series* 264:137-154.

Right Whale Habitat: Study Area



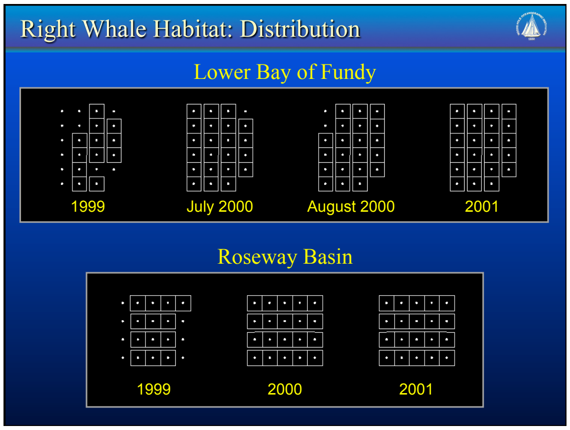
Right Whale Habitat: Study Area

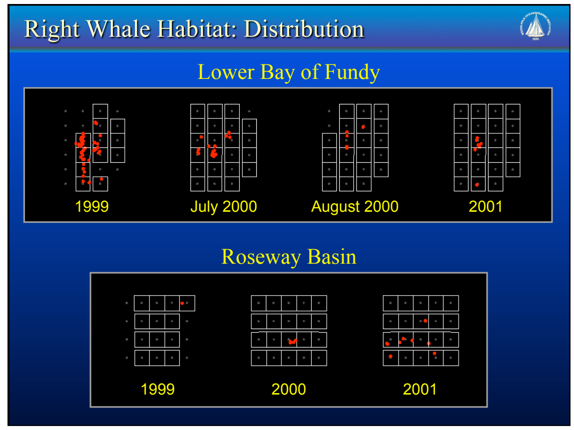


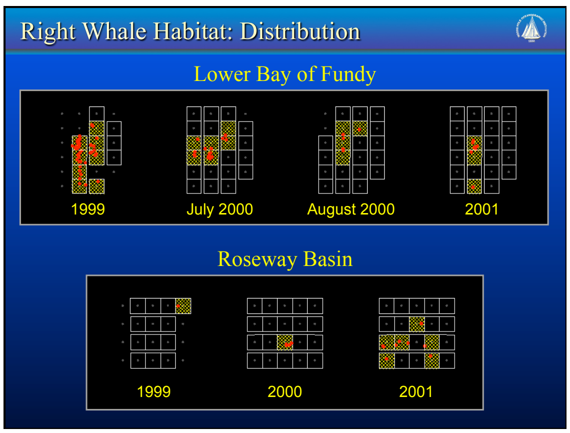


Right Whale Habitat: Environmental Variables

	Variable	Source
Physiography	Depth	Echo sounder
	Depth gradient	Digital bathymetery
Stratification	Surface stratification (density)	CTD
	Surface stratification (temperature)	CTD
Bottom mixed layer (BML) properties	BML temperature	CTD
	BML salinity	CTD
	BML density	CTD
	BML depth	CTD
C. finmarchicus abundance & distribution	Depth of maximum Calanus abundance	OPC
	Maximum Calanus abundance	OPC
	Average water column Calanus abundance	OPC
	Calanus abundance above BML	OPC
Remotely-sensed properties	Surface temperature	Satellite (AVHRR)
	Surface temperature gradient	Satellite (AVHRR)
	Surface chlorophyll	Satellite (SeaWiFS)
	Surface chlorophyll gradient	Satellite (SeaWiFS)







Right Whale Habitat: Logistic Regression

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1(\text{SSTATE}) + \beta_2(\text{BOF}) + \beta_3(\text{Y2000}) + \beta_4(\text{Y2001})$$
$$+ \beta_5(\text{BOF} \times \text{Y2000}) + \beta_6(\text{BOF} \times \text{Y2001})$$
$$+ \beta_7(\text{Anomaly of Environmental Variable})$$

π:Probability of sighting one or more right whales in a survey unit
SSTATE:Sea state (Beaufort scale)
BOF:Bay of Fundy (BOF=1) and Roseway Basin (BOF=0) indicator variable
Y2000:Year 2000 indicator variable
Y2001:Year 2001 indicator variable

Right Whale Habitat: Logistic Regression

Sighting Conditions (detectability)

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1(\text{SSTATE}) + \beta_2(\text{BOF}) + \beta_3(\text{Y2000}) + \beta_4(\text{Y2001})$$
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Regional/Interannual Variability in Sighting Probability

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Right Whale Habitat: Logistic Regression

Sighting Conditions (detectability)

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Regional/Interannual Variability in Environmental Variable

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Right Whale Habitat: Results

Variable	Standardized Coefficient	pvalue
Depth gradient	-0.16	0.48
Surface stratification (density)	-0.15	0.53
Surface stratification (temperature)	-0.02	0.93
BML temperature	-0.37	0.21
BML salinity	**0.98*** **	**0.0003**
BML density	**1.13*** **	**0.0001**
BML depth	**0.63** **	**0.0070**
Depth of maximum abundance	**1.06*** **	**0.0001**
Maximum abundance	**0.85*** **	**0.0007**
Avg. water column abundance	**0.68** **	**0.0047**
Abundance above BML	**0.51* **	**0.046**
SST	-0.02	0.94
SST gradient	0.27	0.34
Surface chlorophyll	-0.34	0.14
Surface chlorophyll gradient	-0.32	0.20

Right Whale Habitat: Results

Variable	Standardized Coefficient	pvalue	Correlation with Depth
Depth gradient	-0.16	0.48	-0.280**
Surface stratification (density)	-0.15	0.53	-0.072
Surface stratification (temperature)	-0.02	0.93	0.060
BML temperature	-0.37	0.21	-0.222*
BML salinity	0.98***	0.0003	0.761***
BML density	1.13***	0.0001	0.783***
BML depth	0.63**	0.0070	0.868***
Depth of maximum abundance	1.06***	0.0001	0.749***
Maximum abundance	0.85***	0.0007	0.537***
Avg. water column abundance	0.68**	0.0047	0.412***
Abundance above BML	0.51*	0.046	0.388***
SST	-0.02	0.94	0.055
SST gradient	0.27	0.34	-0.057
Surface chlorophyll	-0.34	0.14	-0.138
Surface chlorophyll gradient	-0.32	0.20	-0.113

Right Whale Habitat: Logistic Regression

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1(\text{SSTATE}) + \beta_2(\text{BOF}) + \beta_3(\text{Y2000}) + \beta_4(\text{Y2001})$$
$$+ \beta_5(\text{BOF} \times \text{Y2000}) + \beta_6(\text{BOF} \times \text{Y2001})$$
$$+ \beta_7(\text{Depth}) + \beta_8(\text{Anomaly of Environmental Variable})$$

π:Probability of sighting one or more right whales in a survey unit
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Y2000:Year 2000 indicator variable
Y2001:Year 2001 indicator variable

Right Whale Habitat: Results

Variable	Standardized Coefficient	pvalue
Depth		
Depth gradient	0.03	0.92
Surface stratification (density)	-0.02	0.94
Surface stratification (temperature)	0.01	0.97
BML temperature	-0.10	0.79
BML salinity	0.05	0.91
BML density	0.16	0.77
BML depth	-1.19*	0.018
Depth of maximum abundance	0.45	0.27
Maximum abundance	0.44	0.16
Average water column abundance	0.28	0.32
Abundance above BML	0.13	0.67
SST	-0.03	0.92
SST gradient	0.48	0.15
Surface chlorophyll	-0.26	0.28
Surface chlorophyll gradient	-0.26	0.36

Right Whale Habitat: Results

Probability of encountering a right whale
→ increases with water depth

Right Whale Habitat: Results

Probability of encountering a right whale
→ increases with water depth
and
→ increases with the thickness of the bottom mixed layer

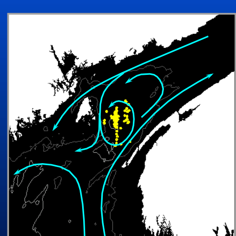
Right Whale Habitat: Conclusions

Probability of encountering a right whale
→ increases with water depth

Lynch, D.R., J.T.C. Ip, C.E. Naimie and F.E. Werner. 1996. Comprehensive coastal circulation model with application to the Gulf of Maine. *Continental Shelf Research* 16:875-906.

Right Whale Habitat: Conclusions

Probability of encountering a right whale
→ increases with water depth



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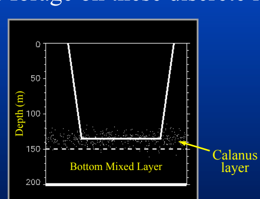
Right Whale Habitat: Conclusions

Probability of encountering a right whale
→ increases with the thickness of the bottom mixed layer

Right Whale Habitat: Conclusions

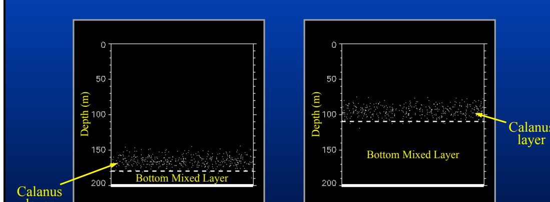
- *Calanus finmarchicus* aggregate in discrete layers just above the bottom mixed layer
- Right whales forage on these discrete layers



Baumgartner, M.F. and B.R. Mate. 2003. Summertime foraging ecology of North Atlantic right whales. *Marine Ecology Progress Series* 264:123-135.

Right Whale Habitat: Conclusions

Probability of encountering a right whale
→ increases with the thickness of the bottom mixed layer



Right Whale Habitat: Conclusions

Probability of encountering a right whale
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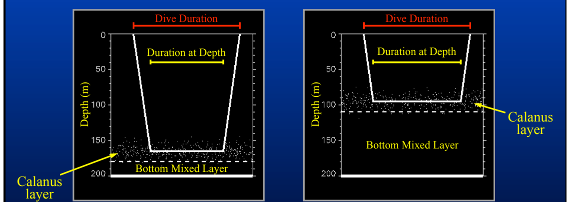

Recommendations

- Develop hypotheses
- Informed choice of environmental variables
- Test for and include detectability variables
- Account for other "non-spatial" factors (temporal variability, regional variability)
- Use models to unambiguously test for associations

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Observers
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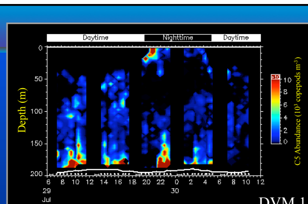
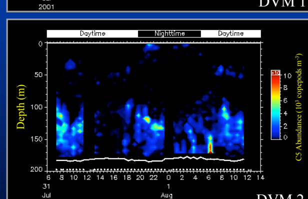
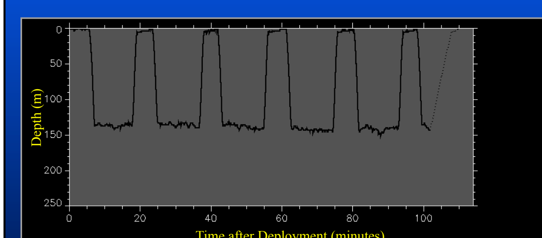




Right Whale Foraging Ecology: Study Area



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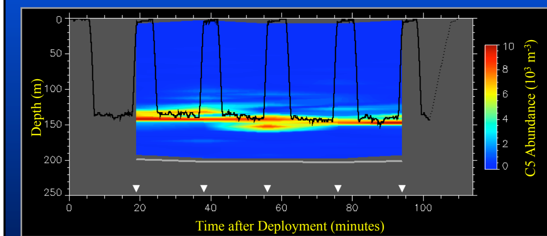

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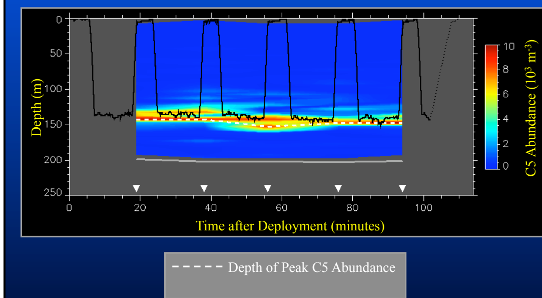

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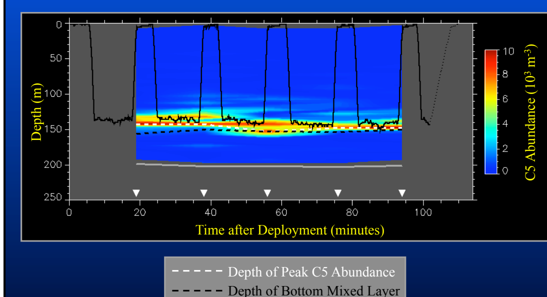
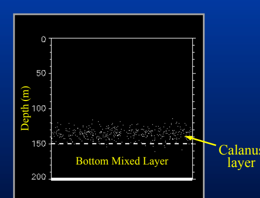


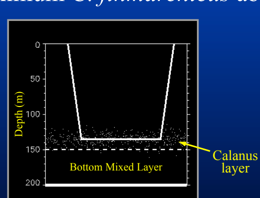
Foraging Ecology: Conclusions

- *Calanus finmarchicus* aggregate just above the bottom mixed layer

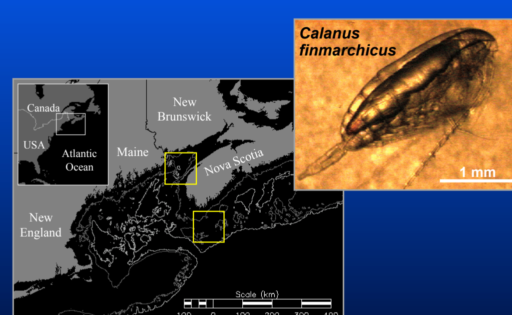


Foraging Ecology: Conclusions

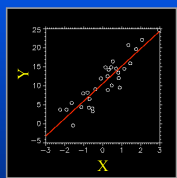
- *Calanus finmarchicus* aggregate just above the bottom mixed layer
- Right whales dive to and presumably feed at the depth of maximum *C. finmarchicus* abundance



Right Whale Foraging Ecology: Study Area

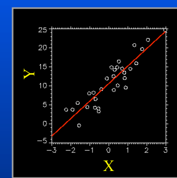


Logistic Regression Primer



Linear Regression
Y: continuous variable
$\mu[Y] = \beta_0 + \beta_1 X$

Logistic Regression Primer



Linear Regression
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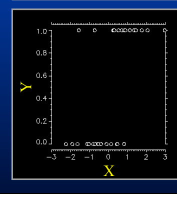
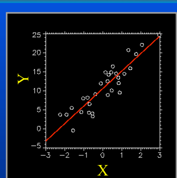


Logistic Regression
Y:binary variable

Logistic Regression Primer



Linear Regression
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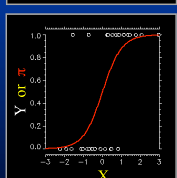
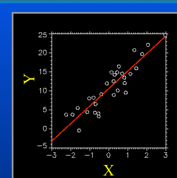


Logistic Regression
Y: binary variable
$\mu[Y] = \pi$:probability of Y = 1

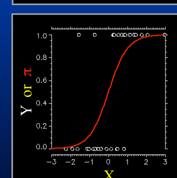
$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 X$$

Logistic Regression Primer



Linear Regression
Y: continuous variable
$\mu[Y] = \beta_0 + \beta_1 X$

Interpretation is analogous



Logistic Regression
Y: binary variable
$\mu[Y] = \pi$:probability of Y = 1

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 X$$

Logistic Regression Model

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 \text{(Environmental Variable)}$$

π:Probability of sighting one or more right whales in a survey unit

Logistic Regression Model

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 \text{(Environmental Variable)}$$

- *Sighting conditions (detectability)*

π:Probability of sighting one or more right whales in a survey unit

Logistic Regression Model

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1\,(\text{Environmental Variable})$$

- *Sighting conditions (detectability)*
- *Regional/interannual variability in sighting probability*

π:Probability of sighting one or more right whales in a survey unit

Logistic Regression Model

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1\,(\text{Environmental Variable})$$

- *Sighting conditions (detectability)*
- *Regional/interannual variability in sighting probability*
- *Regional/interannual variability in environmental variables*

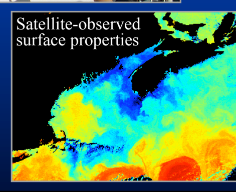
π:Probability of sighting one or more right whales in a survey unit

Logistic Regression Model

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1(\text{SSTATE}) + \beta_2(\text{BOF}) + \beta_3(\text{Y2000}) + \beta_4(\text{Y2001}) + \beta_5(\text{BOF} \times \text{Y2000}) + \beta_6(\text{BOF} \times \text{Y2001}) + \beta_7(\text{Anomaly of Environmental Variable})$$

π:Probability of sighting one or more right whales in a survey unit
SSTATE:Sea state (Beaufort scale)
BOF:Bay of Fundy (BOF=1) and Roseway Basin (BOF=0) indicator variable
Y2000:Year 2000 indicator variable
Y2001:Year 2001 indicator variable

Investigating Right Whale Habitat



$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1(\text{SSTATE}) + \beta_2(\text{BOF}) + \beta_3(\text{Y2000}) + \beta_4(\text{Y2001}) + \beta_5(\text{BOF} \times \text{Y2000}) + \beta_6(\text{BOF} \times \text{Y2001}) + \beta_7(\text{Depth}) + \beta_8(\text{BML Depth})$$

Term		Coeff	SE	Wald z statistic	p	Drop in Deviance	df	p
Intercept	β_0	1.14	1.75	0.65	0.51			
Sea state	β_1	-0.871	0.330	-2.64**	0.0083	8.15**	1	0.0043
Region						10.24*	3	0.017
BOF	β_2	1.70	1.46	1.17	0.24			
Year						15.42**	4	0.0039
Y2000	β_3	-2.80	1.75	-1.60	0.11			
Y2001	β_4	-0.00422	1.36	0.00	1.00			
Region × Year						6.52*	2	0.038
BOF × Y2000	β_5	0.808	2.03	0.40	0.69			
BOF × Y2001	β_6	-2.53	1.89	-1.33	0.18			
Depth	β_7	0.0708	0.0193	3.67***	0.0002	17.88***	1	0.0000
BML depth	β_8	-0.0413	0.0179	-2.31*	0.021	5.61*	1	0.018