FFI Forsvarets forskningsinstitutt

Overview of the 3S-project in Norwegian waters

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3S chief scientist

Sea Mammals and Sonar Safety project

International research project with the aim to investigate behavioral reactions of cetaceans to naval sonar signals, in order to establish safety limits for sonar operations.

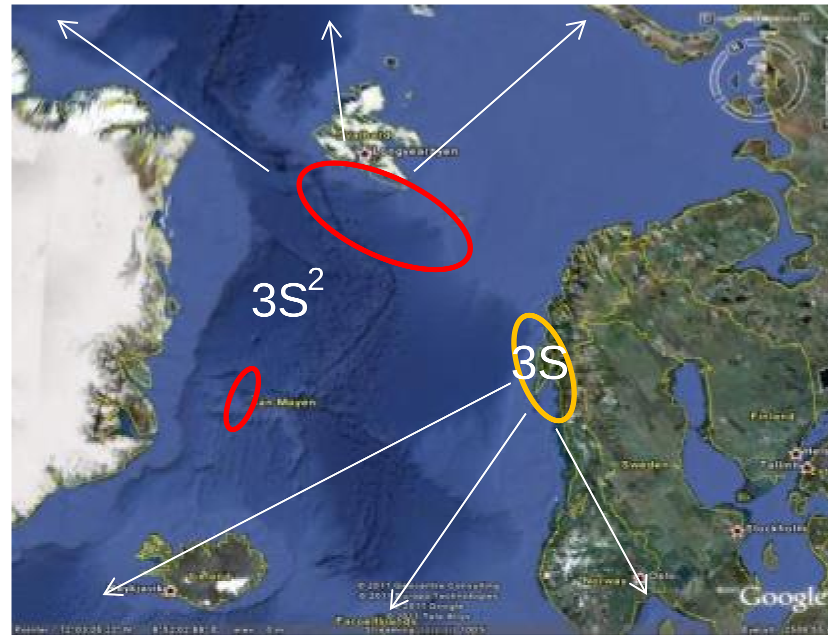
- Partners: FFI (NO), TNO (NL), SMRU (UK), WHOI (USA)
- Sponsors: RNoN/MOD, RNLN/MOD, US-ONR, DGA Fr-MOD
- 30 scientists from 10 different countries.

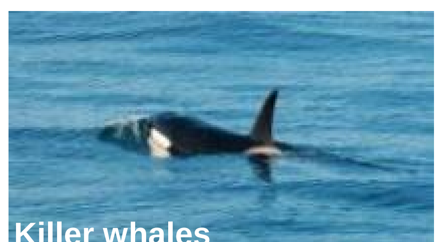
3S

Sea mammals
Sonar
Safety

3S-II
2011-2015

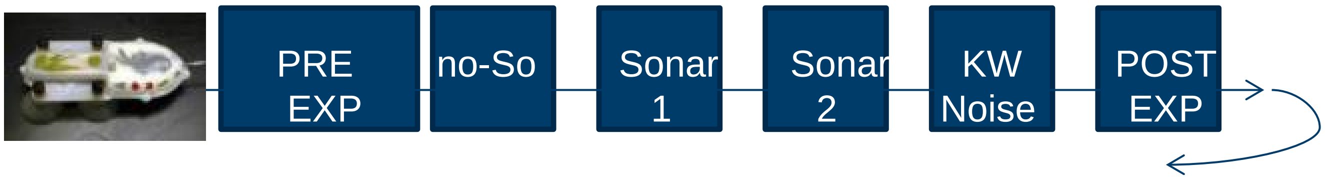
3S-I
2006-2010





3S Data collection

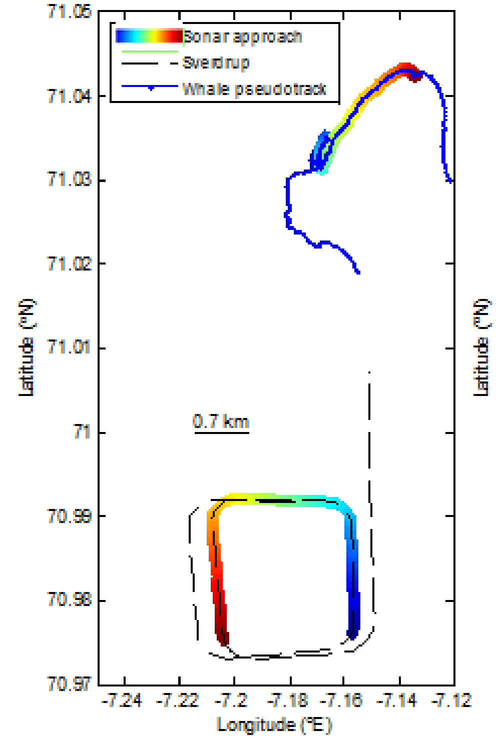
6 BRS cruise (2006, 2008, 2009, 2011, 2012, 2013)
7 baseline cruises (2007, 2010, 2013, 2014, 2015)

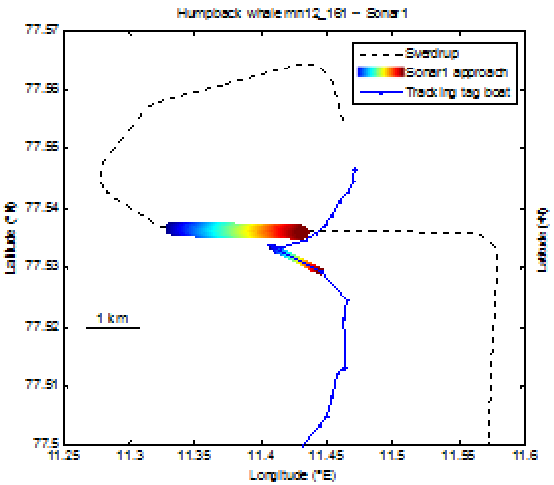


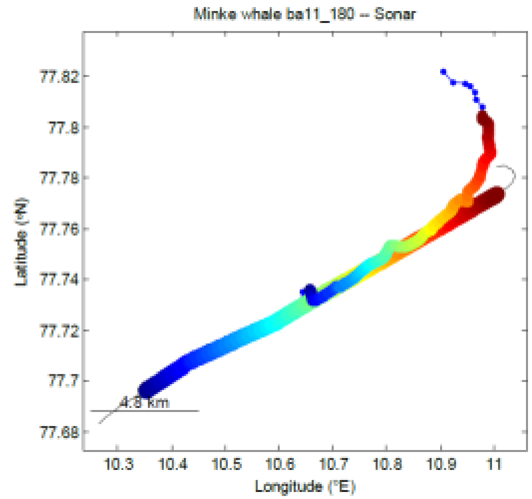
Species	# TAGs deployed	# Sonar exp.	# Control exp.	Trials/year
Killer whales	22	8	3	3S-05, 3S-06, 3S-08, 3S-09, ICE-09
Pilot whales	34	14	28	3S-08, 3S-09, 3S-10, 3S-13
Sperm whales	10	10	9	3S-08, 3S-09, 3S-10
Herring	0	38	25	3S-06, 3S-08
Minke whales	2	1	2	3S-10, 3S-11
Bottlenose whales	16	1	3	3S-13, JM-14, JM-15
Humpback whales	27	20	29	3S-11, 3S-12
SUM	**111**	**92**	**99**	

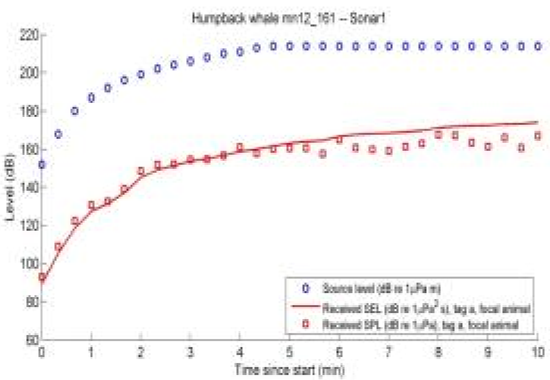
Basic 3S experimental design

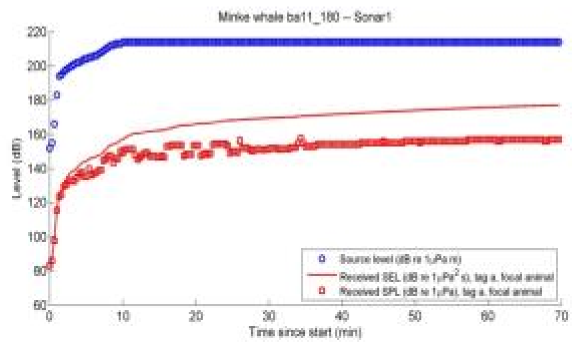
- Dose escalation design
- Threshold of response
- Type of response (severity)
- Slightly different approaches for different species.

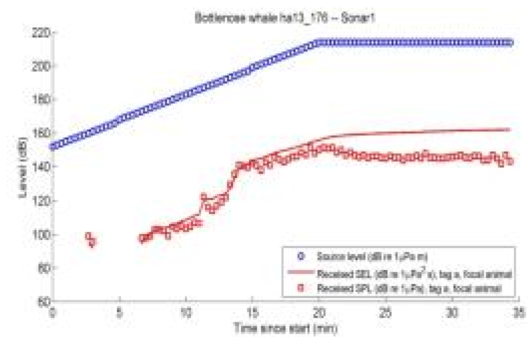






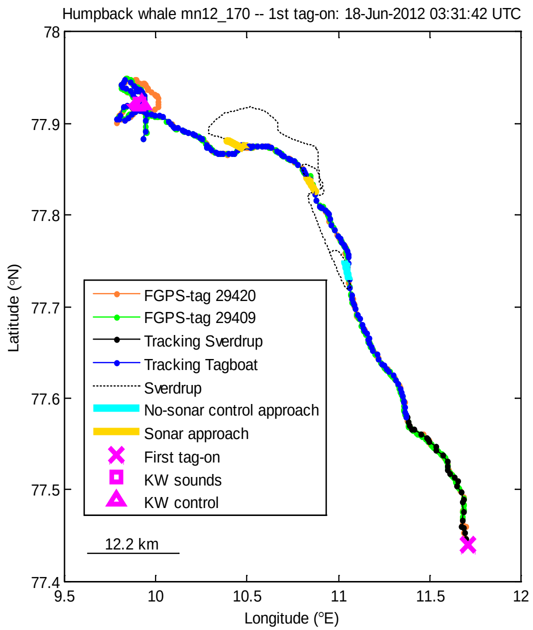


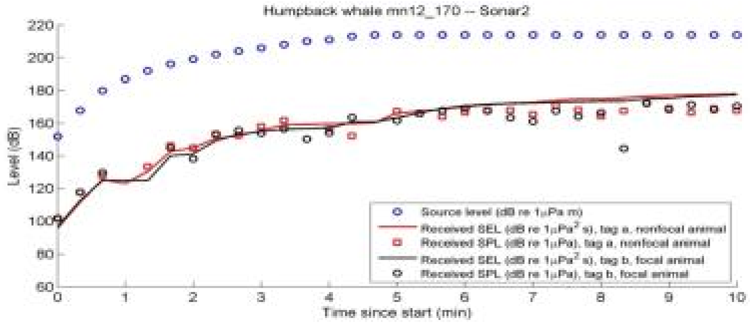




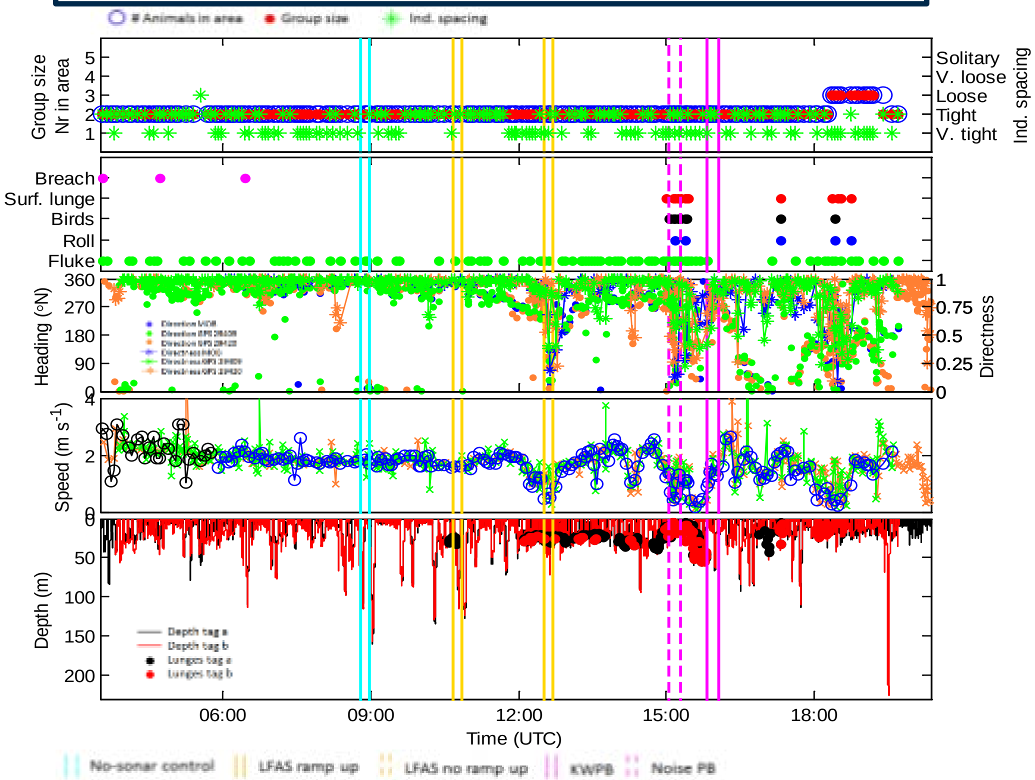
*Kvadsheim, et all. 2015. The 3S2 experiments - Studying the behavioural effects of naval sonar on northern bottlenose whales, humpback whales and minke whales. *FFI-rapport* 2015/01001 (*In press*)

Data streams



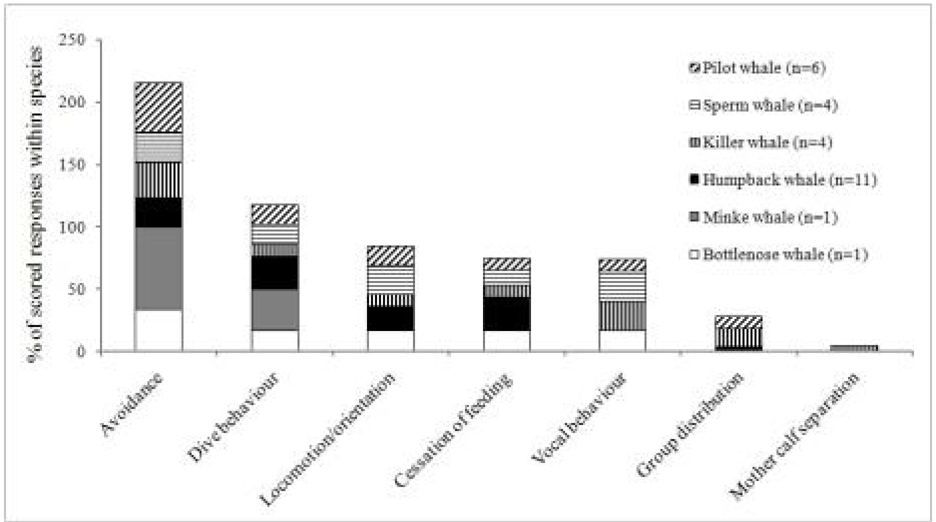


Vocalization



*Kvadsheim, et all. 2015. The 3S2 experiments - Studying the behavioural effects of naval sonar on northern bottlenose whales, humpback whales and minke whales. *FFI-rapport* 2015/01001 (*In press*)

Expert severity scoring



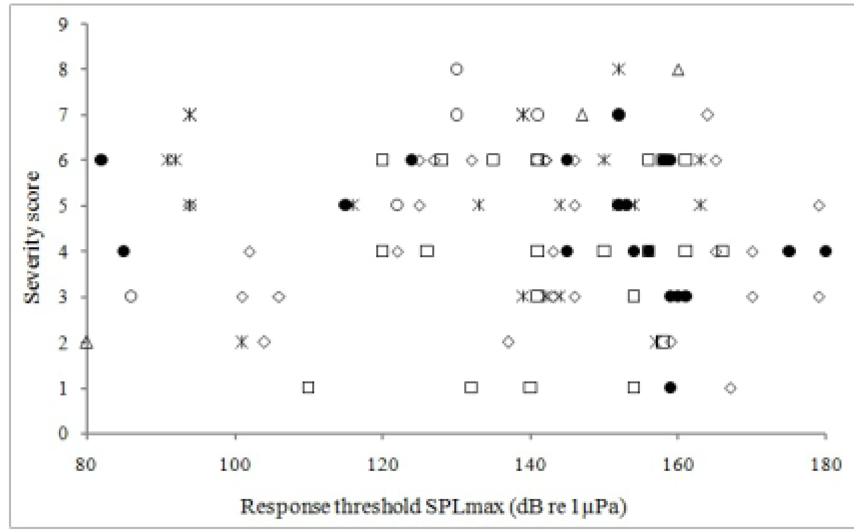
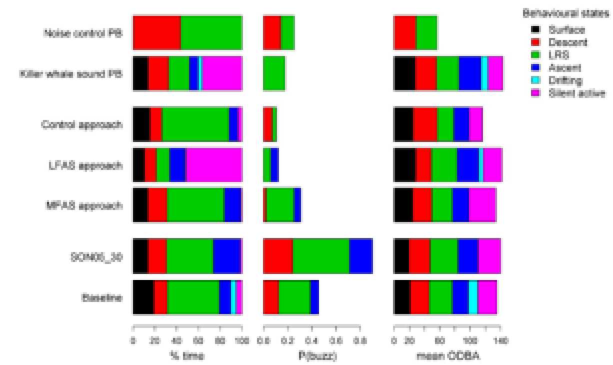


Figure 5. Scored severity vs threshold of all responses in the three species of this study and the three species of Miller et al. (2012): humpback whale (◇), minke whale (Δ), bottlenose whale (○), pilot whale (●), killer whale (*), and sperm whale (□).

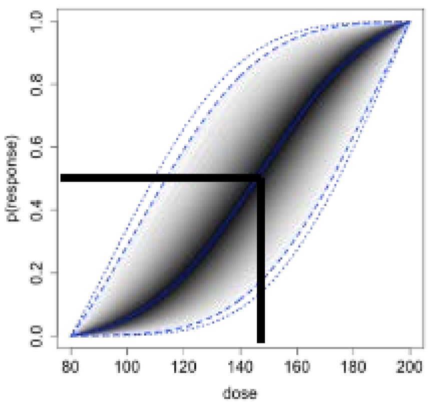
Sivle et al. (*in press*). Severity of expert-identified behavioural responses of humpback whale, minke whale and northern bottlenose whale to naval sonar. *Aquatic Mammals*
*Miller, P.J.O., Kvadsheim, P.H., Lam, F.P.A.., Wensveen, P.J., Antunes, R., Alves, A.C., Visser, F., Kleivane, L., Tyack, P.L., Sivle, L.D. (2012). The severity of behavioral changes observed during experimental exposures of killer (Orcinus orca), long-finned pilot (Globicephala melas), and sperm whales (Physeter macrocephalus) to naval sonar. *Aquatic Mammals* 38: 362-401.

Quantitative analysis

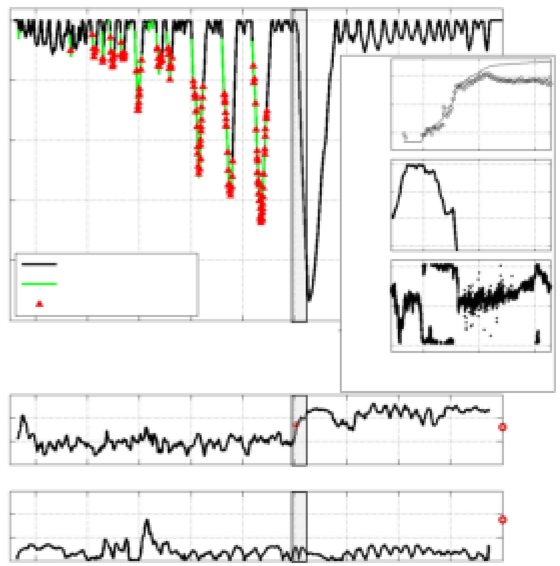
Changes in behavioral states



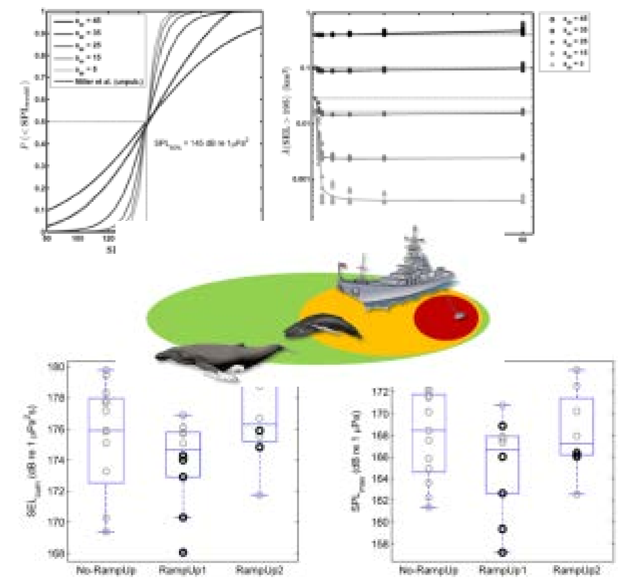
Dose response analysis



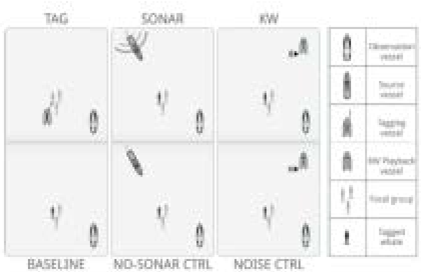
Breakpoint analysis



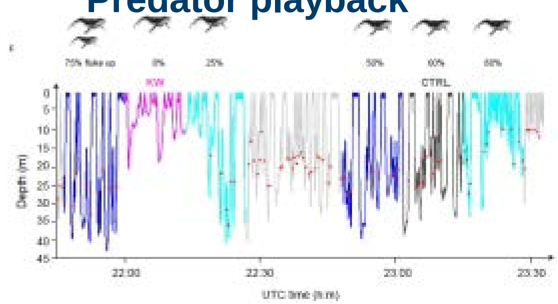
Effectiveness of Ramp Up



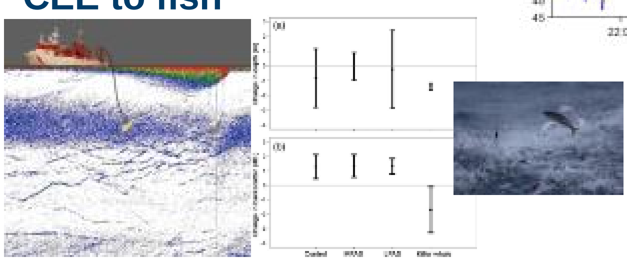
Social responses



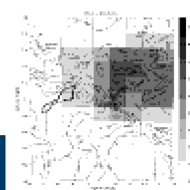
Predator playback

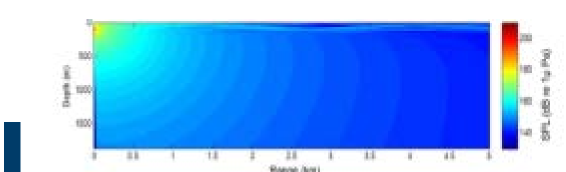


CEE to fish

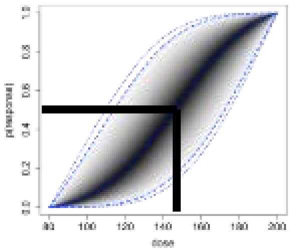


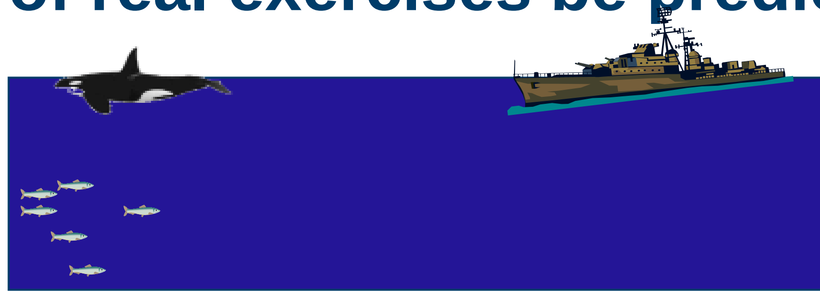
Application of BRS results in management





Can effects of real exercises be predicted by BRS?





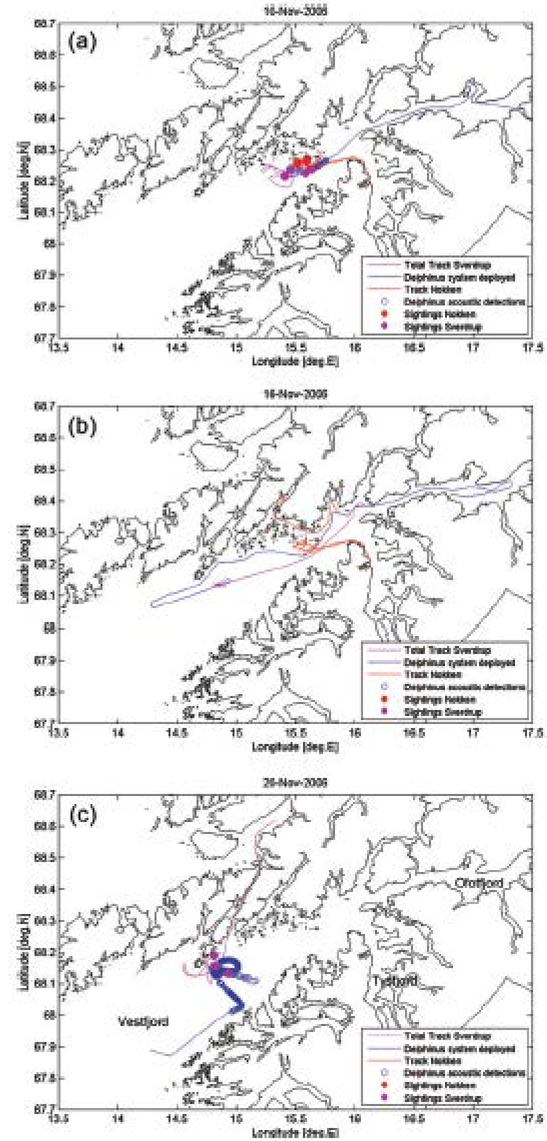


Table 3. Sightings recorded by the whale-watching (WW) company (Orca Tysfjord), our own visual and acoustic detections of killer whales, and naval sonar activity days within fjord system in November 2006, with a key to colours

	November																									
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
WW sightings																										
Visual																										
Acoustic																										
Sonar activity																										

	Colour
Detections	
No detections	
No effort	
Navy sonar	
CEE sonar	

Monitoring FLOTEX-Silver 2006

Kuningas et al. (2013). Killer whale presence in relation to naval sonar activity and prey abundance in northern Norway. *ICES J. Mar. Sci.* doi:10.1093/icesjms/fst127)

Why deep divers have higher risk of DCS

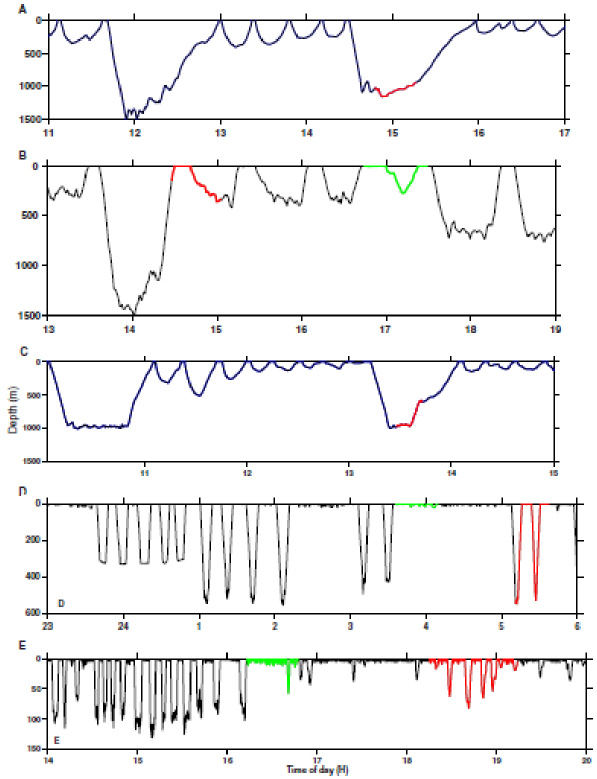
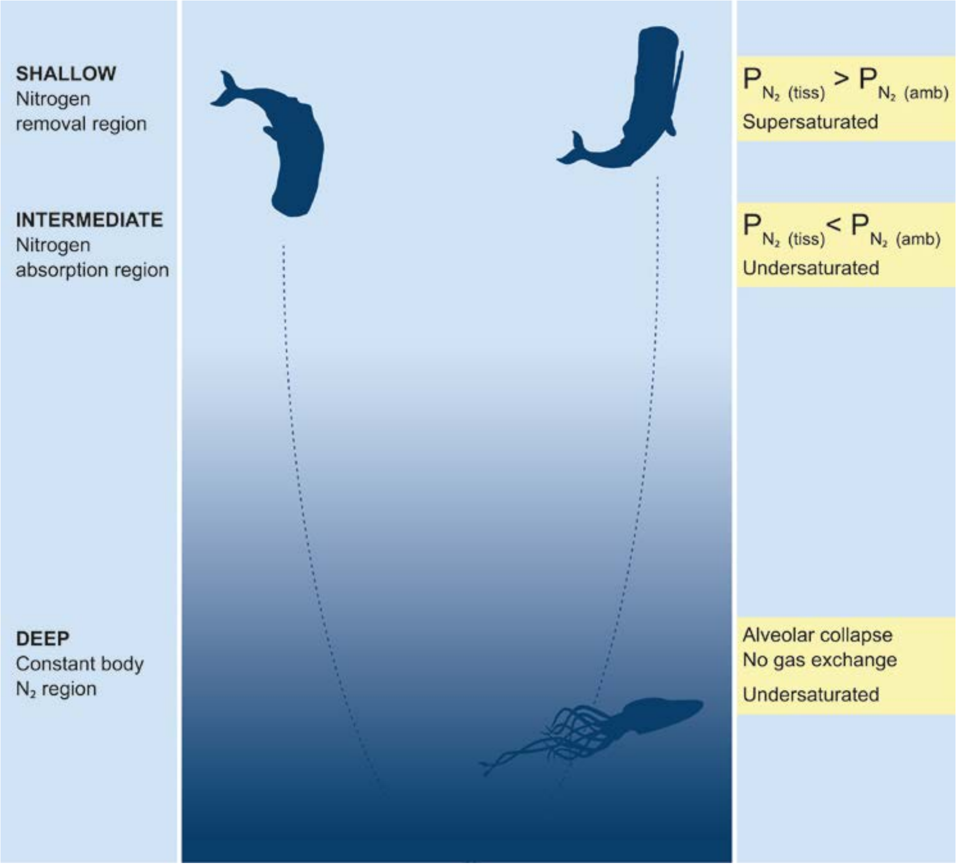


FIGURE 1 | Typical examples of changes in dive behavior in response to sonar. **(A)** Cuvier's beaked whale (zc10_272a), **(B)** sperm whale (sw09_160a), **(C)** Blainville's beaked whale (md07_245a), **(D)** pilot whale (gm09_156b), **(E)** killer whale (oo09_144a). The red part of the dive profile is exposure to MFAS sonar and the green to LFAS sonar. Time is in hours GMT and depth is in meters. Note the differences in depth scale between the different panels.



*Kvadsheim, P.H., Miller, P.J.O., Tyack, P., Sivle, L.D., Lam, F.P.A., and Fahlman, A. (2012). Estimated tissue and blood N_2 levels and risk of in vivo bubble formation in deep-, intermediate and shallow diving toothed whales during exposure to naval sonar. *Frontiers in Aquat. Phyisol.* 3: article 125.

*Fahlman A, Tyack PL, Miller PJ and Kvadsheim PH (2014). How man-made interference might cause gas bubble emboli in deep diving whales? *Frontiers in Physiology* 5: 1-6.

Unique features of 3S

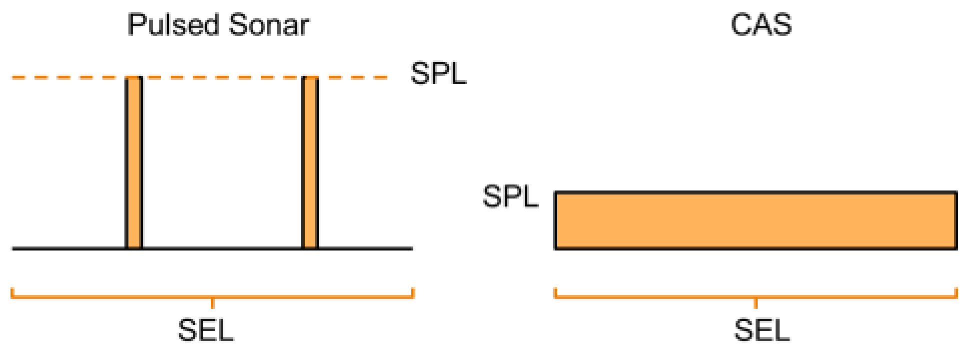
3S
Sea mammals
Sonar
Safety

- International effort (scientist and sponsors)
- BRS off sonar ranges
- Relatively realistic source and exposure regime
- Control experiments
  - No-sonar-control
  - Predator and noise playbacks
- BRS on prey (herring)
- We have added social behavior as an important response variable
- We have used different sonars – frequency specificity of responses
- Successfully tested the efficacy of a mitigation measure – ramp up
- Published dose response functions for 4 species
- We have developed a new technique to deploy DTAGs more effectively on *«evasive species».*

Data gaps - 3S3?

- **3S project has contributed to major improvement of our understanding of environmental effects of sonar.**
- We have identified four important data gaps, which will also greatly increase the value of the existing data.

Research gap 1: Confirmation of sensitivity in apparently sensitive species (n=1)
Research gap 2: Is received level or proximity the main response driver?
Research gap 3: What is the effect of exposure duration?
Research gap 4: What is the effects of future CAS versus pulsed sonars?



Project partners:

FFI Forsvarets forskningsinstitutt
Norwegian Defence Research Establishment

SMRU

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

TNO innovation for life

kelp

Cerema

INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET

Research fundings:

DEPARTMENT OF THE NAVY ONR Science & Technology

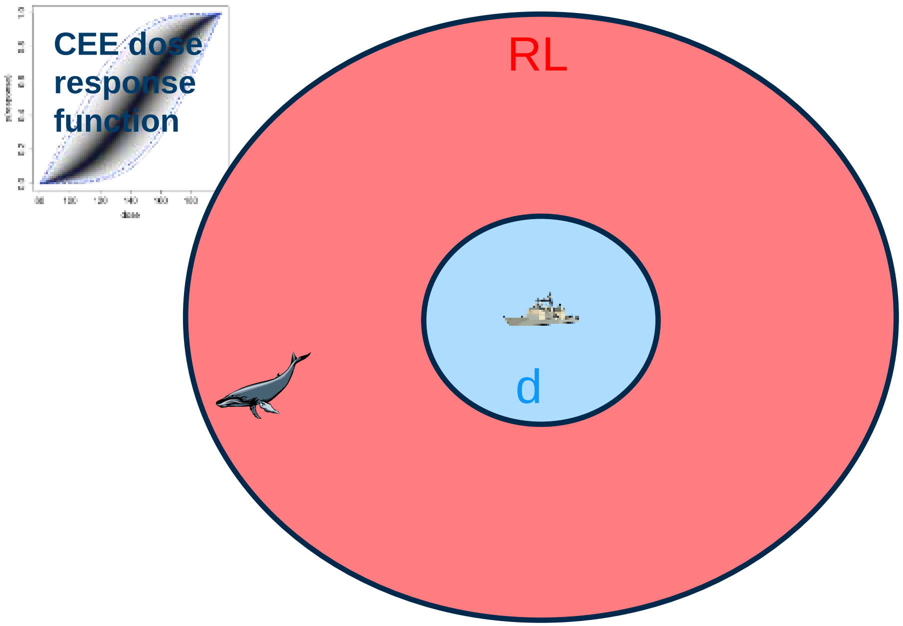
Defensie

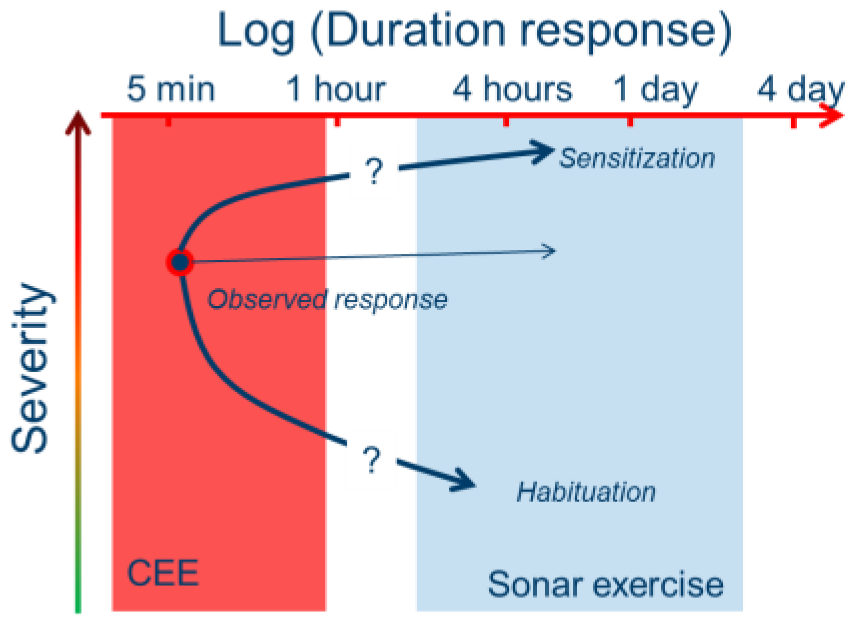
Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
MINISTÈRE DE LA DÉFENSE

DGA


Eirik Grønningsæter

How to extrapolate from CEE to real ASW?



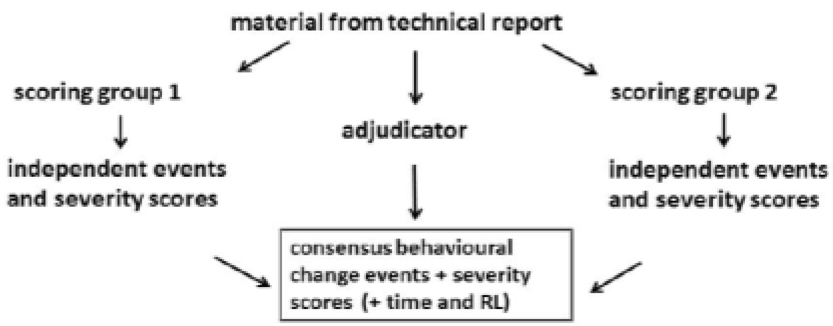


Research gap 2: Is received level or proximity the main response driver?

Research gap 3: what is the effect of exposure duration?

Expert severity scoring

- Expert scoring methodology
  - Based on phase I medical trials
  - Experts are scoring putative responses (not just any changes in behavior).
  - Not blind to the experimental condition
  - Severity score



Severity scale

0= No Response

1-3 Minor/Brief Responses NOT likely to affect vital rates

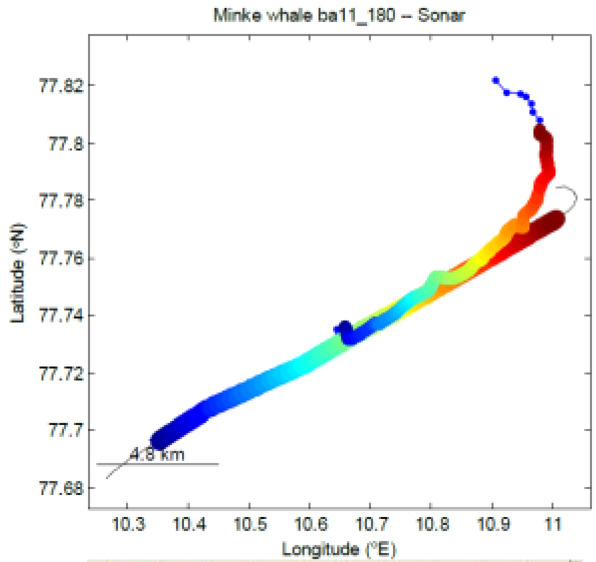
4-6 Potential to affect vital rates (foraging, survival, reproduction)

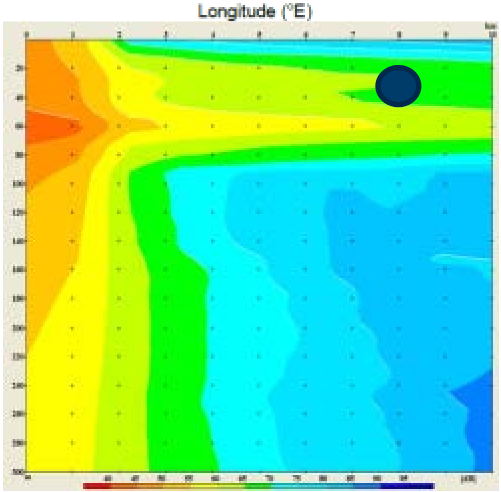
7-9 Likely to affect vital rates

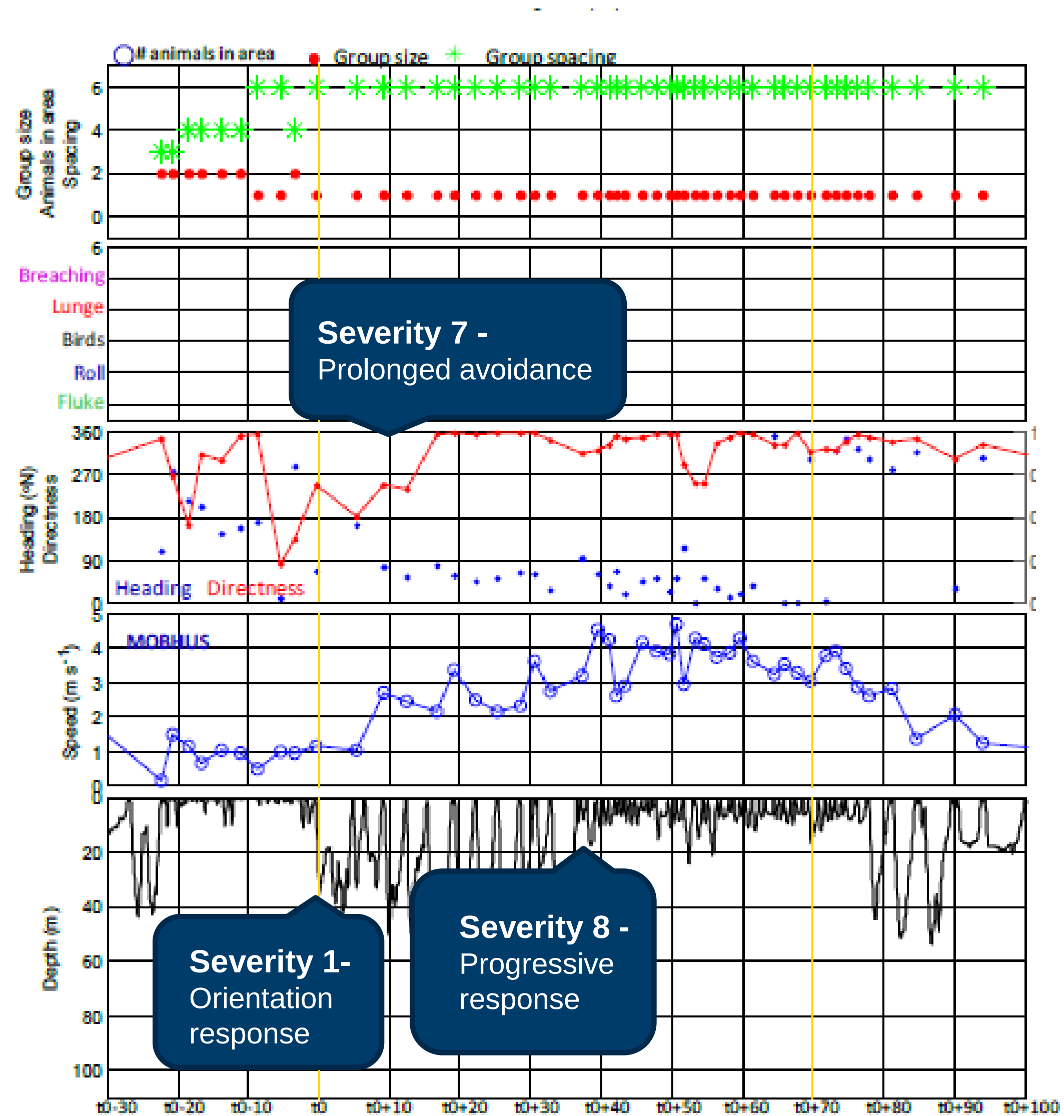
Response score[1]	Corresponding behaviors (Free-ranging subjects)[2]
0	- No observable response
1	- Brief orientation response (investigation/visual orientation)
2	- Moderate or multiple orientation behaviors - Brief or minor cessation/modification of vocal behavior - Brief or minor change in respiration rates
3	- Prolonged orientation behavior - Individual alert behavior - Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate change in respiration rate - Minor cessation or modification of vocal behavior (duration < duration of source operation), including the Lombard Effect
4	- Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Brief, minor shift in group distribution - Moderate cessation or modification of vocal behavior (duration ≈ duration of source operation)
5	- Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source - Moderate shift in group distribution - Change in inter-animal distance and/or group size (aggregation or separation) - Prolonged cessation or modification of vocal behavior (duration > duration of source operation)
6	- Minor or moderate individual and/or group avoidance of sound source - Brief or minor separation of females and dependent offspring - Aggressive behavior related to noise exposure (e.g., tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds) - Extended cessation or modification of vocal behavior - Visible startle response - Brief cessation of reproductive behavior
7	- Extensive or prolonged aggressive behavior - Moderate separation of females and dependent offspring - Clear anti-predator response - Severe and/or sustained avoidance of sound source - Moderate cessation of reproductive behavior
8	- Obvious aversion and/or progressive sensitization - Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms - Long-term avoidance of area (> source operation) - Prolonged cessation of reproductive behavior
9	- Outright panic, flight, stampede, attack of conspecifics, or stranding events - Avoidance behavior related to predator detection

Southall et al 2007. *Aquatic Mammals*

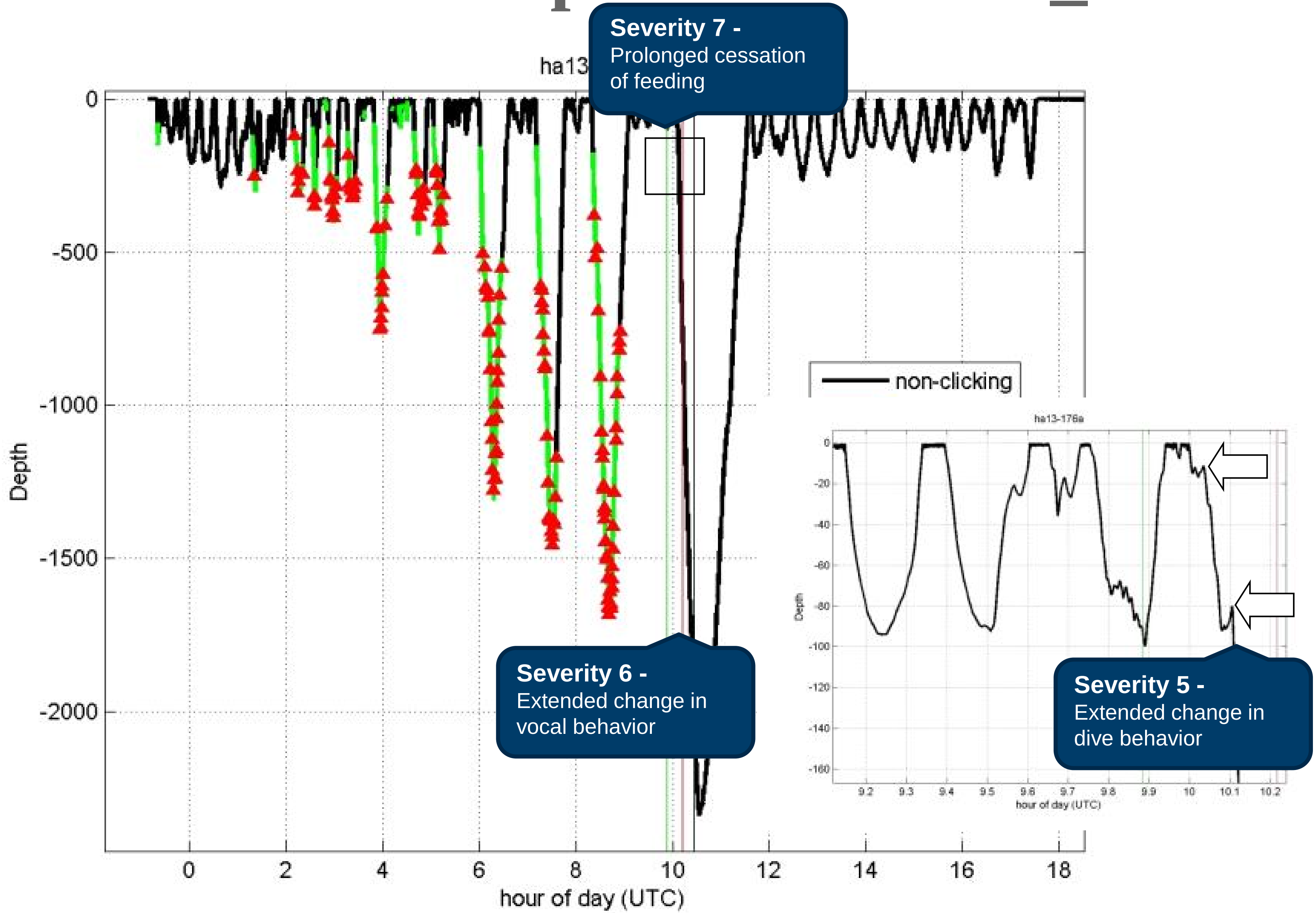
Example data plot – minke whale Ba11_180a



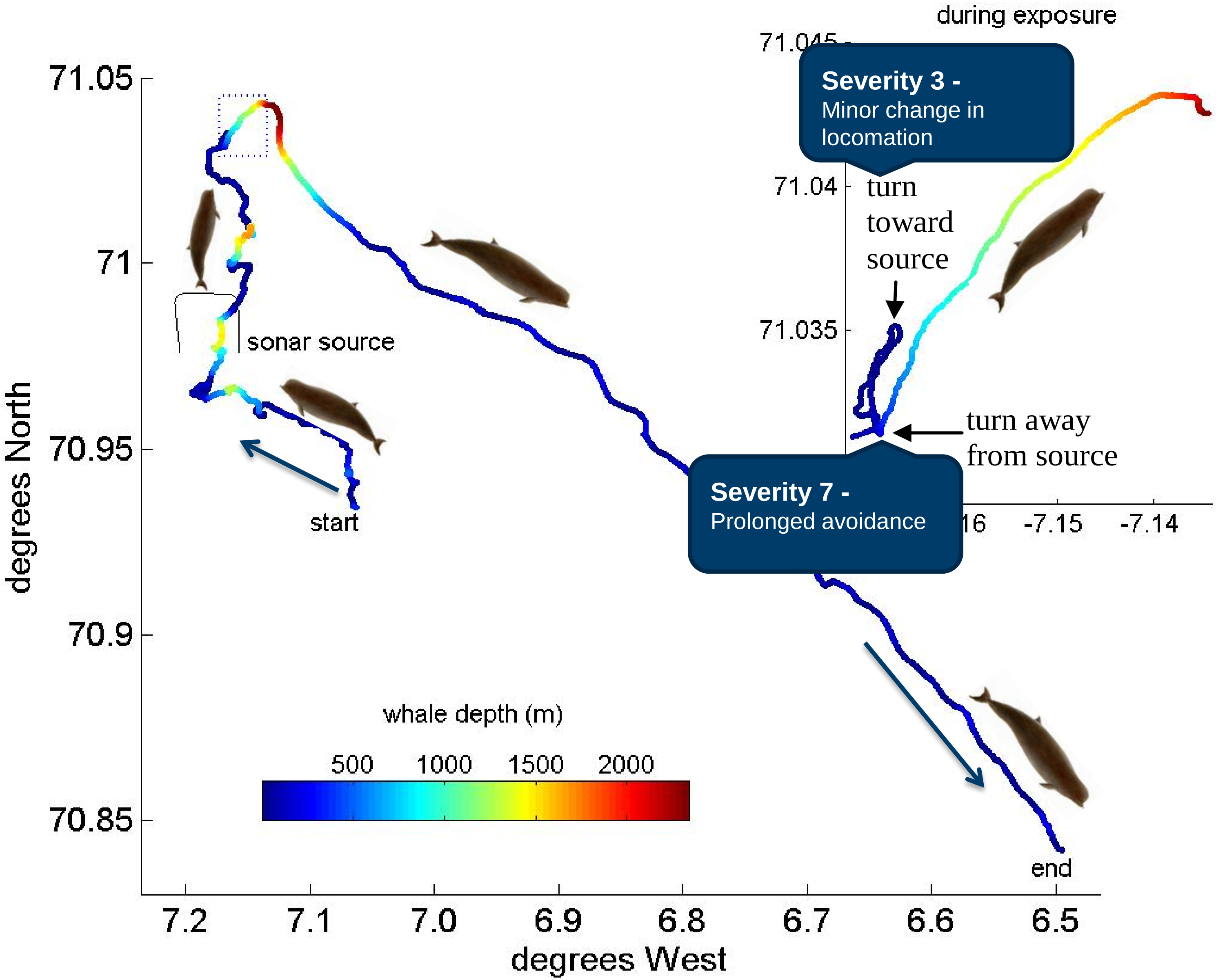




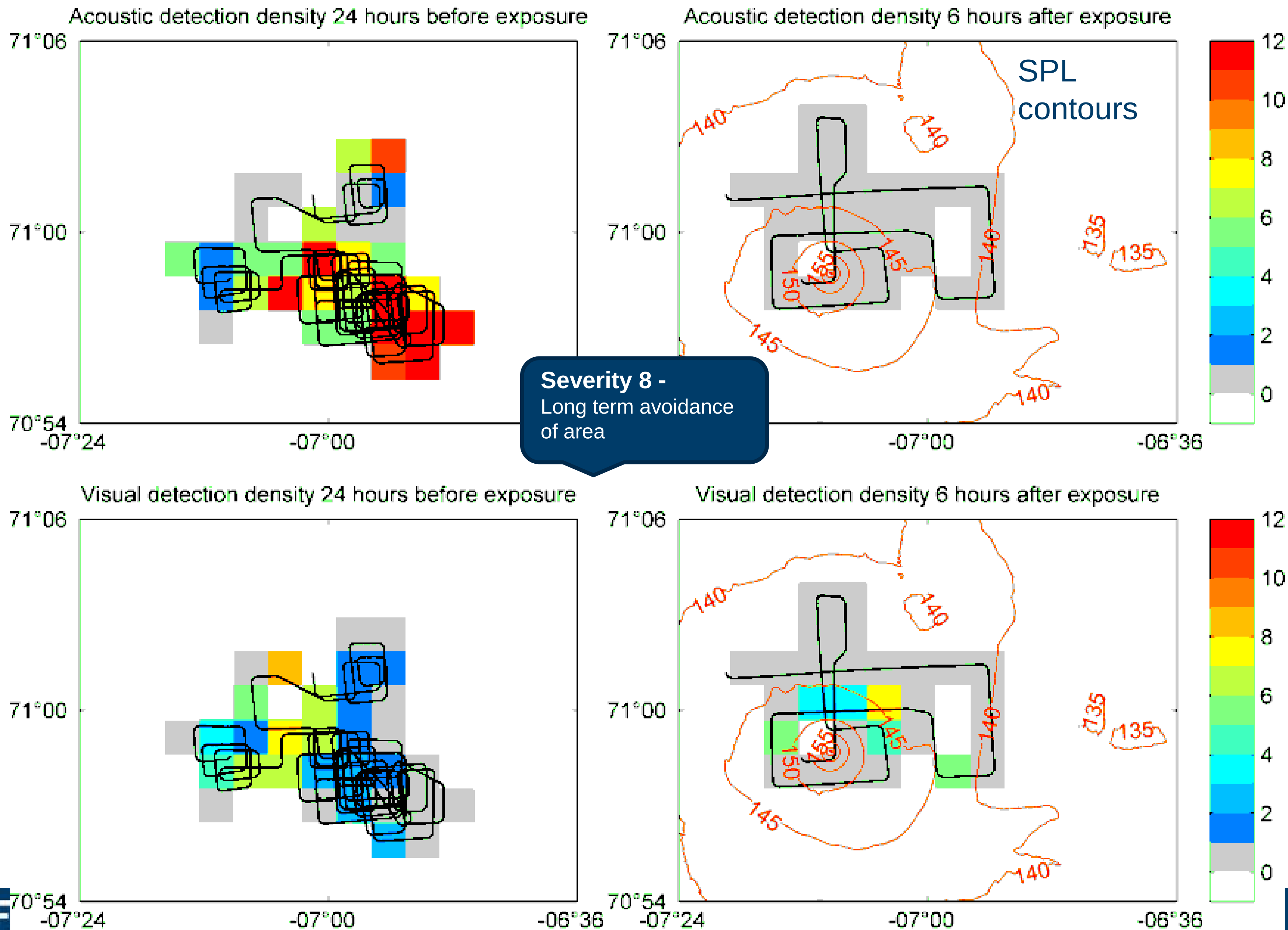
Bottlenose whale experiment: ha13_176a



Bottlenose whale experiment: ha13_176a

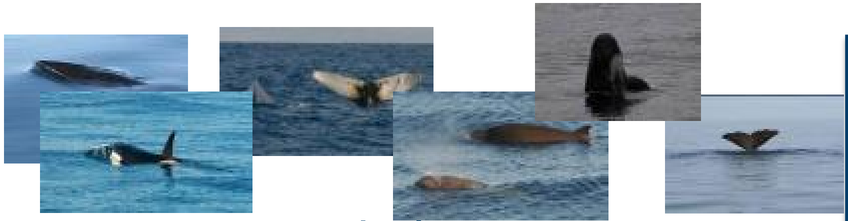


Fewer whales were detected after exposure



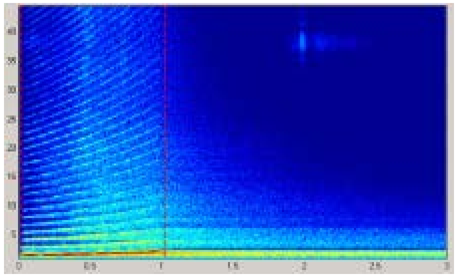
Severity 8 -
Long term avoidance of area

3S Experimental components



Target animals

- -LFAS 1-2 kHz @ 214 dB
- -MFAS 6-7 kHz @ 199 db
- -1 s hyperbolic up-sweeps
- -20s pulsintervall, 5% duty cyclev



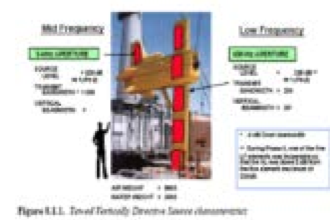
Why – species?

- **3S-I** (killer whales, pilot whales, sperm whales)
- No (or very little) data available on behavioral responses to sonar.
- Killer whales because of conflicts between whale watching and sonar (Haro straits - and Flotex incidents).
- Pilot whales and sperm whales because they were available and “easy” to work with.
- Everybody else were working on beaked whales

- **3S-II** (Minke whales, Humpback whales, Northern Bottlenose whales)
- Minke whales and Humpback whales because we needed data on baleen whales.
- Minke whales have been associated with mass stranding in relation to sonar exercises.
- Humpback whale was a good experimental model for our ramp-up studies.
- Northern Bottlenose whales is a beaked whale, thus thought to be very sensitive.

Why study behavioral responses to sonar?

- Relatively good understanding of direct effects of sonar (injury)
- Behavioral effects are a much bigger data gap
- Most nations are basing their management of the problem on criteria for injury (mitigate risk of injury).
- Stranding events imply a behavioral component to the cause effect relationship mechanism (indirect injury).
- Behavioral effects might also affect the population without causing direct injury (PCAD).
- National and international legislations require that humans avoid behavioral influences.



It all started in Greece May 1996 - NATO testing of LFAS system

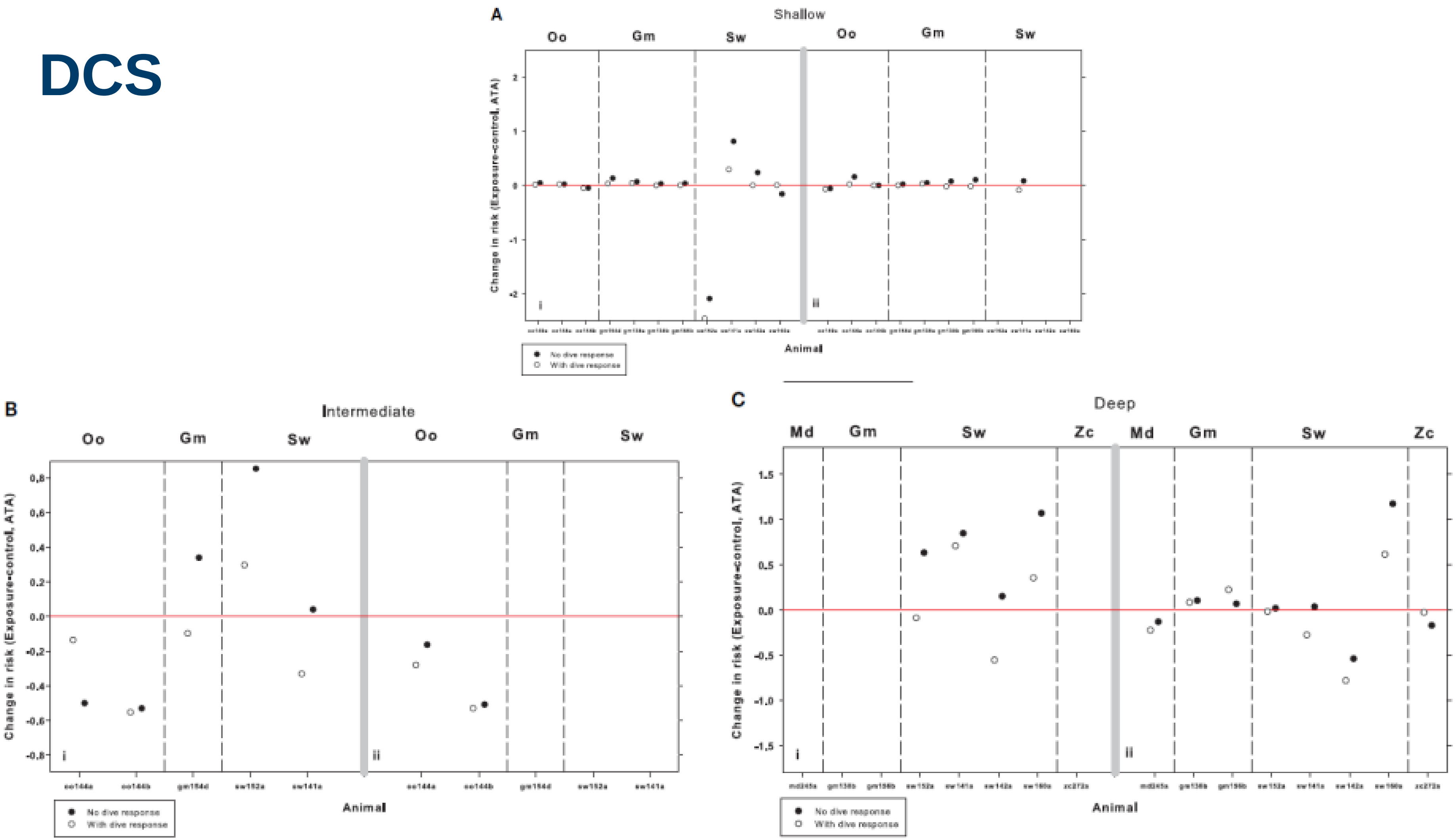
3S key questions

- How does cetaceans respond to sonar and at what levels do they respond?
  - Are there major differences between species? (identity sensitive species)
  - Is there any frequency specificity in the response? (related to hearing)
  - How does responses to sonar compare to natural anti predator responses?
  - Does Ramp Up reduce risk of hearing impairment?
  - Do the animals habituate or become sensitized?
- What is the biological significance of such responses?
- How can experimental data be used in managing the real sonar issue?

Some conclusions

- Cetaceans respond to sonar in a way which raises concerns of population level effects.
- Avoidance of sonar is the most commonly observed response, but cessation of feeding and change in vocal-, dive- and social behavior are also observed.
- Big differences in sensitivity (responsiveness) between different species.
  - Among the 3S species, bottlenose whales respond at lowest levels and with most severe responses.
  - Minke whales, sperm whales and killer whales seem to have an intermediate sensitivity.
  - Humpback whales and pilot whales seem to be the least sensitive
- Responses might occur at very low levels (even levels expected to be barely audible to the animals).
- Risk of more severe responses increases at levels above 140 dB.
- Deep divers are more at risk of developing decompression sickness and thus more vulnerable to disturbance.
- Effects of real exercises might be predicted from BRS results.

DCS


A
Shallow
Oo
Gm
Sw
Oo
Gm
Sw
Change in risk (Exposure-control, ATA)
2
1
0
-1
-2
i
ii
Animal
No dive response
With dive response
B
Intermediate
Oo
Gm
Sw
Oo
Gm
Sw
Change in risk (Exposure-control, ATA)
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
i
ii
oo144a
oo144b
gm154d
sw152a
sw141a
oo144a
oo144b
gm154d
sw152a
sw141a
Animal
No dive response
With dive response
C
Deep
Md
Gm
Sw
Zc
Md
Gm
Sw
Zc
Change in risk (Exposure-control, ATA)
1,5
1,0
0,5
0,0
-0,5
-1,0
-1,5
i
ii
Animal
No dive response
With dive response

List of key papers from 3S

- *Curé et al. (submitted). Biological significance of sperm whale responses to sonar: comparison with anti-predator responses. *Endangered Species Research*
- *Visser et al. (submitted). Disturbance-specific social responses in long-finned pilot whales. *Royal Society Proceeding B*
- *Wensveen et al. (in review). The effectiveness of ramp-up of naval sonar to reduce sound levels received by marine mammals: experimental tests with humpback whales. *Royal Society Proceeding B*
- Lam, FP & Kvadsheim, PH (2015). Effects of Sound in the Ocean on Marine Mammals - ESOMM-2014 Conference. *Aquatic Mammals* (in press).
- *Sivle, L, PH Kvadsheim, C Curé, S Isojunno, PJ Wensveen, FPA Lam, F Visser, L Kleivane, PL Tyack, C Harris, PJO Miller (*in press*). Severity of expert-identified behavioural responses of humpback whale, minke whale and northern bottlenose whale to naval sonar. *Aquatic Mammals*
- Wensveen P.J., Thomas, L. Miller, PJO. (in press). A path reconstruction method integrating dead reckoning and position fixes applied to humpback whales. *Movement ecology*
- *Harris, C.M., D. Sadykova, S.L. DeRuiter, P.L. Tyack, P.J.O. Miller, P.H. Kvadsheim, F.P.A. Lam, and L. Thomas. (*in press*). Dose response severity functions for acoustic disturbance in cetaceans using recurrent event survival analysis. *Ecosphere*
- *Isojunno, S, C. Curé, P. H. Kvadsheim, F. P. A. Lam, P. L. Tyack, P. J. Wensveen, P. J. O. Miller (*in press*). Sperm whales reduce foraging effort during exposure to 1-2 kHz sonar and killer whale sounds. *Ecological Applications*
- Samarra, F and Miller PJO (2015). Prey-induced behavioural plasticity of herring-eating killer whales. *Marine Biology* 162, 809-821. doi:10.1007/s00227-015-2626-8
- *Miller PJO, PH Kvadsheim, FPA Lam, PL Tyack, C. Cure, SL DeRuiter, L Kleivane, L Sivle, SP van IJsselmuide, F Visser, PJ Wensveen, AM von Benda-Beckmann, L Martin López, T Narazaki, SK Hooker (2015). First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise. *R. Soc. open sci.* 2: 140484. http://dx.doi.org/10.1098/rsos.140484
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- *Sivle, L.D., Kvadsheim, P.H. and Ainslie, M.A. (2014). Potential for population-level disturbance by active sonar in herring. *ICES J. Mar. Sci.* doi: 10.1093/icesjms/fsu154
- Visser F., Miller P.J.O., Antunes R.N., Oudejans M.G., Mackenzie M.L., Aoki K., Lam F.P.A., Kvadsheim P.H., Huisman J. and Tyack P.L. (2014). The social context of individual foraging behaviour in long-finned pilot whales (Globicephala melas). *Behaviour* 151: 1453-1477. DOI: 10.1163/1568539X-00003195.
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- *Miller, P.J.O., Antunes, R., Wensveen, P., Samarra, F.I.P., Alves, A.C., Tyack, P., Kvadsheim, P. H., Kleivane, L., Lam, F. P., Ainslie, M. and Thomas, L (2014). Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. *J. Acoust. Soc Am.*135, 975-993
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