Effects of sound exposure on the behaviour of toothed whales:
Behavioral Response Study (BRS)

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Marine Mammals and Sonar:
The Need for a Thorough Scientific Approach

- **Marine mammal strandings during/following some sonar training exercises point to a potential problem (under certain circumstances)**

- **High degree of scientific uncertainty regarding these circumstances leads to widely divergent views on the scale of possible adverse impacts; speculation extends to other species**

- **The direct result is the delay or interruption of operations, public misperception, regulatory difficulties, protracted legal wrangling, and mitigation procedures of unknown efficacy**

Are sonar tests harming whales? The Supreme Court weighs in

CNN.com INTERNATIONAL

Narrowing scientific uncertainty regarding the effects of sonar and other sounds on marine mammals (not just beaked whales) is imperative in supporting and improving environmental assessments and science-based mitigation measures related to future operations

BRS Design and Objectives

BRS is not designed to test whether sonar is linked to stranding in certain conditions. Rather, *BRS aims to identify behavioral responses* in several species that may indicate their relative sensitivity to, and susceptibility to harm from, sonar.
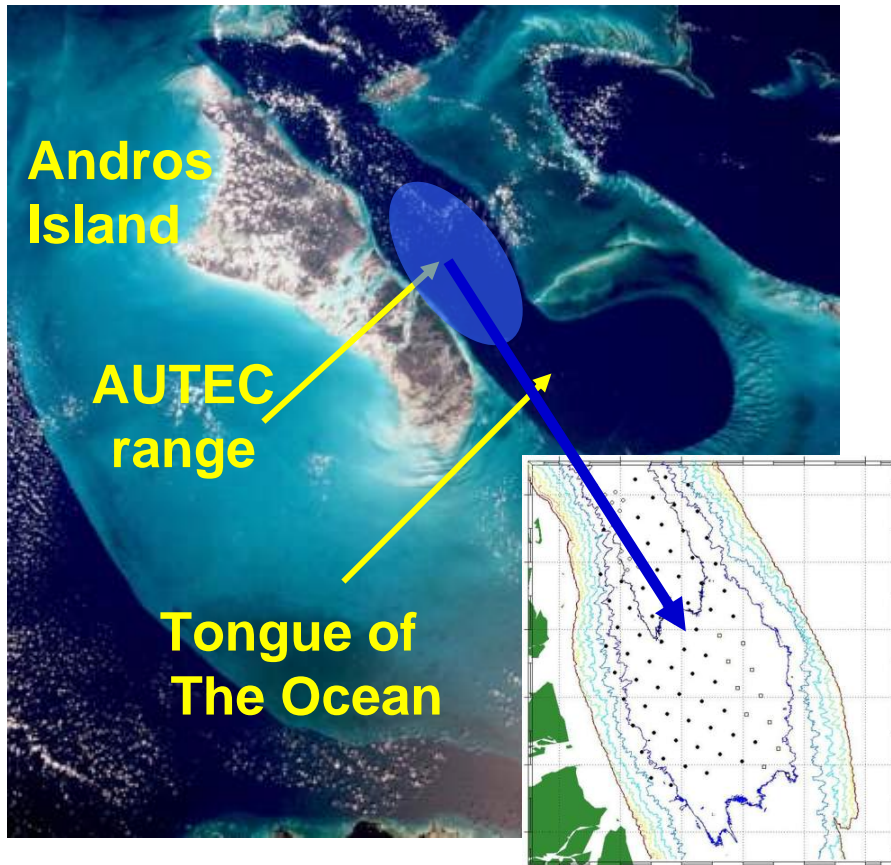
BRS Objectives: Reducing Scientific Uncertainty on Key Questions

– What is the causal link between sonar exposure and stranding?

– Does it extend to other stimuli and other species?

– Does knowledge of cause suggest mitigation measures?

– Is there a dose:response relationship between exposure and risk of stranding?

– If not, is there another relationship, perhaps relating to exposure context?
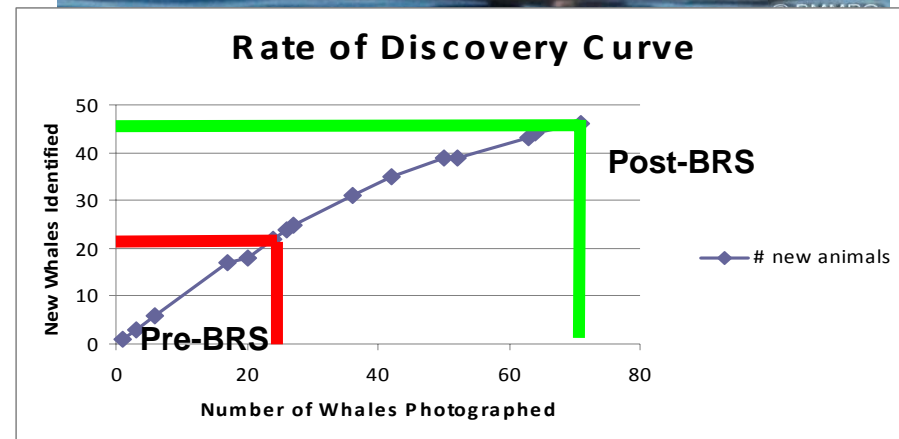

md08_271a - 27 September 2008 - PRN Exposure Levels
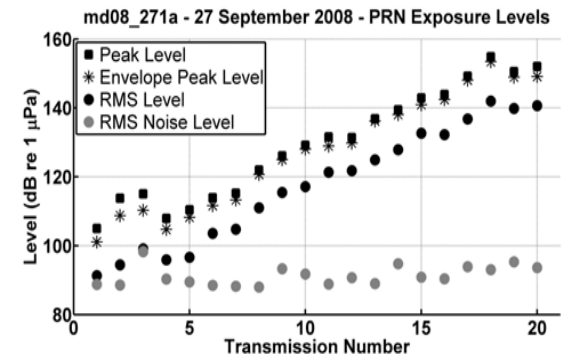
Field Site: AUTEC, Bahamas

Critical Enablers: Real time passive acoustic monitoring, on-going marine mammal research efforts

Andros Island

AUTEC range

Tongue of The Ocean

82 hydrophones cover ~ 600 sq mi

23-Aug-2007 (Md517)
© BMMRO

3-Jun-2006 (Md517)

Rate of Discovery Curve

Post-BRS

Pre-BRS

New Whales Identified

Number of Whales Photographed

new animals

BRS Basic Methodology (A-B-A)

- (*A: no exposure*) **Using various sensor platforms (acoustic tags on individual animals, visual observers, bottom-mounted and/or towed hydrophones), measure the behavior of cetaceans** *before sound exposure*

- (*B: exposure*) **Present various test and control sounds in a controlled manner to individuals under observation; measure responses** *during exposure* **for comparison with baseline conditions**

- (*A: no exposure*) **Measure behavior of animals** *after sound exposure*; **compare with observations during baseline (pre-exposure) and exposure periods**
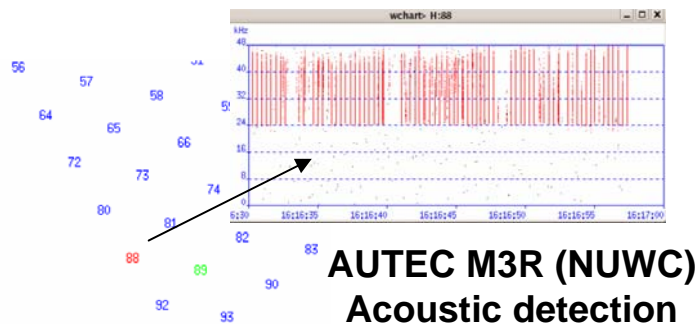
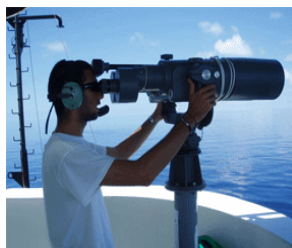# BRS Deployments and Multidisciplinary Team at AUTEC (2007 & 2008)

2007: 14 Aug to 27 Sept using AUTEC vessel *Ranger*; operating out of AUTEC base

2008: 18 Aug to 2 Oct based aboard UNOLS R/V *Roger Revelle* (27 functional days available; 12 days evacuated due to weather)
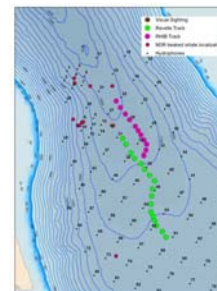

AUTEC M3R (NUWC) Acoustic detection

Source transmissions (NUWC (07); SSC-PAC (08))

Visual observations (Multi-national team)

Tagging and DTag data retrieval (WHOI)


GIS & data mgmt (SSC-PAC)

Photo ID& Behavioral Observations (BMMRO)

Combined BRS Achievements (2007-08)

- **16 tags deployed on four species – 6 on pilot whales, 7 on beaked whales, 2 on false killer whales, 1 on melon-headed whales**

- **Playback of (some combination of) MF sonar, killer whale calls and PRN controls to 4 pilot whales and 2 beaked whales, 2 false killer whales and 1 melon-headed whale**

- **16 vessel noise playbacks (range sensors)**

- **Group/local population responses to playbacks (range sensors)**

**Tagging a beaked whale**
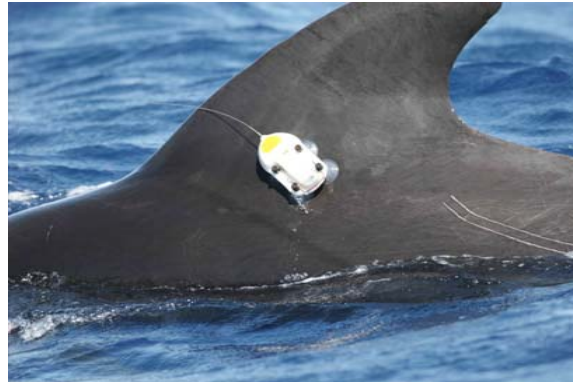
D-Tag on a pilot whale
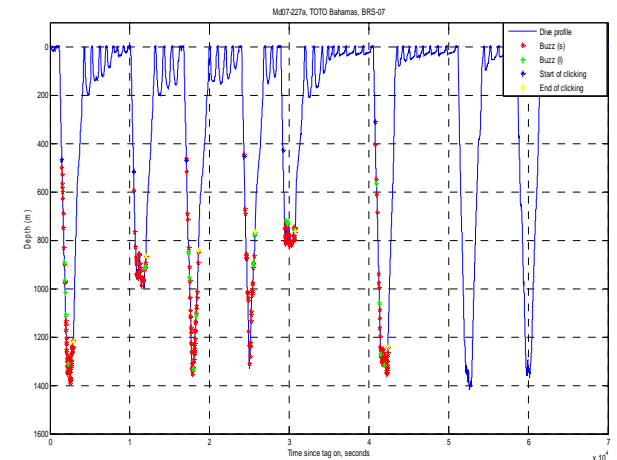
Beaked whale dive record

BRS combined playback sequences

| Date	Species	Stimulus	Response	
17 Aug 07	**Pilot Whale A**	**MFA1** **MFA2** **ORCA**	**No silence, no avoid** **Silence, no avoid** **No silence, no avoid**	
17 Aug 07	**Pilot Whale B**	**MFA1** **ORCA**		
2 Sep 07	**Blainville's beaked whale**	**MFA1** **ORCA**	**Silence, End foraging dive** **Silence, End foraging dive** **Prolonged avoidance**	
22 Sep 08	**Pilot Whale**	**PRN1** **MFA1**		
26 Sep 08	**False killer whale**	**PRN1** **MFA1**		
27 Sep 08	**Blainville's beaked whale**	**PRN1**	**Silence, End foraging dive**	**Tag off early**
28 Sep 08	**False killer whale**	**MFA1** **PRN1**		
29 Sep 08	**Pilot Whale**	**PRN1** **MFA1**		
29 Sep 08	**Melon-headed whale**	**PRN1** **MFA1**		

Dtagged Whale Producing Clicks and Buzzes During Early Low-level MFA Sonar Exposure
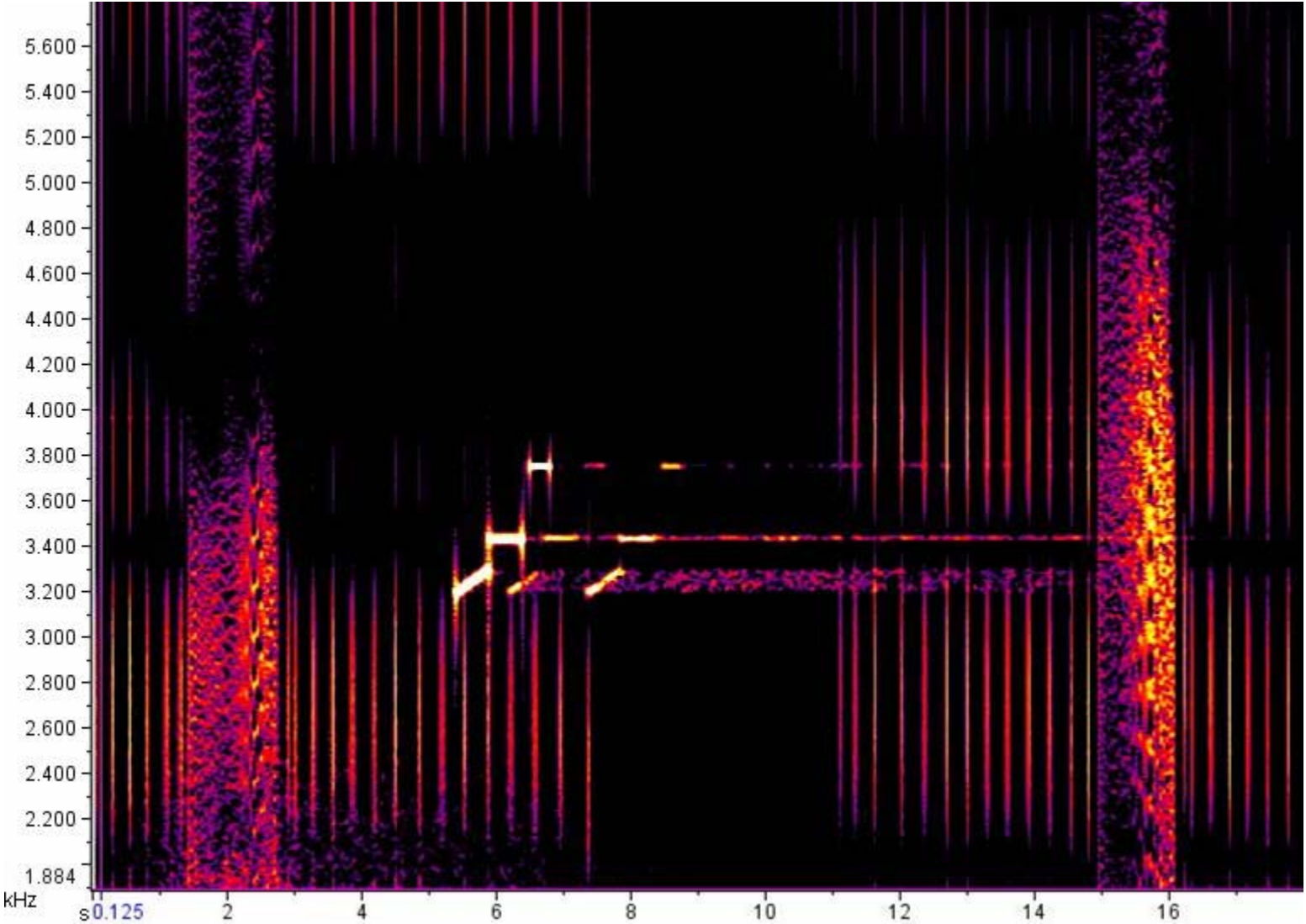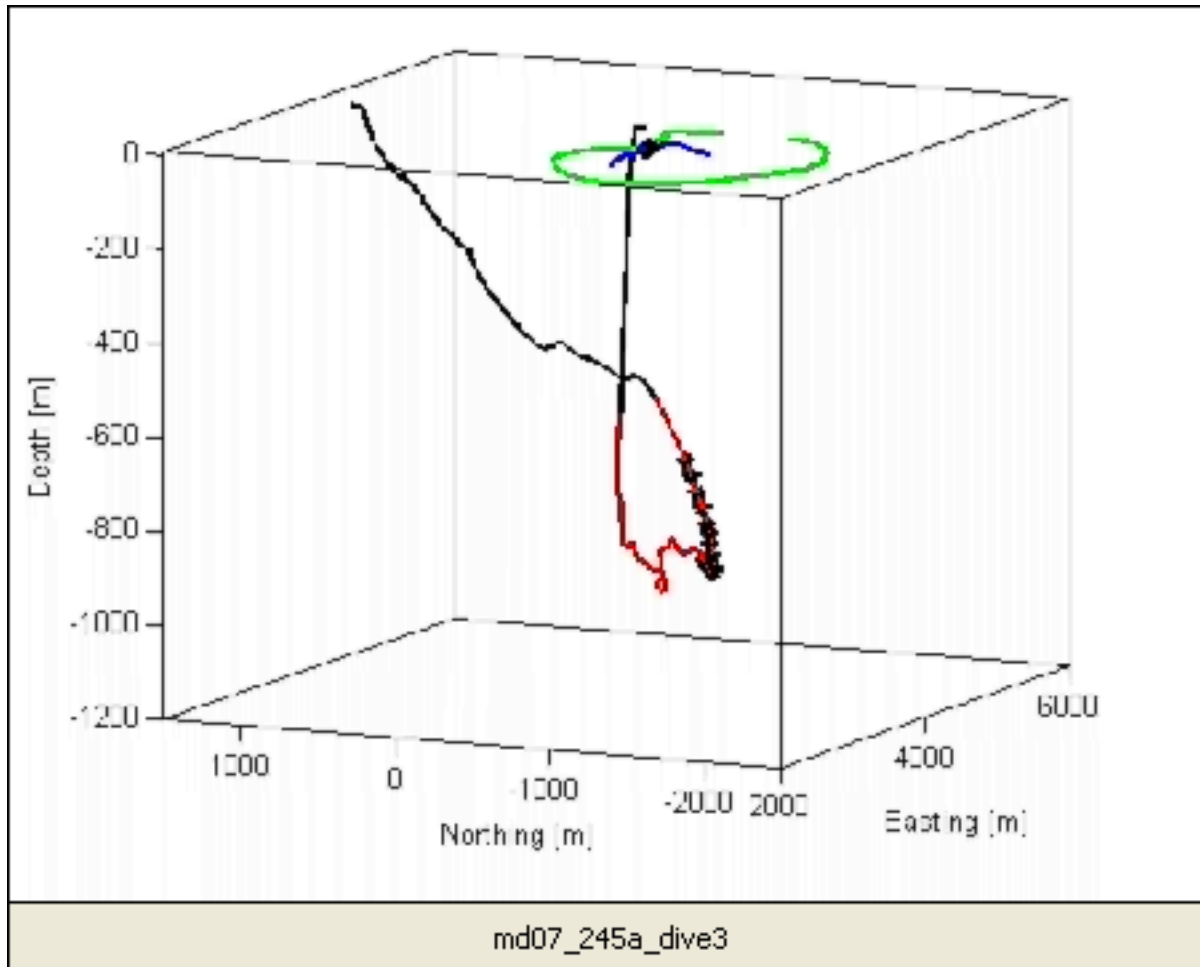
Beaked whale responses to sonar/orca playbacks

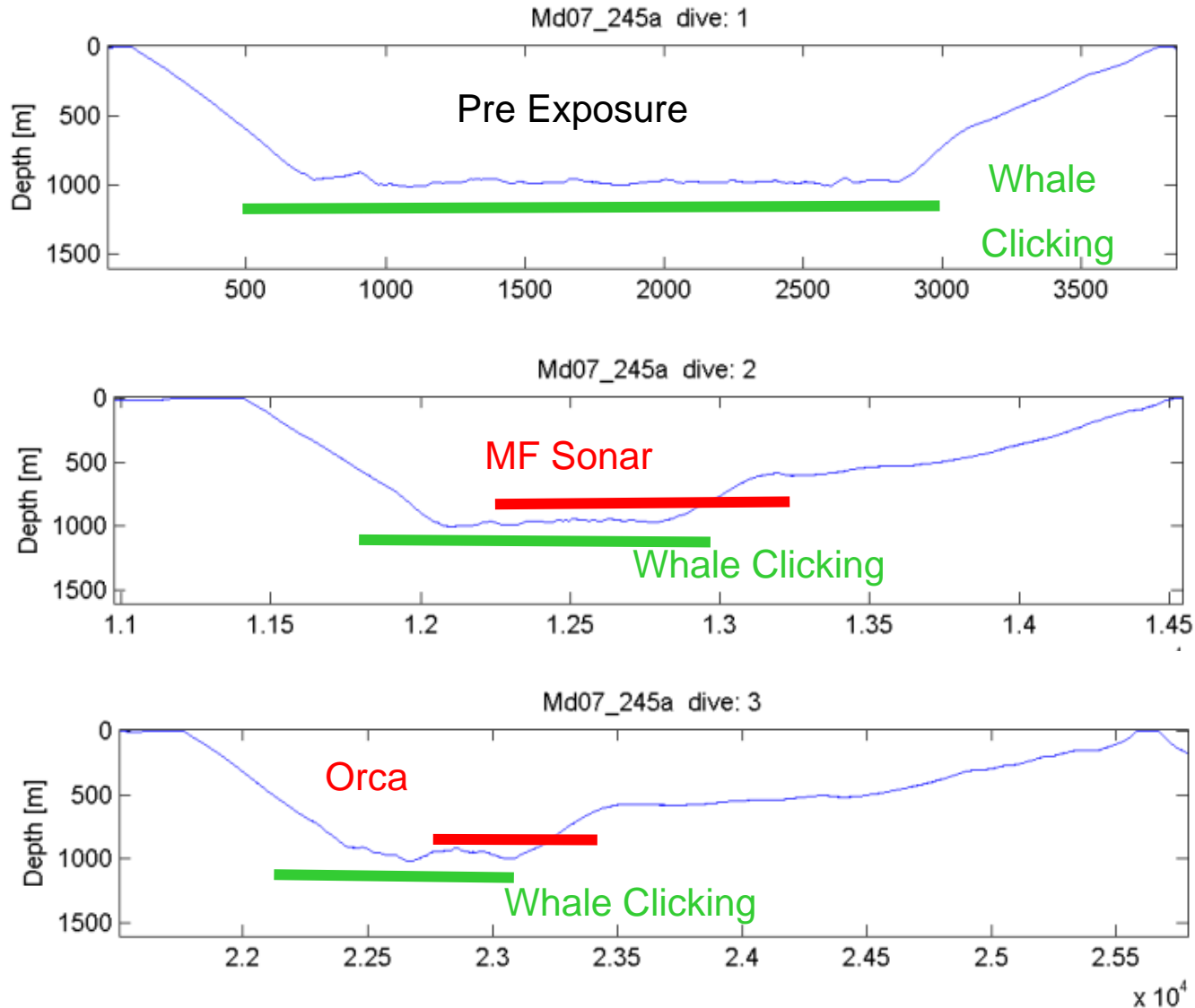
md07_245a
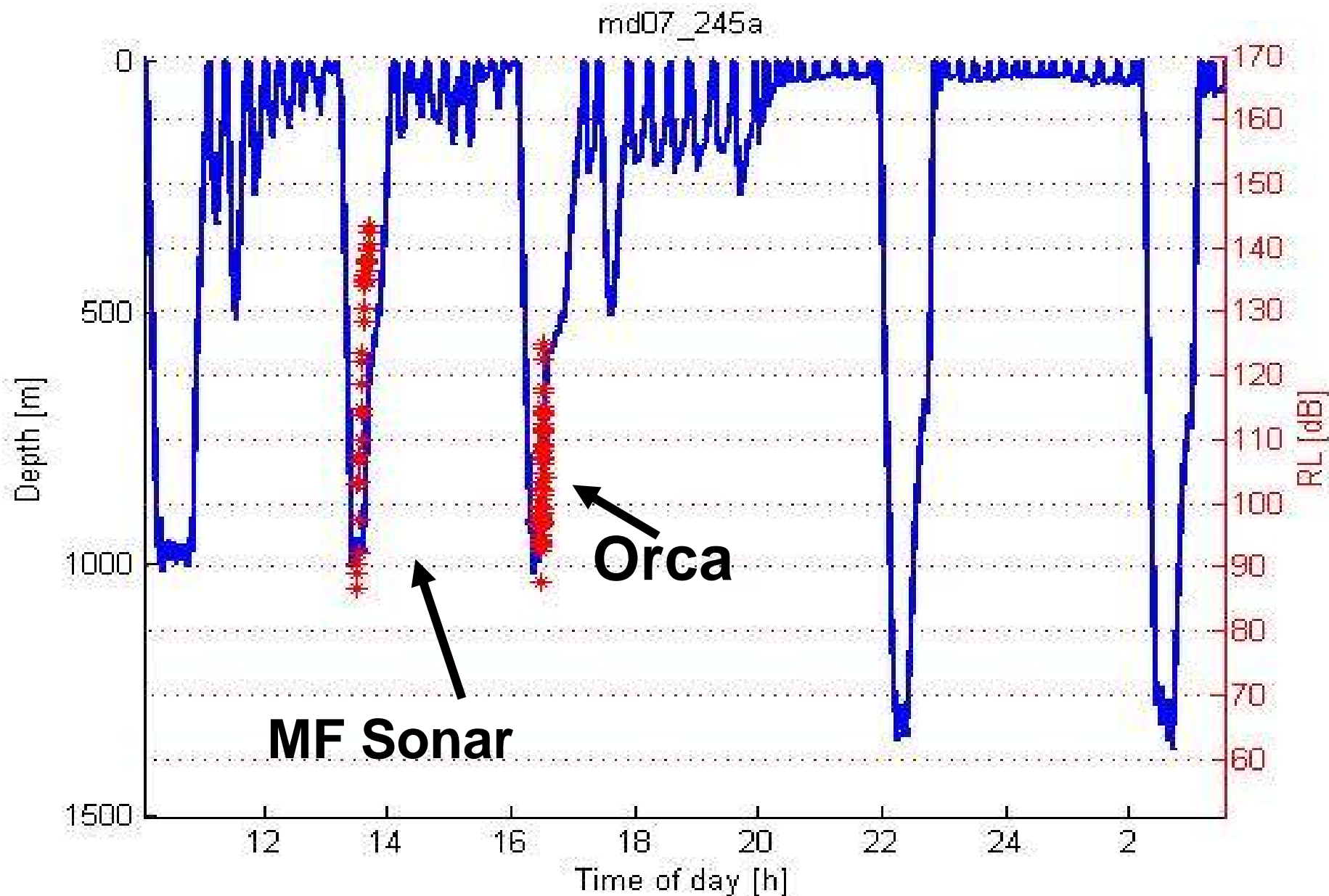
Animation of beaked whale (BRS-07) pre-exposure dive

md07_245a_dive1
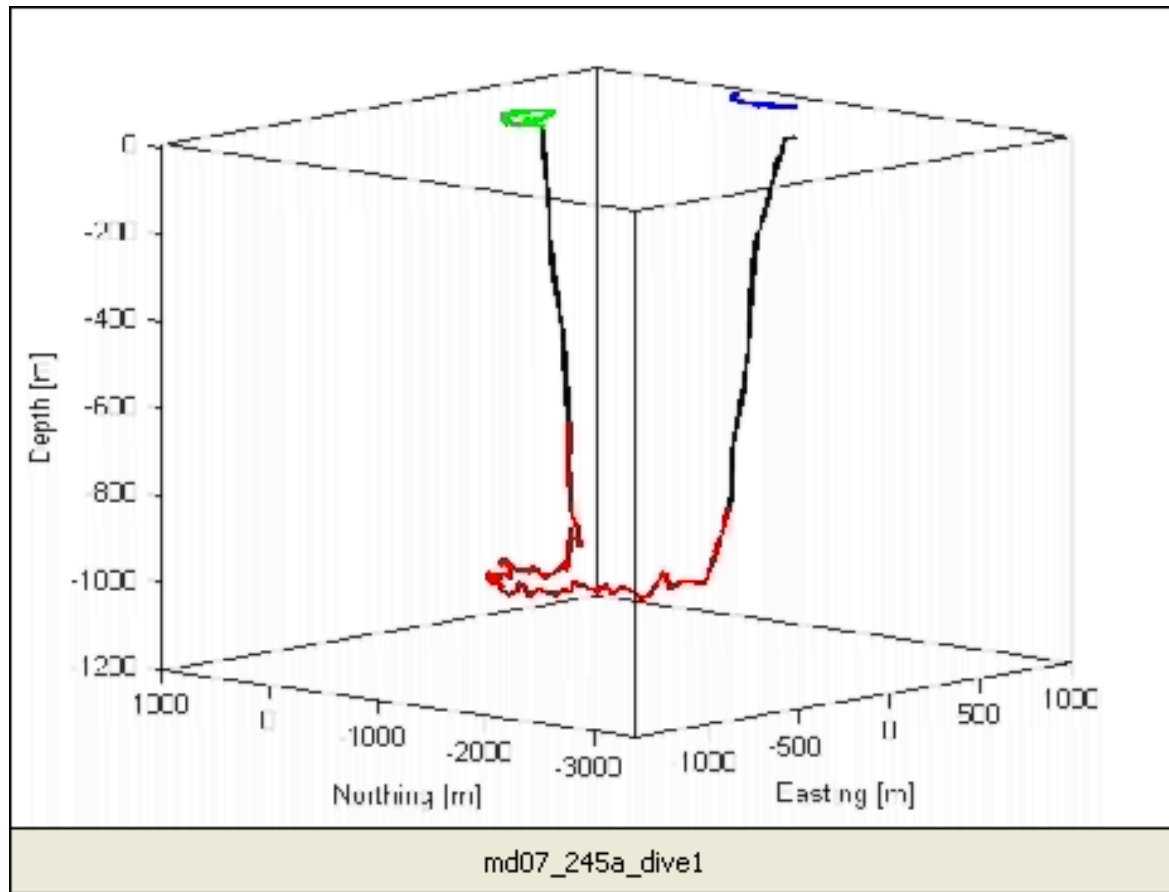
Animation of beaked whale (BRS-07) MFA exposure dive

md07_245a_dive2
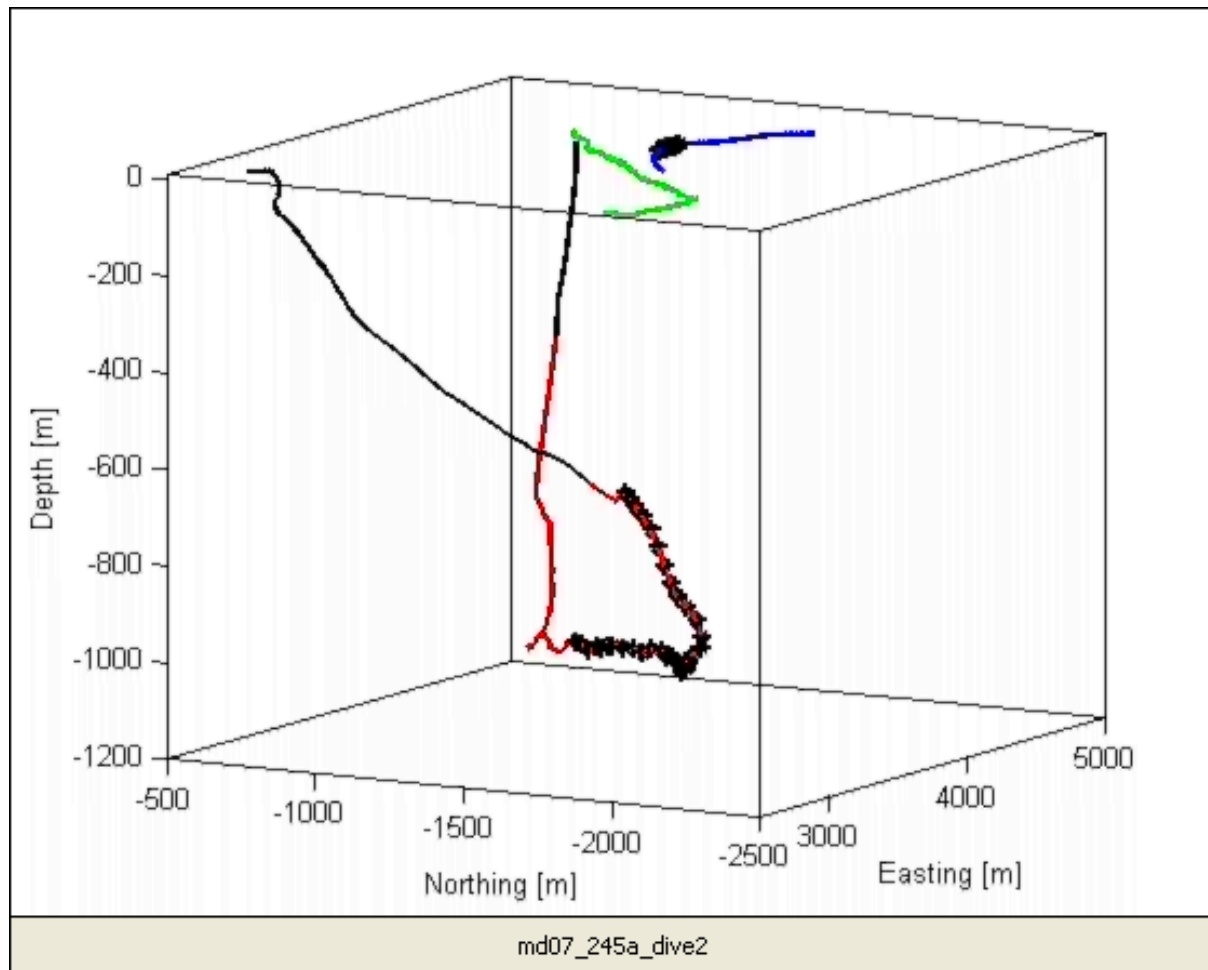
Animation of beaked whale (BRS-07) Orca exposure dive

md07_245a_dive3

Changes in beaked whale (BRS-07) exposure dives

Md07_245a dive: 1

Pre Exposure

Whale Clicking

Md07_245a dive: 2

MF Sonar

Whale Clicking

Md07_245a dive: 3

Orca

Whale Clicking

This beaked whale (BRS-07) appears to have moved 20 km over 10 hours in a sustained and directed movement avoiding the playback area
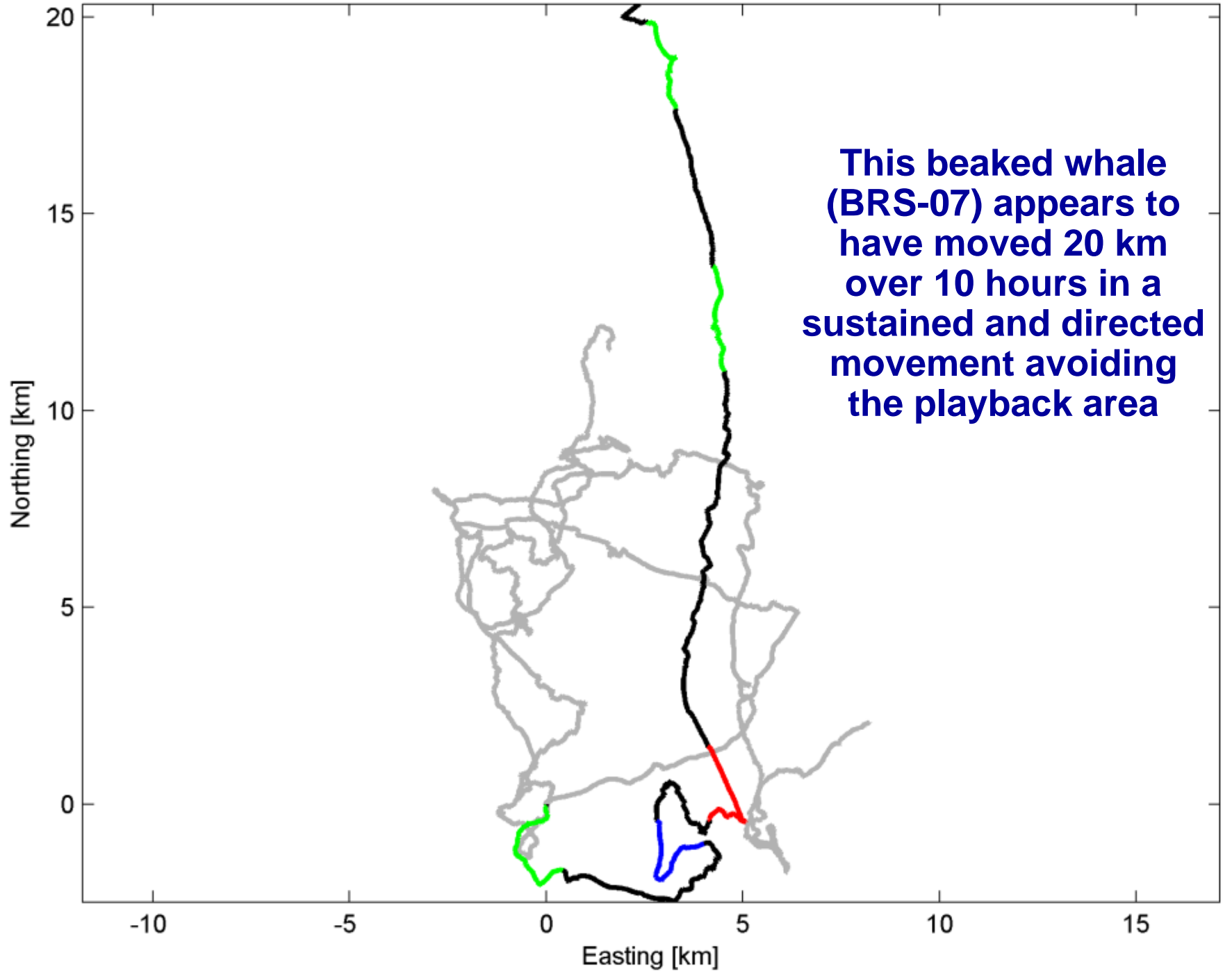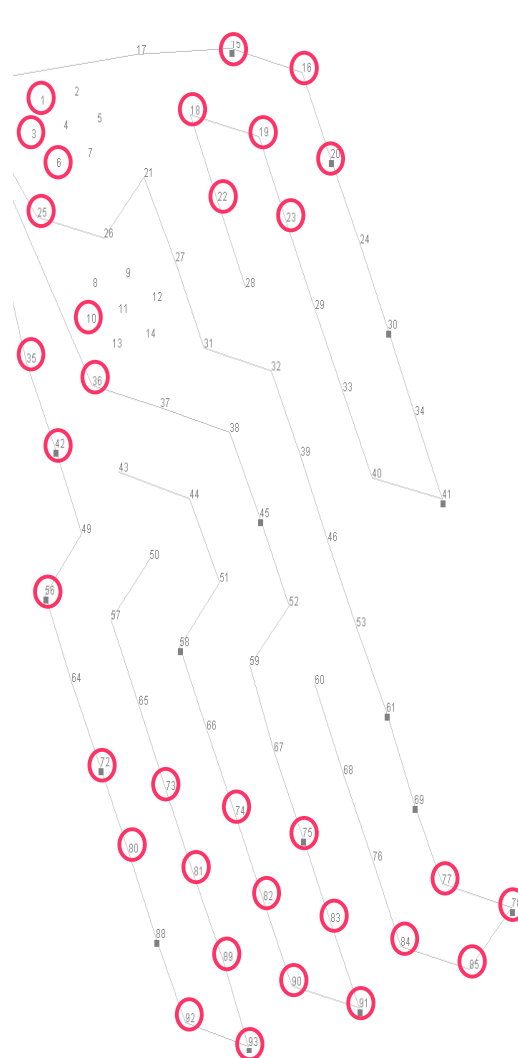
Blainville's Beaked Whale Vocalization Distribution
Before, During, After Active Sonar Operations
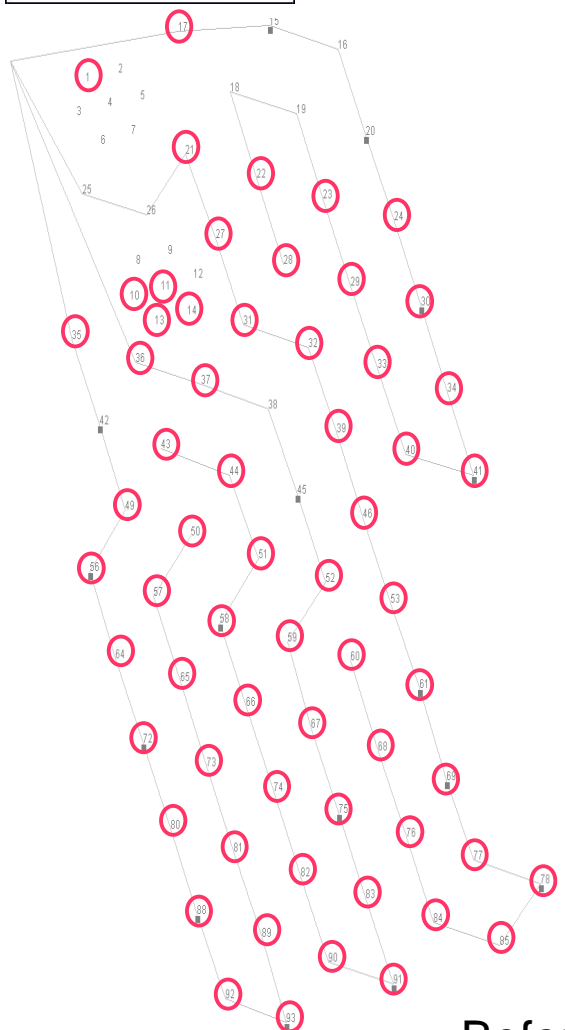
Before

Record Duration= 17 hour
Groups on Range= 56

Mean	32.56
Max	49
Min	11
Stand Dev	9.05

During

Record Duration= 22:56 hours:min
Groups on Range= 36

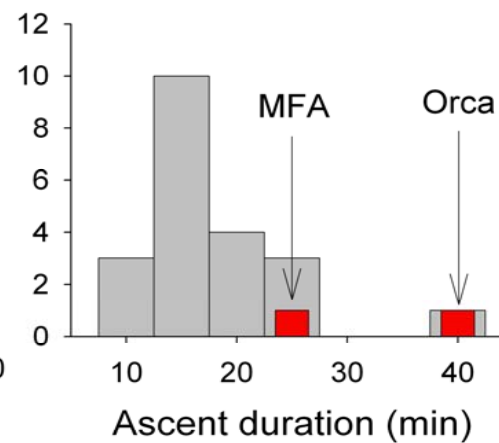|	
Mean	20.42
Max	32
Min	2
Stand Dev	8.58
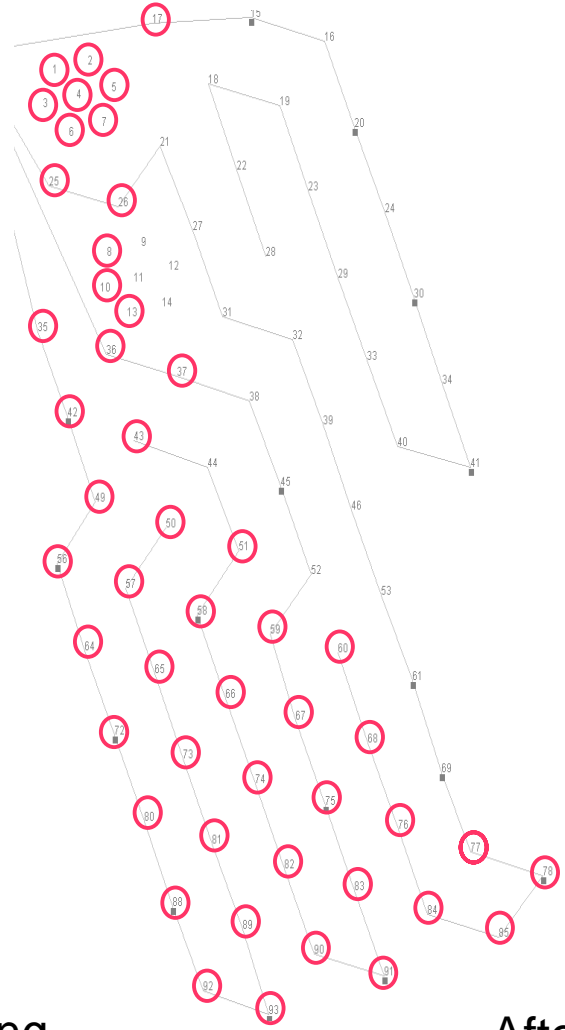
After

Record Duration= 22:01 hours:min
Groups on Range= 50

Mean=	29.76
Max=	50
Min=	7
Stand Dev=	8.45

16

Second beaked whale (BRS-08) exposed to PRN

md08_271a -- Dive Profile with Peak PRN Received Levels

+ PRN level
— dive profile
■ start of clicking
● end of clicking
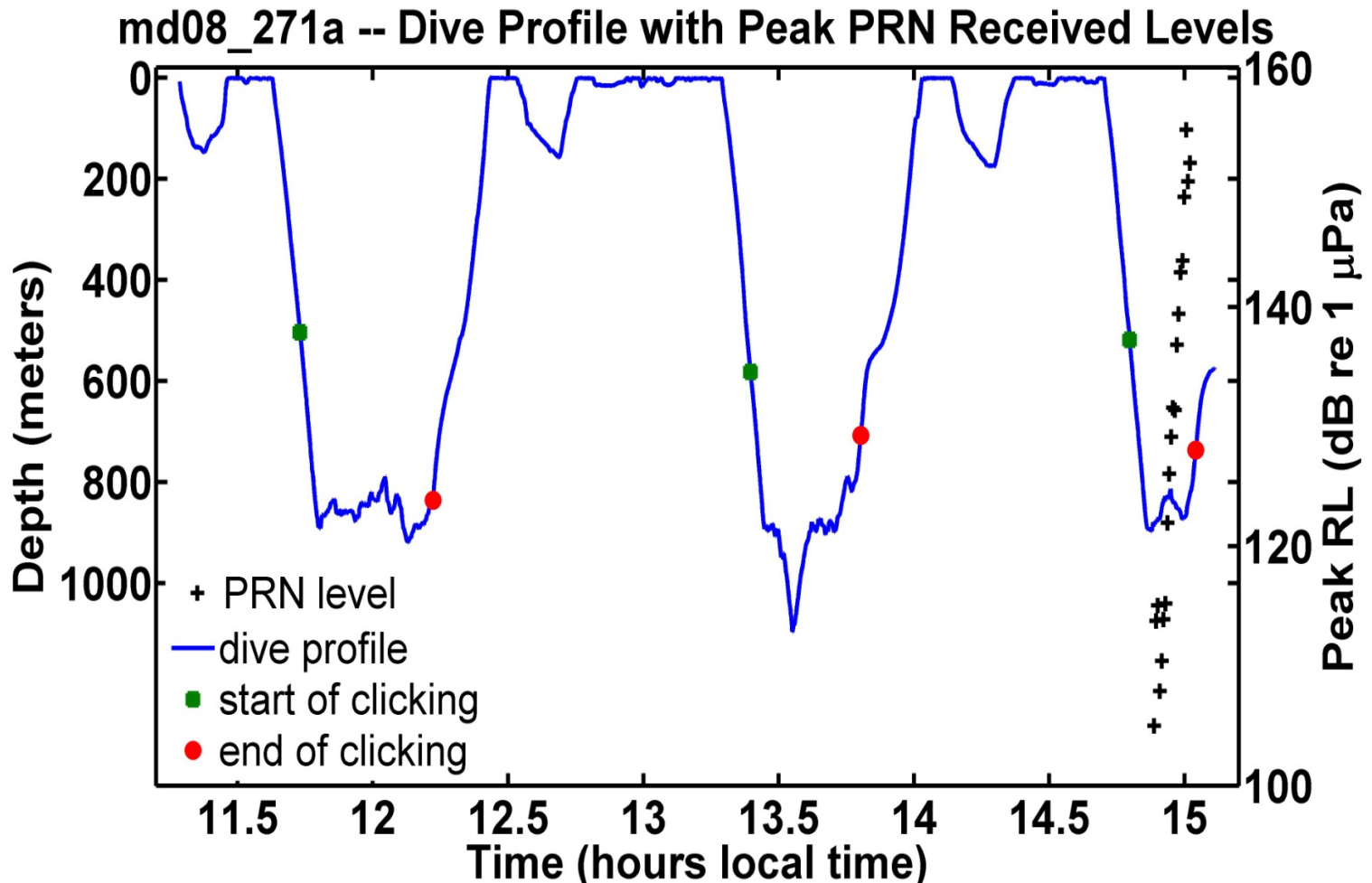
Beaked whale exposure dives stop earlier and ascend slower than normal dives
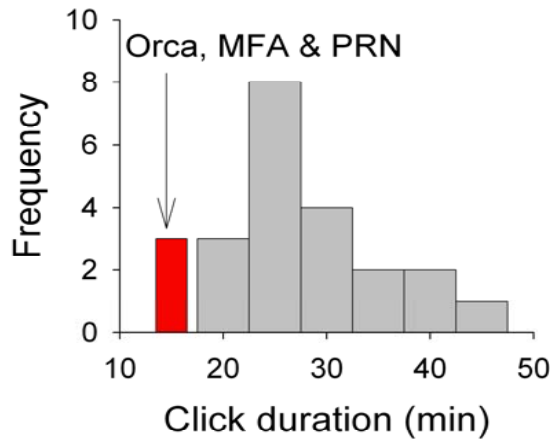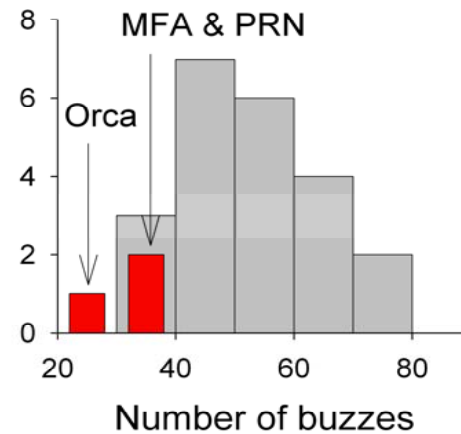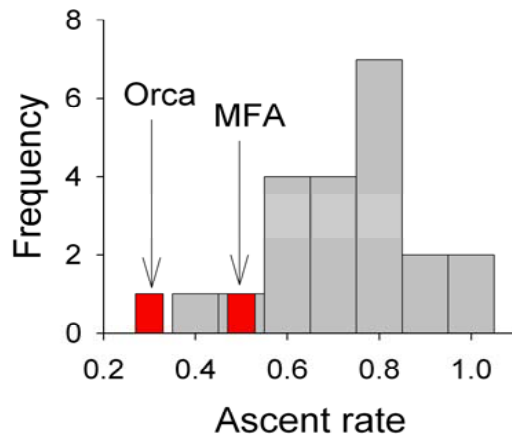
Statistical comparison of various beaked whale dive parameters in baseline and exposure conditions

Dependent variable	Playback effects (after controlling for individual and sex)	
	F	p
Duration of clicking	14.02	0.002***
No. Buzzes	10.81	0.004***
Buzz rate	0.05	0.820
Descent rate	0.79	0.386
Decent duration	1.73	0.206
Ascent rate	10.41	0.005***
Duration of silent ascent	11.50	0.004***
Dive duration	0.02	0.891
Dive depth	1.90	0.180
Pre-dive interval	0.92	0.359
Post-dive interval	5.88	0.034*

Dive variables during/post exposure show a statistically significant effect

BRS-07 Pilot whale exposure:
No Avoidance Response to MFA or Orca
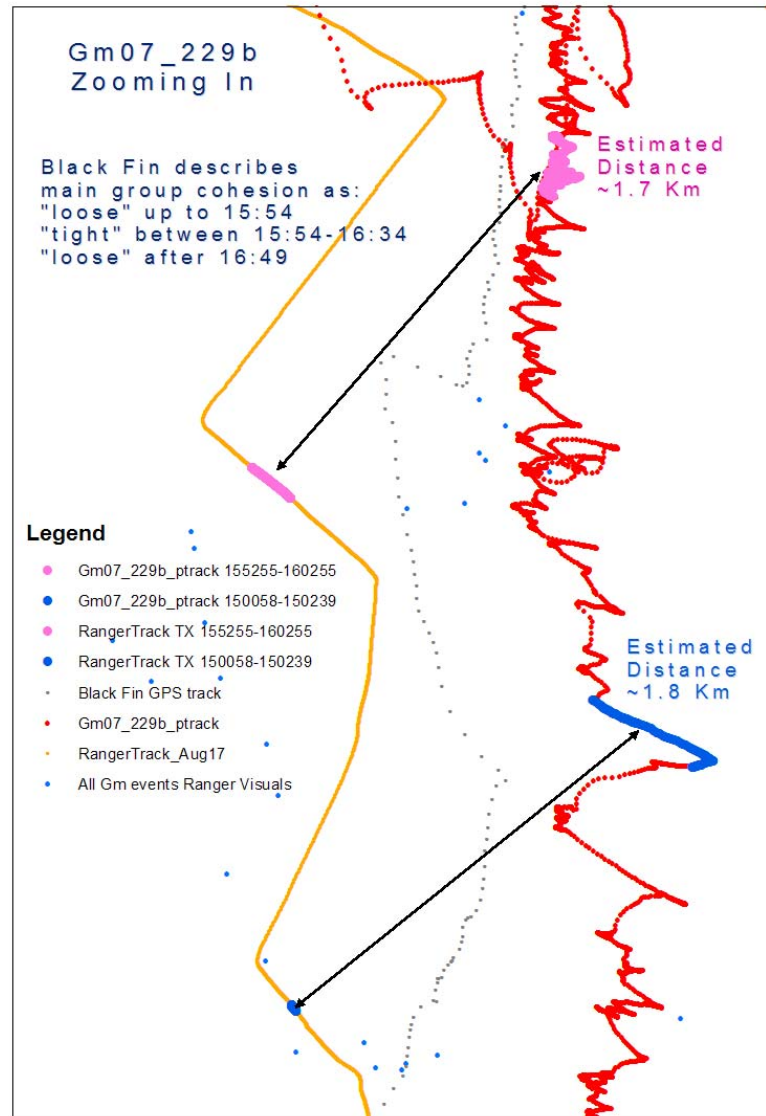
BRS-07 Pilot whale exposures: Silencing to second MFA but not to Orca
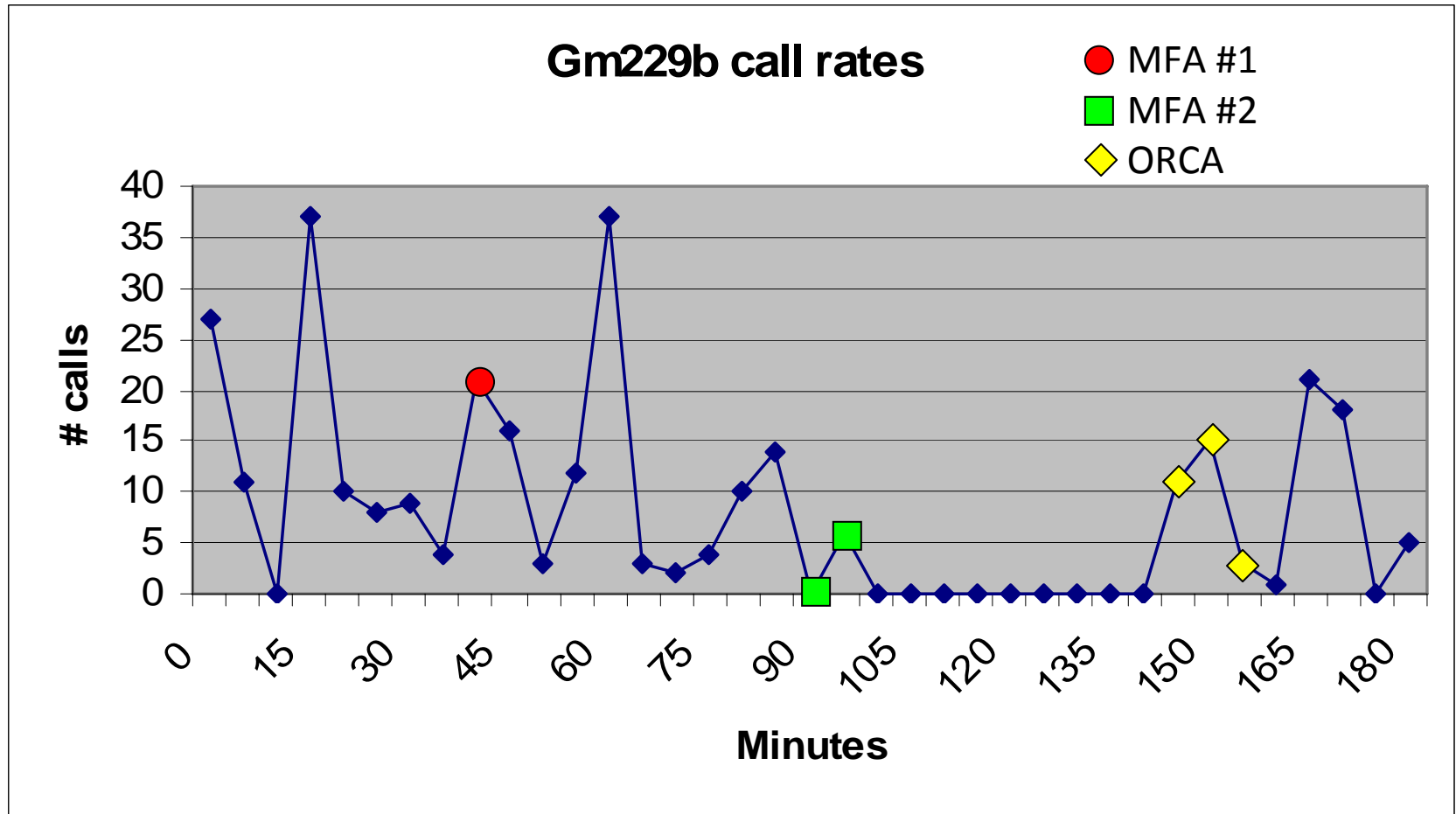
Pilot whale whistle-back to MFA
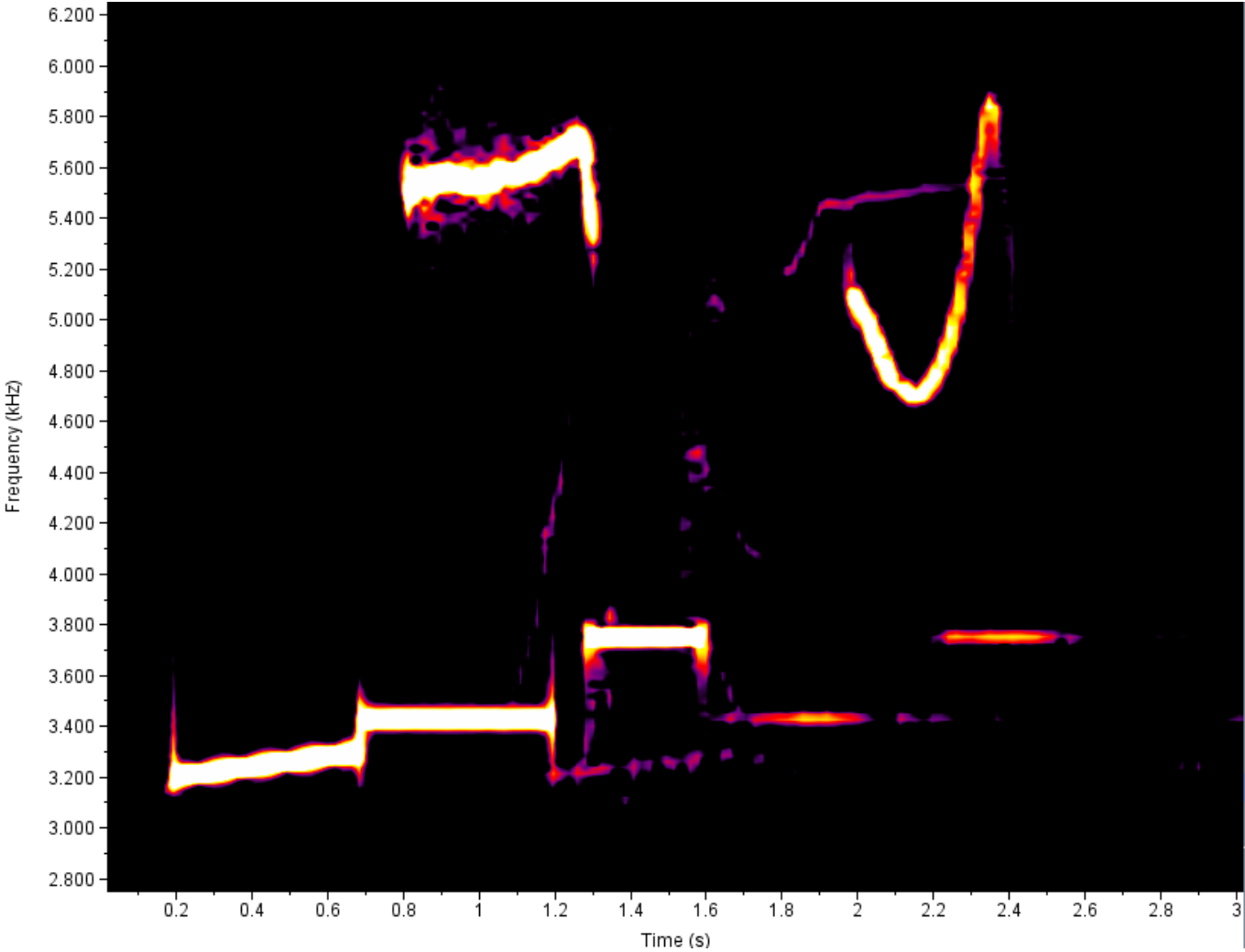
False Killer Whale-1 (BRS-08)

pc08_270a - 26 September 2008 - PRN Exposure Levels

- Peak Level
- Envelope Peak Level
- RMS Level
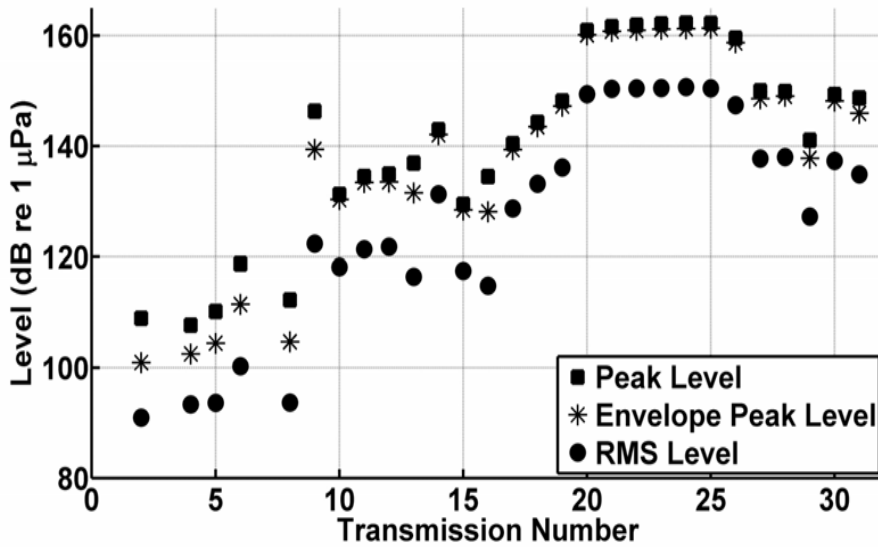
pc08_270a - 26 September 2008 - MFA Exposure Levels

- Peak Level
- Envelope Peak Level
- RMS Level
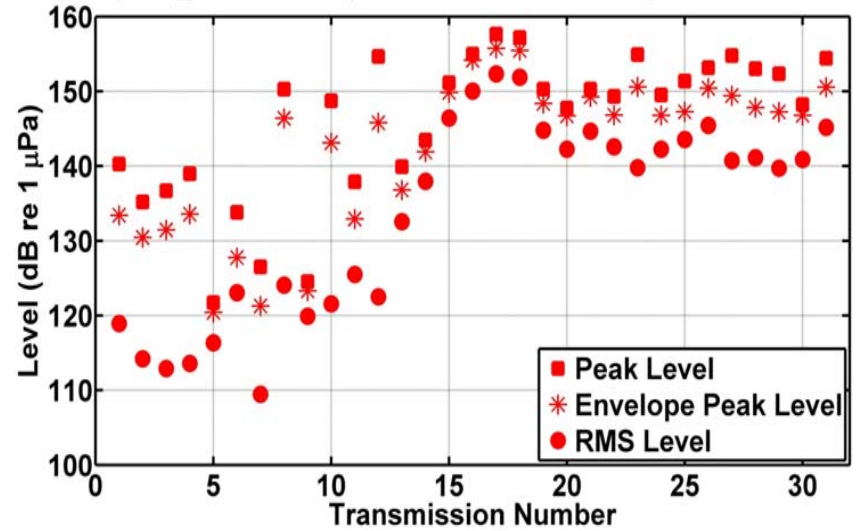
False Killer Whale-1 (BRS-08) (low-level response)

pc08_270a - 26 September 2008 - Uncorrected Pseudotrack
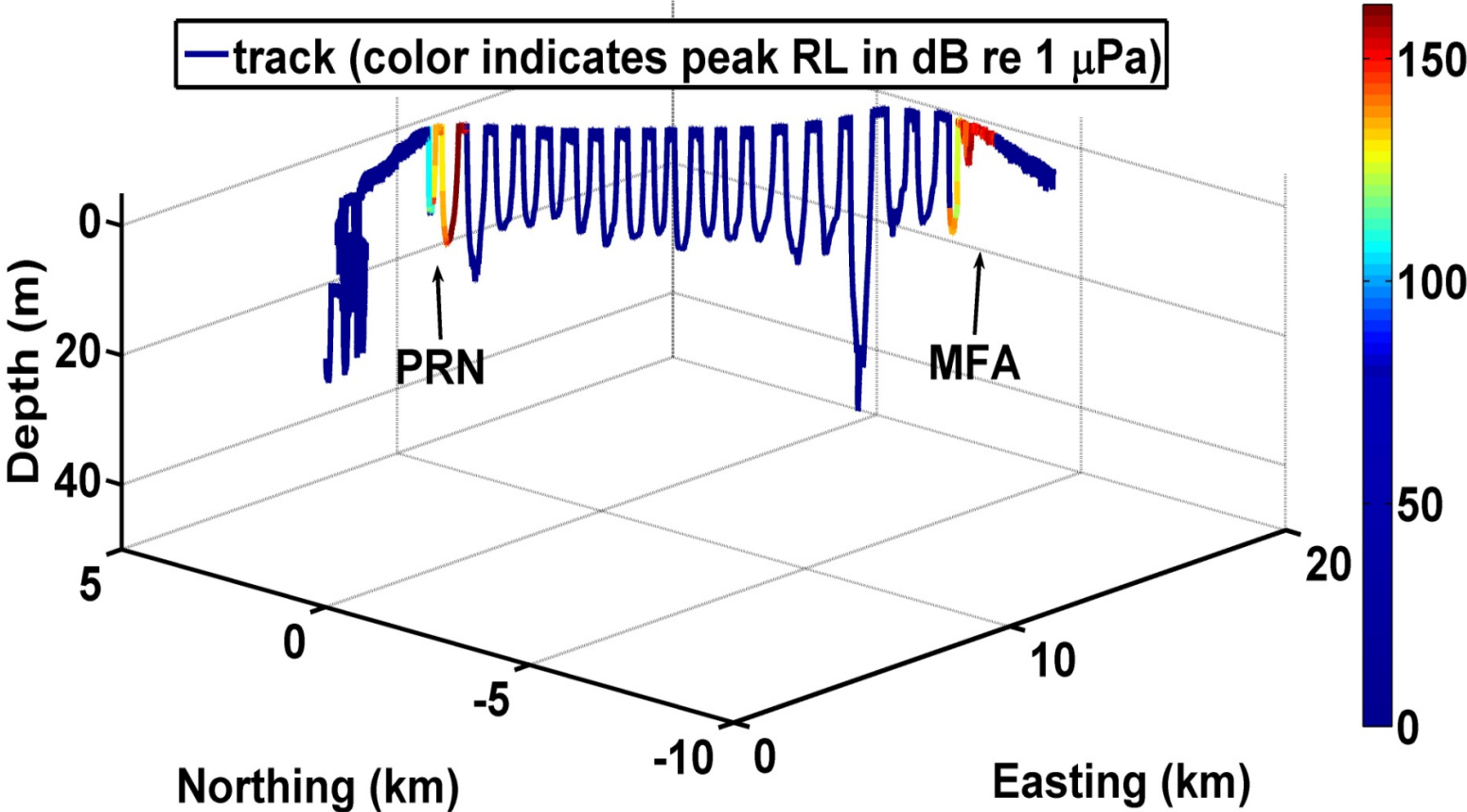
False Killer Whale-2 (BRS-08) (no response)

pc08_272a - 28 September 2008 - Uncorrected Pseudotrack

Combined BRS Achievements (07-08) vs. expectations

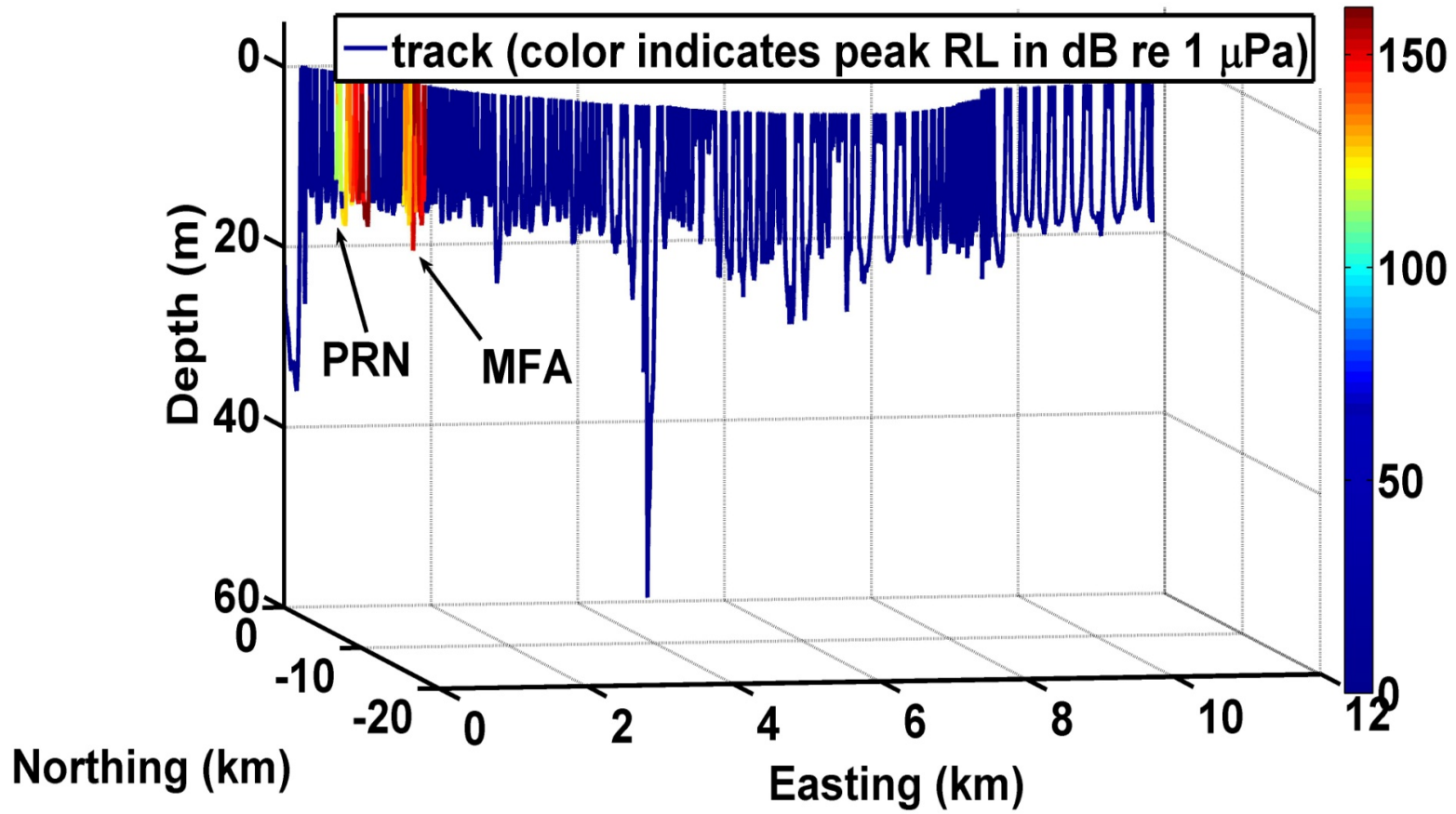| Expectations	Achievements
Establish, test and refine new protocols for studying beaked whales (demonstrate feasibility)	Demonstrated concept works; significant lessons-learned
Engage with NGO concerns and initial resistance to playback approach	Important progress made through fair and open dialog
Collect base-line (control) data to provide a basis for comparison with playback results	Achieved for four species, most importantly beaked whales
Examine behavioral responses, sound exposure type/context and received levels in beaked whales and other species	Behavioural responses from beaked whales and other species indicate variable responses within adaptive behaviour; data very informative but greater sample size is needed
Begin to build a population-level dose:response relationship to predict probability of inducing a behavioral response leading to stranding	Insufficient samples obtained to support such an assessment yet
Characterize whether and how responses differ between different age/sex/ stages in life cycle/behavioral contexts, and also between different types of sound	Insufficient samples obtained to support such an assessment yet

Comparison of Responses of Beaked vs. Pilot Whales to Playback of Anthropogenic Sounds and Killer Whale Calls

Response Type	Beaked Whales	Pilot Whales
Dive	Premature Surfacing	No obvious change
Vocal	Premature Silencing	Variable, some cases with elevated Whistle Rate, some with silencing
Approach/ Avoid	Prolonged Avoidance	Variable, some cases with short avoidance, some with none
Social Cohesion	Group splits	SubGroups Join

Received levels associated with premature cessation of beaked whale foraging clicks

Species	Stimulus	Received Level	Source
Ziphius cavirostris	**Ship propulsion**	136 **dB re 1 µPa rms broadband**	**Aguilar et al. (2006) Marine Mammal Science, 22(3): 690–699**
Mesoplodon densirostris 1	**MFA**	136 **dB re 1 µPa rms broadband**	**BRS07**
Mesoplodon densirostris 1	**Orca**	102 **dB re 1 µPa rms broadband**	**BRS07**
Mesoplodon densirostris 2	**PRN**	~140 **dB re 1 µPa rms broadband**	**BRS08**

BRS Initial Conclusions

- **Caveat on all conclusions is that sample size is small.**

- **Primary limitation to increasing number of playbacks is requirement for very calm seas state for visual detection and tagging (lessons for visual-based mitigation)**

- **Beaked whale responded in a generally similar way to MFA, killer whale and PRN playback with RLs ~120-150 dB re: 1 µPa (supports conclusions of particular sensitivity); while the response data are outliers from baseline, there is no suggestion that these responses posed a risk of injury.**

- **All tests were at RLs below the 160 dB from relatively small, immobile, single sources so this may say little about how animals might respond at higher RLs and/or to sounds from real military operations.**

- **Other species of toothed whales showed generally little response to playbacks of MFA, PRN and killer whale; beaked whales appear to be *categorically more responsive* to sound stimuli than other odontocetes.**

BRS Next Steps

Based on lessons-learned from BRS 07&08 as well as other related efforts (SCORE, AUTEC, RIMPAC, Norway), we see a three-pronged attack as the most constructive way to continue to narrow scientific uncertainty.

1. **<u>Analysis of current data</u>:** BRS has produced rich and diverse data with detailed information on (i) individual responses to playbacks; (ii) group-level response; (iii) population-level responses.

2. **<u>Building, testing and fitting a behavioural model for beaked whales</u>** (using array measurements of movement and behavior during real operations)

3. **<u>Continue to seek opportunities to conduct playbacks</u>** (leaner, more agile experimental design with a combination of tags likely appropriate, with particular focus on areas with predictable good weather and the use of real operational sources)

Behavioral Response Study 07-08

- **Atlantic Undersea Testing and Evaluation Center:** Jose Arteiro; Marc Cimonella; Tod Michaelis

- **Bahamas Marine Mammal Research Organization:** Edward Adderley; Monica Arso; Diane Claridge; Jaclyn Daly; Charlotte Dunn; Kuame Finlayson; Leigh Hickmott; Janelle Morano; Alesha Naranjit; Olivia Patterson;

- **Cornell University:** David Brown; Christopher Clark; Ian Fein

- **Duke University:** Ari Friedlaender; Douglas Nowacek; Elliot Hazen, Anna McGregor

- **Florida State University:** Lou St. Laurent; Ken Decoteau; Eric Howarth

- **Marine Acoustics, Inc:** Adam Frankel, Chuck Gagnon; Clay Spikes, Kathy Vigness, Kimberly Skrupky; Mark Wilson

- **NOAA; National Marine Fisheries Service:** Brandon Southall; Jaclyn Daly; Howie Goldstein

- **Naval Undersea Warfare Center NPT:** Nancy DiMarzio; Susan Jarvis; David Moretti; Ron Morrissey; Jessica Ward;

- **Sea Mammal Research Unit**: Ian Boyd, Gordon Hastie; Nicola Quick;

- **SPAWAR San Diego:** Angela D'Amico; Rowena Carlson, Buddie Gilstrap; Chris Kyburg;

- **Woods Hole Oceanographic Institution:** Ann Allen, Marco Ballardini; Yara Bernaldo de Quirós Miranda: Stacy DeRuiter; Nicolo' Gavazzi; Tom Hurst; Selena Klöti; Todd Pusser; Maria Elena Quero; Eletta Revelli; Stephanie Watwood; Matt Weingartner; Jeremy Winn; Becky Woodward; Alex Bocconceli.

Reserve Slides

Marine Mammal Monitoring on Navy Ranges (M3R) Opportunistic Study

Measure spatial and temporal distribution, and vocal behavior of marine mammals *before, during, and after active sonar operations* on Navy ranges using passive acoustics.
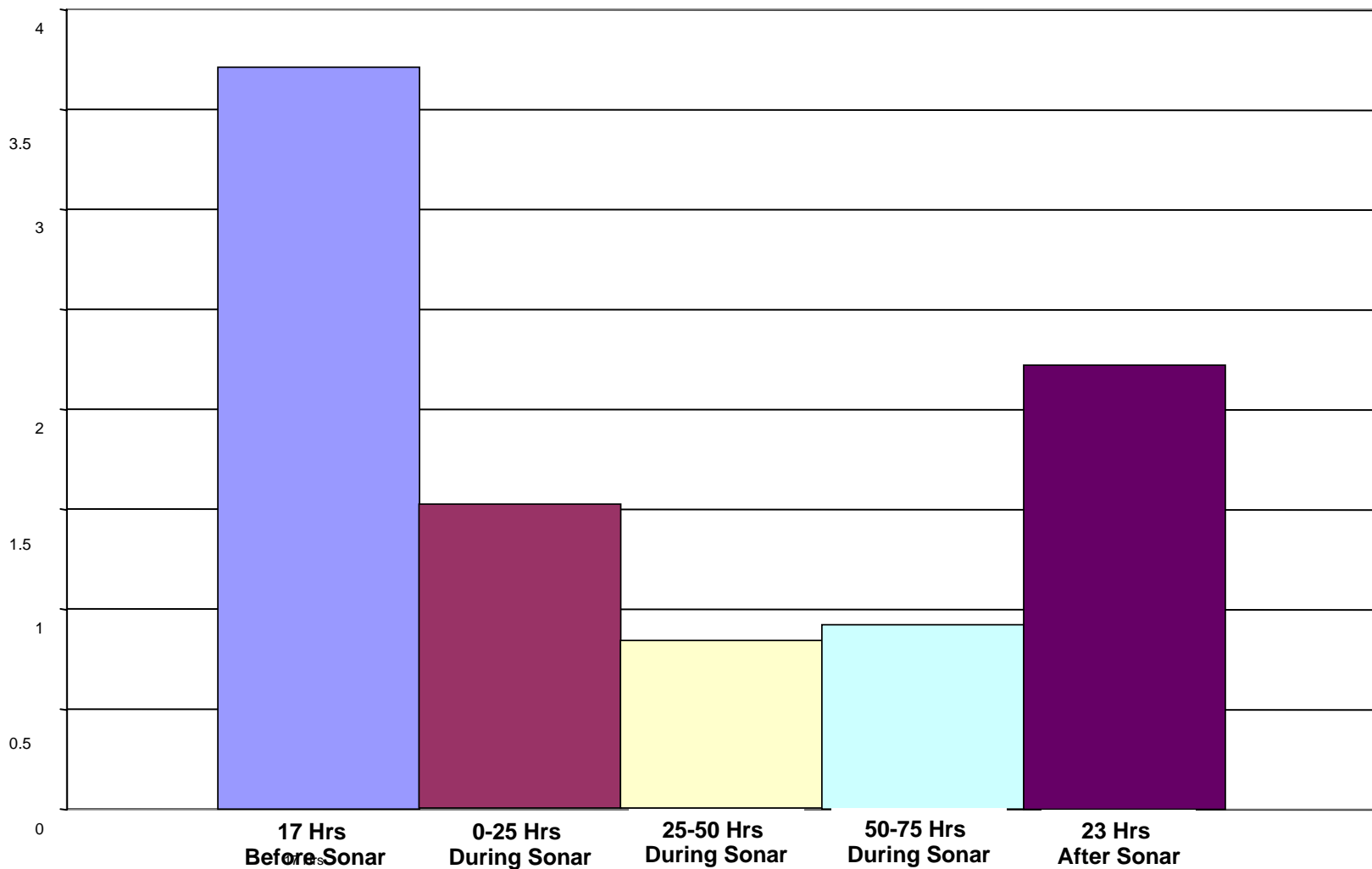

Blainville's Beaked Whale Vocalizations

Active Sonar Signal
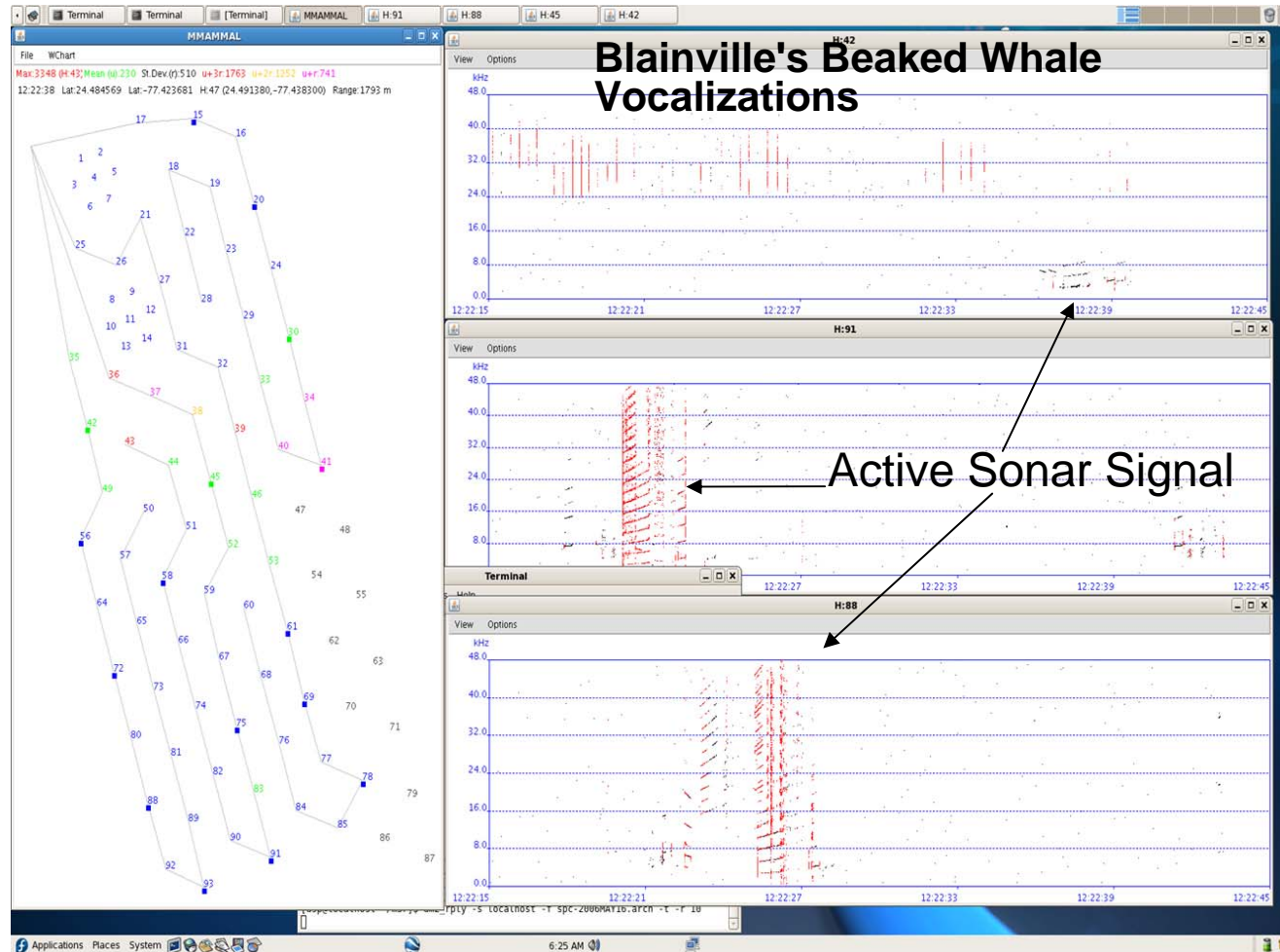
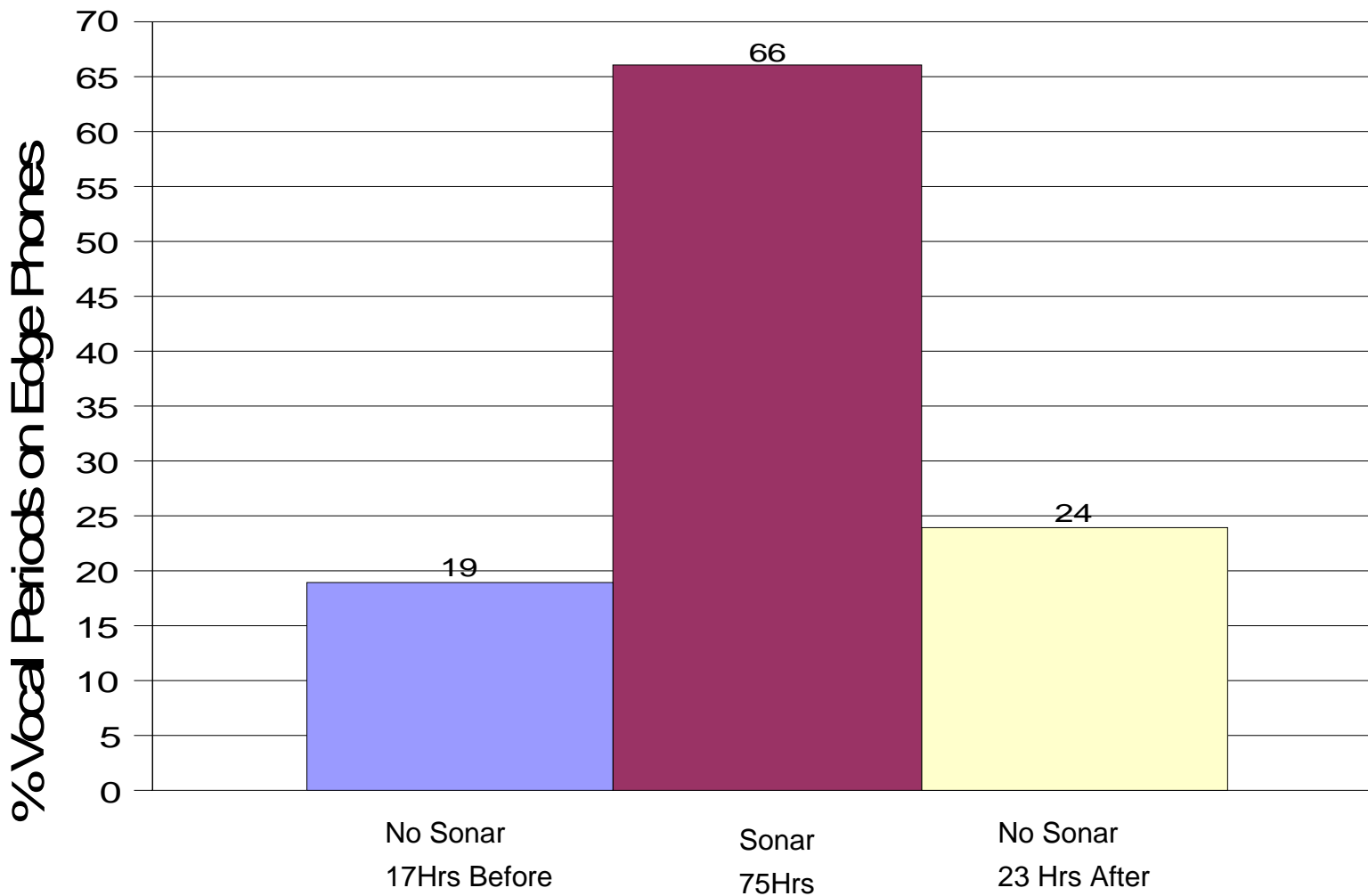Blainville's Beaked Whale
(Mesoplodon densirostris)
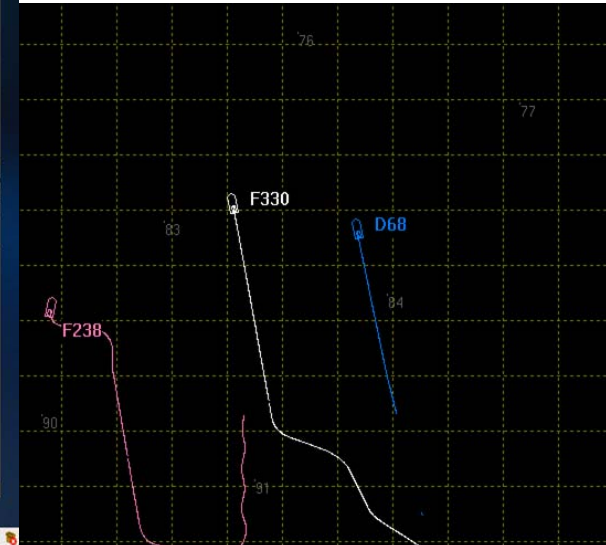
Range activity monitor with beaked

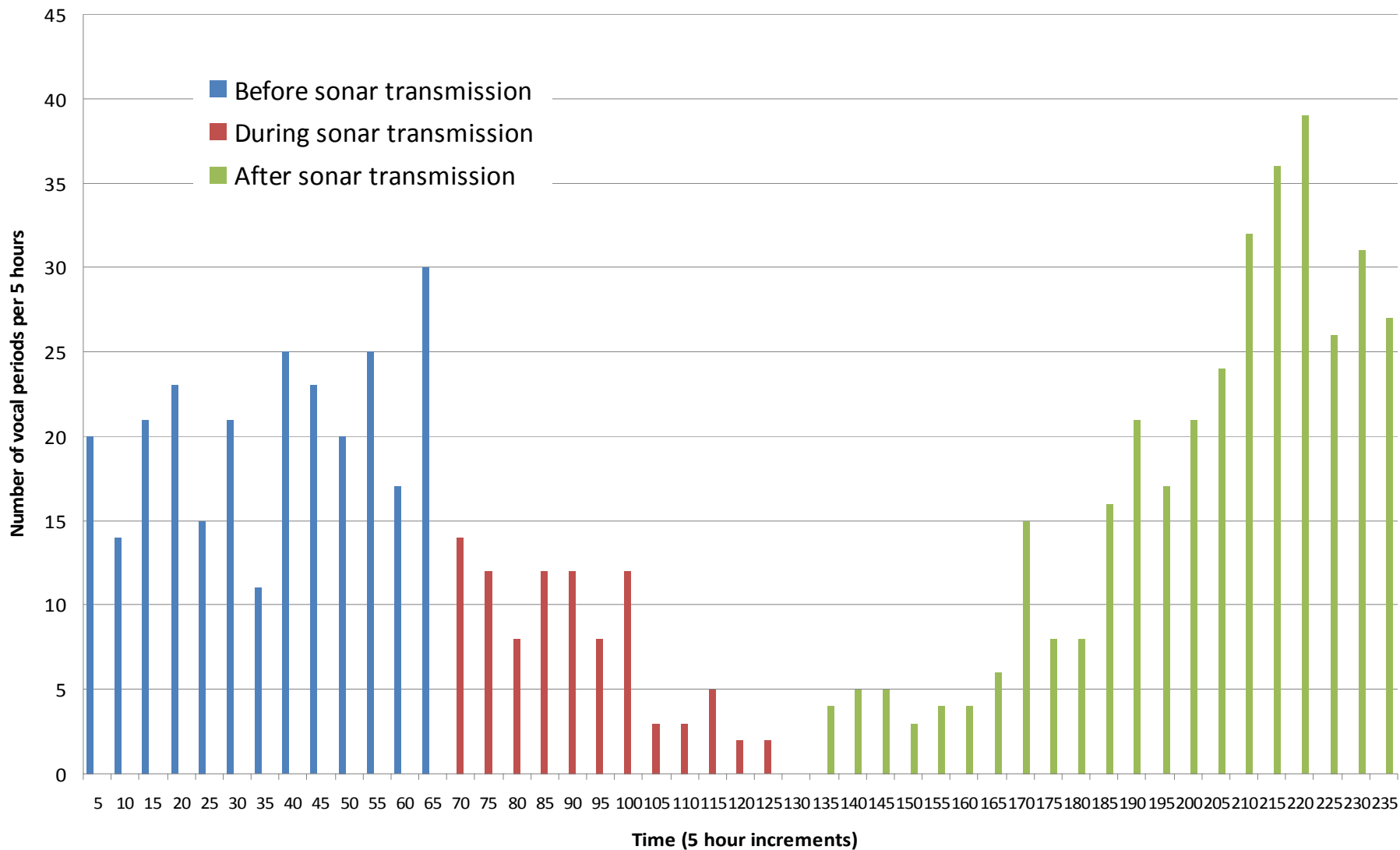# Group Vocal Periods/Hr. Before, During, and After Mid-Frequency SONAR Exercises

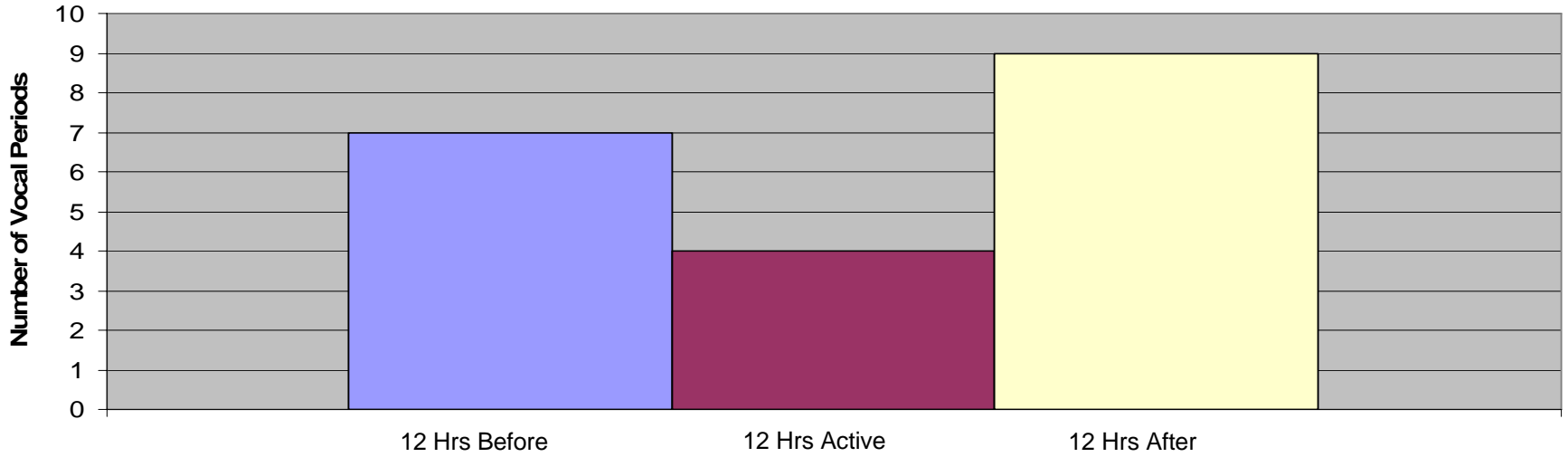*% Blainville's Beaked Whale Group Vocal Periods on Range Edge*

May, 2007

Number of Vocal Periods
SCC_May 2008

Legend:
- Before sonar transmission
- During sonar transmission
- After sonar transmission

Y-axis: Number of vocal periods per 5 hours

X-axis: Time (5 hour increments)

**Vocal Periods over Comparable 12 Hr. Periods
Before/During/After Active Event**

**Vocal Periods over Comparable 12 Hr. Periods Before/During/After Acive Event
(BW during 1st Hr of Operations Omitted)**