Measuring the Population Health of Sonar Exposed Beaked Whales, an Energetics Approach

Friday 12 August, 2011

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Diane Claridge
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A new study suggests that beaked whales—the size of a rhino and the weight of a bus—are confused by the presence of wind farms at sea, leading them to beach.

Newsweek
20 March, 2011

Acknowledgements

- Chief of Naval Operations (Dr. F. Stone)
- Office of Naval Research (Dr. Mike Weise)
- National Oceanic Partnership Program (NOPP)
- Strategic Environmental Research and Development Program
- (SERDP)

AUTEC Collaborations:

- Bahamas Marine Mammal Research Organisation (BMMRO)
- Cascadia Research Collective
- University of St. Andrews
  - Sea Mammal Research Unit (SMRU)
  - Centre for Environmental and Ecological Modelling (CREEM)
- Marine Mammal Commission
- Scripps Oceanographic Institution
- Woods Hole Oceanographic Institution
- NOAA
- SPAWAR San Diego
- Cornell University
- Duke University
- Oregon State University

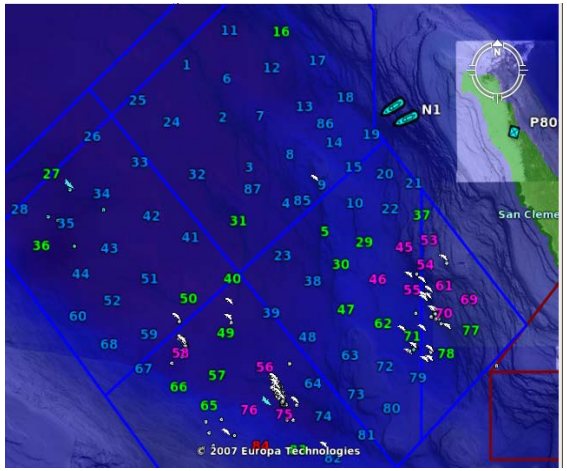
Objectives

- Develop tools for long-term passive acoustic monitoring
- Document the spatial and temporal distribution, movement, and foraging behavior or marine mammals with and without sonar w/ a focus on **beaked whales**.
- Measure the "**Health of Populations**"

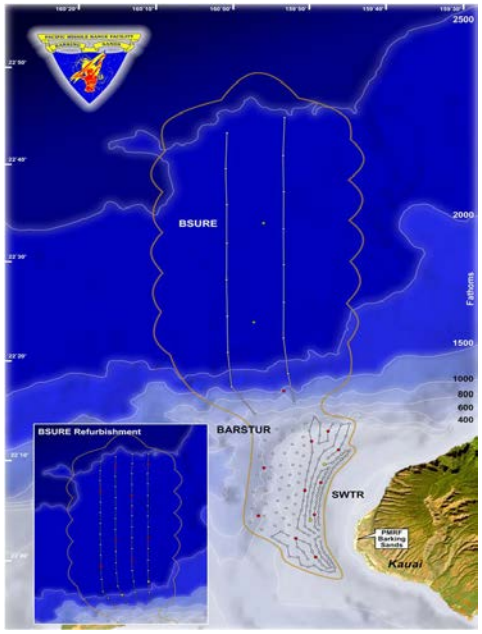
Adult male Blainville's beaked whale (Mesoplodon densirostris)
Courtesy of BMMRO

M3R Study Sites

Atlantic Undersea Test and Evaluation Center (AUTEC)

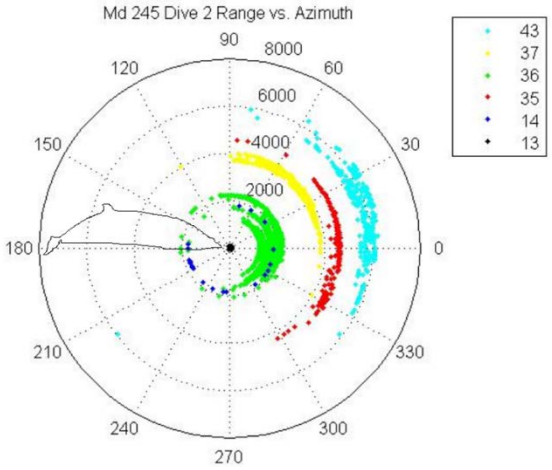


SCORE Sensor Field &
marine mammal posits



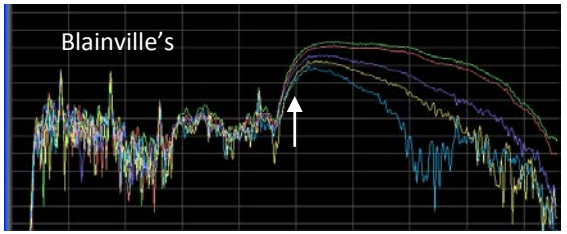
PMRF Sensor Field

Click Characteristics



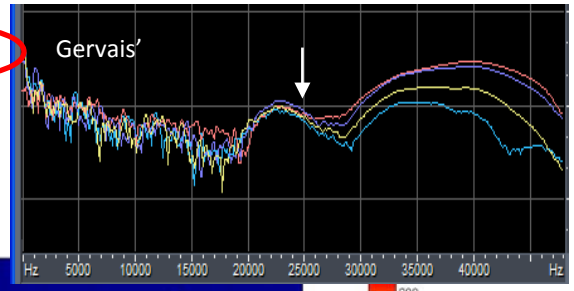
Md Detection Distance and Angle to Hydrophone

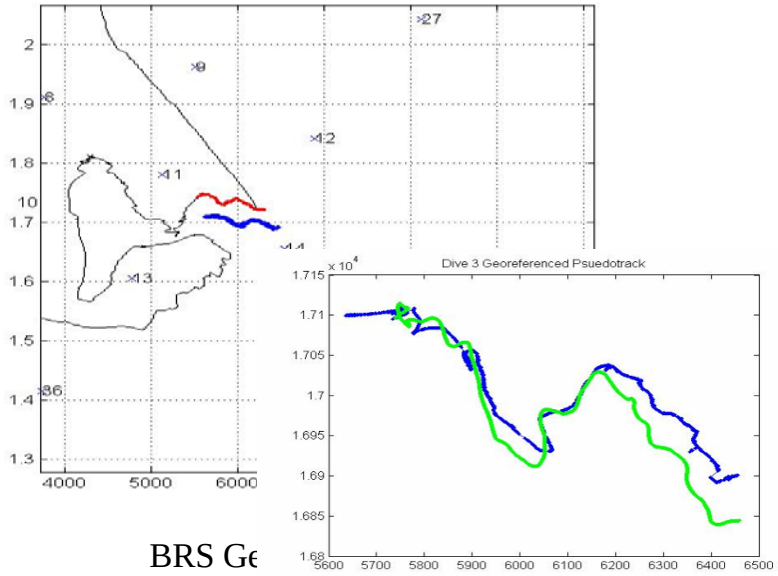
Average	0.303175
Max	0.4813
Min	0.1738
Standard deviation	0.047



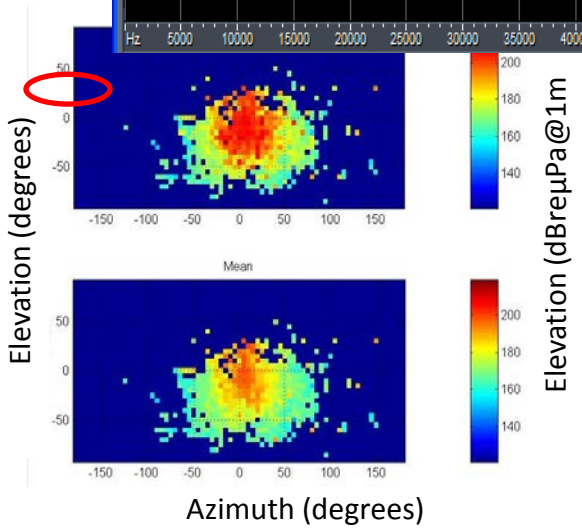
Average	0.543
Maximum	0.679
Minimum	0.392
Standard Deviation	0.067

Average	0.279
Maximum	0.379
Minimum	0.22
Standard Deviation	0.031



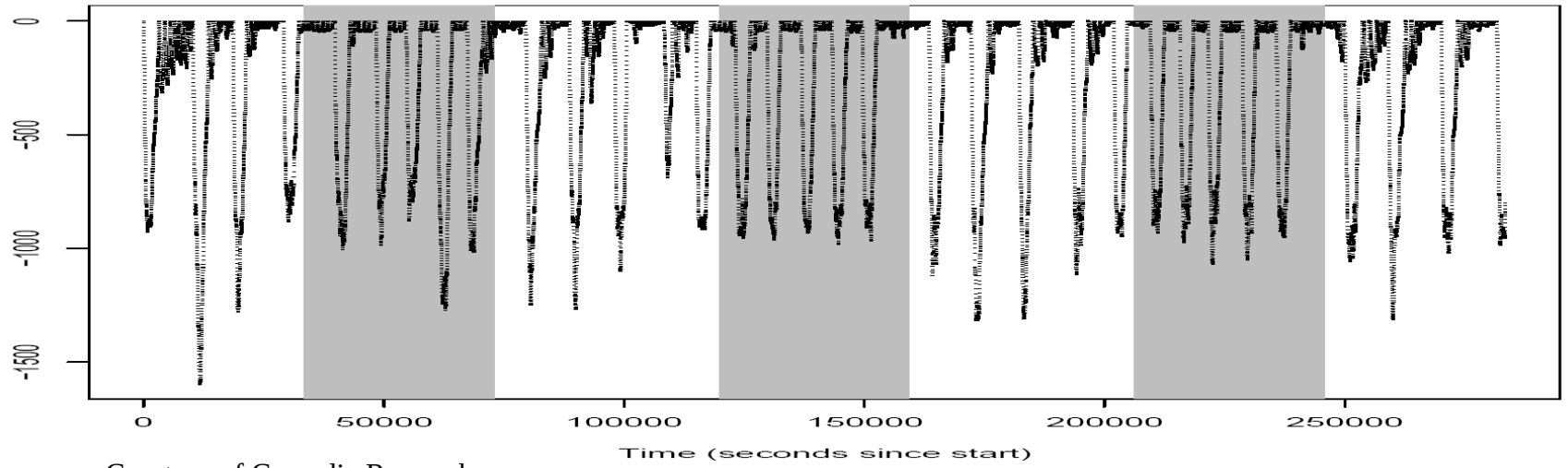


BRS Ge



Md Beam Pattern and Maximum Source Level

Beaked Whale Dive Pattern

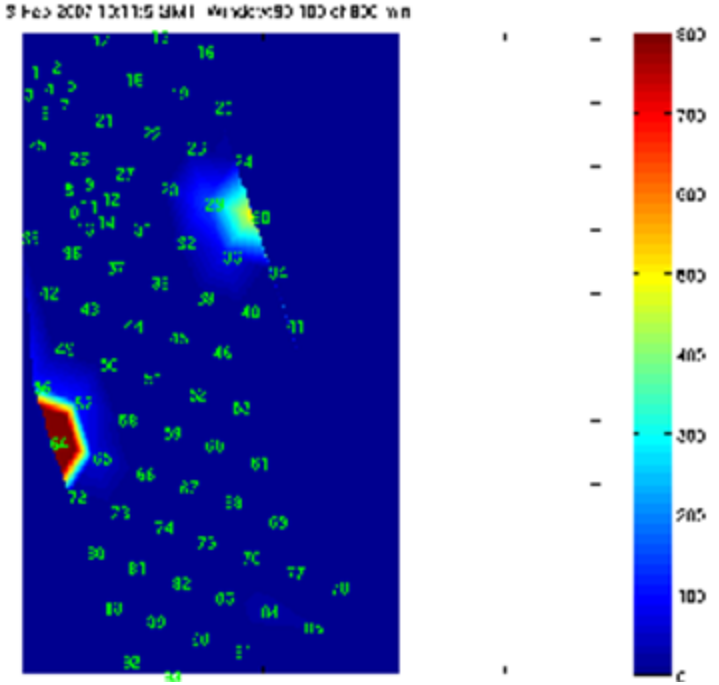


Courtesy of Cascadia Research

•Dives metronomic (Rate established)

•Click produced only during deep foraging dives

•Clicks are loud (>200 db re µPa @ 1m)
- Assume AUTEC phones will detect vocalizing groups



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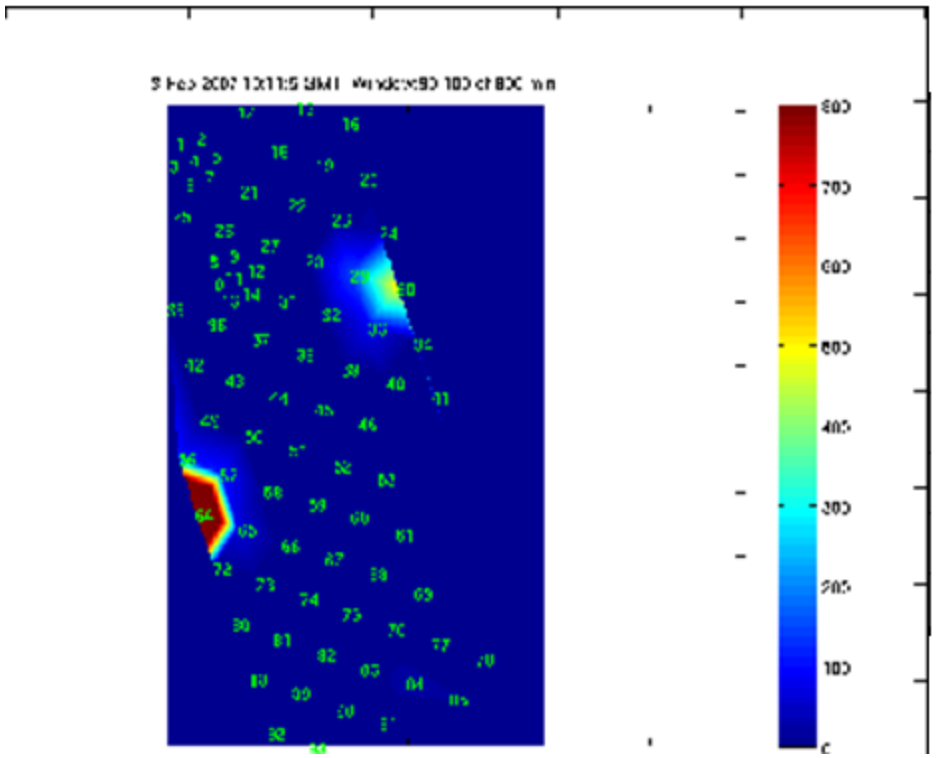

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The Effect of Sound on Md

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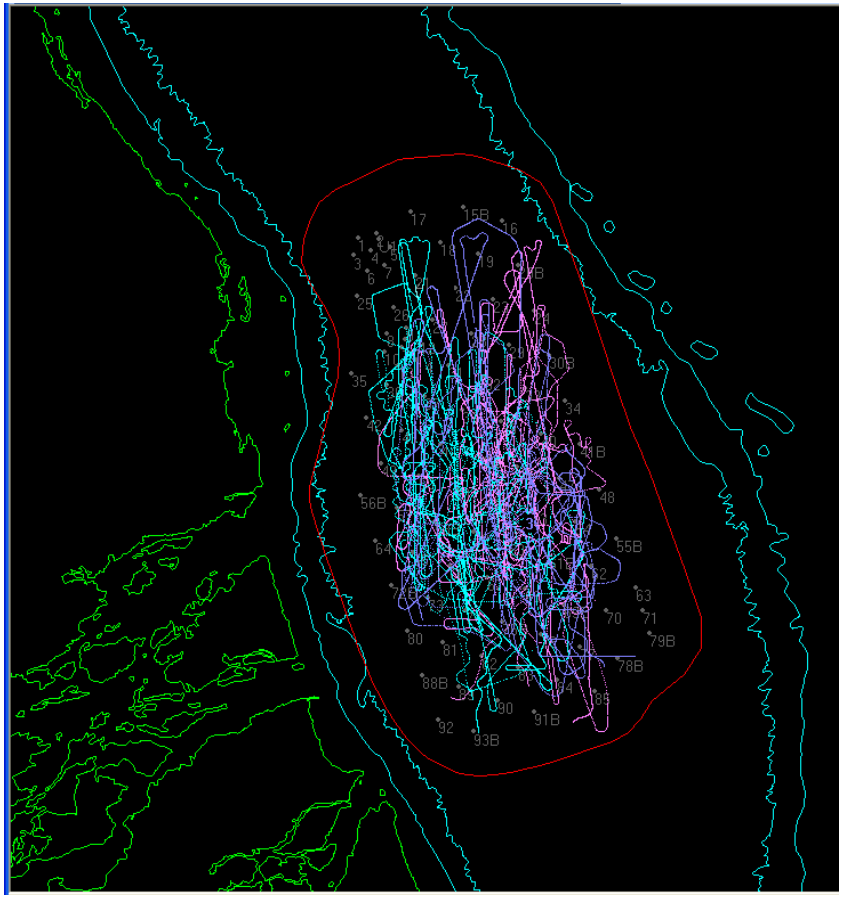
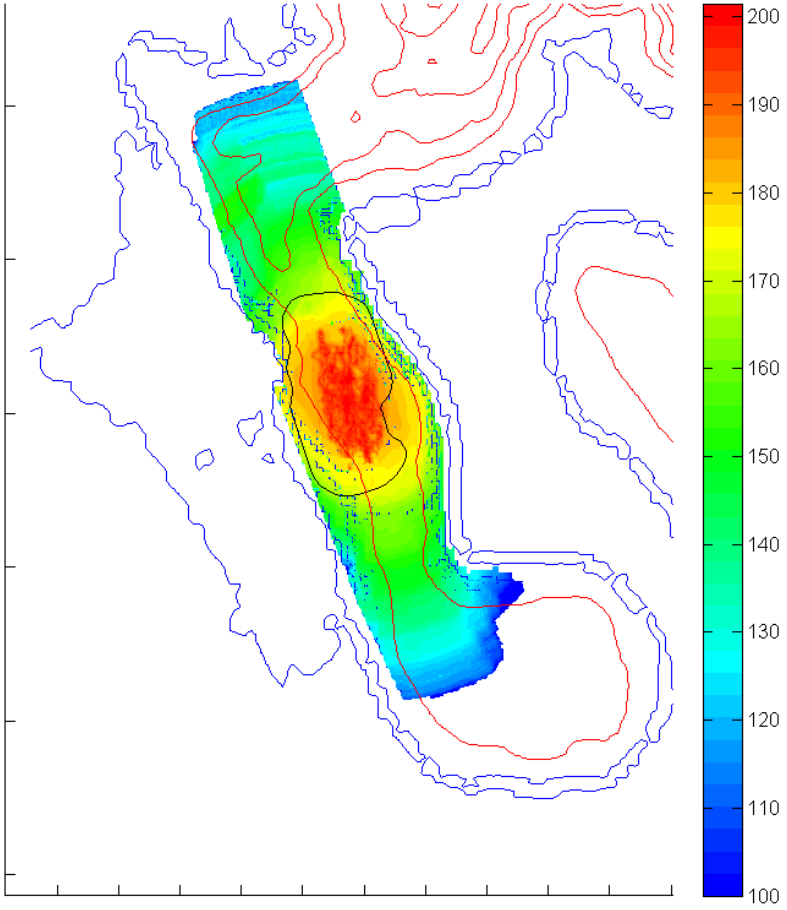
AUTEC 3-days of ship track and integrated energy





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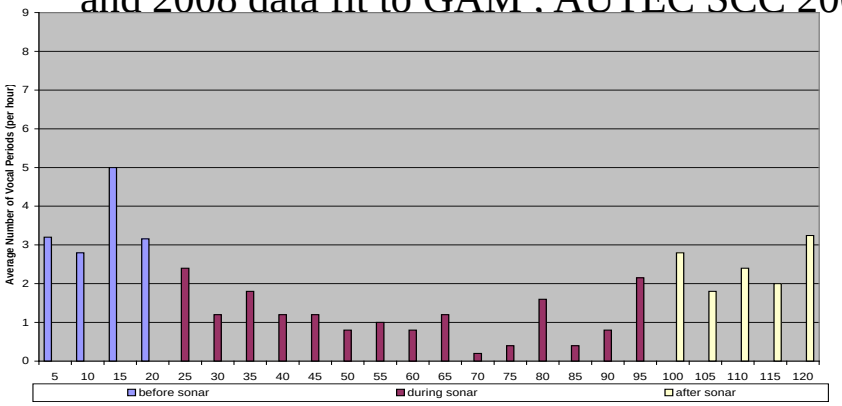
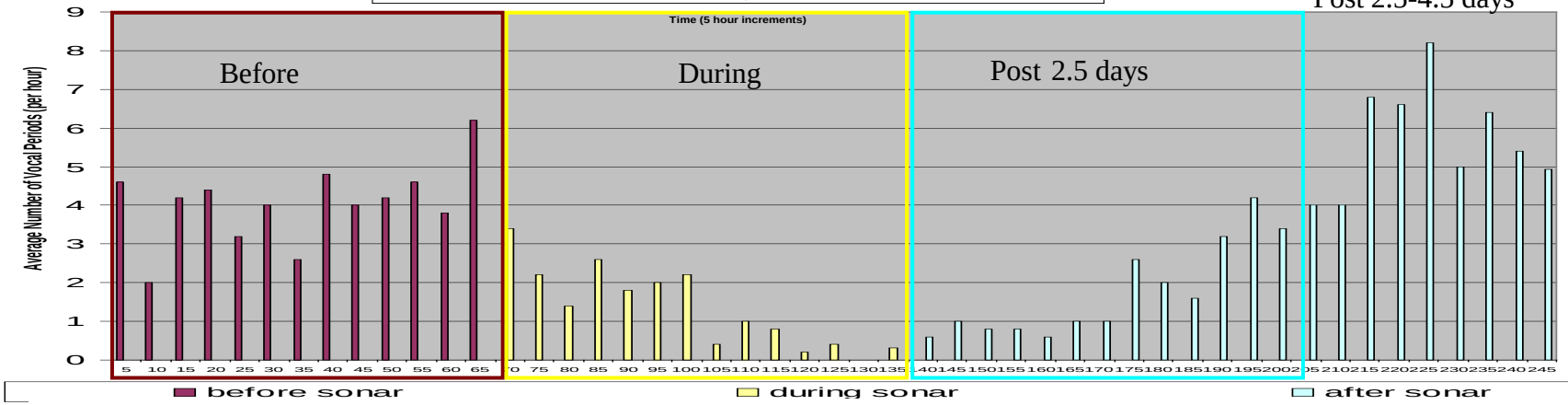
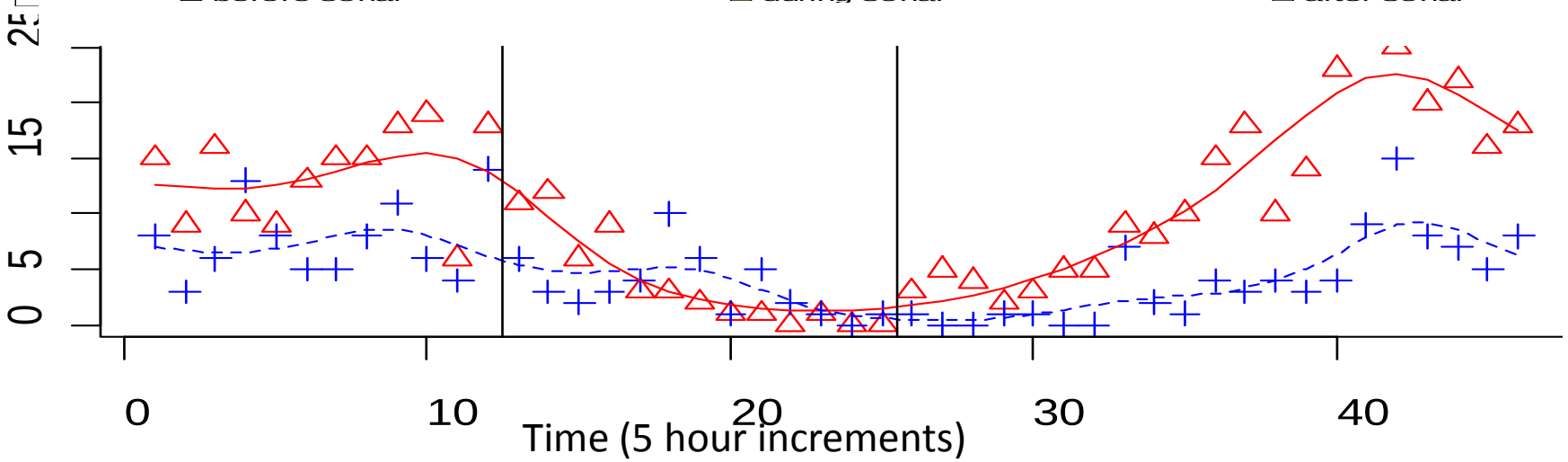
Histogram Group Vocal Periods/5 hr. Before, During, and AfterMid-Frequency SONAR Exercises and 2008 data fit to GAM : AUTEC SCC 2007/2008



Post 2.5-4.5 days





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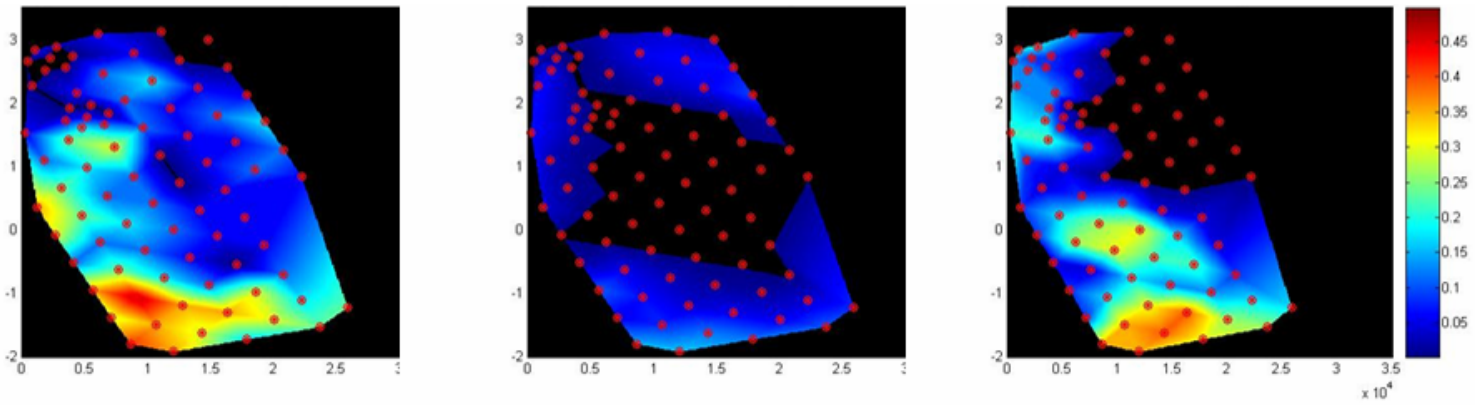
Average Number Of M. Densirostris Vocalizations Per Hour During 2007/2008 during a Multi-Day, Multi-Ship Sonar Exercise

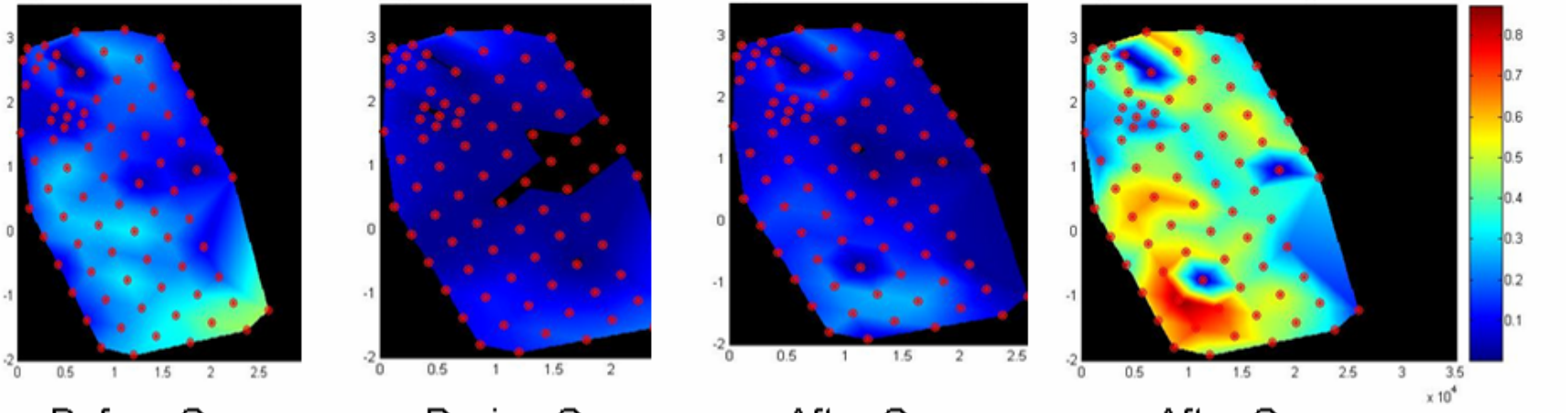


Before Sonar
(0-17 hours)

During Sonar
(17-92 hours)

After Sonar
(92-115 hours)

average number of M. densirostris vocalizations per hour during 2007 SCC



Before Sonar
(0-65 hours)

During Sonar
(65- 130 hours)

After Sonar
(130-195 hours)

After Sonar
(195-240 hours)

McCarthy, E. , Moretti, D. , Thomas, L., DiMarzio, N., Dilley, A., Morrissey, R., Ward, J., Jarvis, S., 2010, Changes in Spatial and Temporal Distribution and Vocal Behavior of Blainville's Beaked Whales (Mesoplodon densirostris) during Multi-Ship Exercises with Mid-Frequency Sonar, Marne Mammal Science, 2010

SCC-08 An Estimate of Blainvilles Beaked Whale Abundance
Marques Dive Counting Method

NAVSEA NEWPORT Undersea Warfare Center Division

Before sonar	
hrs prior to sonar	65
Dive Starts	263
Density, animals/km²	18

During sonar	
hrs during sonar	68.13
Dive Starts	93
Density, animals/km²	5

65 Hours Post Sonar	
hrs of recovery	65
Dive Starts	114
Density, animals/km²	9

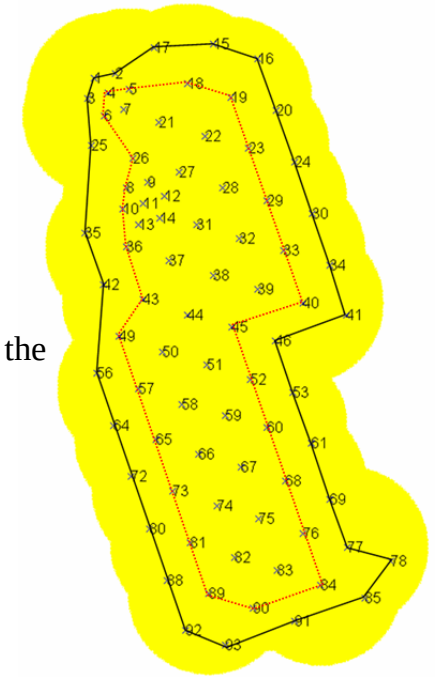
>65 Hours Post (43 hrs)	
hrs of post recovery	43.25
Dive Starts	248
Average number of Md in Recovery/Density	27

$$N = \frac{sg}{dTA}$$

s = total number of dive starts
g = average group size
d = dive rate (dives/unit time)
T = measurement period
A = measurement area

•Dive rate for Blainville's beaked whale at AUTEC derived from BRS07 WHOI DTags 6, 7 & 8

- Dive Rate = 0.432 Dives / Hour
- Average Group Size = 2.62 Animals**
- Measurement Area = 1291 km²

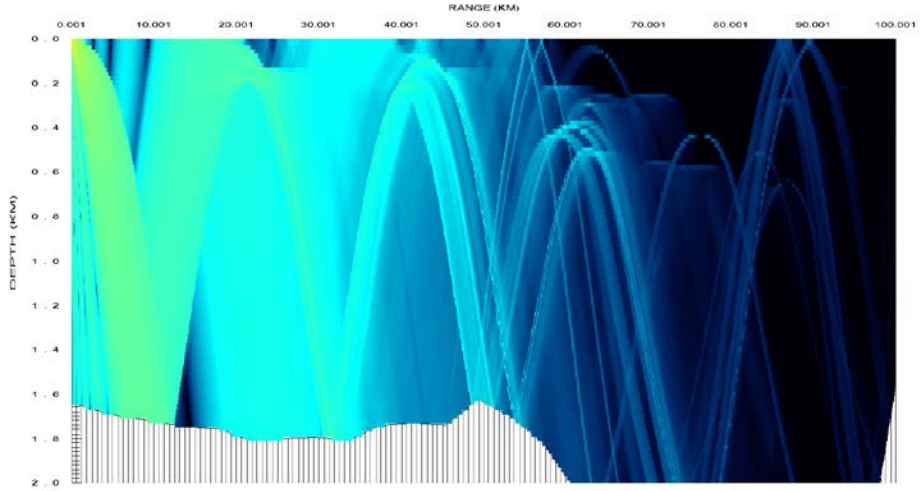


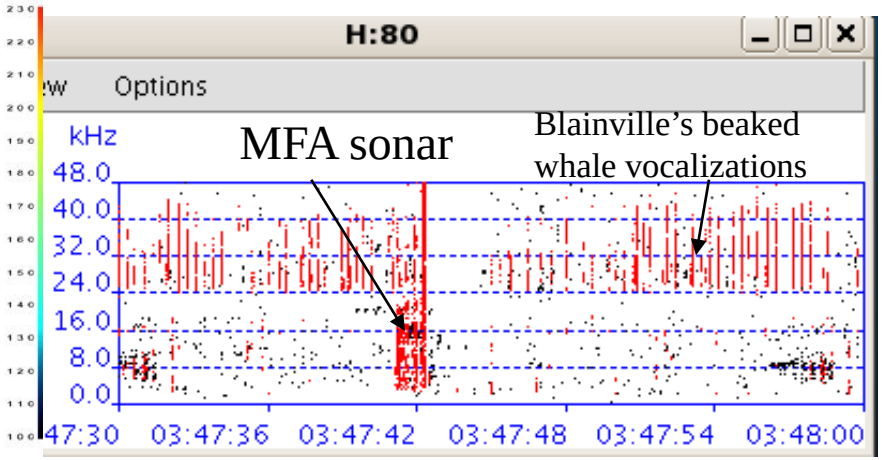
*If dive rate is higher in "post recovery" the average number of animals will be over-estimated

**Courtesy of D.Claridge/C. Dunn BMMRO

Moretti, D., T.A. Marques, L. Thomas, N. DiMarzio, A. Dilley, R. Morrissey, E. McCarthy, J. Ward, S. Jarvis, 2010 A dive counting density estimation method for Blainville's beaked whale (*Mesoplodon densirostris*) using a bottom-mounted hydrophone field as applied to a Mid-Frequency Active (MFA) sonar operation. Applied Acoustics. 71 (11), pp1036-1042

Receive Level at Animal During Actual Active Event





Example

- Foraging clicks continued for 6 minutes after exposure

  RL= ~ 140 dB (CASS/GRAB estimate)

  (4.5 – 8 kHz, n=17)

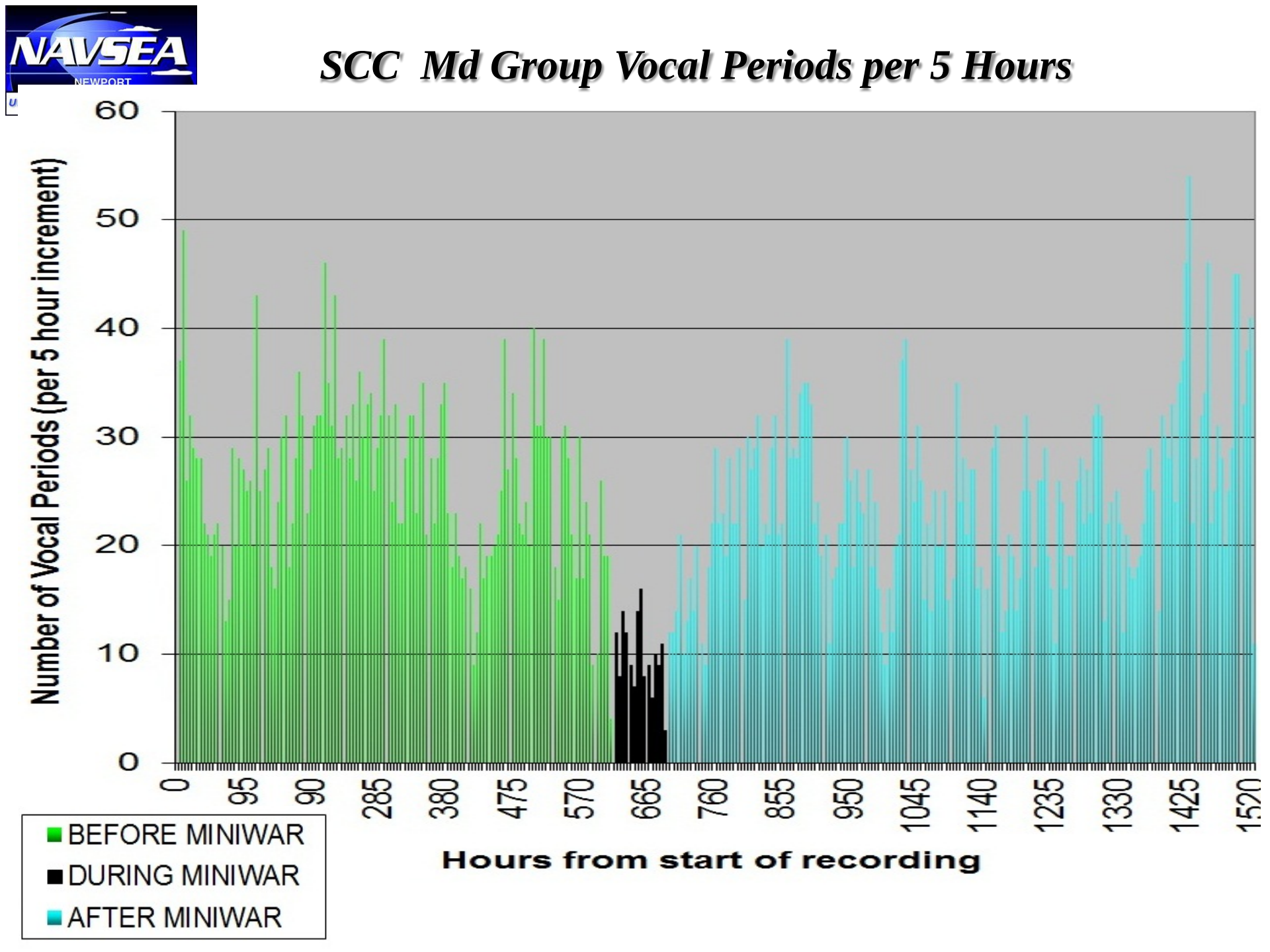
- Average Rx level = 129.6 dB

  (3.5 kHz, n=)

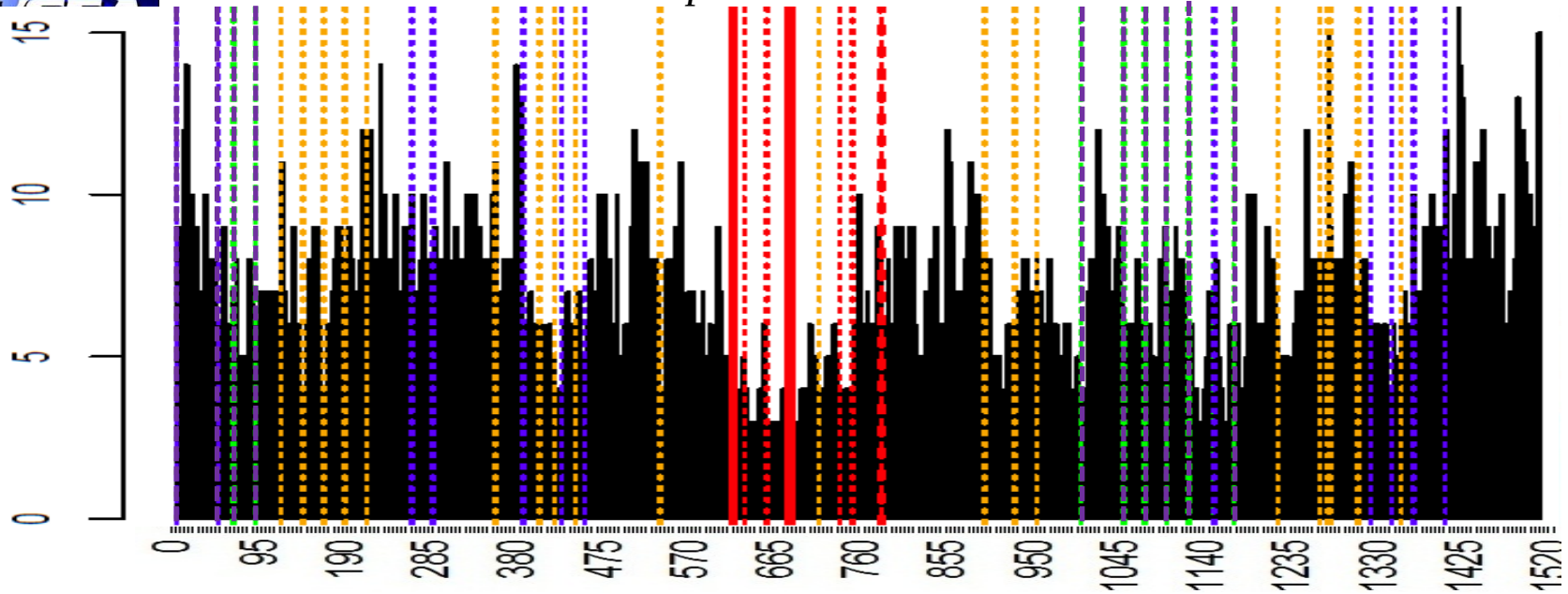
- Average Rx Level =130.25

	Source Freq (kHz)	Range (m)	Bearing (true)	Receive Level (dBreuPa)	Vocal Period (min)	Exposure Duration (min)	Edge Phones Only (E)
case2-07	17.5	7718	195	44	23	23	E
Case2	8	21391	7	114	8	8	E
case13	8	12586	229	126	20	20	E
case14	8	11354	159	129	8	8	E
case3	3.5	18193	263	133	19	19	E
case12	8	7011	135	143	30	22	E
case4	8	25216	352	112	28	28	
case7	8	12212	228	117	26	10	
case8	4.5	24311	338	117	36	36	
case6	8	21101	177	118	31	13	
case3-07	8	28853	348	124	21	12	
case1	3.5	18976	327	127	26	4	
case4-07	3.5	18117	335	128	37	37	
case9	8	10983	161	131	21	7	
case5	3.5	14727	215	133	29	29	
case1-07	8	7612	291	141	35	7	
case10	4.5	3416	259	154	26	26	
case11	4.5	2161	44	157	20	17	

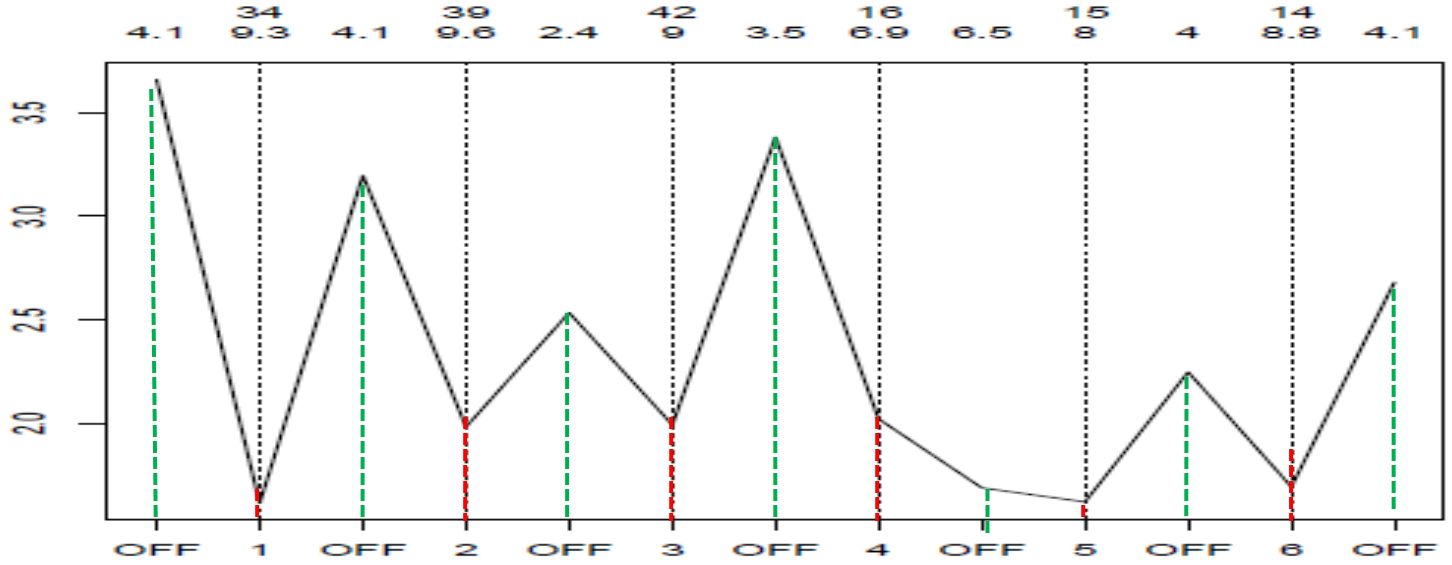
SCC Md Group Vocal Periods per 5 Hours



Group Vocal Periods vs. Active Events

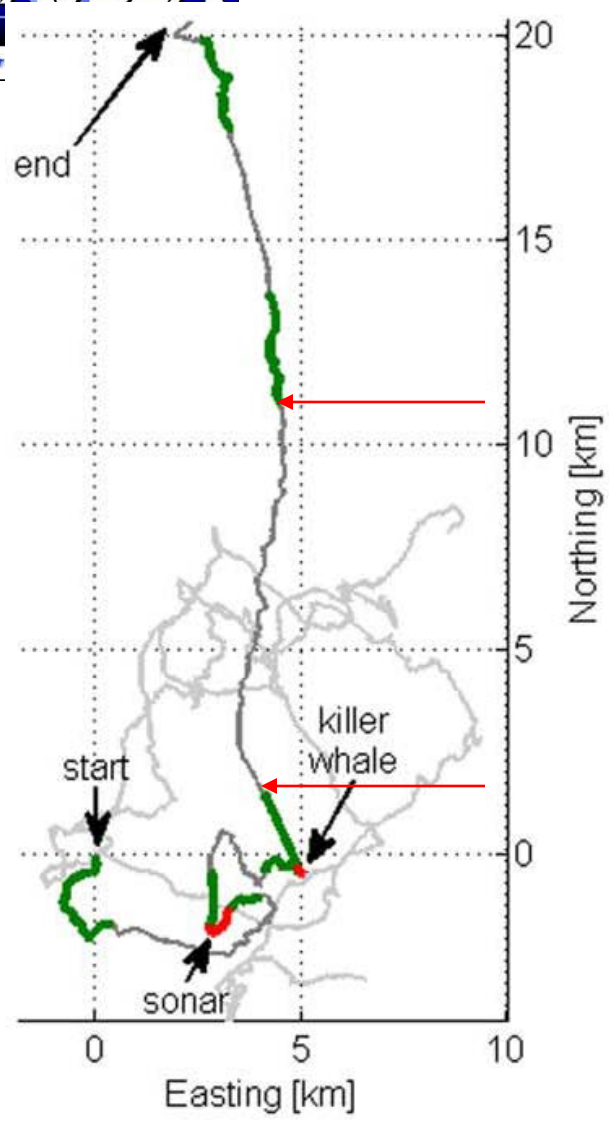


Number of Group Vocal Periods in 5 hr. intervals vs. hours. Multi-ship sonar exercise bounded by bold red lines with last level 3 event (53C) in bold dashed red. Dashed vertical lines indicate level 1, 2, 3 events in purple, orange, and red. (<175, 175-230, >230 dB). 63hr total duration.



Courtesy of T. Marques (LATTE)

Mean Number of Group Vocal Periods during active exercises (red) and quiet periods (green) between each event over 3 days exercise



Dive Rate: AUTEC Tag

	playback included		playback excluded	
mean interval (samples/minutes)	52079.13	173.60	47760.79	159.20
No. of animals	5		4	
No. dive intervals	24		19	
Standard Dev (samples/minutes)	23911.54	79.71	22067.92	73.56
95% CI	9772.19	32.57	9922.76	33.08
dives/24 hours	8.30		9.05	
95% CI	+/-1.36		+/-1.38	

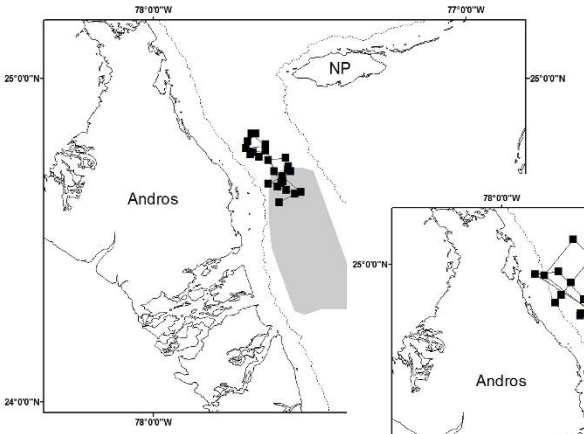
Number Play

Killer Whale Playback to next foraging dive = 4.8 hrs

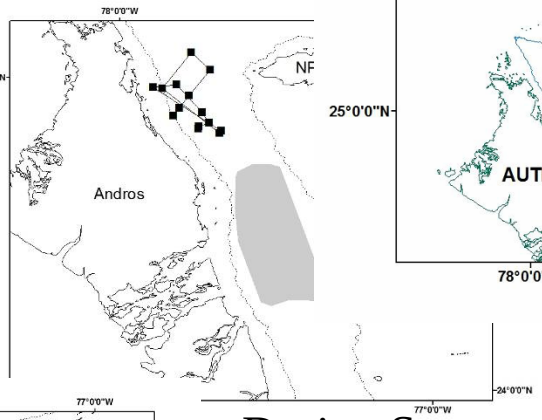
From DTag animals:

- 9.05 dives/24 hrs
- 1 dive/2.7 hrs
- 1 missed foraging dive
- Travel Speed = 1.73 km/hr post orca exposure
- Travel Speed = 2.27 km/hr dive 1 to dive 2
- Range Width ~= 22 km
- Max distance to edge = 11 km
- Travel time to range edge = 4.85 hrs @ 2.23 km/hr
- 1-2 missed dives (assuming BRS07 response)

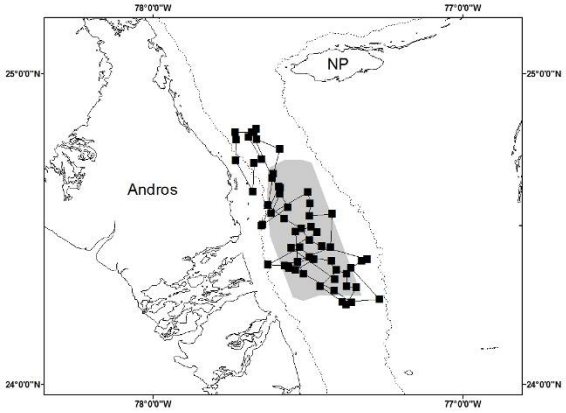
ARGOS Satellite Tag s



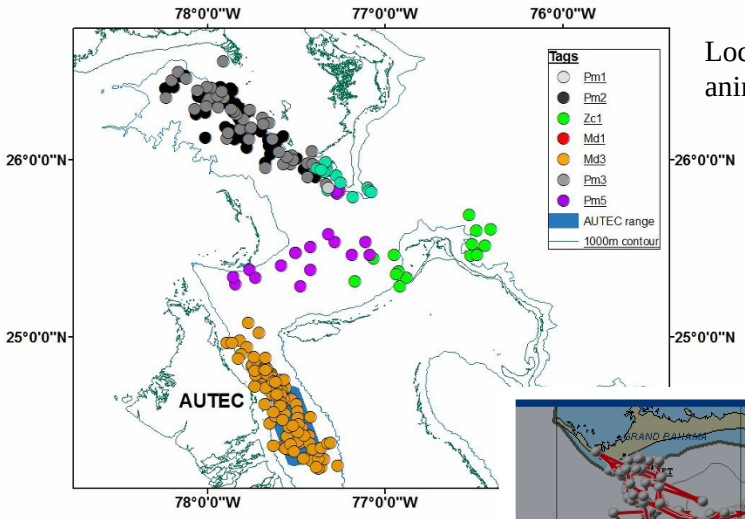
Before Sonar



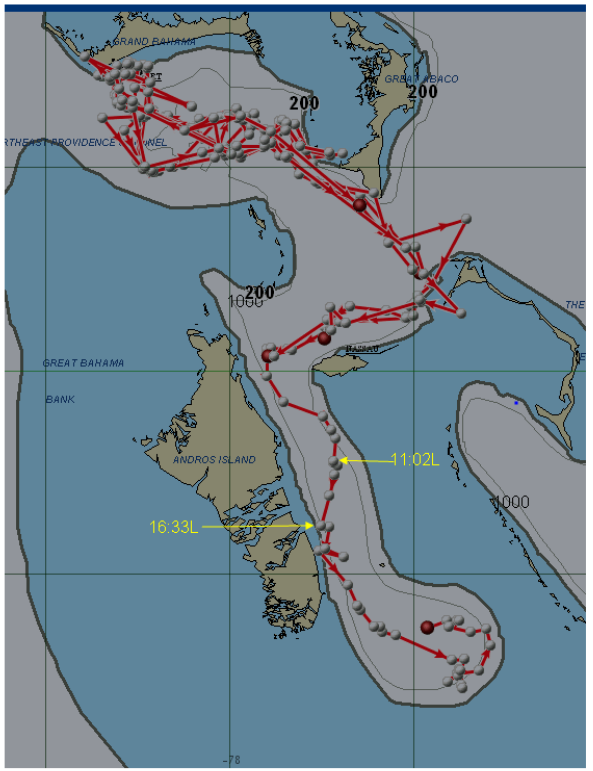
During Sonar



After Sonar



Localizations for all tagged animals, May 2009



November 2009 pilot whale sat tag with transition times through active sonar event indicated in yellow

Md May 2009

Plots courtesy of John Durban, NOAA SWFS

Beaked whales 'scared' by navy sonar

BBC-Earth News
Ella Davies
14 March, 2011

Sonar soundwaves 'drive terrified whales to their death onshore‘

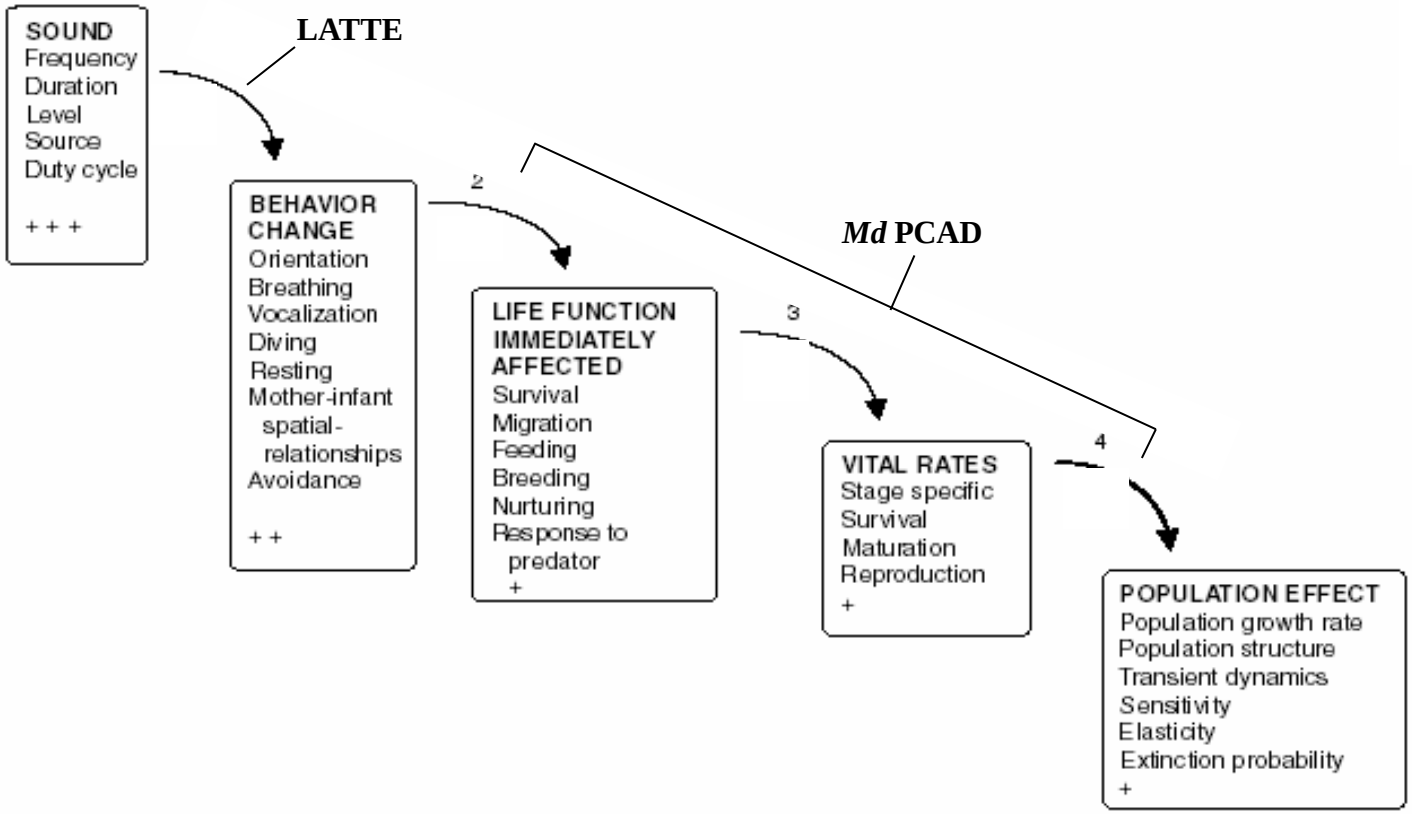
Mail Online
David Derbyshire
15 March, 2011

“Distressing: Researchers have found that sonar, wind turbines and gas and oil drilling can drive some beaked whales to come to the shore (file picture)”

Quest for the Holy Grail: Population Health

Develop PCAD model to predict population health Informed by

- M3R/BMMRO/NOAA (Claridge/Durban/Pittman) species verification tests with tags around SCC events.
- Behavioral Response Studies
- BMMRO observational study (Note Abaco population as means of comparison.)
- BMMRO/NOAA Sat tags and biopsy studies
- LATTE – Linking Acoustic Tests and Tagging using statistical Estimation: Modeling the Behavior of Beaked Whales in Response to Medium Frequency Active Sonar



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Md PCAD BasicProposed Methodology

- Foraging only occurs during deep dives (Johnson, Madsen, & Zimmer, 2006). Therefore, the number of deep dives per day can be used as a proxy for energy gain.

- The energetic gain required from each of these dives calculated from an estimate of daily energy requirements for adult females in different reproductive states (resting, pregnant, lactating, lactating and pregnant).

- Madsen et al. metabolic rate figure for Md will be used to provide baseline estimates of energy requirements for resting adult female Md and their calves.

- Must consider weight of animals, and additional daily costs of pregnancy and lactation (Lockyer 2007)

- Passive acoustic data used to estimate frequency and duration of disruption throughout the year to estimate total yearly disruption and total energy cost to adult females.

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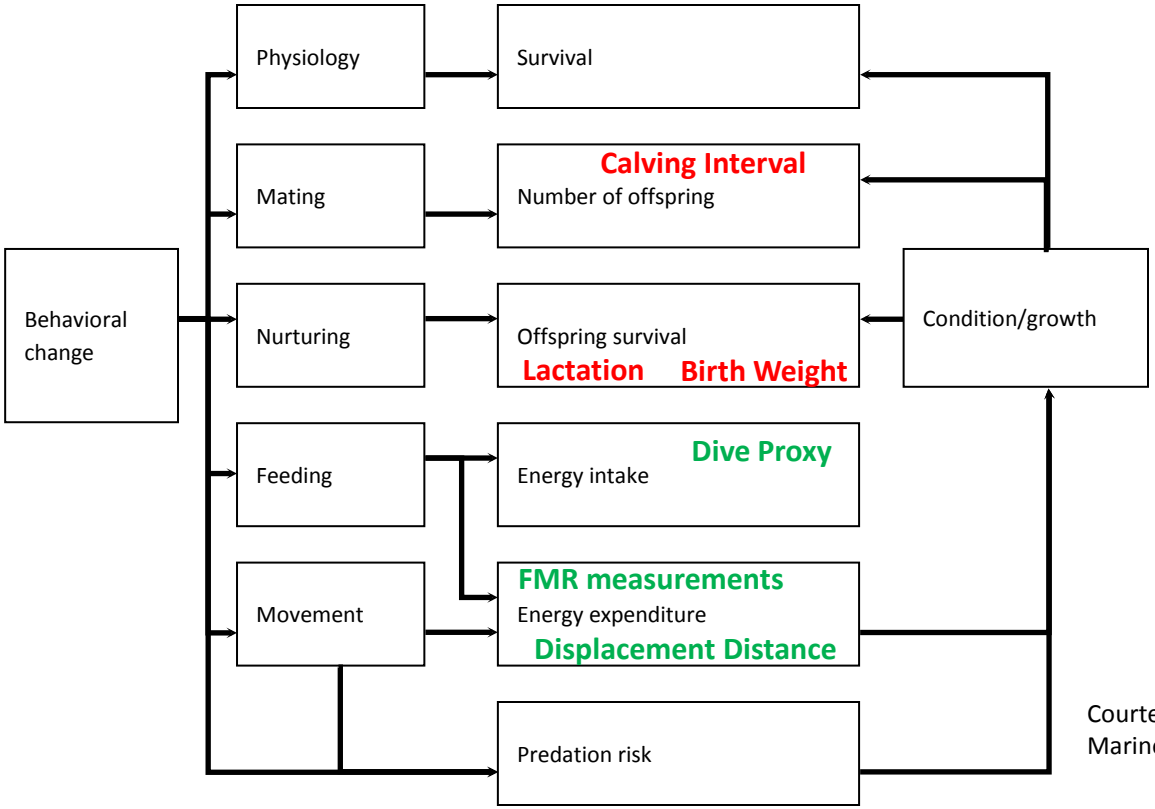
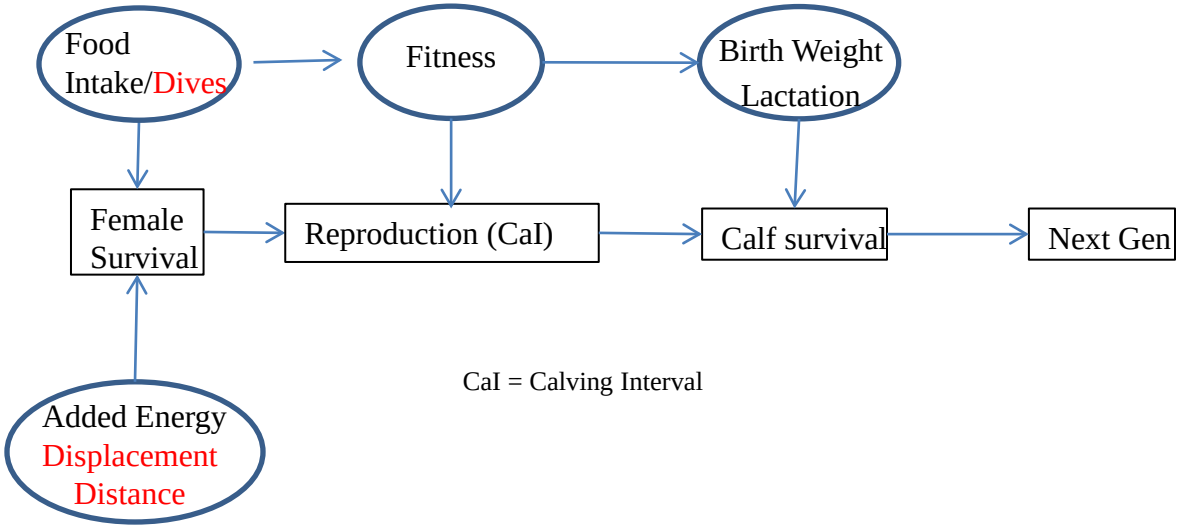
On-Going Data Collection

- Acoustic Directed/Open Ocean Species Verification Test w/ Sat Tags
  - Sat-tags w/ depth
    - baseline movement/foraging
    - movement/foraging with sonar exposure
  - Visual Observations
    - age/class structure
    - group behavior tied to acoustics
      - mother/calf diving behavior
      - gestation period
      - time to weaning
  - Photo IDs for age/class structure
  - Biopsy
    - DNA
    - Adipose tissue (site fidelity)
    - Hormone (reproduction/stress)



Courtesy of Leslie New
Marine Mammal Commission



CaI = Calving Interval

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Questions

Reaction

- Degree of avoidance?
- Foraging?
- Prey distribution?

Affect

- Change in calorie intake?
- Female fitness?
- Inter-calf interval?
- Birth weight?
- Change in Lactaion?
- Calf survival?

Validation

Take Aways

Results

- Significant Beaked whale populations identified on Navy ranges which are areas of repetitive sonar use
  - AUTEC [Blainville's beaked whale (Mesoplodon densirostris)]
  - SCORE [Cuvier's beaked whale (Ziphius cavirostris)]
- No known reported mass strandings at AUTEC or SCORE
- Animals appear to exhibit avoidance behavior to Mid-Frequency Active (MFA) sonar at levels <140 dB re μPa @ 1m
- Animals appear to return after cessation of operations

AUTEC ≠ N.W. Providence Channel
Why?

GOAL

- Linking data to effect
  - Estimate of number of affected animals through long-term passive acoustic density estimates
  - Probability of effect (risk curve)

- Long-term Monitoring – "Health of the Population"
  - Informed by: M3R Passive acoustic study
    - Acoustic directed and open ocean observations w/ biopsy sampling
    - Satellite tags with depth
    - Dtagged animals and playback studies (BRS/SOCAL)
  - Requires linking effect disuption on female reproduction

Beaked whales 'scared' by navy sonar

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Sonar soundwaves 'drive terrified whales to their death onshore‘

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15 March, 2011

“Distressing: Researchers have found that sonar, wind turbines and gas and oil drilling can drive some beaked whales to come to the shore (file picture)”

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15 March, 2011 6:53 A.M.

Wind farms blamed for stranding of whales

The Telegraph

Simon Johnson

“Offshore wind farms are one of the main reasons why whales strand themselves on beaches, according to scientists studying the problem.”

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Undersea Warfare Center Division

17 March, 2011

The Telegraph

Correction: whales and wind farms

Scientists studying why whales strand themselves said yesterday there is no known direct link between those strandings and off-shore wind farms, although the construction of turbines may affect the mammals' behaviour.

2:34PM GMT 17 Mar 2011

Prof Ian Boyd, of the University of St Andrews, said the construction of offshore renewable energy sites is likely to cause some species to move to other areas and to disturb their feeding and reproductive cycles. At present it is not possible to predict precisely how this will affect their populations.

However, he wished to correct a report on this website this week that said there was a proven link between off-shore wind farms and strandings.

The professor said a quotation attributed to him in a press release issued by the university, which discussed strandings related to sonar emissions from naval vessels and which suggested renewable energy sources also contributed to the disturbance of whales, had been taken out of context.

We are happy to make this clear.

NAVSEA
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Undersea Warfare Center Division

15 March, 2011 8:49 AM

Sonar soundwaves 'drive terrified whales to their death onshore'

Mail Online

David Derbyshire

"Distressing: Researchers have found that sonar, wind turbines and gas and oil drilling can drive some beaked whales to come to the shore (file picture)"

16 March, 2011

Science Daily

(Author listed as Staff)

Naval Sonar Exercises Linked to Whale Strandings, According to New Report

Dtag on a beaked whale. (Credit: Photo by Todd Pusser, taken under NMFS permit 14241)

NAVSEA
NEWPORT
Undersea Warfare Center Division

18 March, 2011

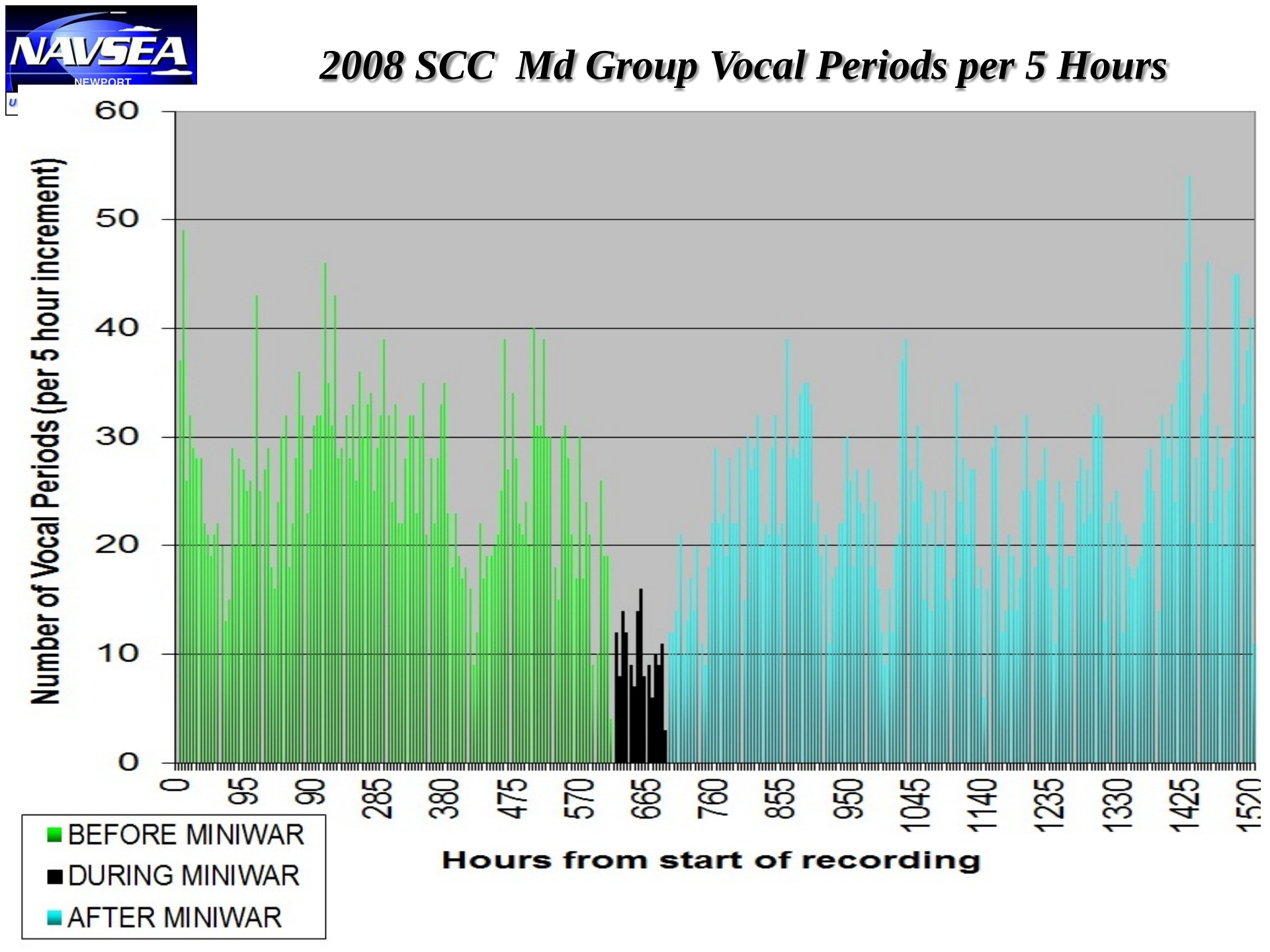
Navy Sonar May Mimic Killer Whale Sounds

John C. Cannon

Science Now (Science online magazine)

Scared by sonar. A speckled Blainville's beaked whale, shown here making a rare trip to the surface for a breath, might mistake Navy sonar for killer whale calls.
Photo Credit: © Robin W. Baird/www.cascadiaresearch.org.

2008 SCC Md Group Vocal Periods per 5 Hours



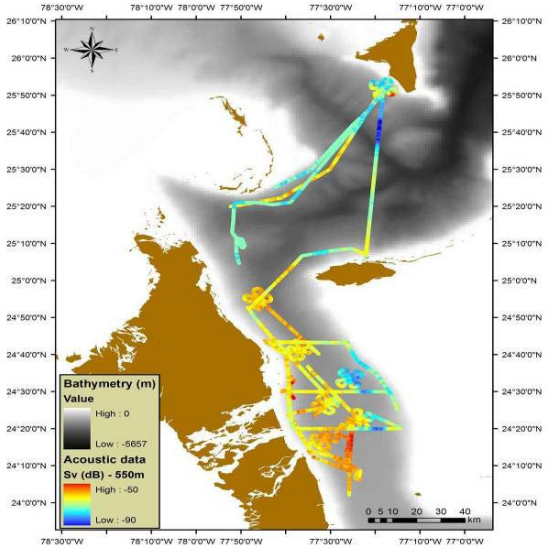
Steps Forward

Moretti, D., T.A. Marques, L. Thomas, N. DiMarzio, A. Dilley, R. Morrissey, E. McCarthy, J. Ward, S. Jarvis. November, 2010. “A dive counting density estimation method for Blainville’s beaked whale (Mesoplodon densirostris) using a bottom-mounted hydrophone field as applied to a Mid-Frequency Active (MFA) sonar operation,” Applied Acoustics 71 (11), pp1036-1042.

Marques, T., L. Thomas, J. Ward, N. DiMarzio and P. Tyack. 2009. “Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales,” J. Acoust. Soc. Am. 125 (4), April 2009.

Initial analysis of prey mapping data completed
(E. Hazen, D. Nowacek)

Hazen EL, Nowacek DP, St. Laurent L, Halpin PN, Moretti DJ (2011) The Relationship among Oceanography, Prey Fields, and Beaked Whale Foraging Habitat in the Tongue of the Ocean. PLoS ONE 6(4): e19269. doi:10.1371/journal.pone.0019269



NAVSEA
NEWPORT
Undersea Warfare Center Division

20 March, 2011

Is There Any Safe Energy?
Newsweek

WIND

For producing clean, renewable energy, wind farming has many proponents. Animals aren't among them. A new study suggests that beaked whales—the size of a rhino and the weight of a bus—are confused by the presence of wind farms at sea, leading them to beach. Birds too find wind farms to be killers. The wind turbines in California's Diablo Mountains chop up thousands of birds a year, including golden eagles and red-tailed hawks. Critics point out that wind power hasn't lowered carbon-dioxide emissions in countries where farms are prevalent.

NAVSEA
NEWPORT
Undersea Warfare Center Division

23 March, 2011

Navy Sonar Chases Whales Away

Kieran Mulvaney

Discovery News

NAVSEA
NEWPORT
Undersea Warfare Center Division

14 March, 2011

Beaked whales 'scared' by navy sonar

BBC-Earth News
Ella Davies

NAVSEA
NEWPORT
Undersea Warfare Center Division

Md PCAD BasicProposed Methodology

- Foraging only occurs during deep dives (Johnson, Madsen, & Zimmer, 2006). Therefore, the number of deep dives per day can be used as a proxy for energy gain.

- The energetic gain required from each of these dives calculated from an estimate of daily energy requirements for adult females in different reproductive states (resting, pregnant, lactating, lactating and pregnant).

- Madsen et al. metabolic rate figure for Md will be used to provide baseline estimates of energy requirements for resting adult female Md and their calves.

- Must consider weight of animals, and additional daily costs of pregnancy and lactation (Lockyer 2007)

- Passive acoustic data used to estimate frequency and duration of disruption throughout the year to estimate total yearly disruption and total energy cost to adult females.

Md PCAD Complications

- The daily cost of lactation increases as the size of the calf increases. However, the cost of lactation is likely to decrease towards the end of lactation as the calf is weaned.

- The presence of a calf does not constrain its mother's foraging behavior. However, data on *Md* from the Canary Islands suggests that females with young calves make shorter (~10 min) dives than females without calves.

- Animals that leave AUTEC do not feed until they return.

Md PCAD validity of assumptions (1)

Bahamas suggest calves remain with their mothers and continue to nurse for at least 2 years. The rate and proportion of independent feeding is unknown.

Examine captive cetaceans an terrestrial animals

How long after parturition mothers resumes normal foraging is unknown.

BMMRO data indicate very young dive synchronously with social group but it is unknown if they dive to depth.

Click counting or groups with young may verify age of deep dives.

Estimating total time of dive disruption is unknown.

New sat tags with dive records will inform time of disruption

Displace animals may forage with lower success and thus reduced caloric intake

Prey mapping

Dtag analysis

Md PCAD validity of assumptions (2)

Knowledge of "normal" movement patterns, reproductive cycle, reproductive success as a function of body condition is limited.

BMMRO observational studies:

Suggest animals move into and out of TOTO, some maintain multi-year site fidelity

Provide group composition data, age/sex class

Biopsy samples to provide data on their foraging ecology and to determine the degree of genetic separation between animals in Abaco and TOTO.

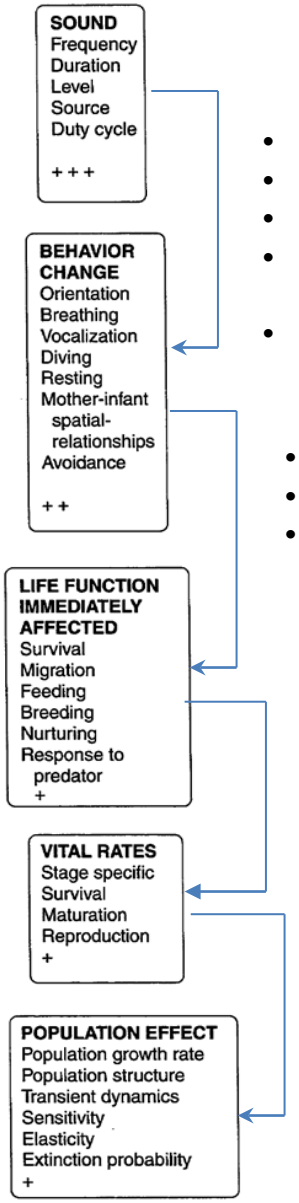
Assumptions regarding weaning:

1. Time to weaning remains constant for disturbed animals. If costs are high may results in compromised calves with lower survival.
2. Disturbed mothers increase duration of lactation period.

BMMRO Abaco study site, for assumption 1, ratio of calves to adult females, and inter-calf interval will be the same in the TOTO (disturbed) and NWPC (undisturbed) populations. The proportion of sub-adult animals in the AUTEC population will be lower

For assumption 2, the ratio of calves to adult females, and inter-calf interval will be lower in TOTO than NWPC.

PCAD Data



- M3R Passive Acoustic Data
- Playback Data (2007, 2008 BRS, 2010 SOCAL10)
- Sat Tag Data (AUTEC, SCORE)
- Observational Data (Group Composition, Mother-calf pairs, Surface Behavior, Photo-ID-Emigration/Immigration)
- Biologics: Fecal/Biopsy sampling (Is AUTEC independent population ?)

- M3R Passive Acoustic Data Density Estimation
- Long-term acoustic data
- Observational (reproduction, migration, etc.)

- M3R Passive Acoustic Data Density Estimation
- Observational (reproduction, migration)
- AUTEC Prey Mapping

- M3R Passive Acoustic Long-Term Data Density Estimation
- Observational (Population Structure)