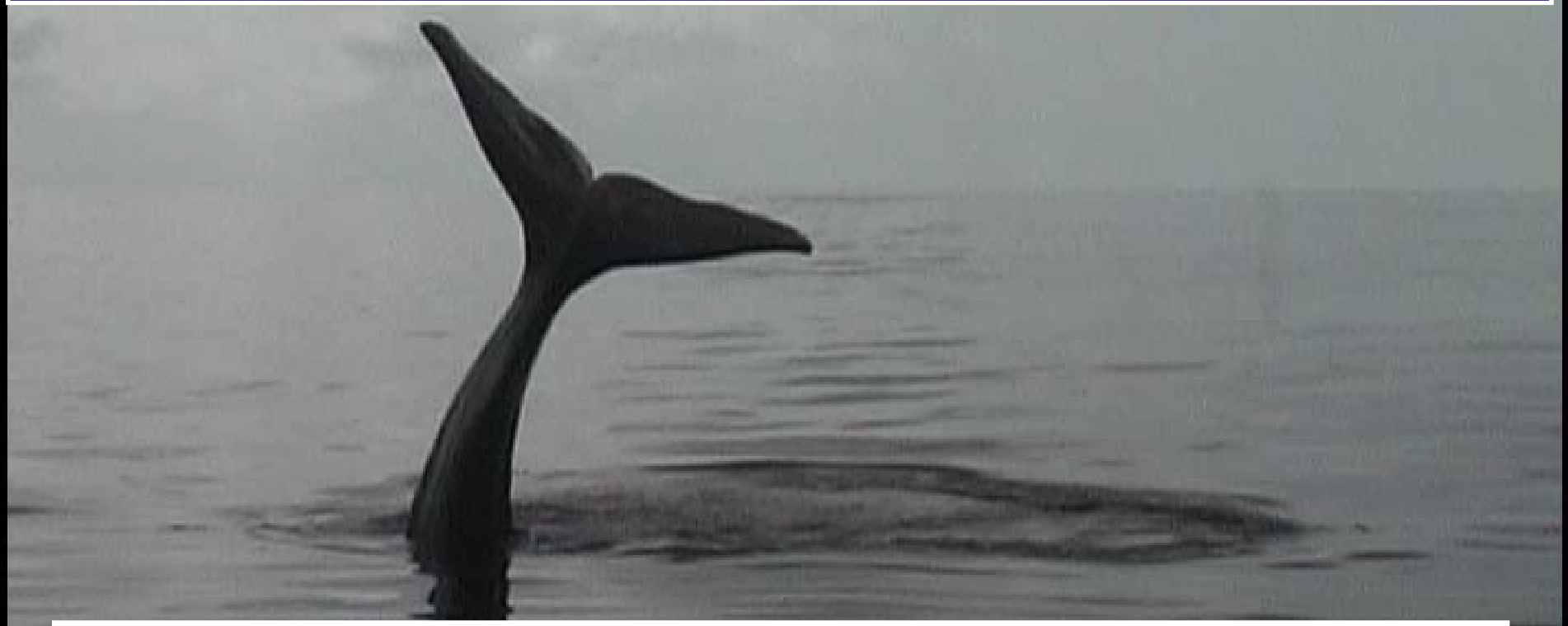
Modeling Sperm Whale Responses to Airgun Signals



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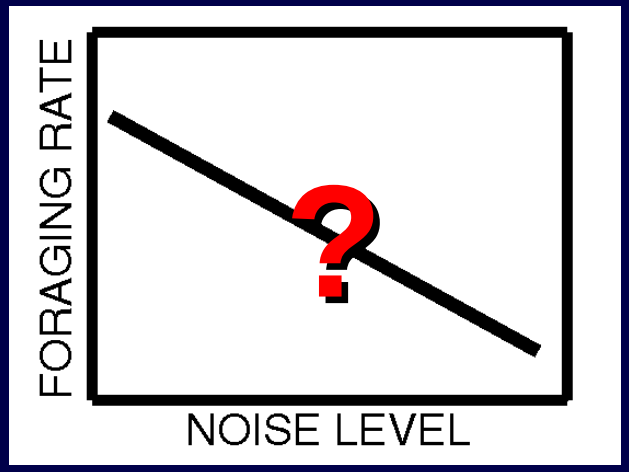
Massachusetts Institute of Technology

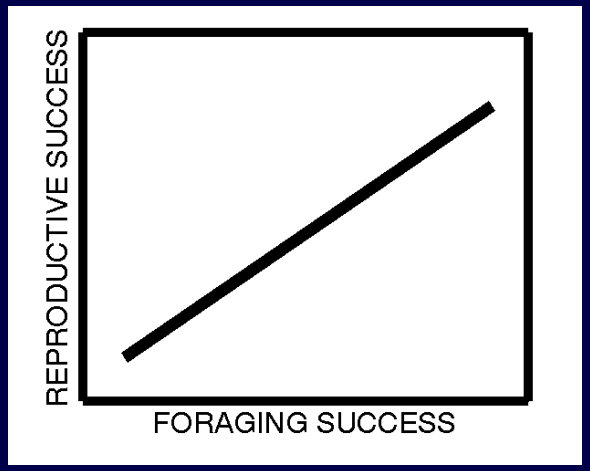
Woods Hole Oceanographic Institution 1930

Outline

- **Introduction:** Goals of study, airguns, sperm whales, and experiments
- **Methods:** Motivation and statistics
- **Results:** Comparison of sperm whale foraging rate during control and airgun conditions
- **Conclusions:** Interpretation and future work

Goal: Quantify Impact of Noise on Population

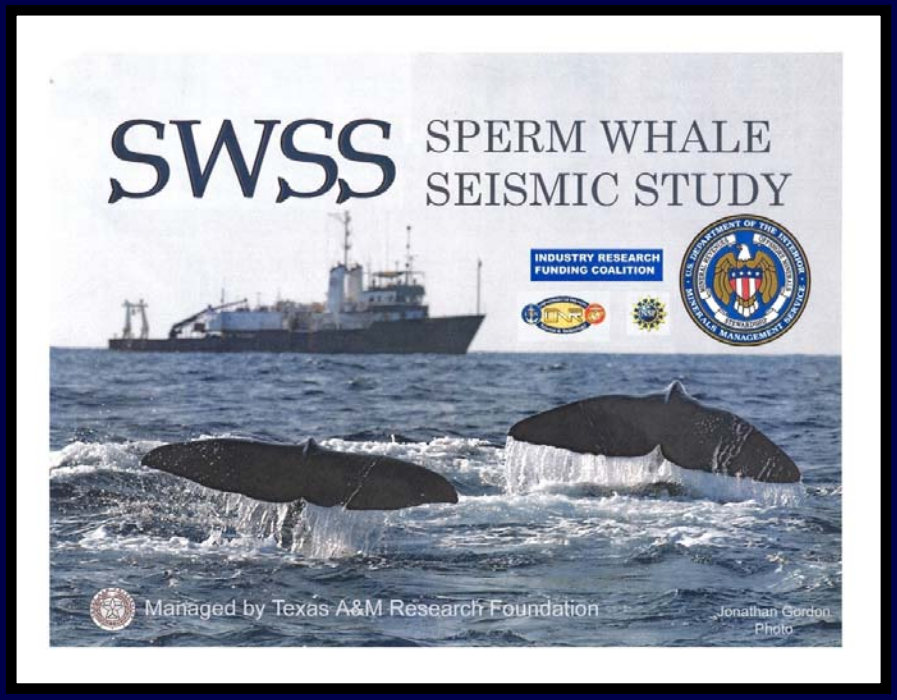




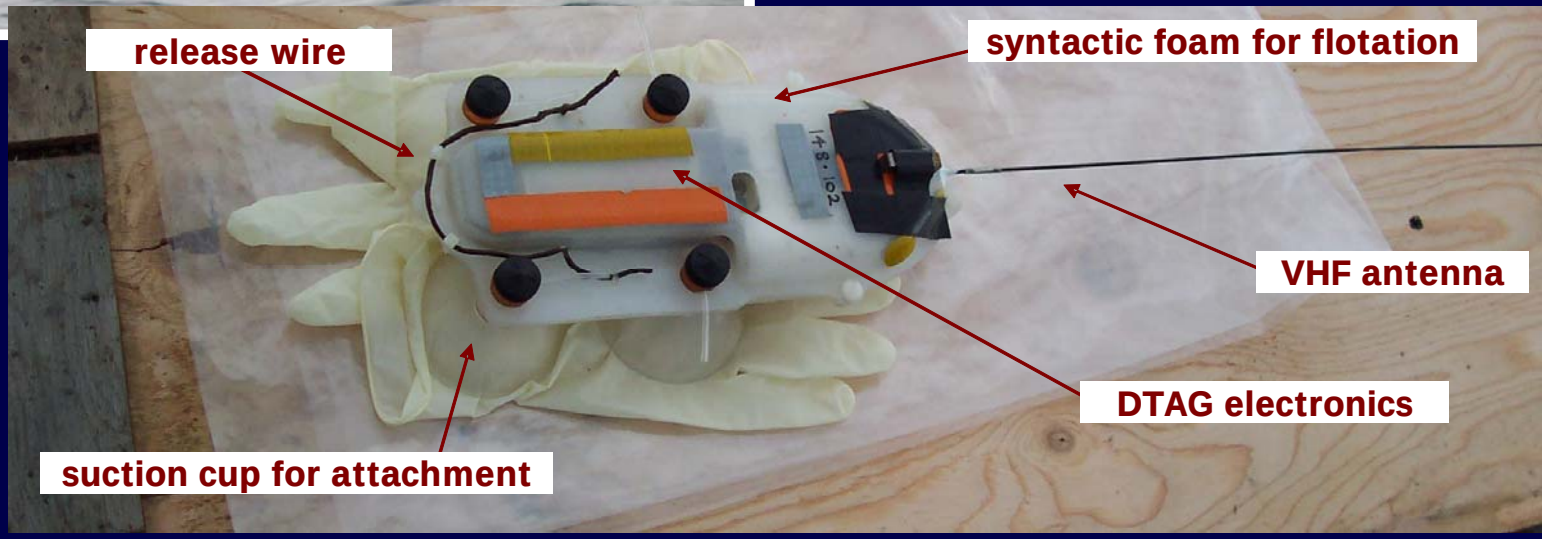
MATRIX MODELS

Sound Sources: Airgun Arrays

- Usually in towed arrays, for oil industry and geophysical data collection
- Powerful source of low frequency sound (<250Hz)
- Typical source levels = 220–260dB re 1μPa
- Sounds may adversely affect marine mammals, including sperm whales

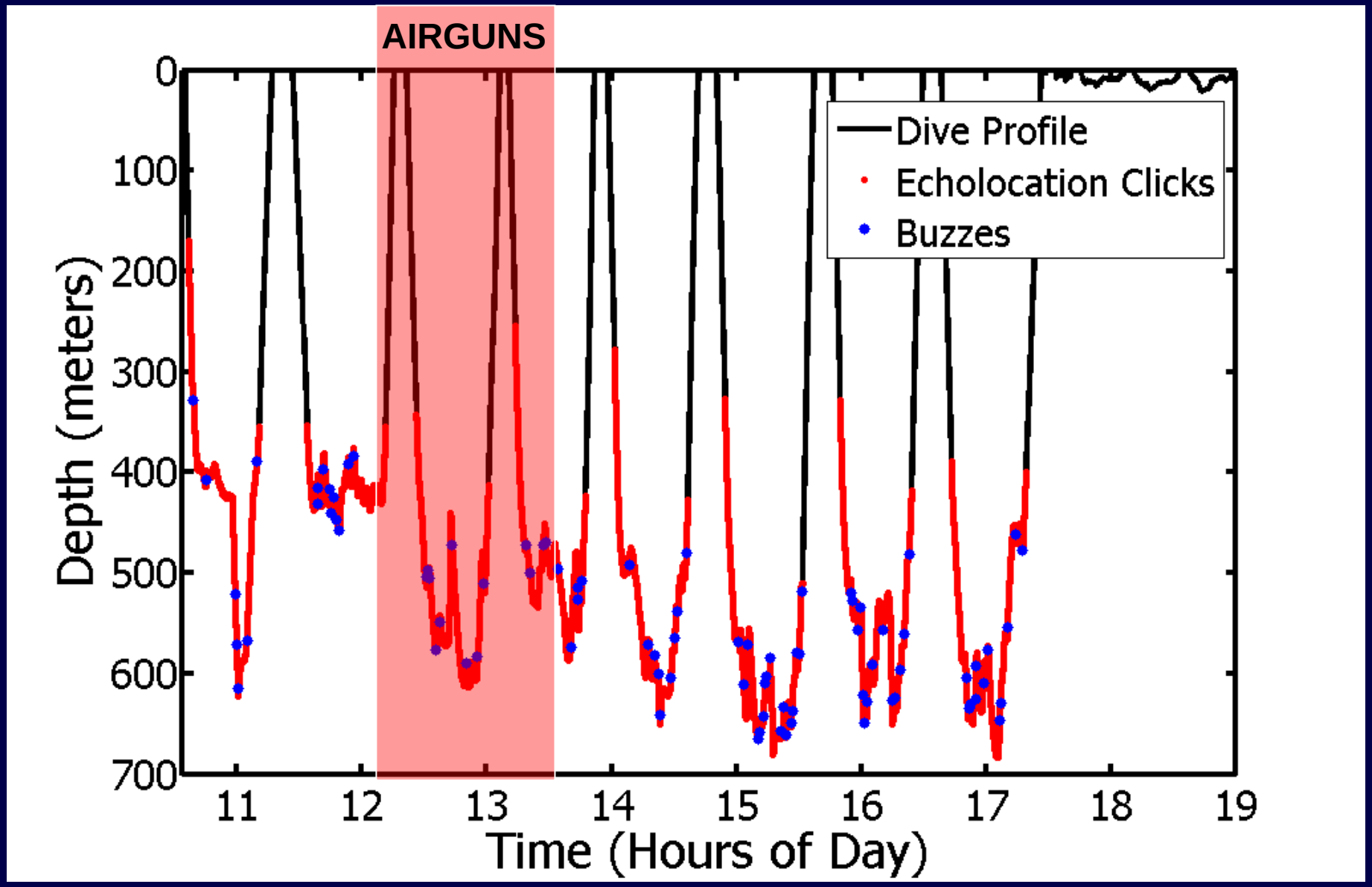


Experiment: Sperm Whales Exposed to Airguns

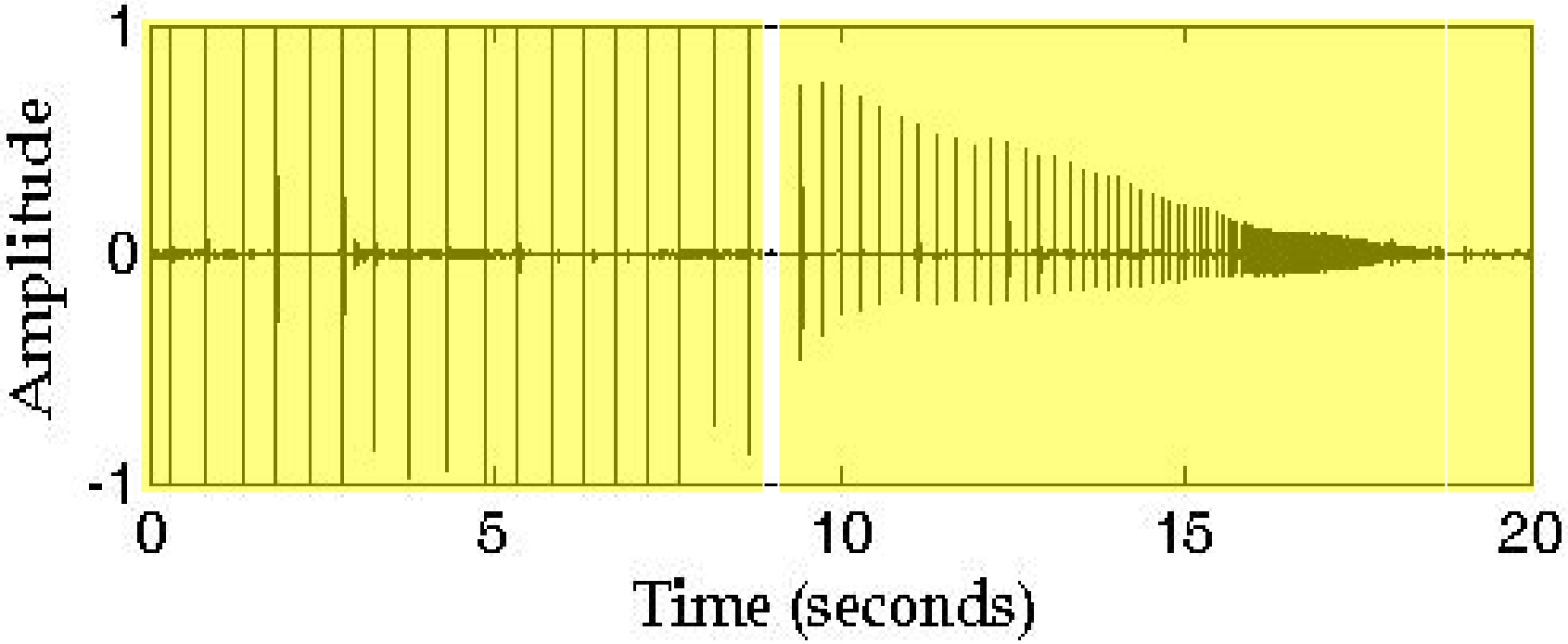


- N = 7 whales
- Whales tagged with Dtag to record sound, movements for 4–17 hours/whale
- Controlled exposure to airgun sounds (every 15 seconds for 1–2 hours; RL = 131 -- 164 dB re 1 uPa pp @ 1-13km)

Sperm Whale Foraging Behavior

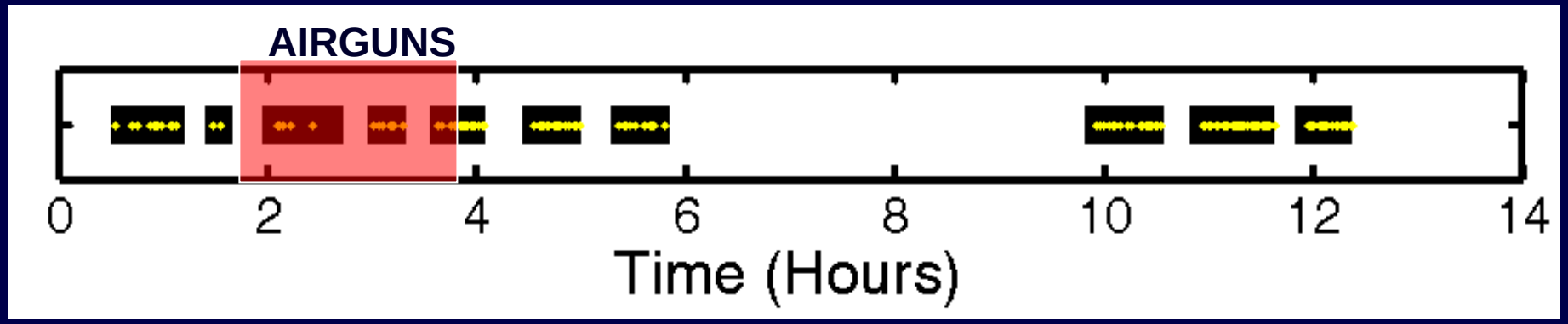


Buzz Rate as Proxy for Foraging Rate

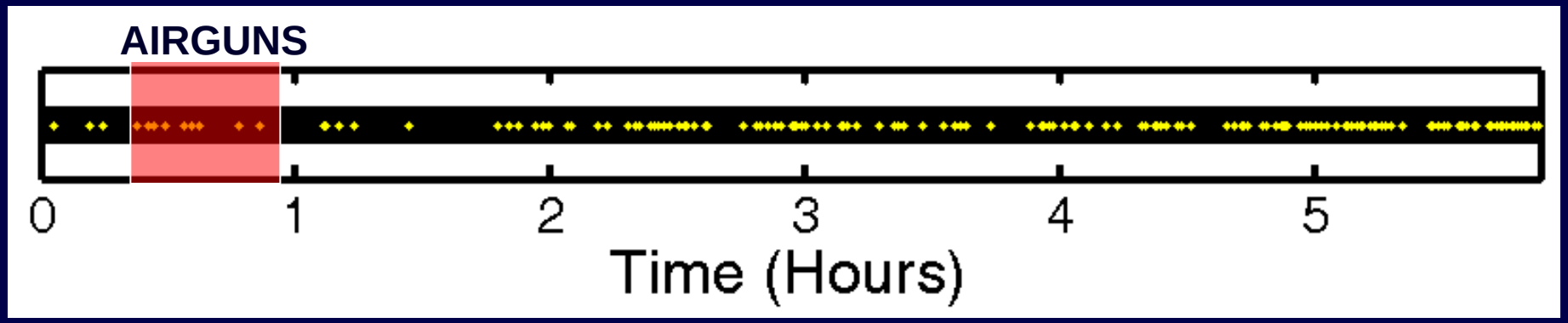


SEARCH	CAPTURE (BUZZ)	PAUSE

Analysis of Foraging (Buzz) Rate



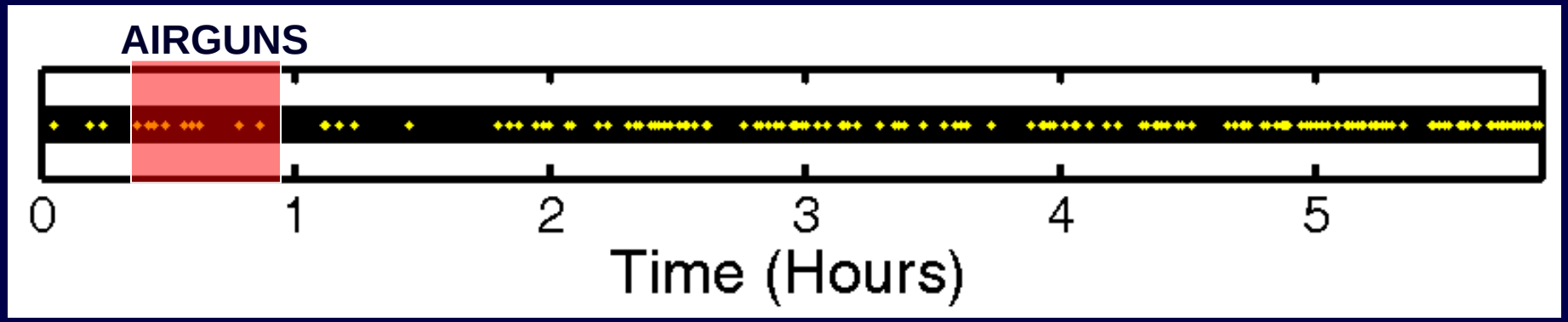
ELIMINATE NON-FORAGING PERIODS FROM ANALYSIS



Is buzz rate lower during exposure?

Parametric Test

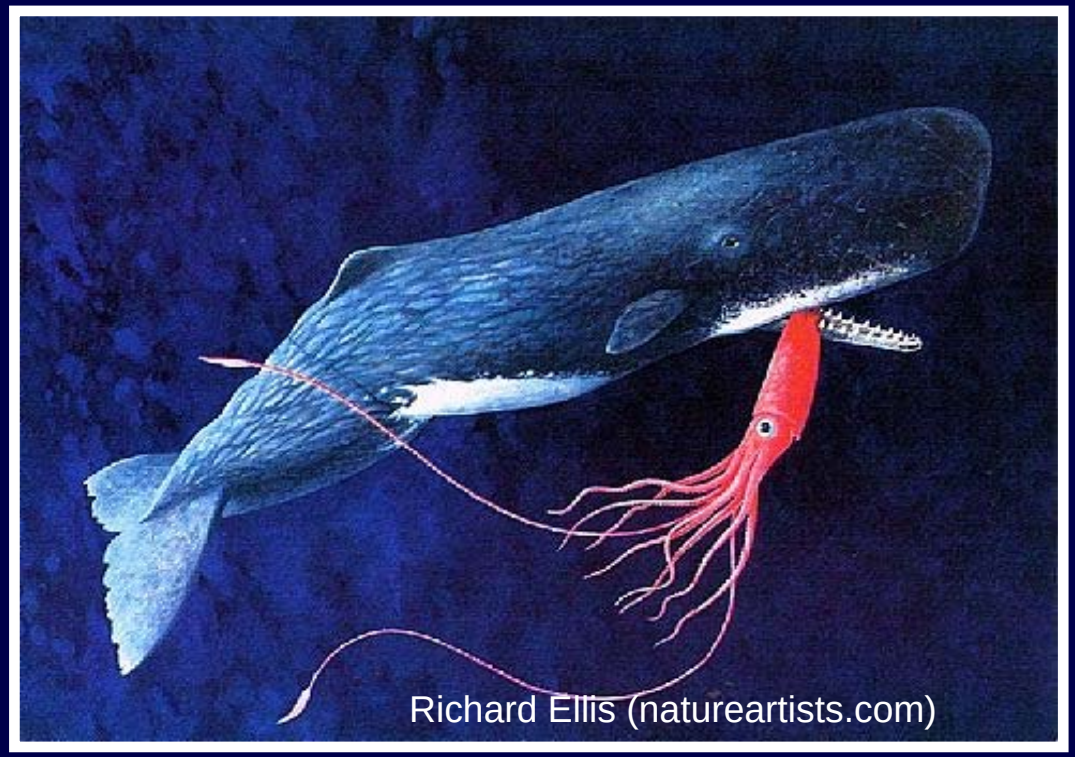
- Assume buzz production is Poisson process
- Conditional on total # buzzes, # of buzzes during control period (N_c) should have binomial distribution
- Determine observed N_c and compare with that expected under the null hypothesis that buzz rate is constant at all times



Is buzz rate lower during exposure?

Parametric Results, Individual Whales

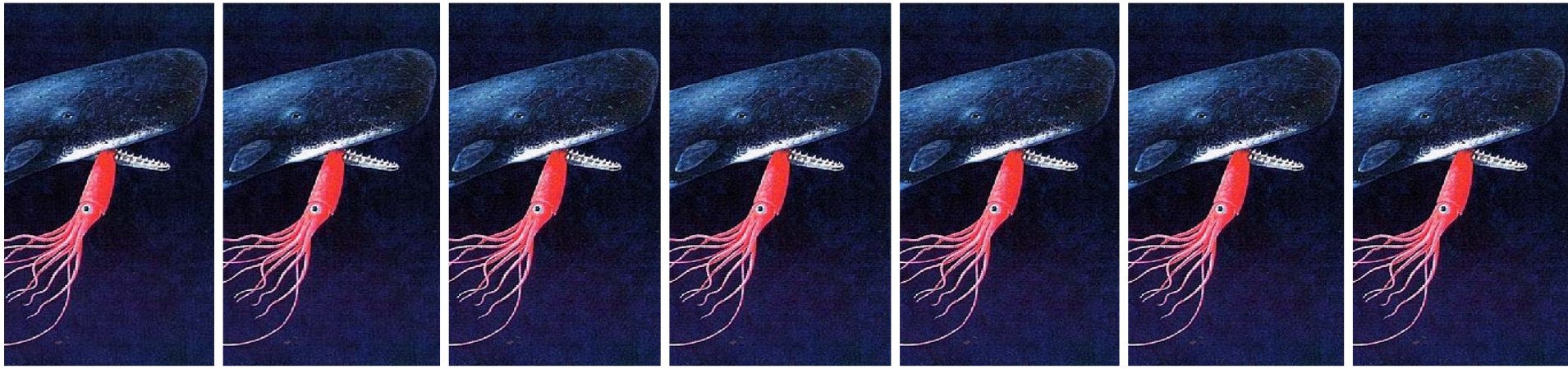
WHALE	1	2	3	4	5	6	7
P-VALUE	0.78	0.54	1.40E-04	5.20E-05	0.93	0.88	0.13
% CHANGE	31%	4%	-59%	-60%	40%	15%	-13%



Is buzz rate lower during exposure?

Parametric Results, ALL 7 Whales

- Fisher's method: p-value = 0.0001
- Concerted change: p-value = 0.083
- Percent change in foraging rate during exposure: -9%



Richard Ellis (natureartists.com)

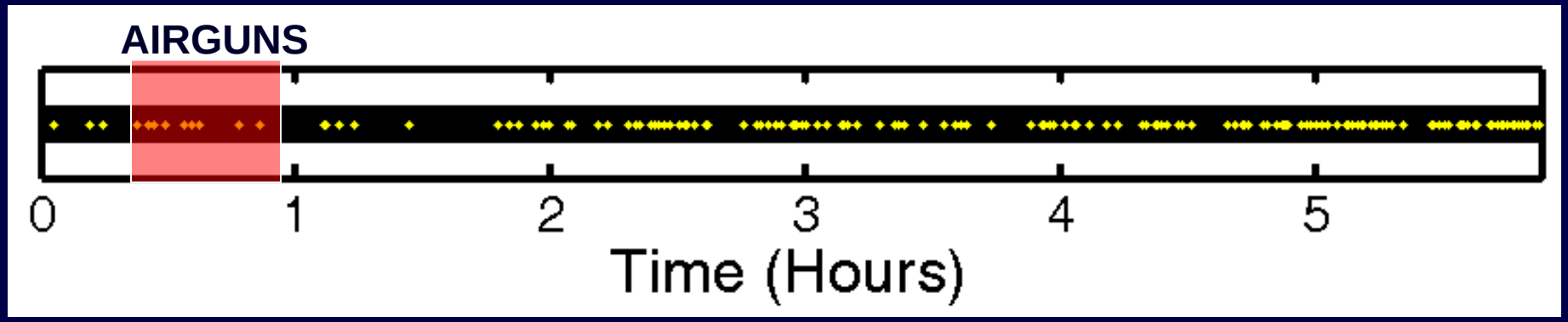
Buzz Production = Poisson Process?

- ✓ Buzz rate will vary over time if food source is patchy in space or time
- ✓ Inter-buzz intervals are not exponentially distributed
- ➔ Assuming buzz production is a Poisson process is probably inaccurate

Is buzz rate lower during exposure?

Nonparametric "Rotation" Test

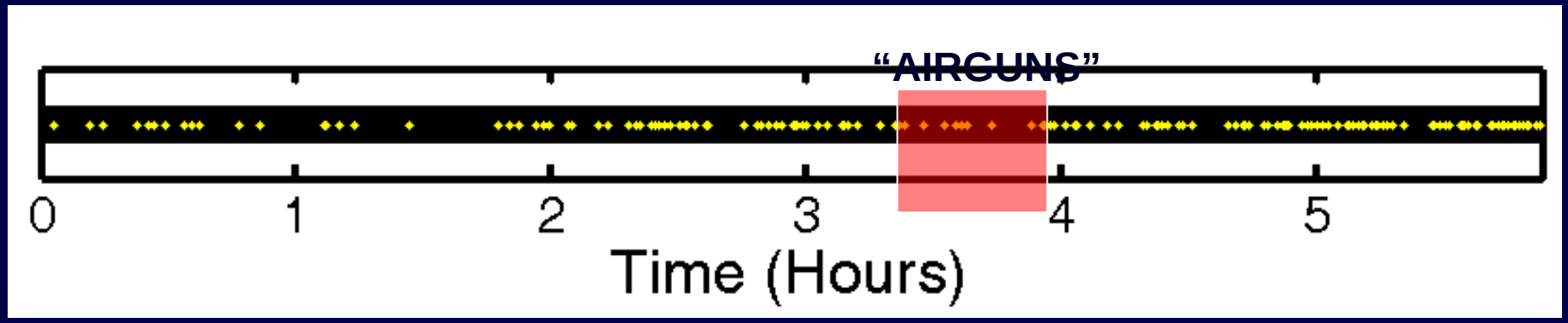
- Calculate observed number of buzzes during control period (N_c)



Is buzz rate lower during exposure?

Nonparametric "Rotation" Test

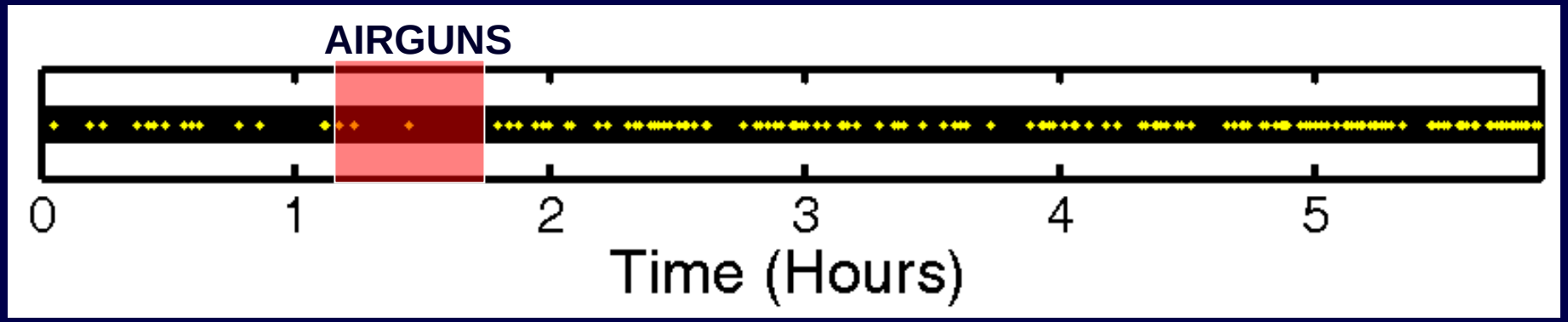
- Calculate observed number of buzzes during control period (N_c)
- Fix time-series of buzzes and duration of the exposure, but randomly re-position exposure start time
- Calculate $N_{c,rot}$ for the "rotated" data



Is buzz rate lower during exposure?

Nonparametric "Rotation" Test

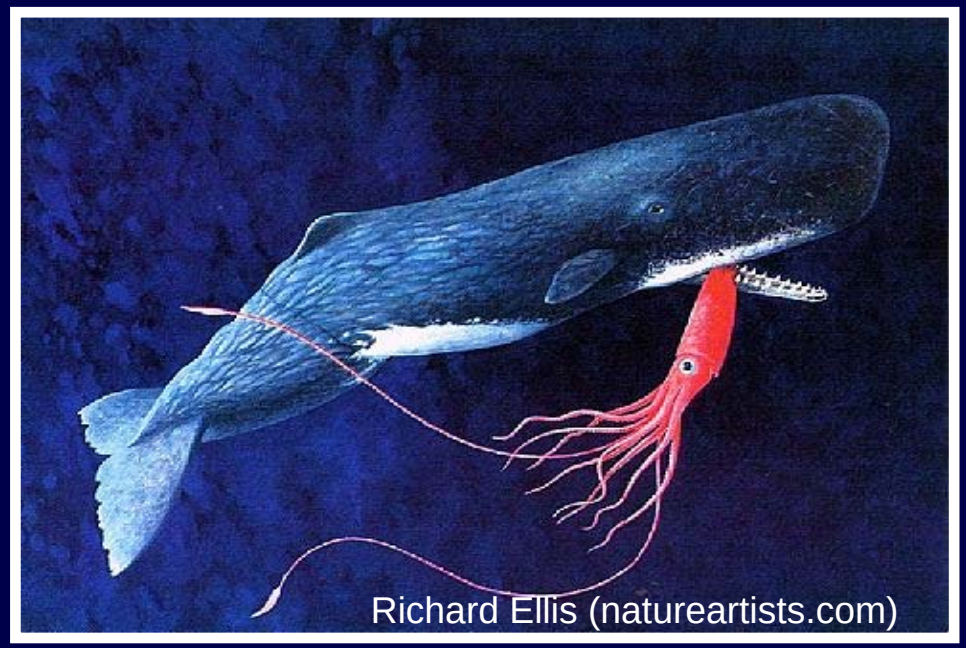
- Calculate observed number of buzzes during control period (N_c)
- Fix time-series of buzzes and duration of the exposure, but randomly re-position exposure start time
- Calculate $N_{c,rot}$ for the "rotated" data
- Repeat many times to get distribution of N_c



Is buzz rate lower during exposure?

Rotation Results, Individual Whales

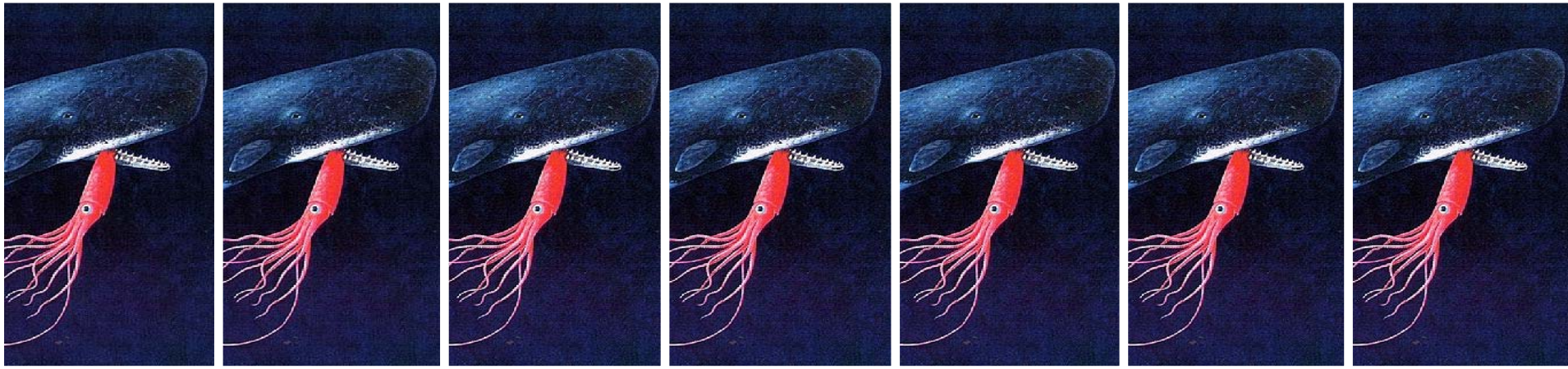
WHALE	1	2	3	4	5	6	7
P-VALUE	0.70	0.54	0.069	0.0021	0.92	0.72	0.13
% CHANGE	31%	4%	-59%	-60%	40%	15%	-13%



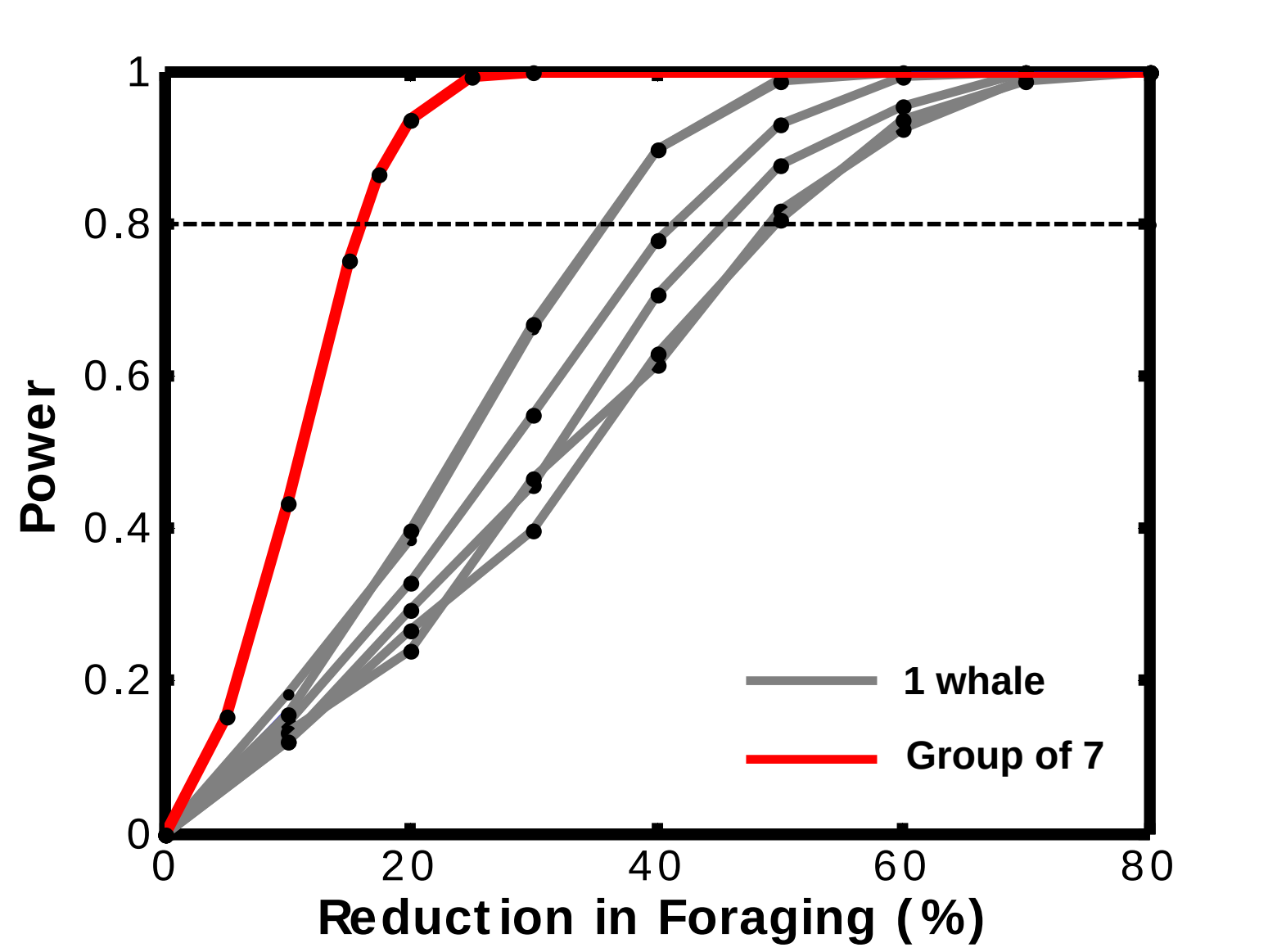
Is buzz rate lower during exposure?

Rotation Results, ALL 7 Whales

- Fisher's method: p-value = 0.036
- Concerted change: p-value = 0.19
- Percent change in foraging rate during exposure: -9%



Power of Parametric Test



Conclusions and Future Work

- There is evidence that at least one whale shows a large reduction in foraging rate during airgun exposure
- This study does not find evidence that all 7 whales had a concerted reduction in foraging rate during exposure
- Future: better estimate power of tests using synthetic datasets
- Future: relate foraging reductions to noise levels, then to reproductive success & population growth rates

Acknowledgments

- I thank my collaborators and co-authors: Andy Solow, Peter Tyack, Patrick Miller

- I thank the crews and scientific staffs of the SWSS 2002 and 2003 cruises

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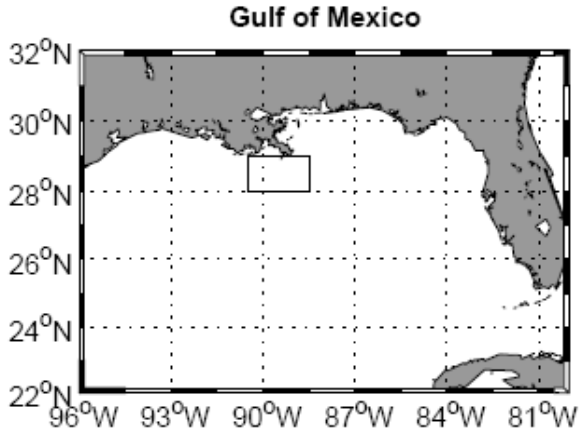
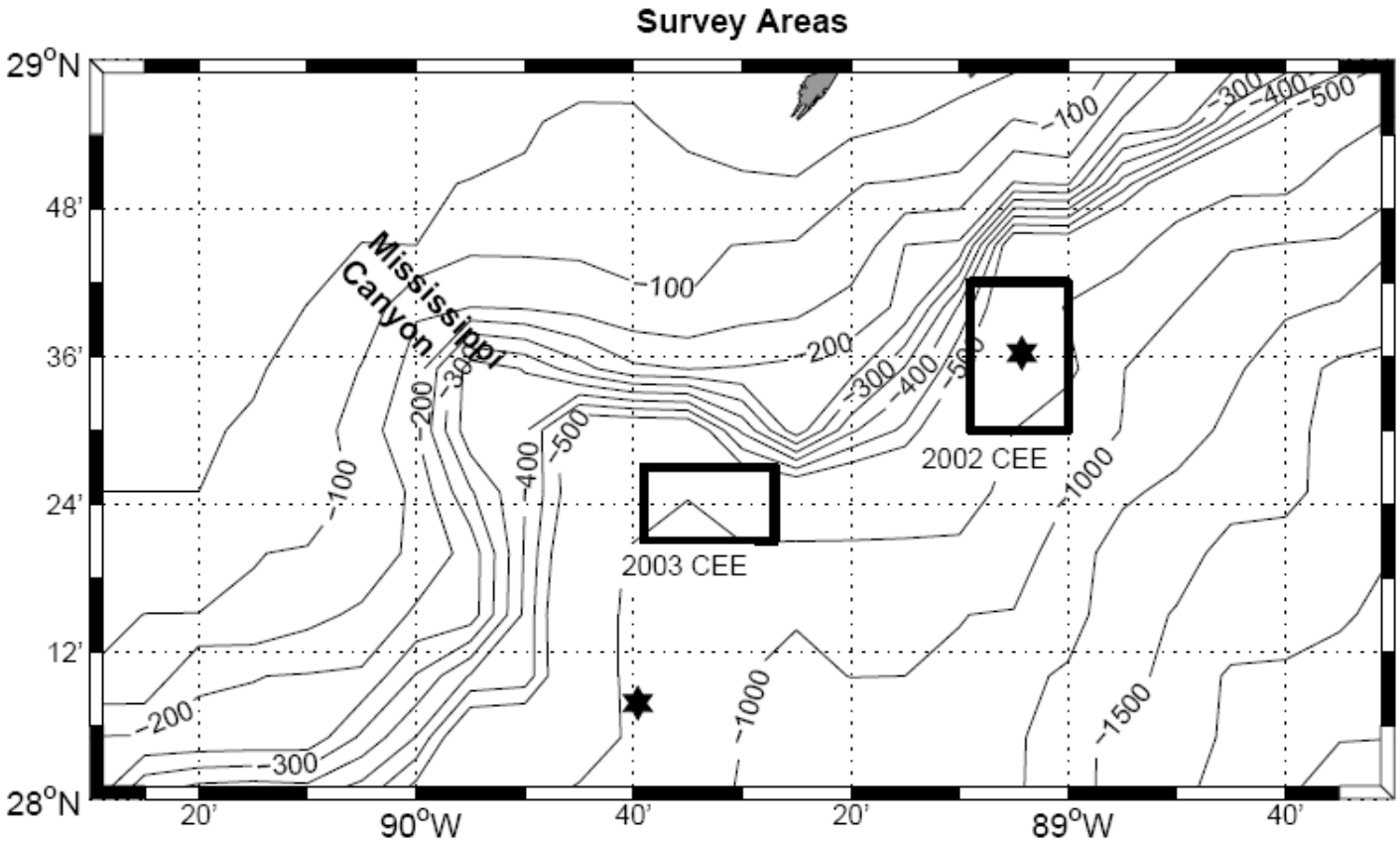
  - Office of Naval Research
  - U.S. Department of the Interior
  - Industry Research Funding Coalition
  - National Science Foundation

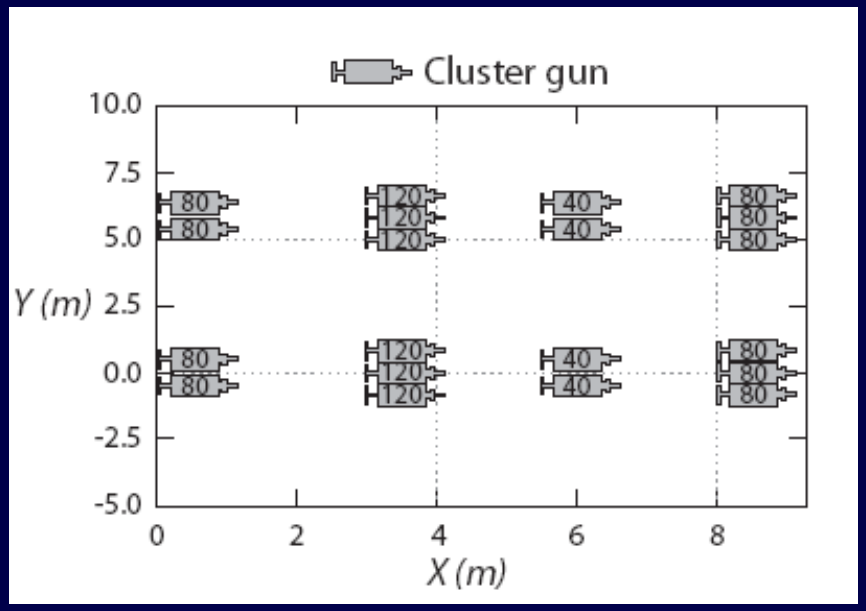
Industry Research Funding Coalition

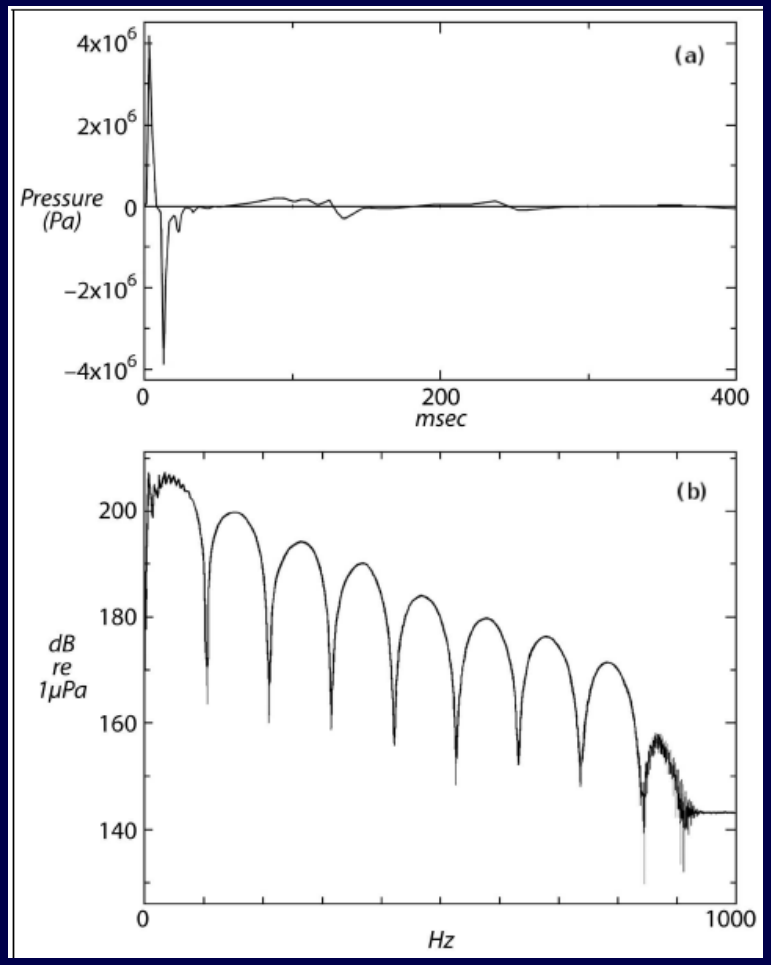
Study Area and Airgun Arrays


Gulf of Mexico
32°N
30°N
28°N
26°N
24°N
22°N
96°W
93°W
90°W
87°W
84°W
81°W

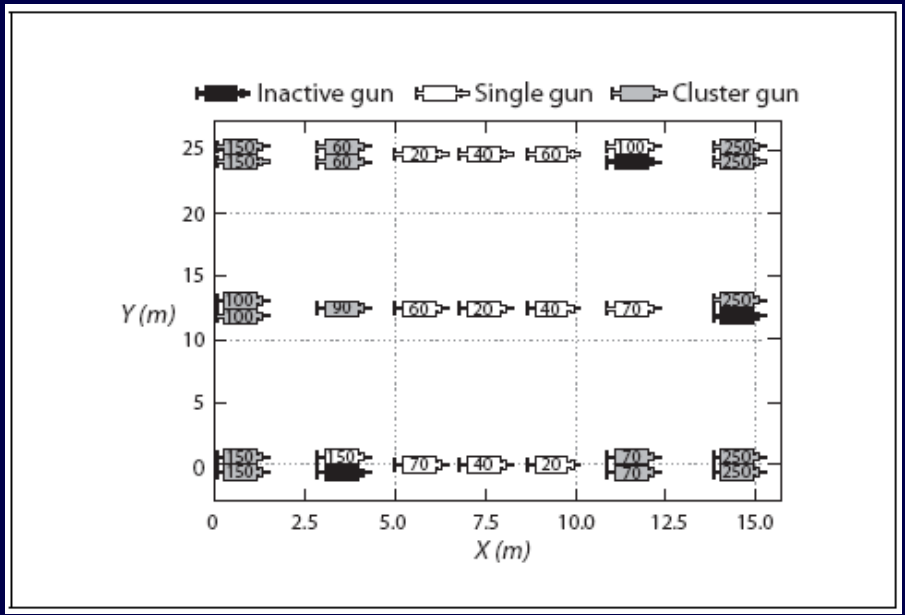

Survey Areas
29°N
48'
36'
24'
12'
28°N
20'
90°W
40'
20'
89°W
40'
Mississippi Canyon
2002 CEE
2003 CEE
-100
-200
-300
-400
-500
-1000
-1500

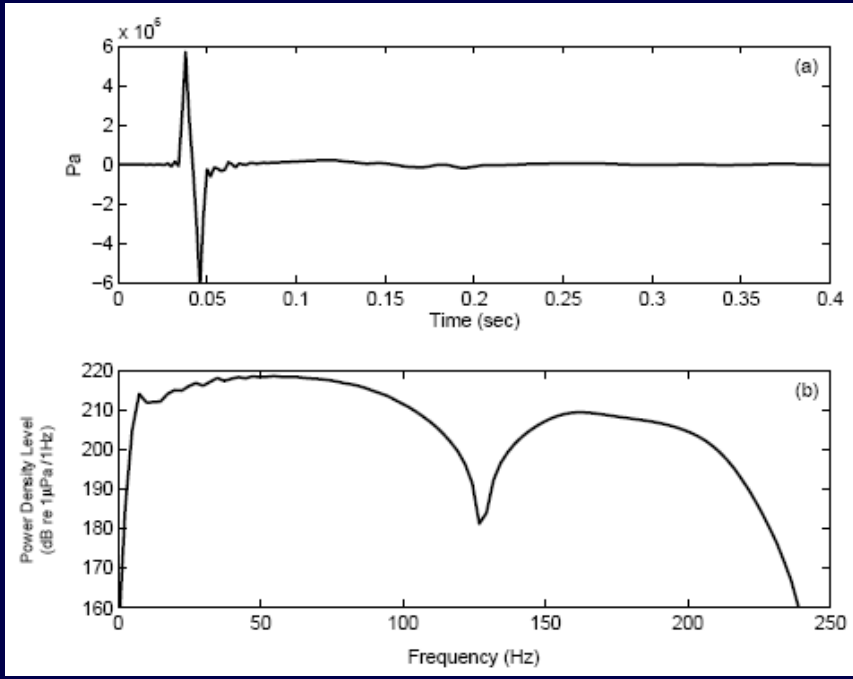
Speculator Array (2002)





Kondor Array (2003)



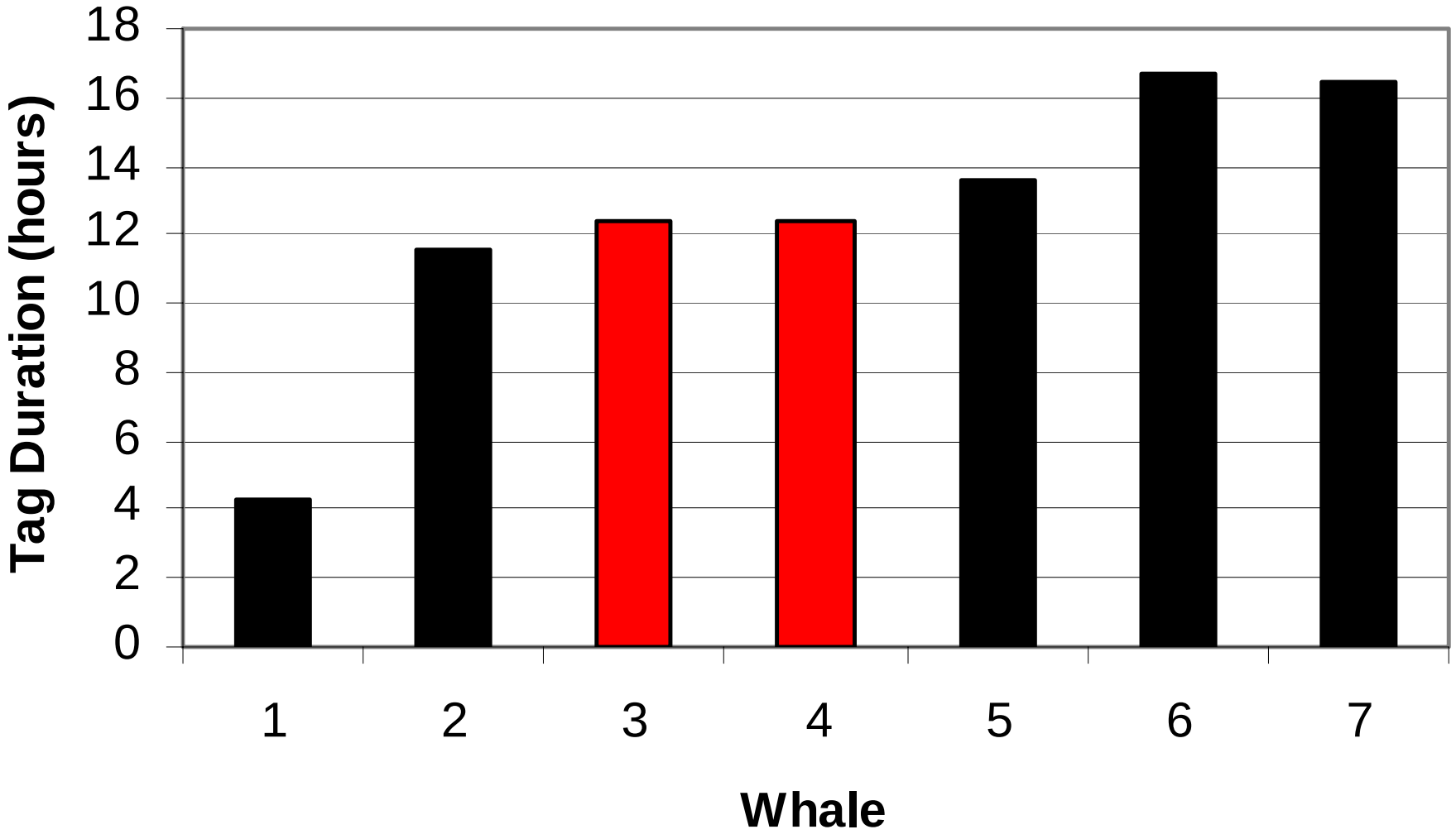


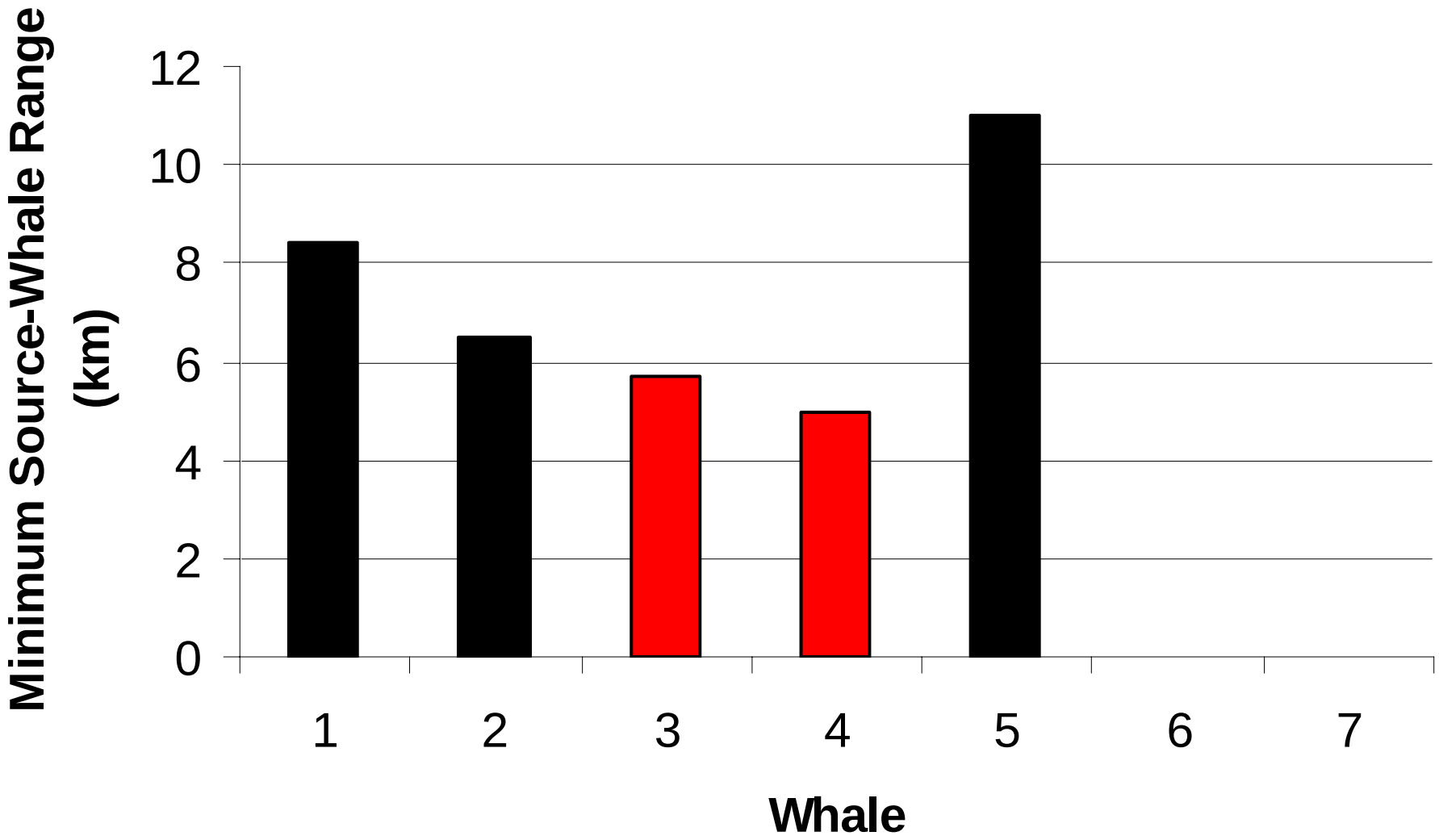
Agreement Between Parametric/Rotation Results

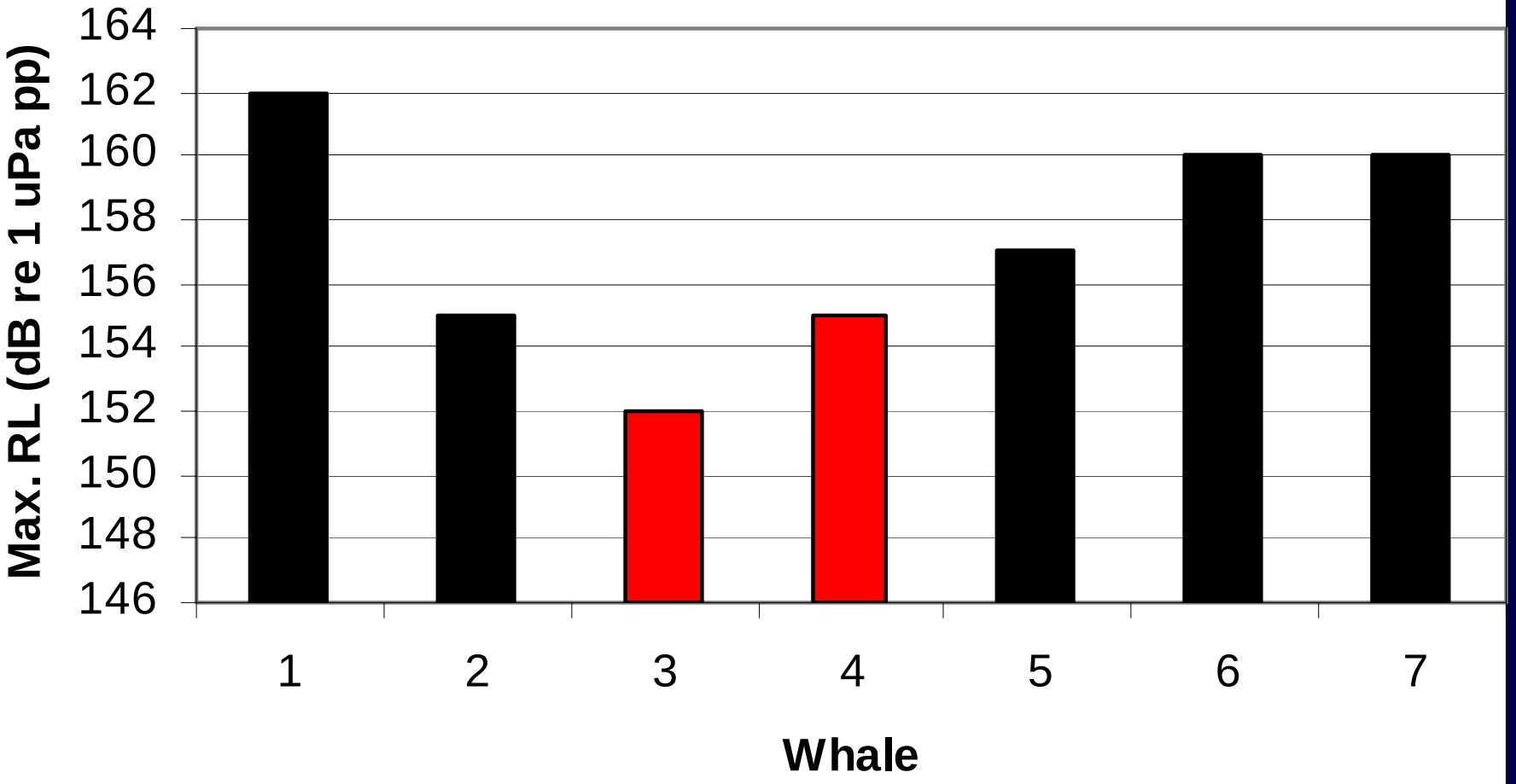
Parametric vs. Rotation Results

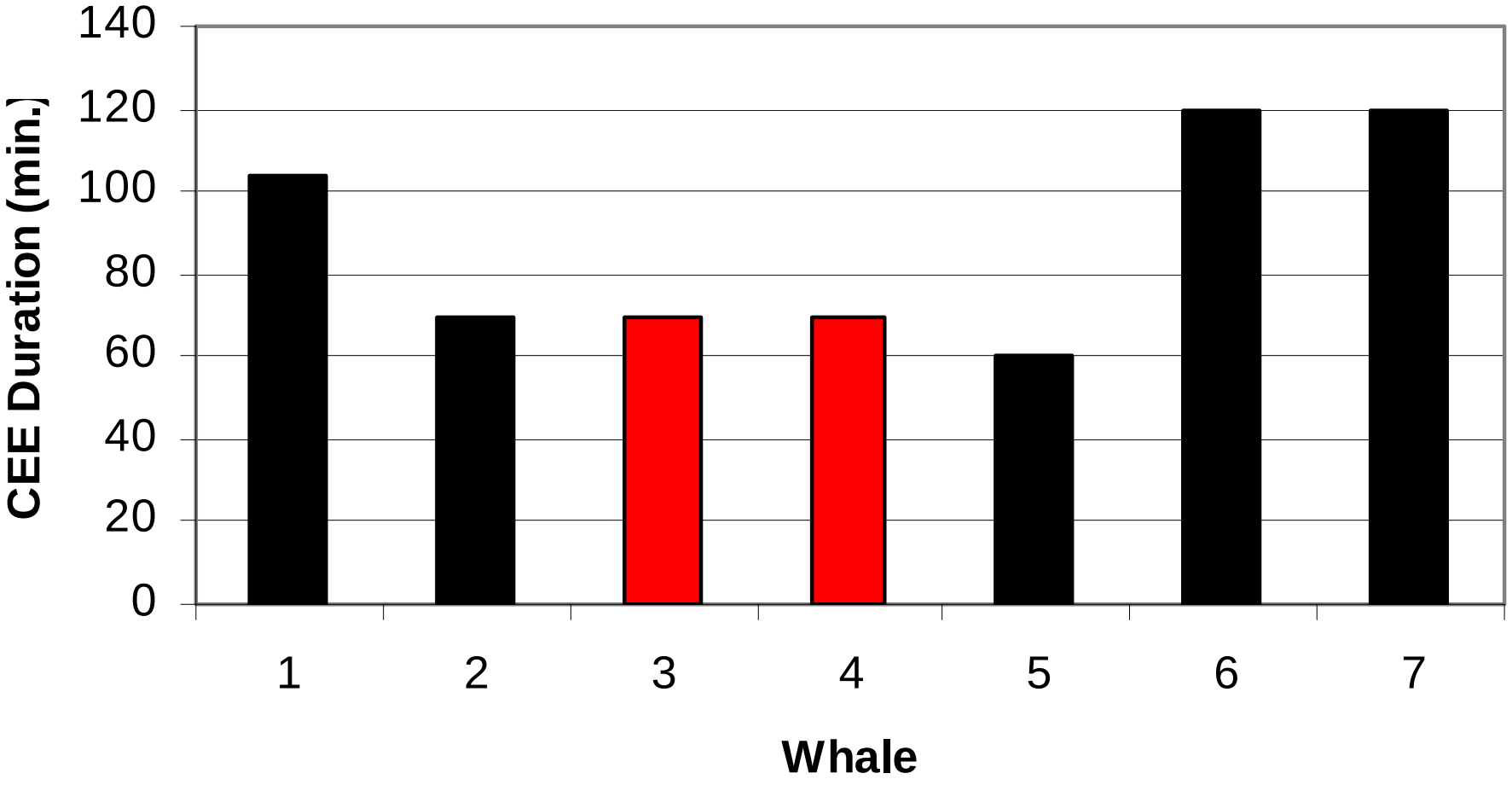
WHALE	1	2	3	4	5	6	7
Parametric	0.78	0.54	1.40E-04	5.20E-05	0.93	0.88	0.13
Rotation	0.70	0.54	0.069	0.0021	0.92	0.72	0.13

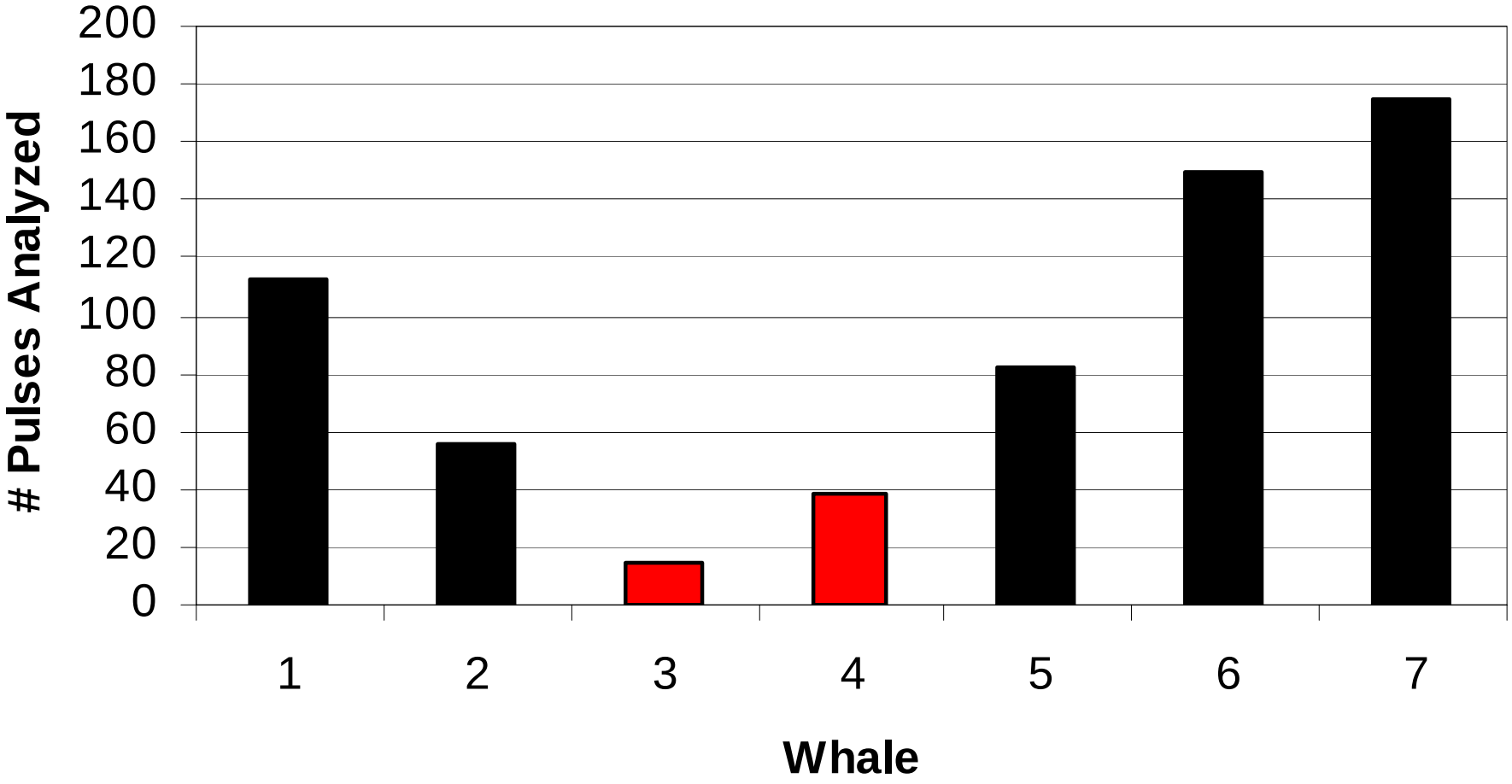
Correlates of Airgun Response


Tag Duration (hours)
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
Whale


Minimum Source-Whale Range (km)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
Whale


Max. RL (dB re 1 uPa pp)
164
162
160
158
156
154
152
150
148
146
1
2
3
4
5
6
7
Whale


CEE Duration (min.)
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
Whale


Pulses Analyzed
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
Whale

Justification of Buzzes as Proxy for Foraging Rate

Whale Sounds: Analogy to Phases of Bat Echolocation

- Search phase (clicking)
- Approach phase
- Terminal phase (“buzz”/prey capture)

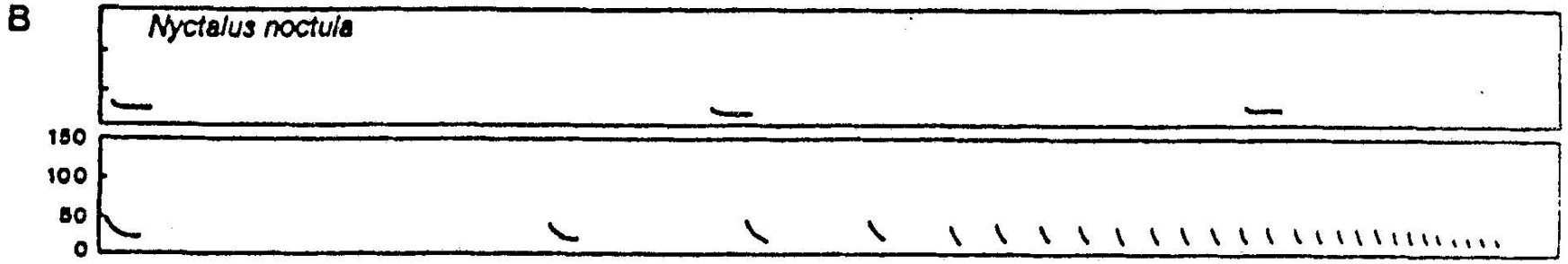
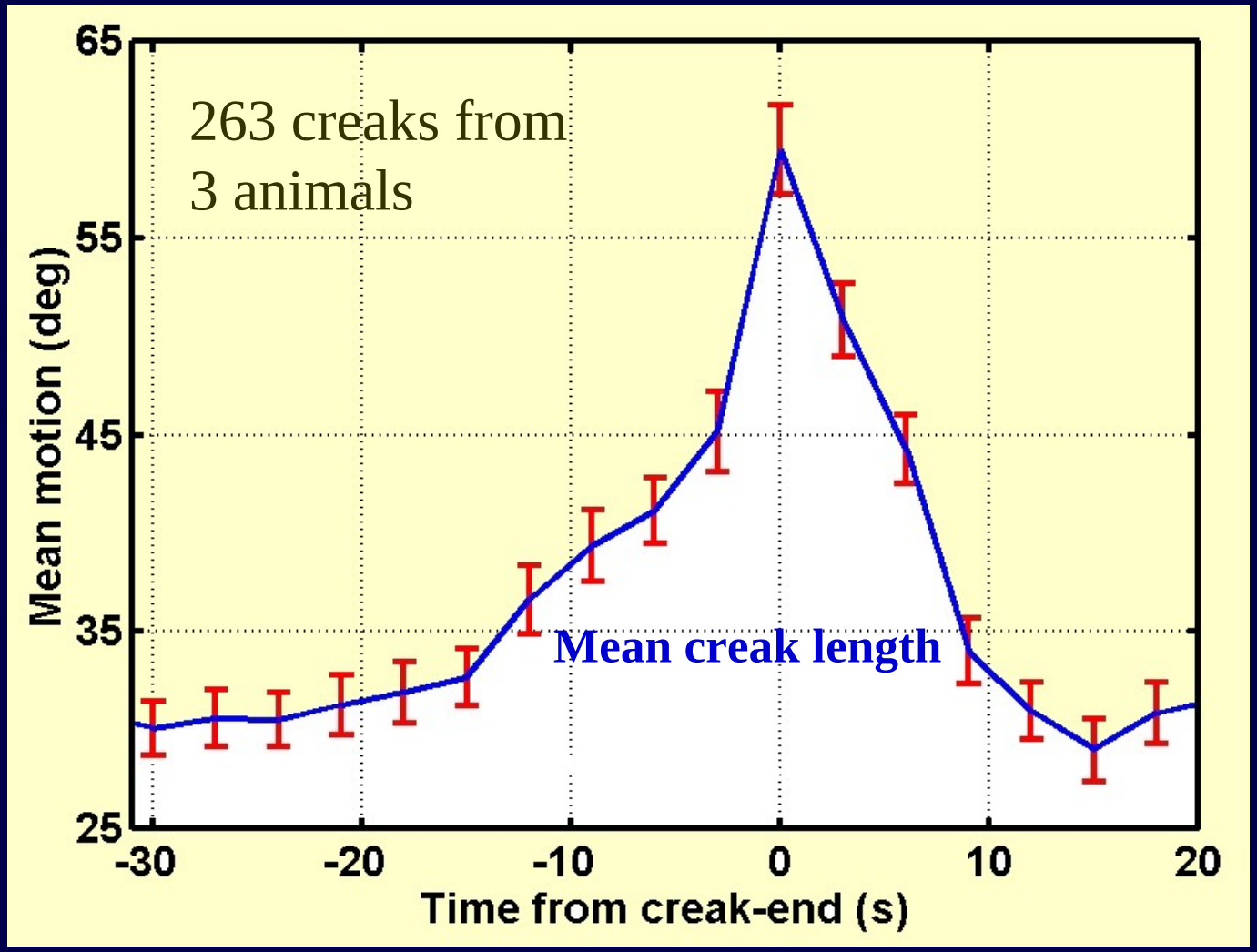


Figure from Schnitzler, H.U. and E.K.V.Kalko. 2001. Echolocation behavior of insect-eating bats. BioScience 51:557-569.

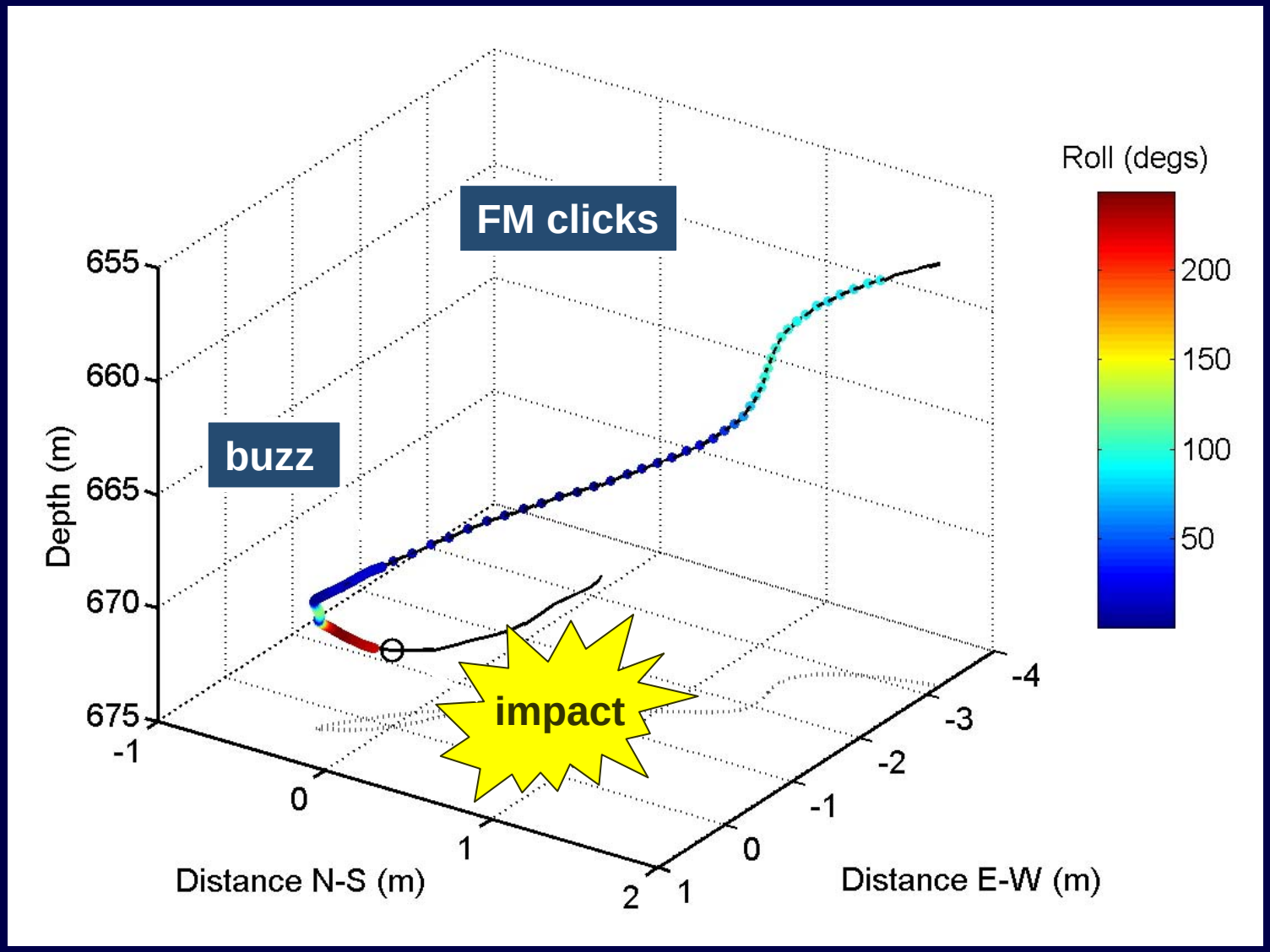
Photo credit: http://www.fledermausschutz.ch/DOWNLOAD/BILDER/Bilder_index.htm

Mean Motion* Is Significantly Greater at Creaks than at Other Bottom Times

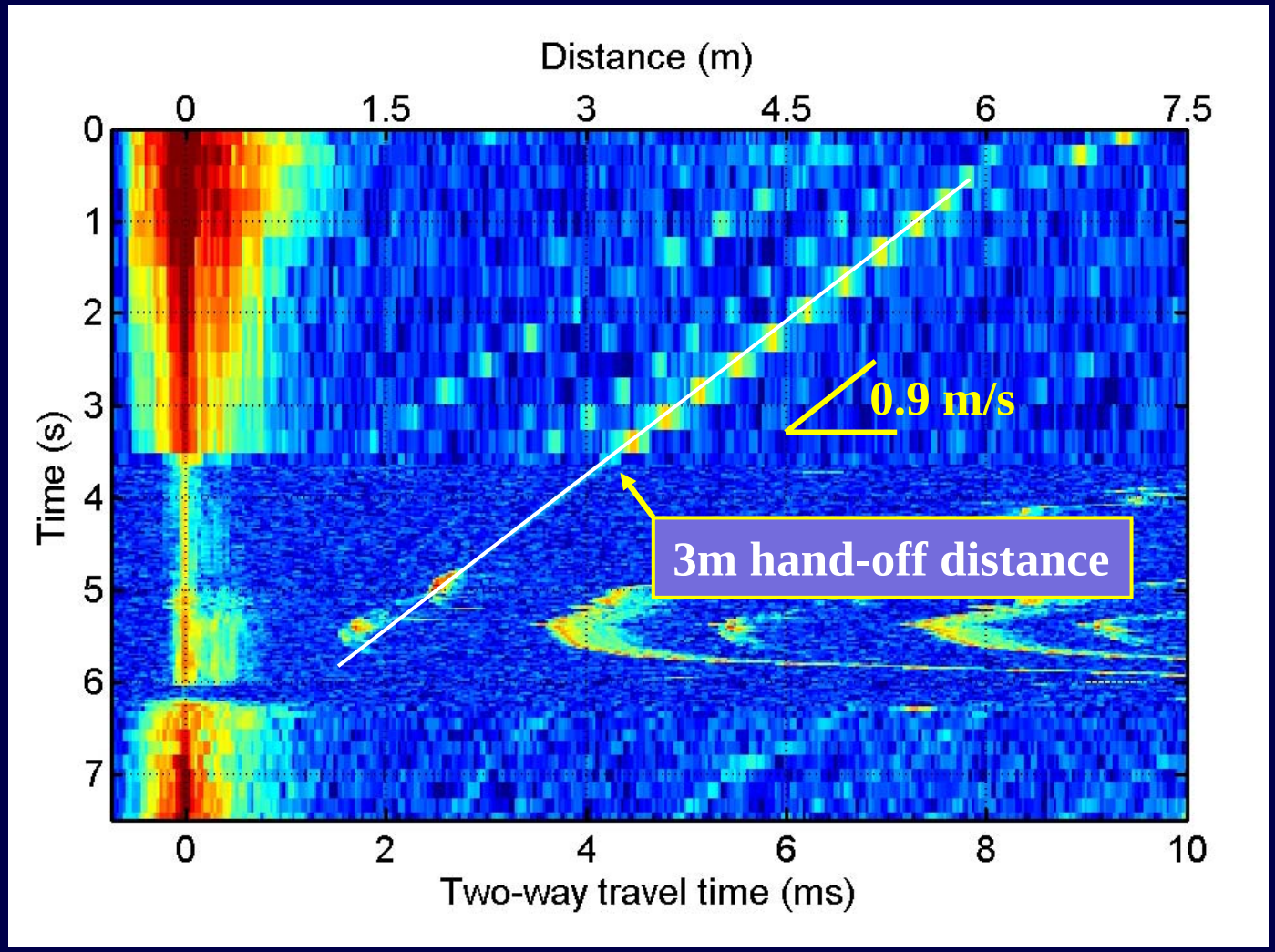


*change in 3-D orientation per 3s interval

Sudden Movements Occur at Buzzes



Some Echo Sequences Continue into a Buzz



Search

Regular clicks

Approach

Buzz

Capture