Use of dose-escalation experiments to derive dose-response functions

Patrick Miller

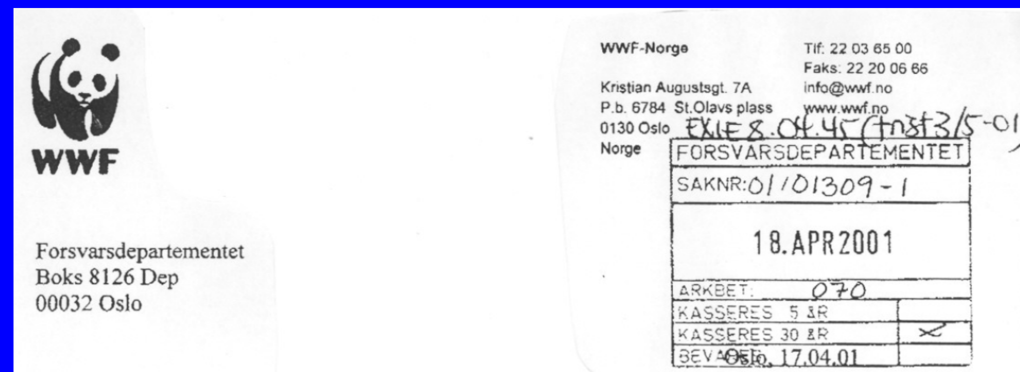
Reader

University of Saint Andrews

Navy sonar and whales recognition of a hazard

Hazard identified– navy sonar may impact behaviour / physiology

Haro Strait, 2003



WWF

WWF-Norge
Kristian Augustsgt. 7A
P.b. 6784 St.Olavs plass
0130 Oslo
Norge

Tlf: 22 03 65 00
Faks: 22 20 06 66
info@wwf.no
www.wwf.no

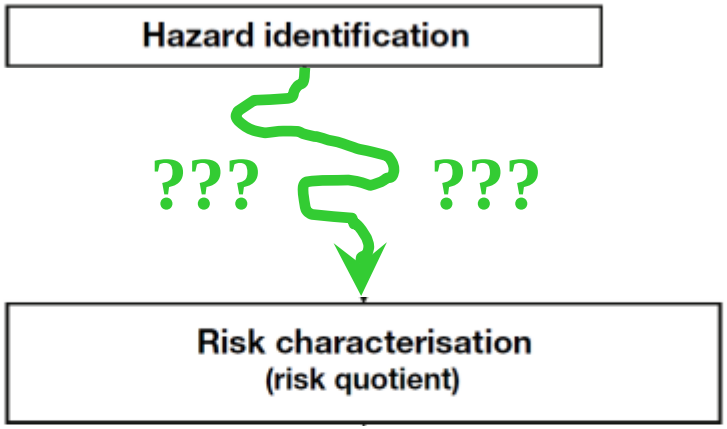
FORSVARSDEPARTEMENTET
SAKNR: 01/01309-1
18.APR2001
ARKBET: 070
KASSERES 5 ÅR
KASSERES 30 ÅR
BEVARES

Forsvarsdepartementet
Boks 8126 Dep
00032 Oslo

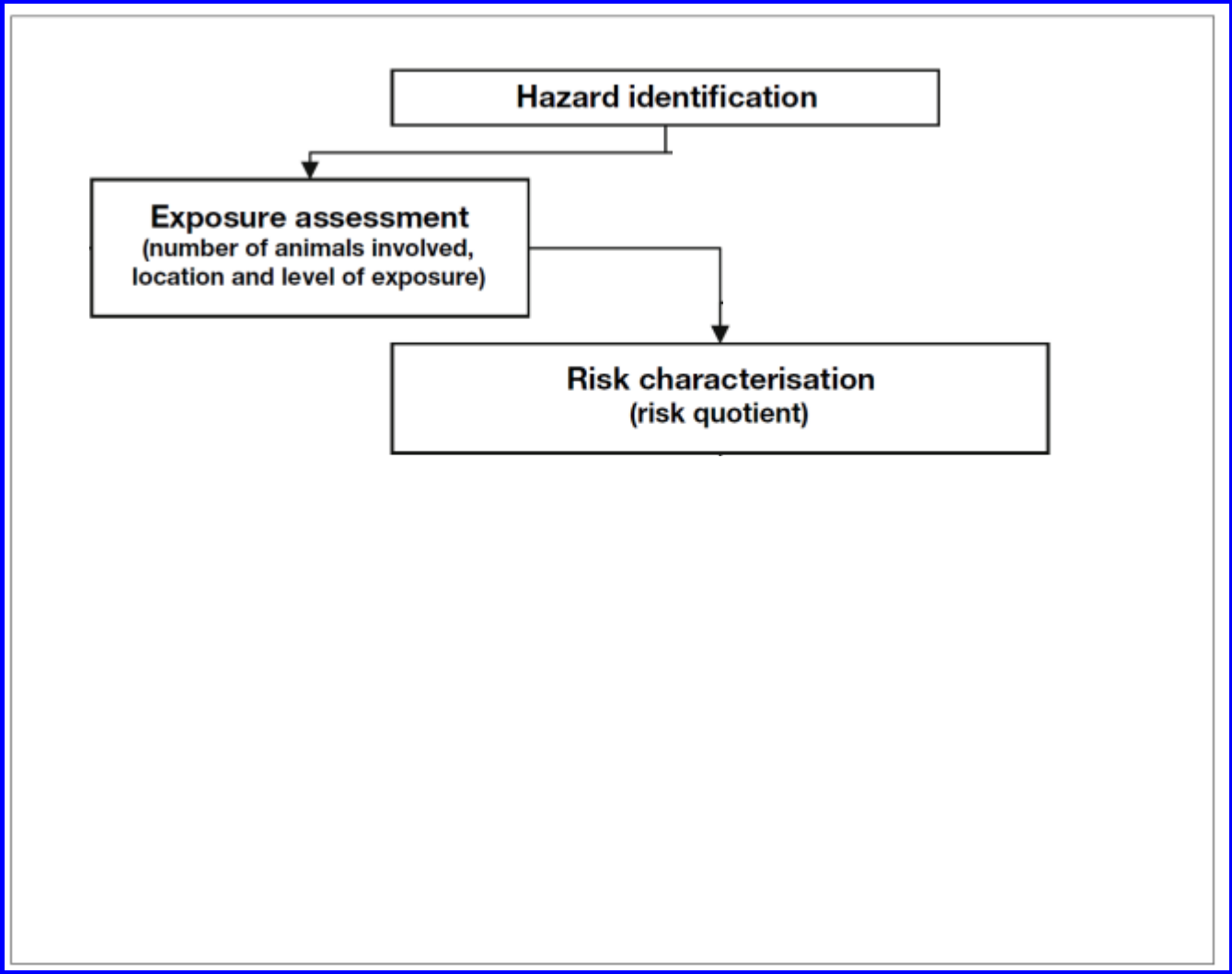
Oslo, 17.04.01

Beaked whales being removed from the beach after a mass stranding, Canary Islands, 2002

How to assess risk?

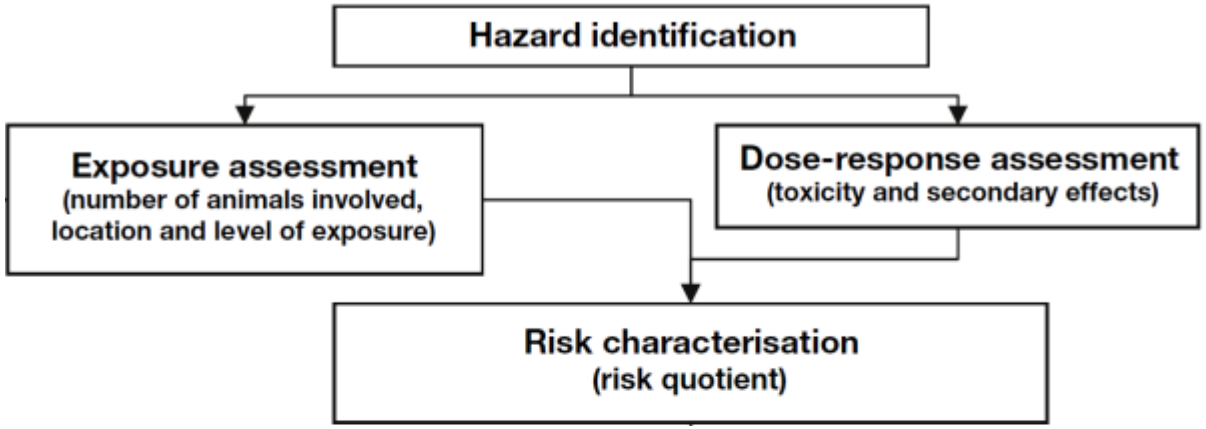


Risk assessment framework



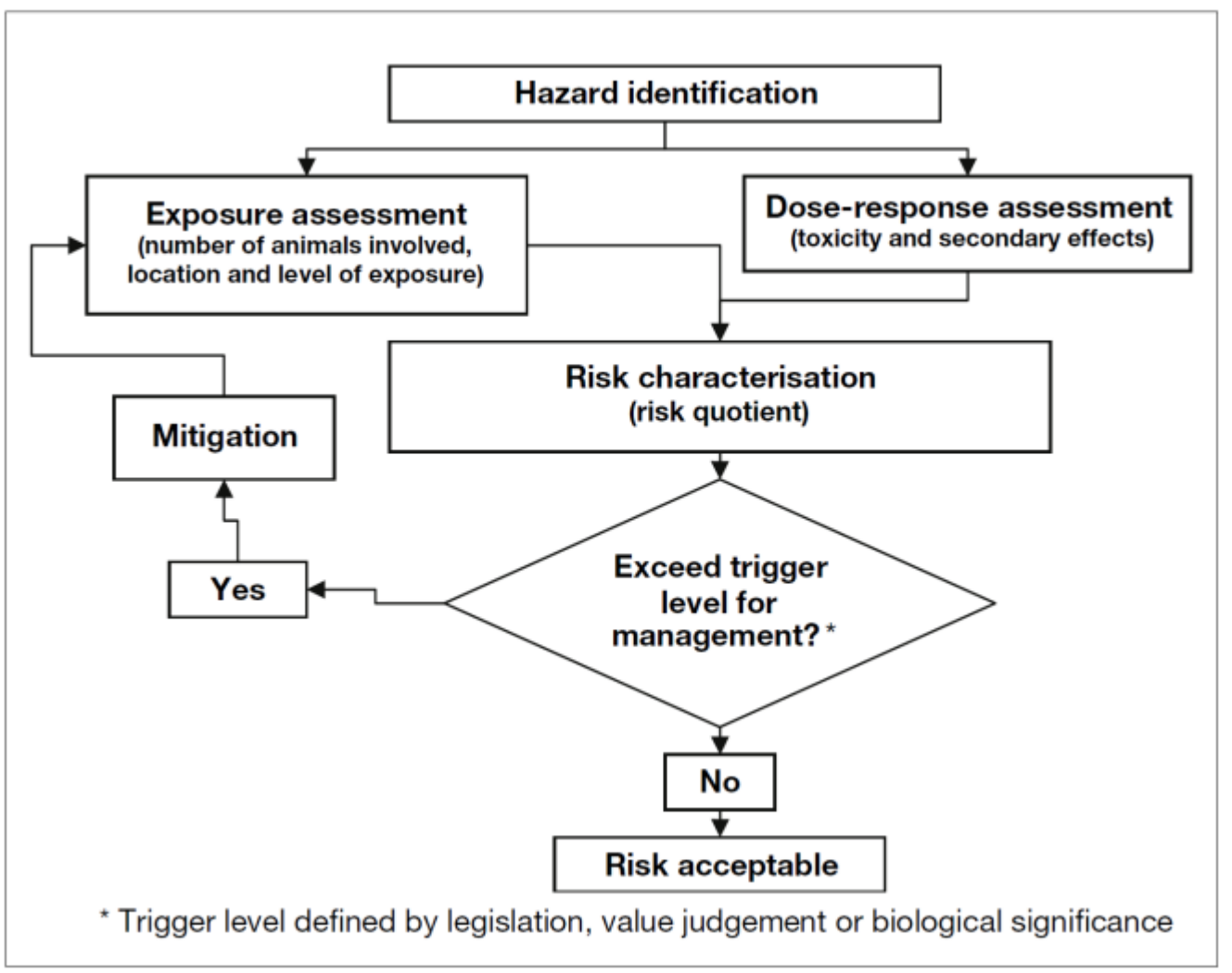
Boyd et al., 2008 ESF Marine Board – Oxford 2005

Risk assessment framework



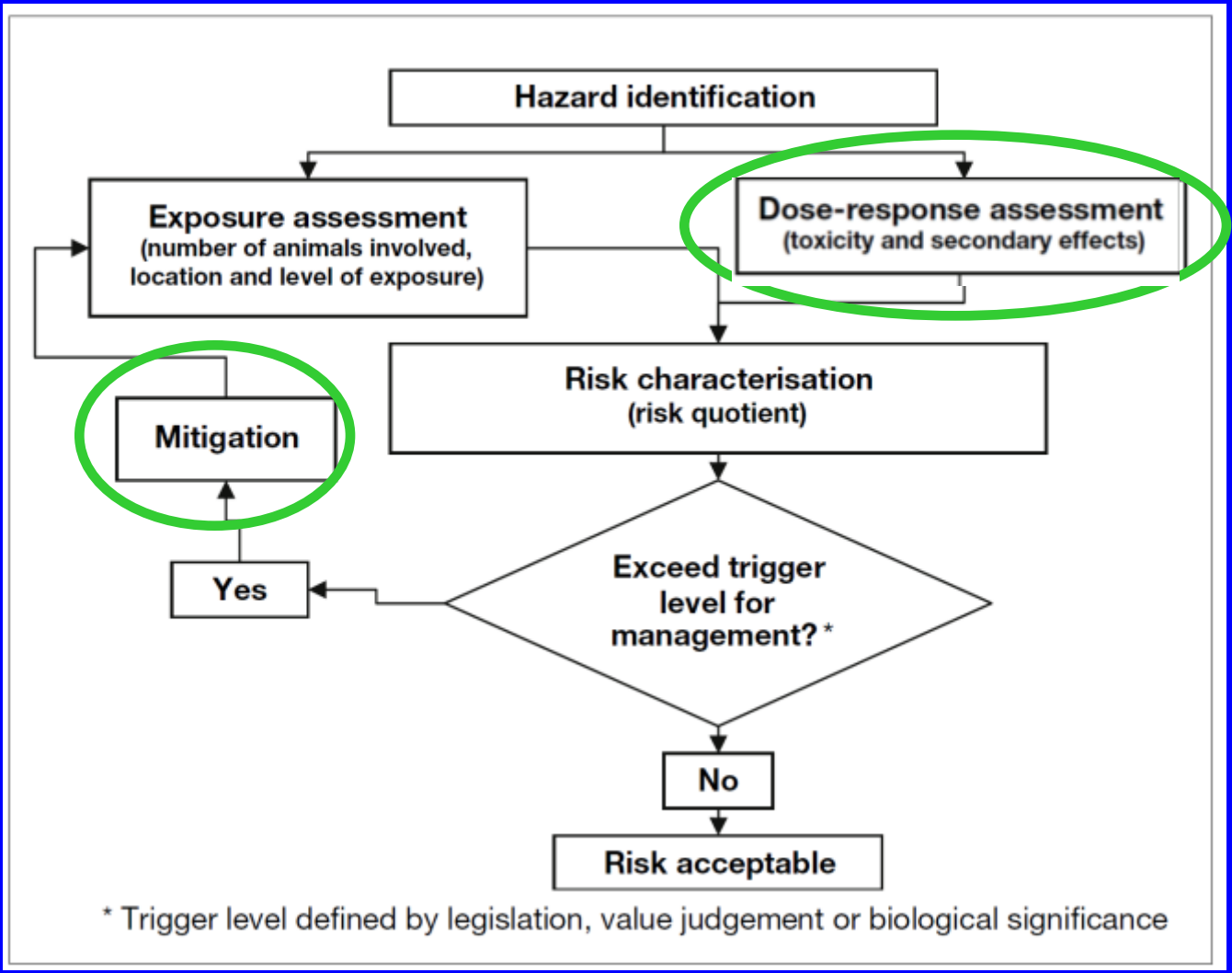
Boyd et al., 2008 ESF Marine Board – Oxford 2005

Risk assessment framework



Boyd et al., 2008 ESF Marine Board – Oxford 2005

Addressed by 3S



Boyd et al., 2008 ESF Marine Board – Oxford 2005

Dose-response

probability of negative effect

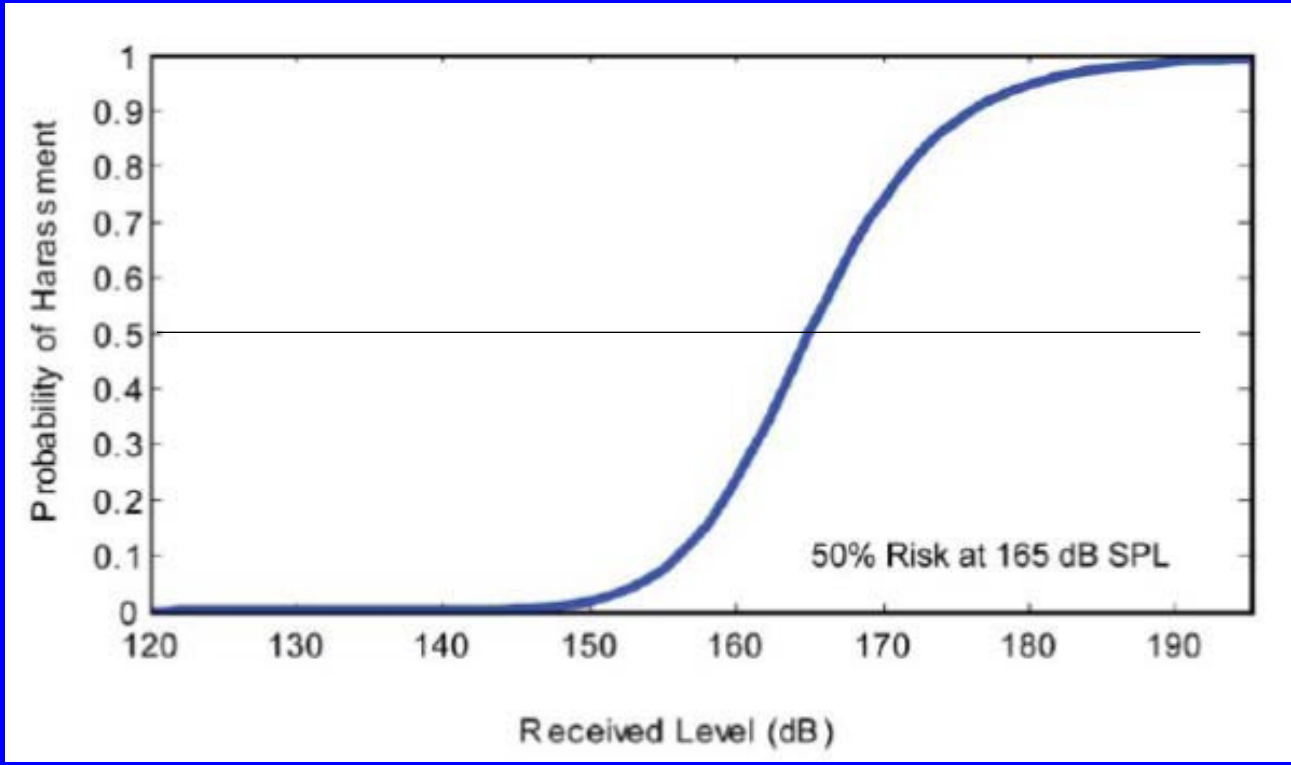
“All substances are poisons: there is none which is not a poison. The right dose differentiates a poison and a remedy.”

Paracelsus (1493-1541)

dose

US Navy approach

Likelihood of harassment as a function of sonar received sound pressure level (SPL)



risk function

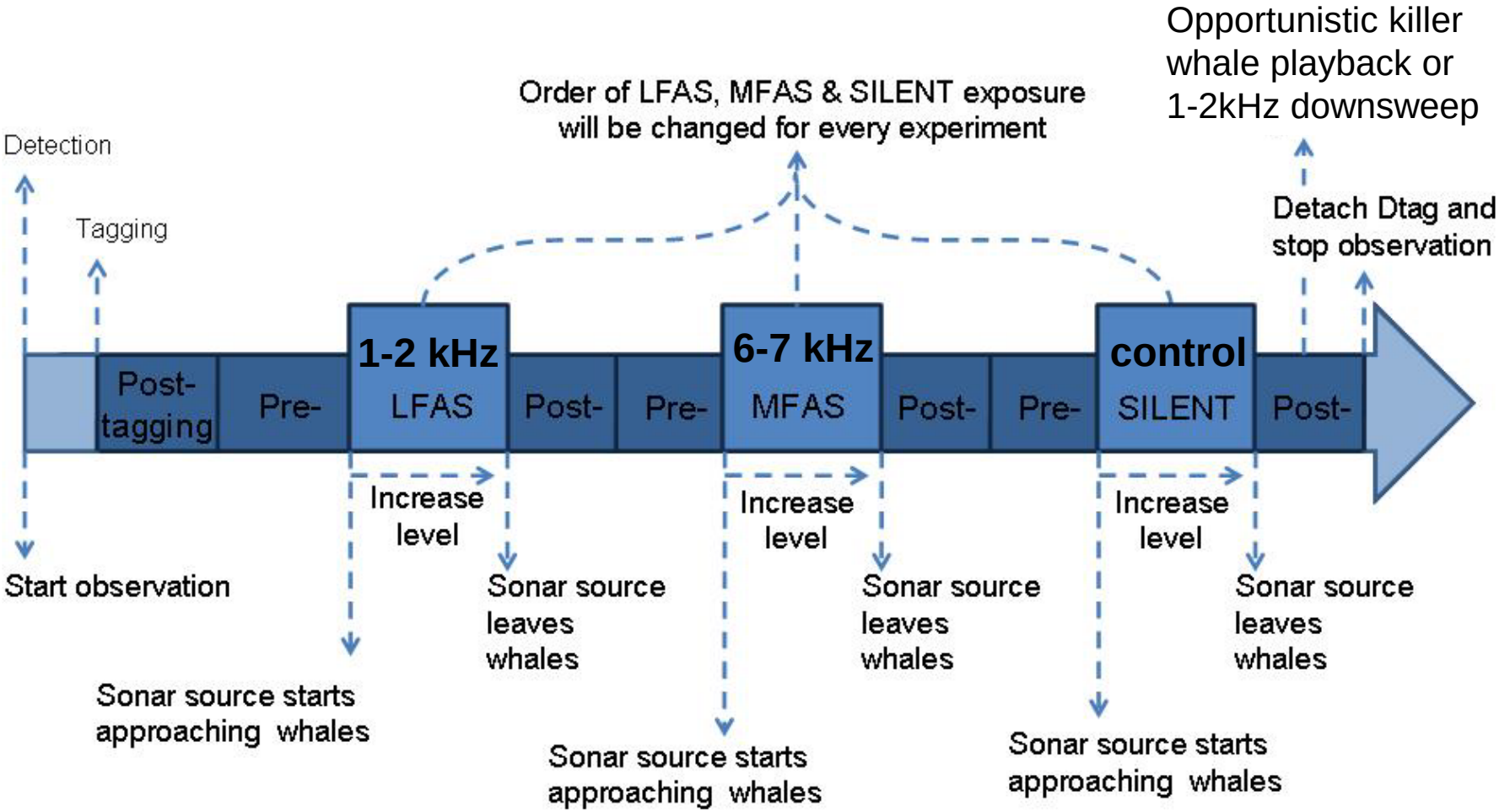
US Navy EIS (2008)

3S Experiments

1-2 kHz
'LFAS'
214 dB

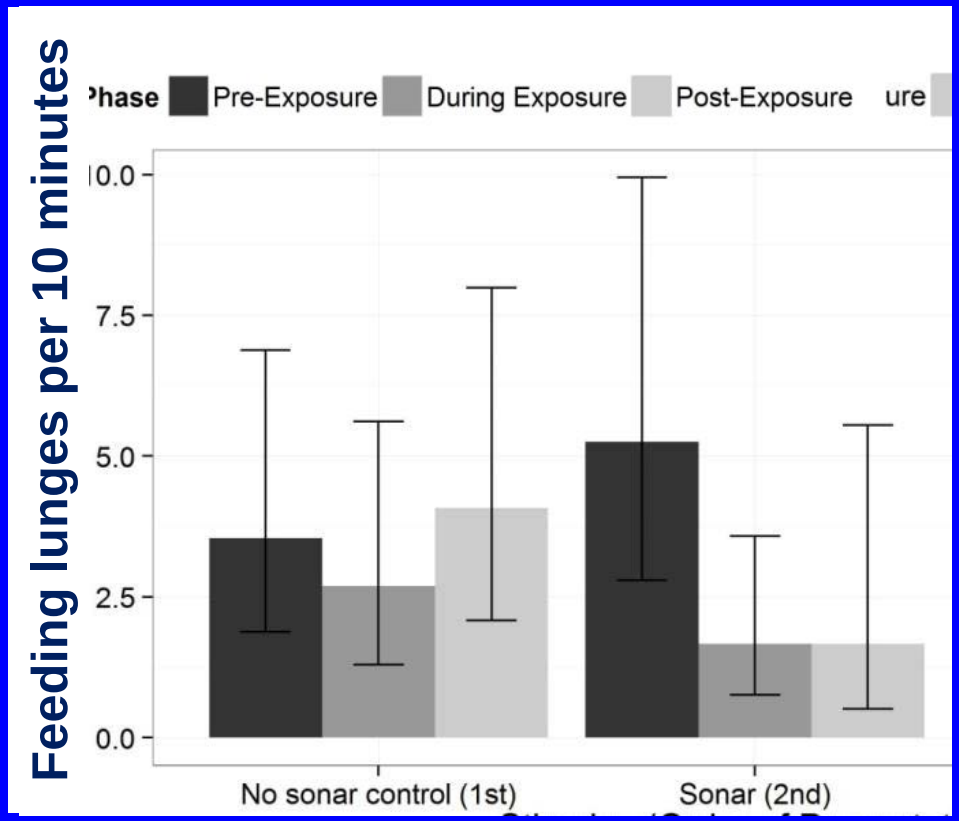
6-7 kHz
'MFAS'
199dB max source level

3S
Experimental design



analysis approach 1

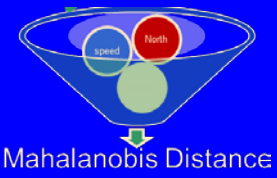
BAA – blocks within experiments. Classic tests of null hypotheses



Sivle et al., in preparation

analysis approach 2

Response threshold detection: What was the sound level associated with a response?

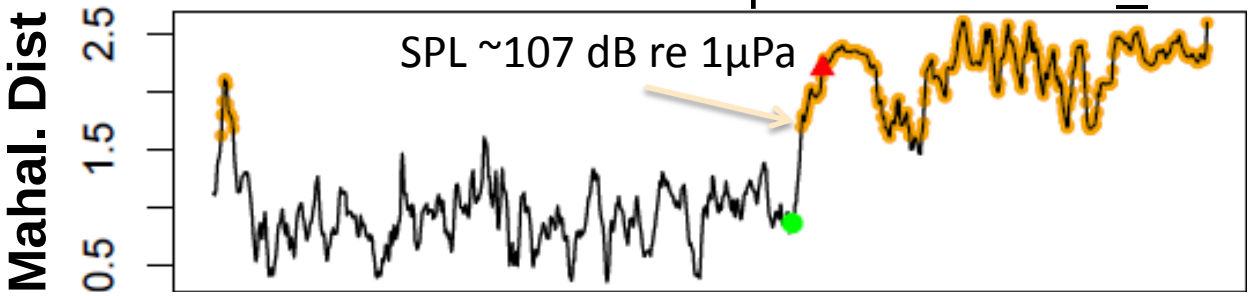


Case-by case analyses:

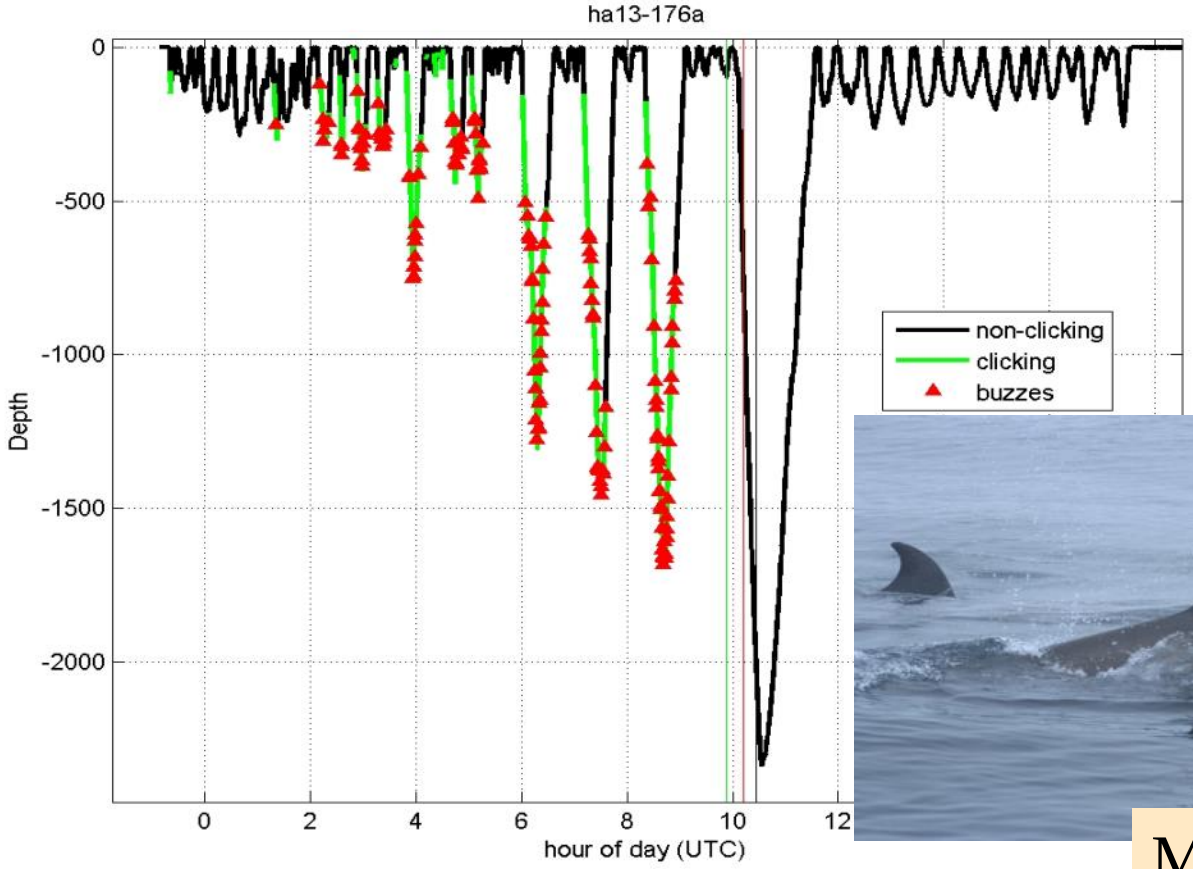
- Quantitative: time-series break-point analysis
- Descriptive: expert-identification

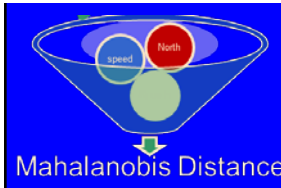
Break-point analysis:

Bottlenose whale experiment: ha13_176a



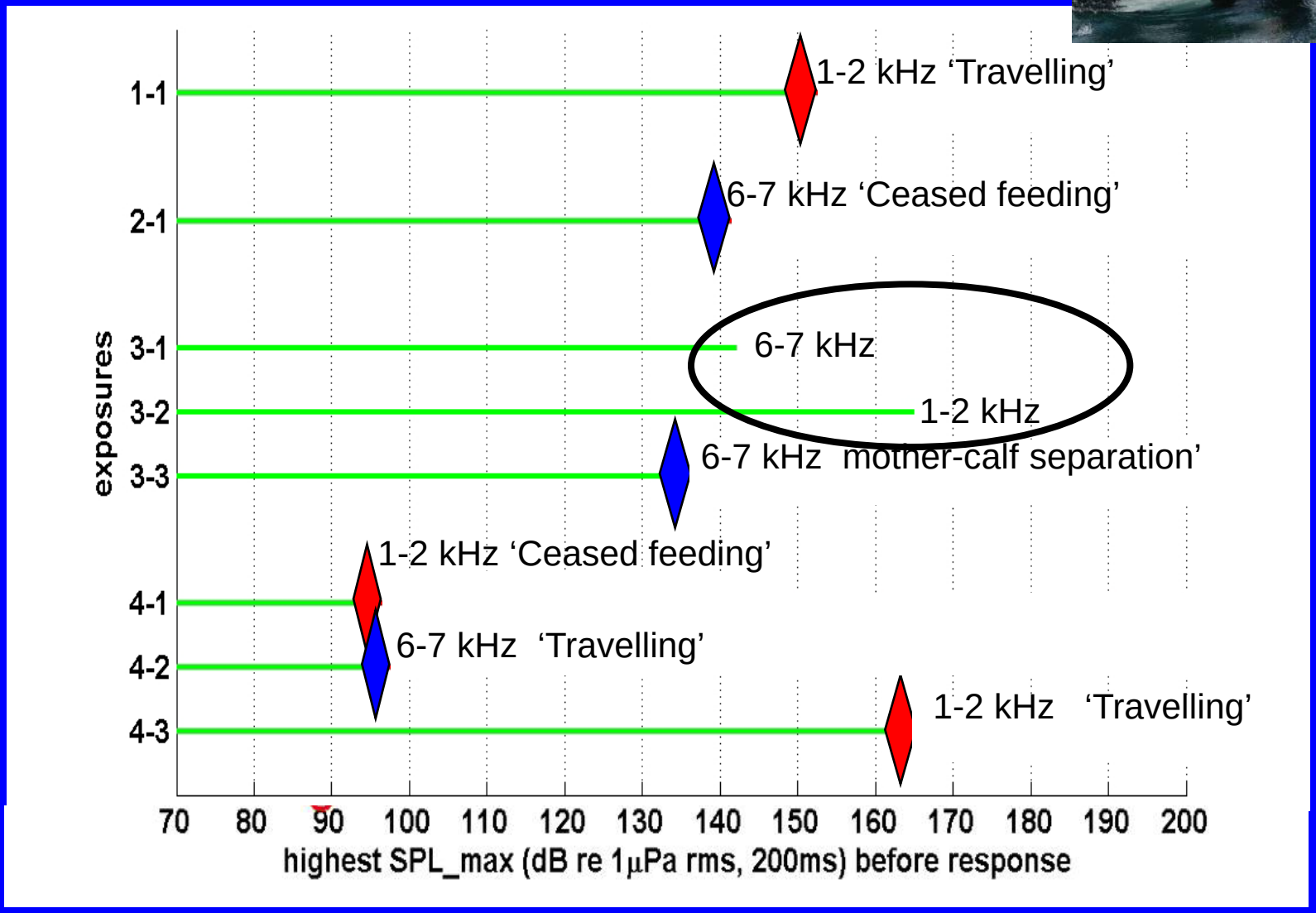
Movement data
-indicate long-duration sonar effect





Miller et al., 2015

SPL thresholds
onset of avoidance



Miller et al., 2014

Censored Data: Less Informative than Titrated

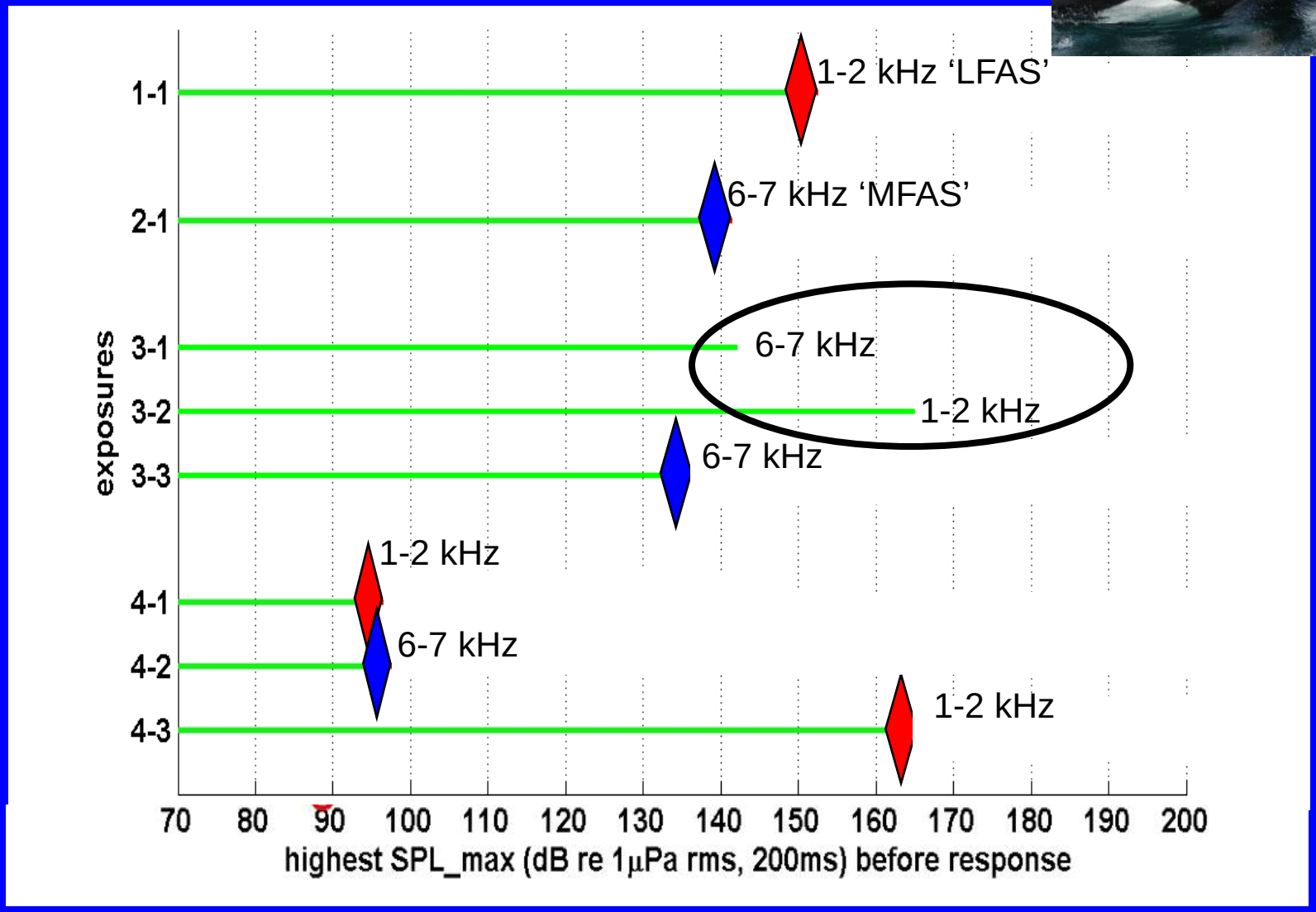
- If dose:escalation works correctly then you know the minimum exposure required to elicit response

- If animal responds on first ping, you only know response threshold ≤ RL_{first}

- If animal never responds during escalation, you only know response threshold > RL_{last}

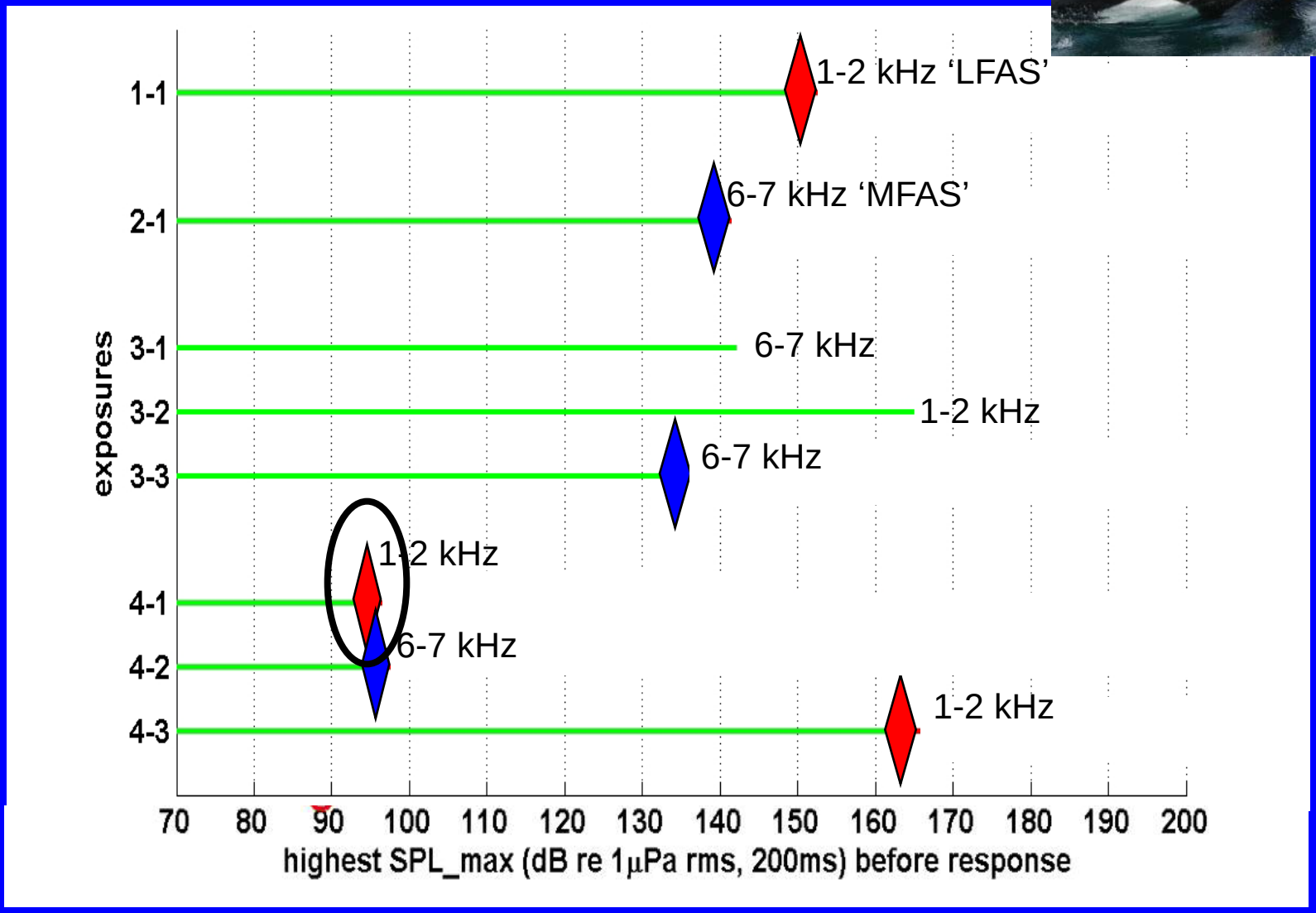
Min ⟵ Received Level ⟶ Max

SPL thresholds
onset of avoidance



Miller et al., 2014

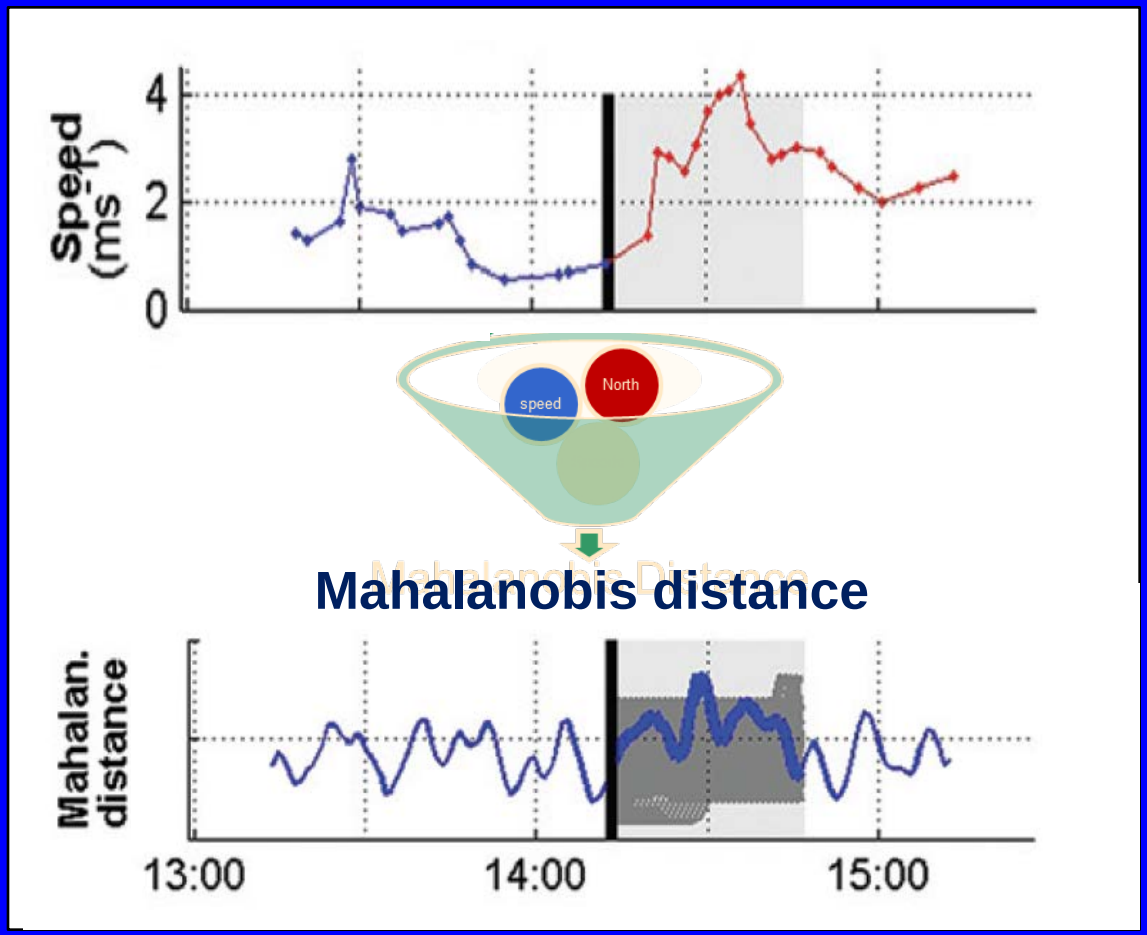
SPL thresholds
onset of avoidance



Miller et al., 2014

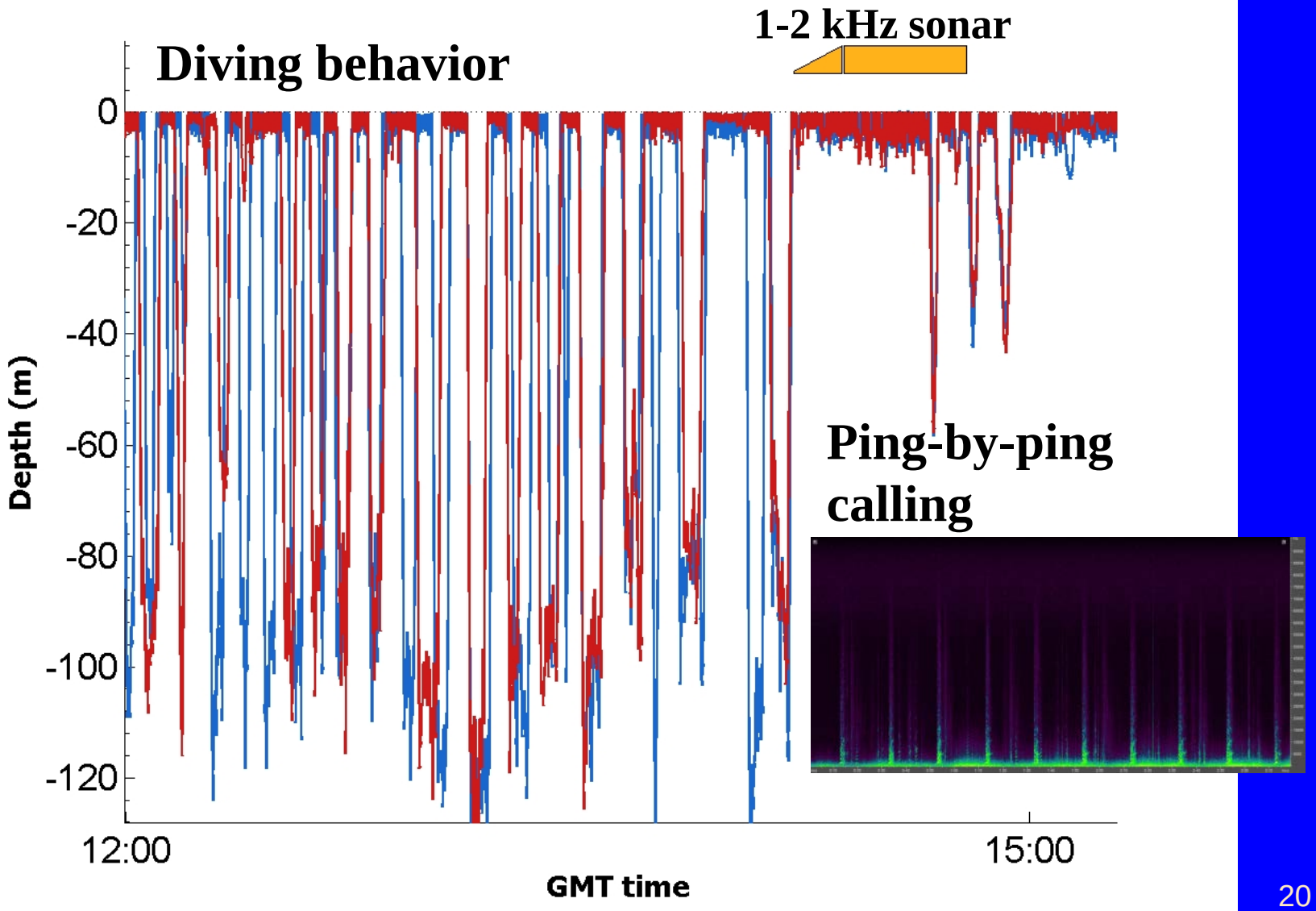
Influential data point:

4-1: 3S-09 oo09_144a



Miller et al., 2014

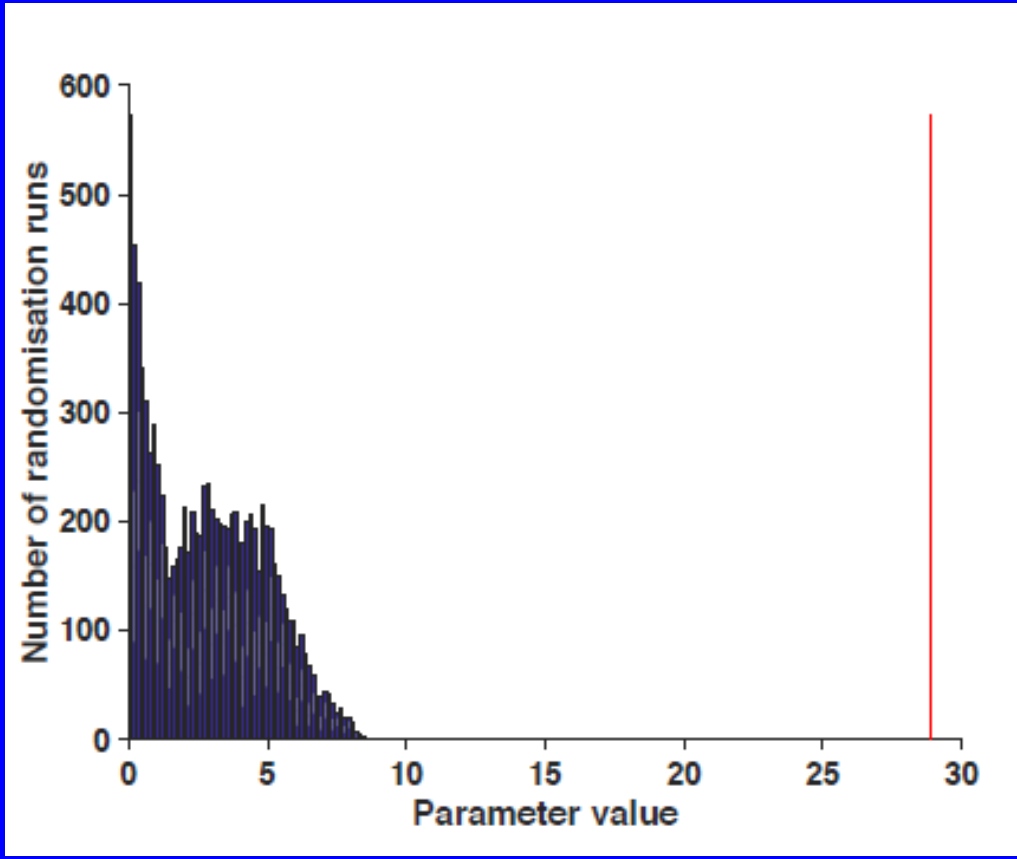
Diving / calling response



Acoustic response

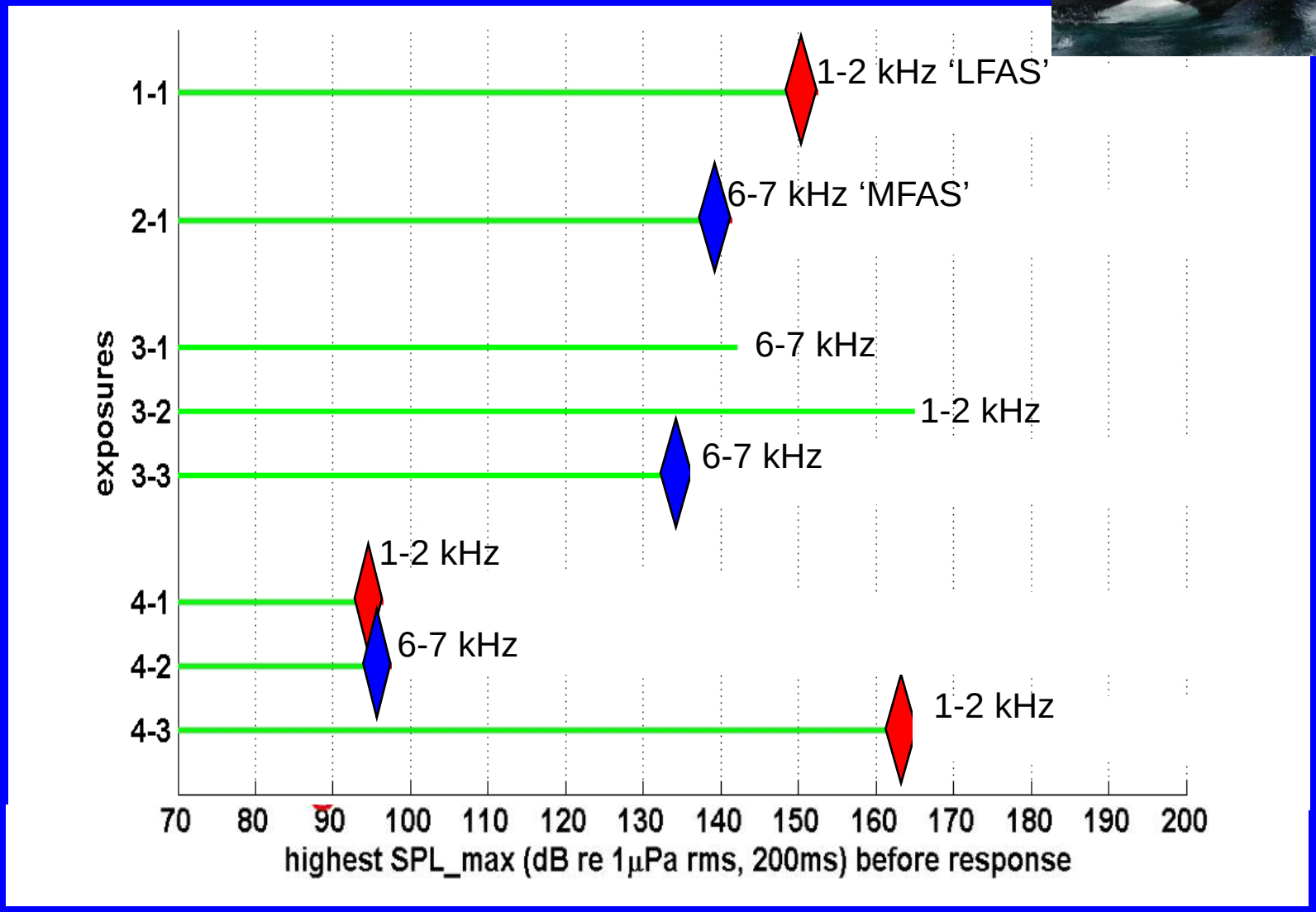
Playback sound file ~ 2 minutes

Acoustic response: quantitative analyses



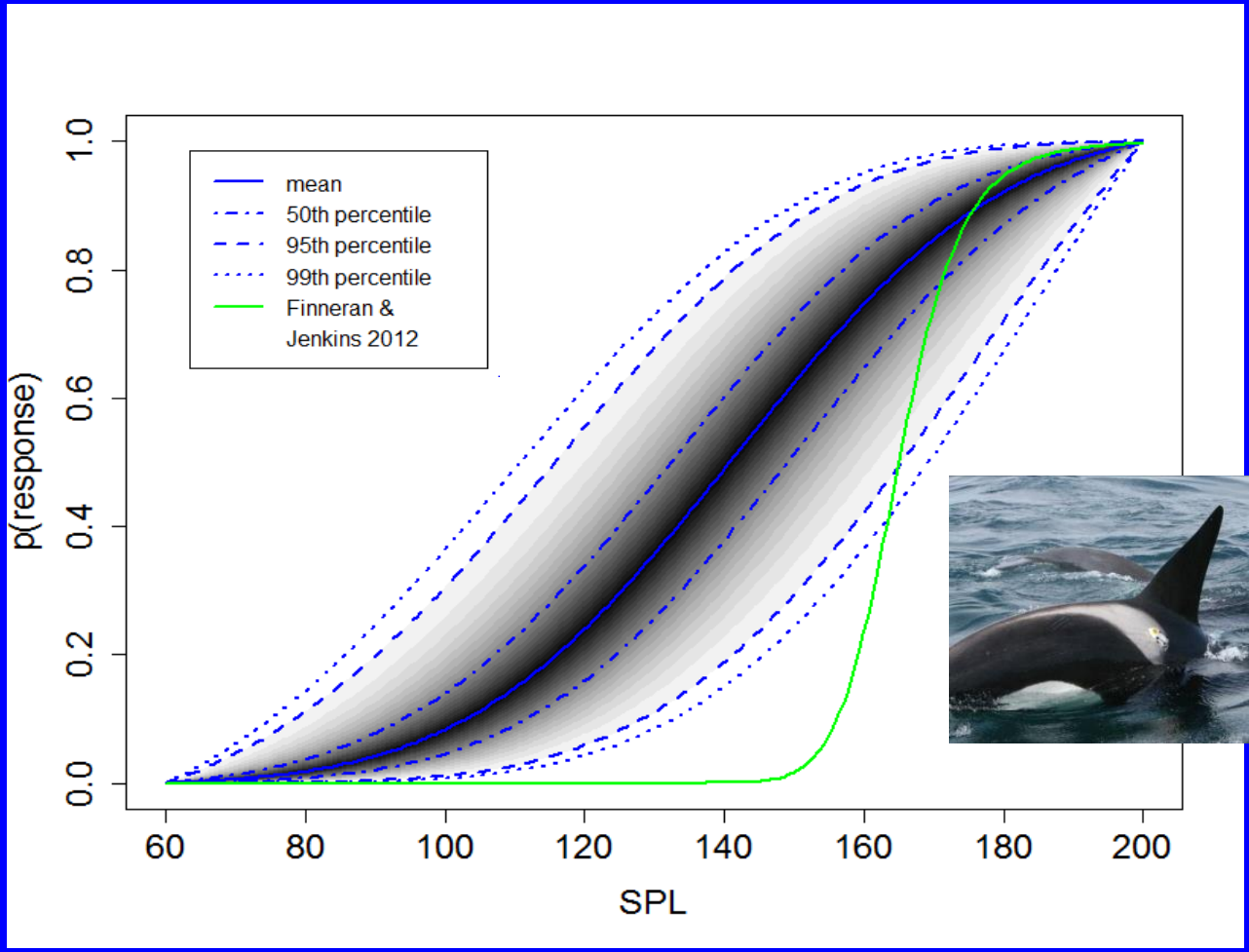
Dr. Filipa Samarra et al., in prep.

SPL thresholds
onset of avoidance



Miller et al., 2014

Dose-response function
onset of avoidance

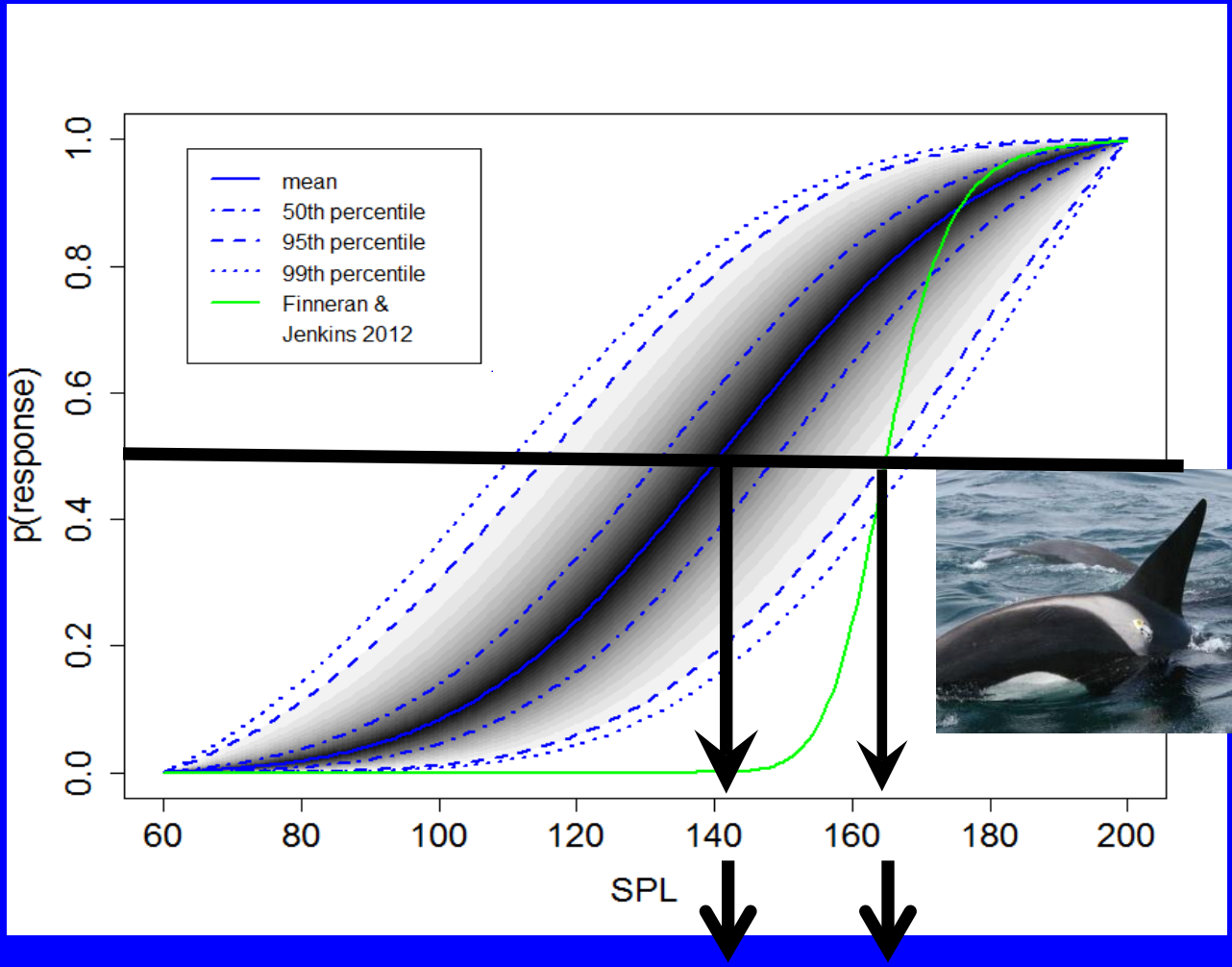


Conclusions

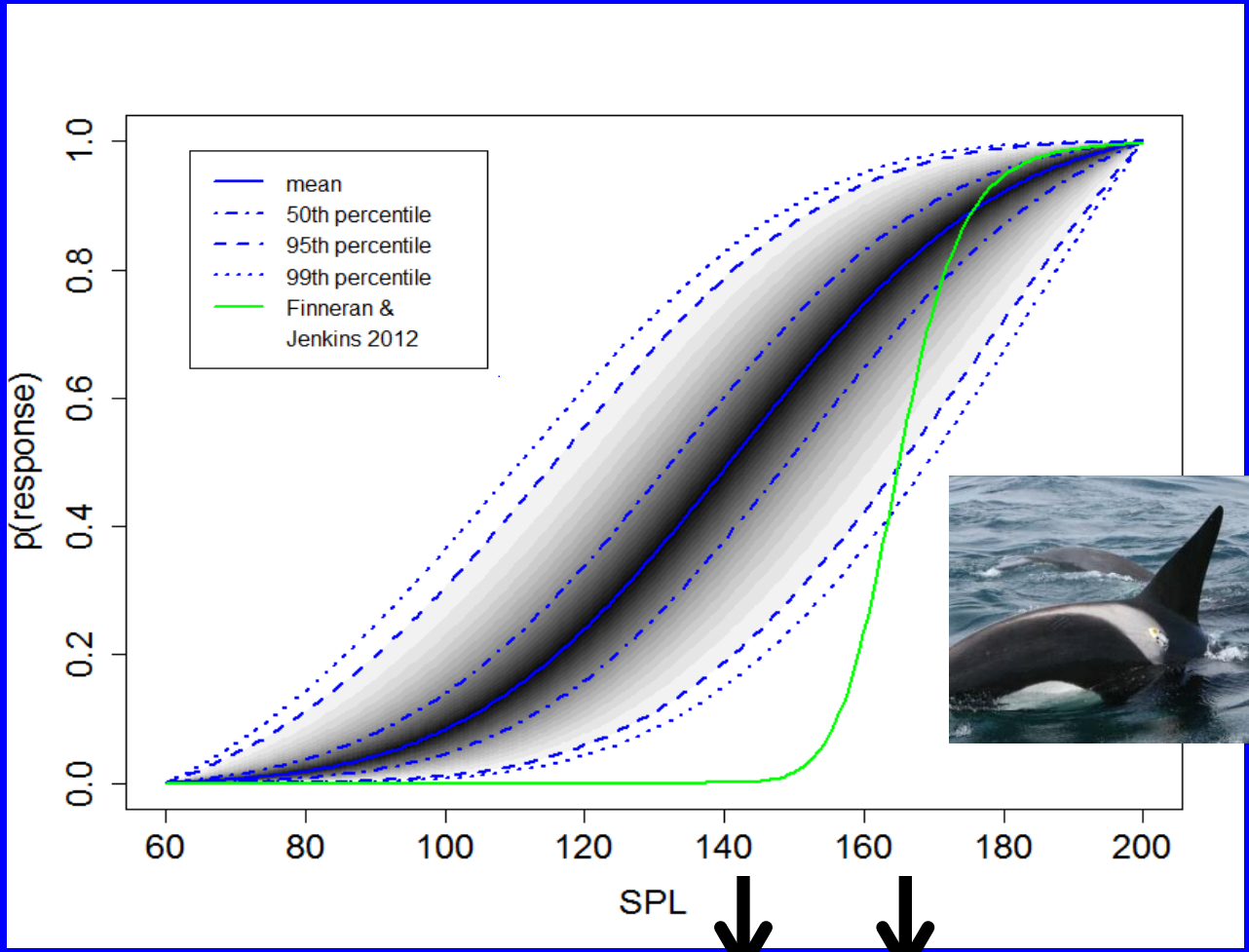
At-sea experiments indicated response thresholds at lower SPL than US Navy curve

- Vessel approach achieved high RLs for dose-response context is of an approaching sonar (precautionary)
- No-sonar controls indicate little effect of vessel alone
- Not clear how distance and RL interact to influence response thresholds – more research needed!!

Dose-response function
onset of avoidance



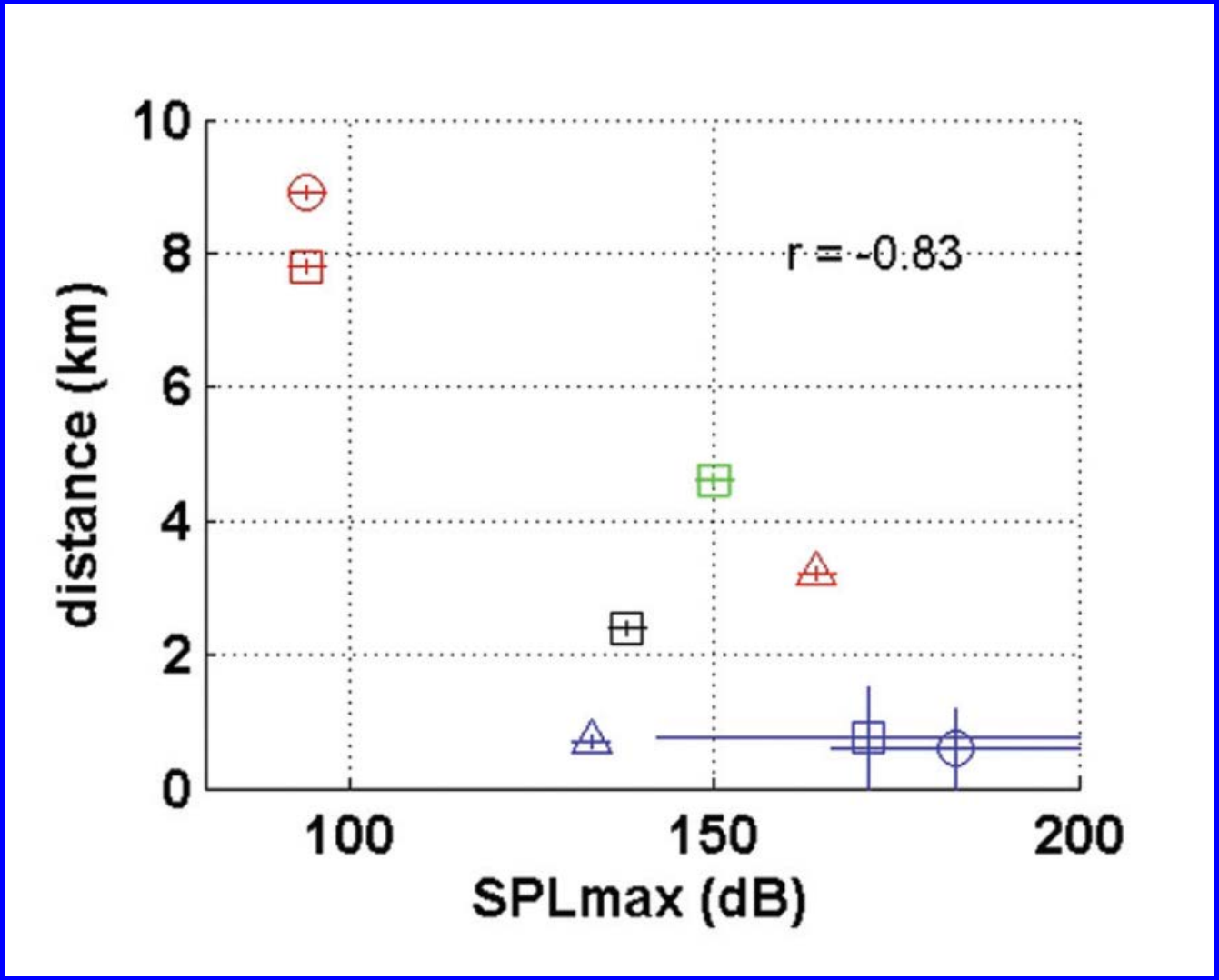
Dose-response function
onset of avoidance



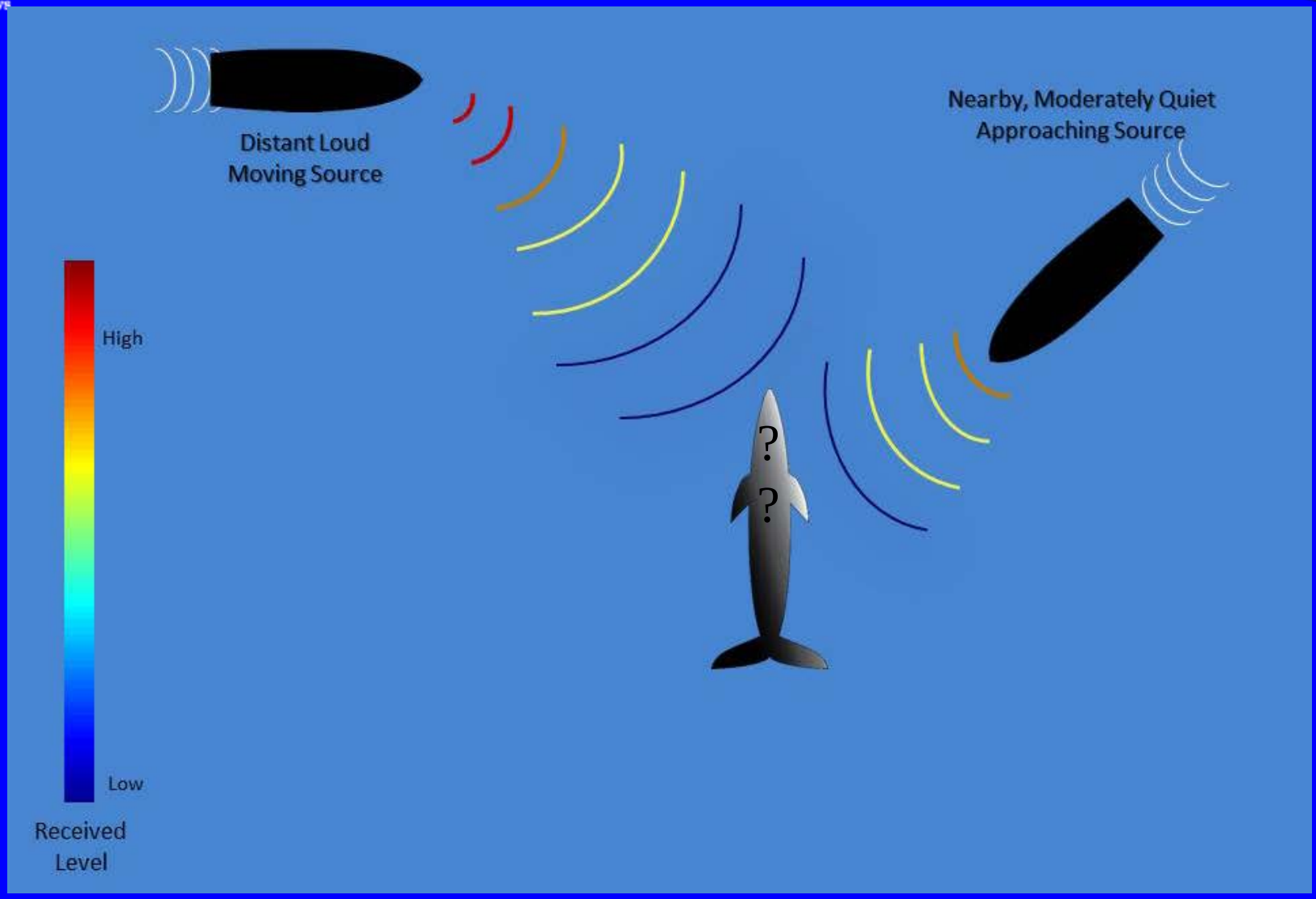
Distance from SQS-53: ~102 km / ~4-11 km

Source: US Northwest Training and testing final EIS 2015

Received SPL vs Distance
kw avoidance thresholds



Received SPL vs Distance



Southall, Nowacek, Miller, Tyack ESR Review in prep.

Conclusions

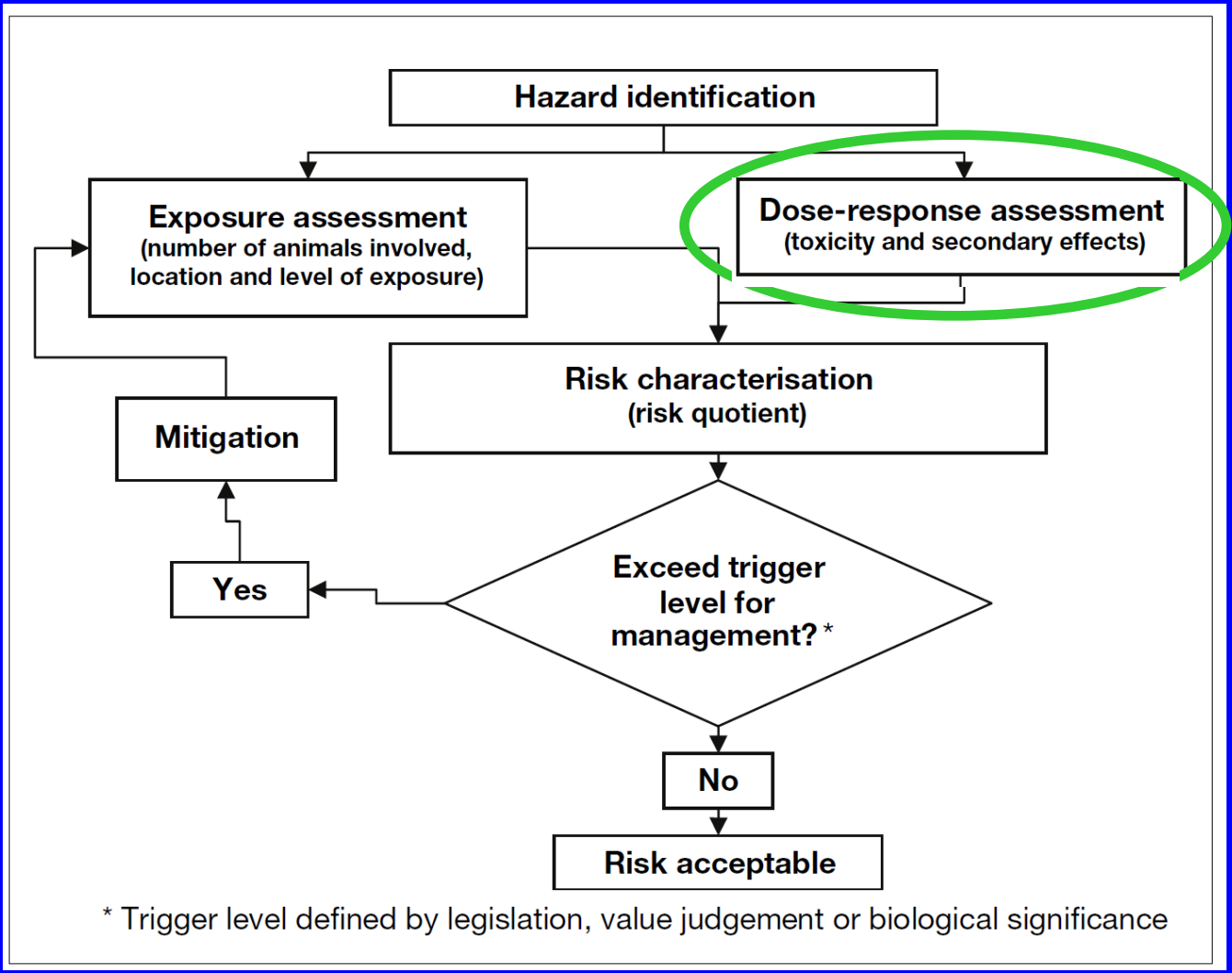
At-sea experiments indicated a lower SPL threshold than US Navy curve

- Vessel approach achieved high RLs for dose-response context is of an approaching sonar (precautionary)
- No-sonar controls indicate little effect of vessel alone
- Not clear how distance and RL interact to influence response thresholds – more research needed!!

What is the biological significance?

- 3S addressed response severity / functional behaviours
- Ultimately, depends upon Exposure Assessment.

Addressed by 3S



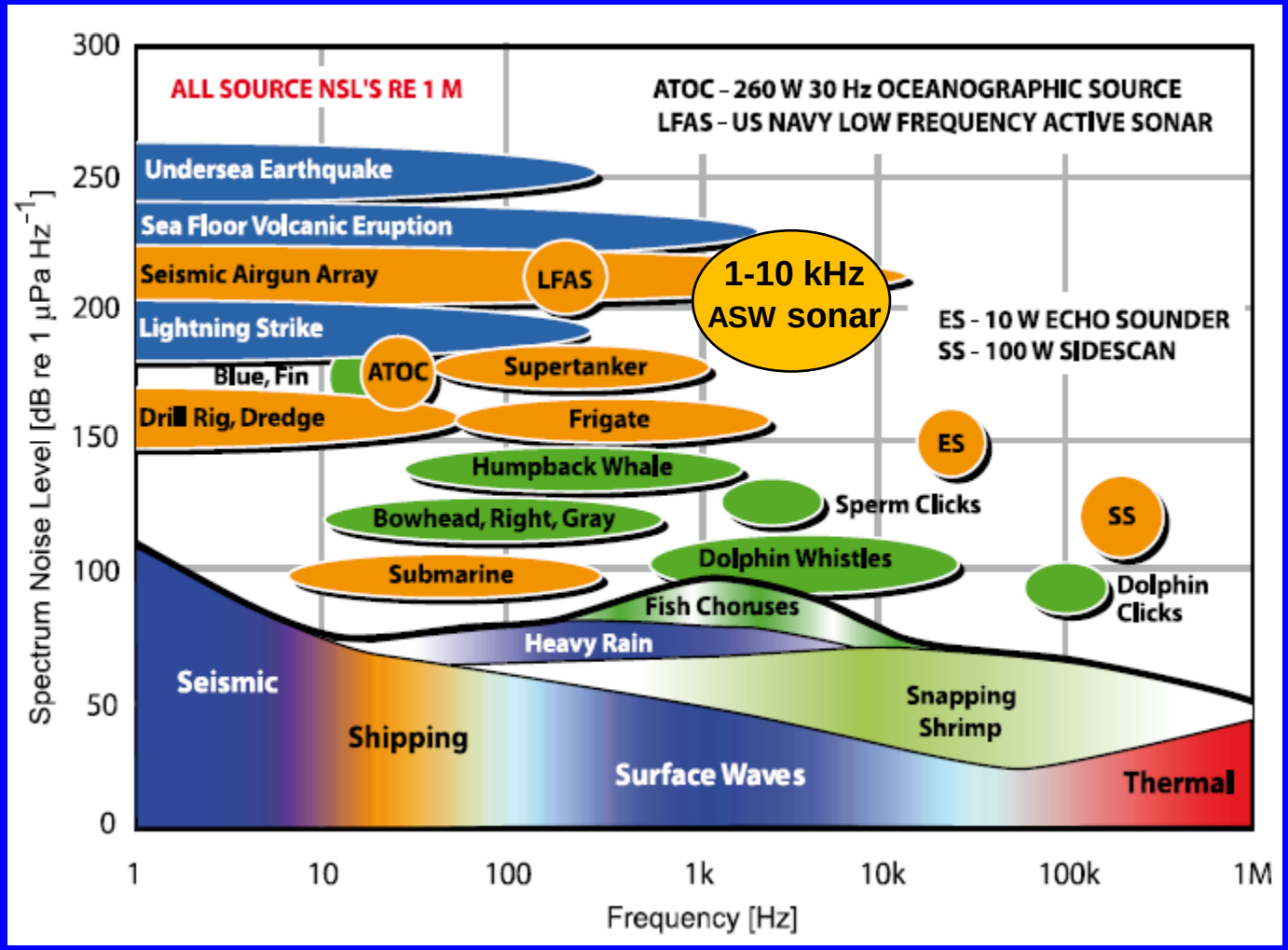
Boyd et al., 2008 ESF Marine Board – Oxford 2005

University of St Andrews

THANK YOU!!

SMRU

A noisy ocean

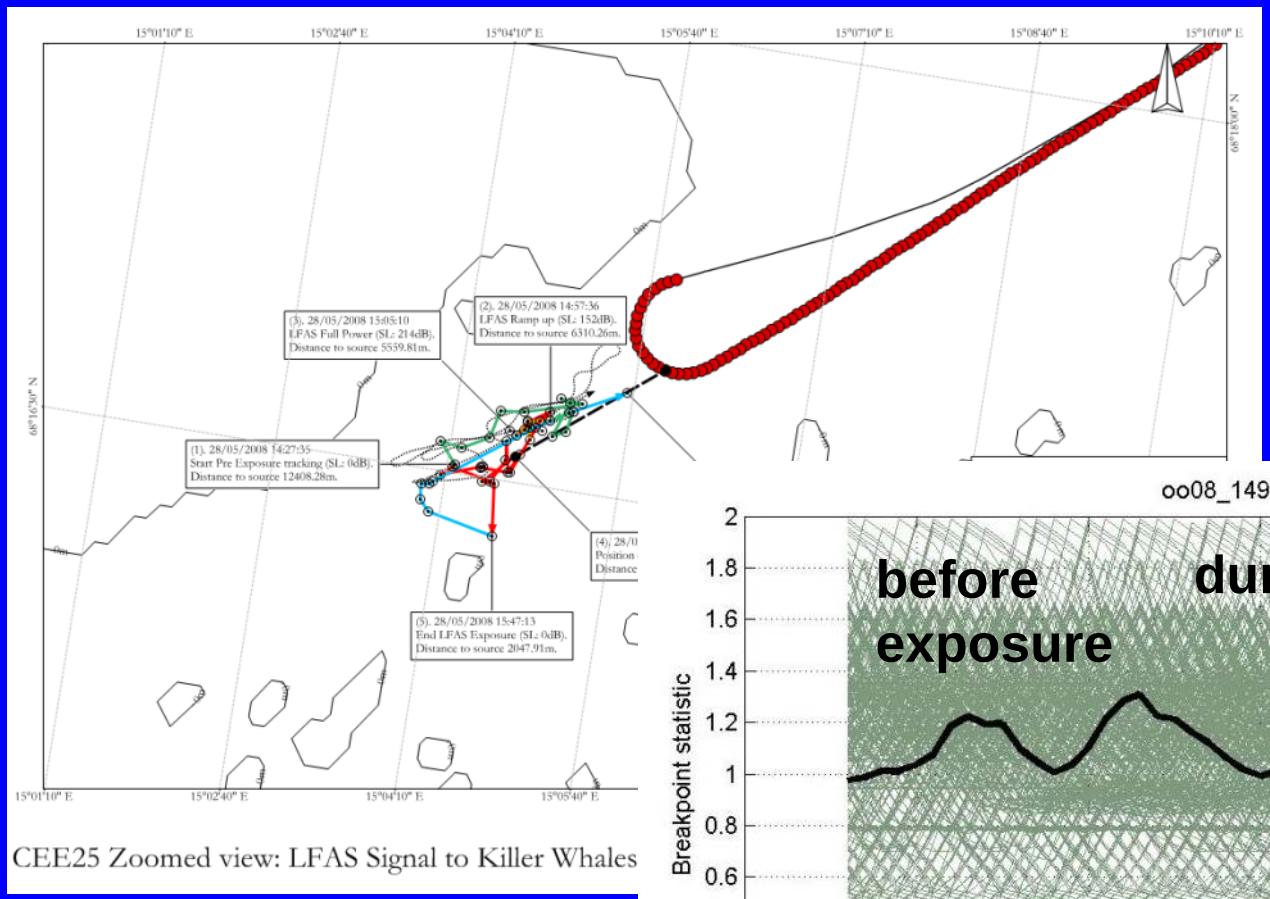


Boyd et al., 2008 ESF Marine Board – Oxford 2005

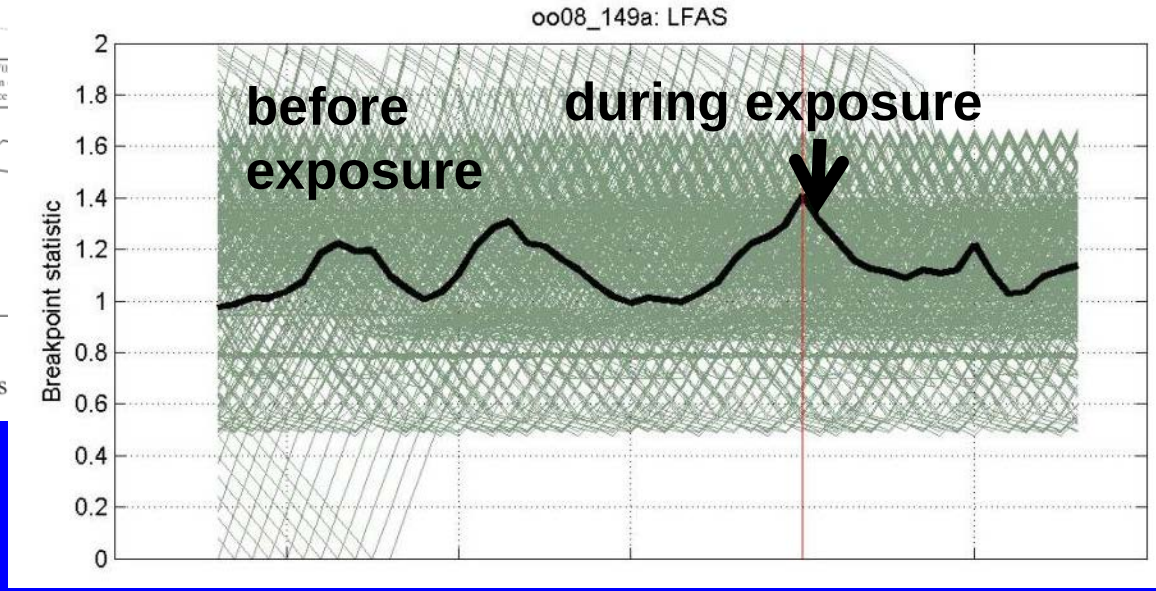
Back up slides after this

No response in some cases

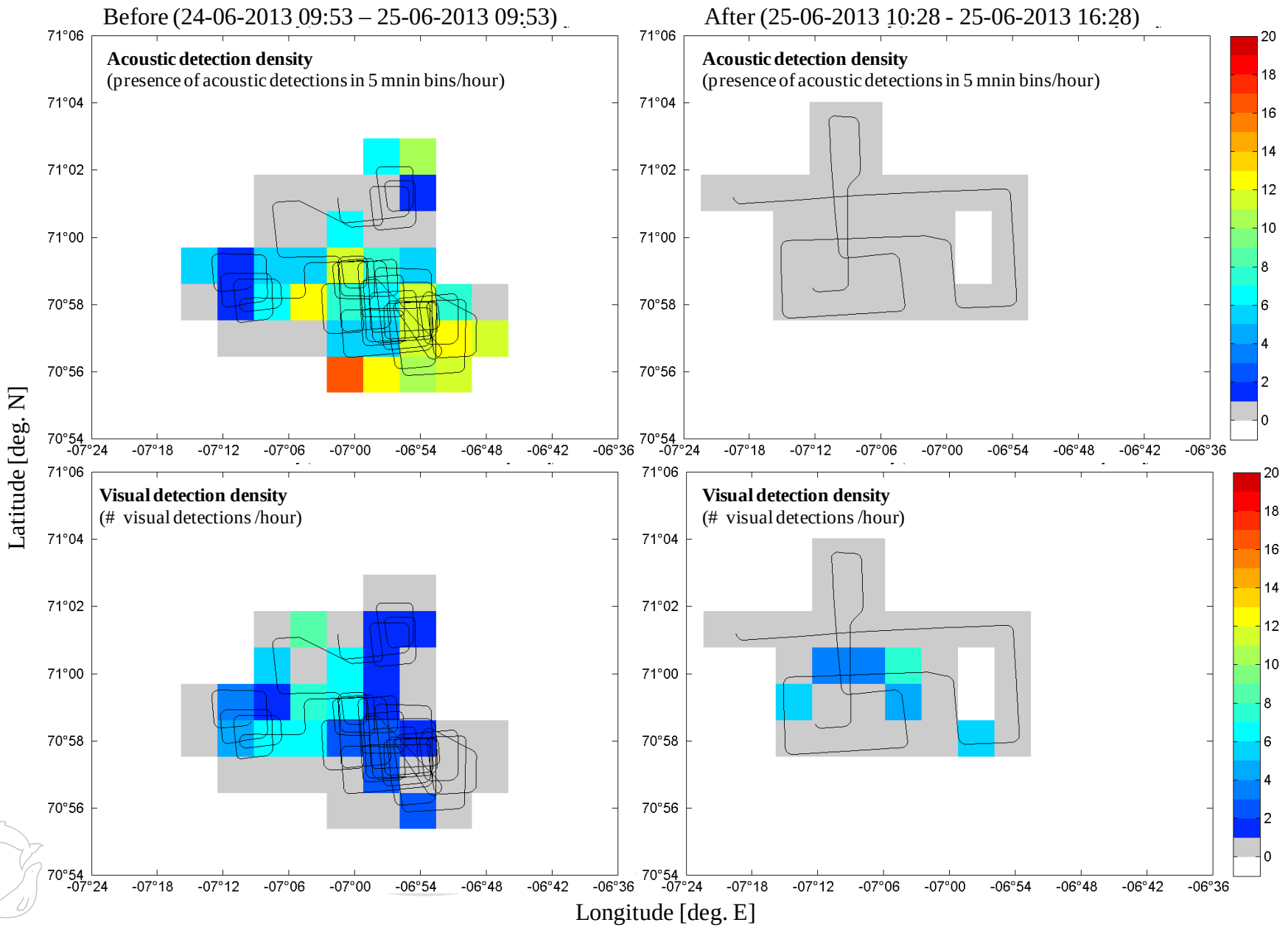
3S-08 oo08_149a



CEE25 Zoomed view: LFAS Signal to Killer Whales



Fewer whales detected after exposure

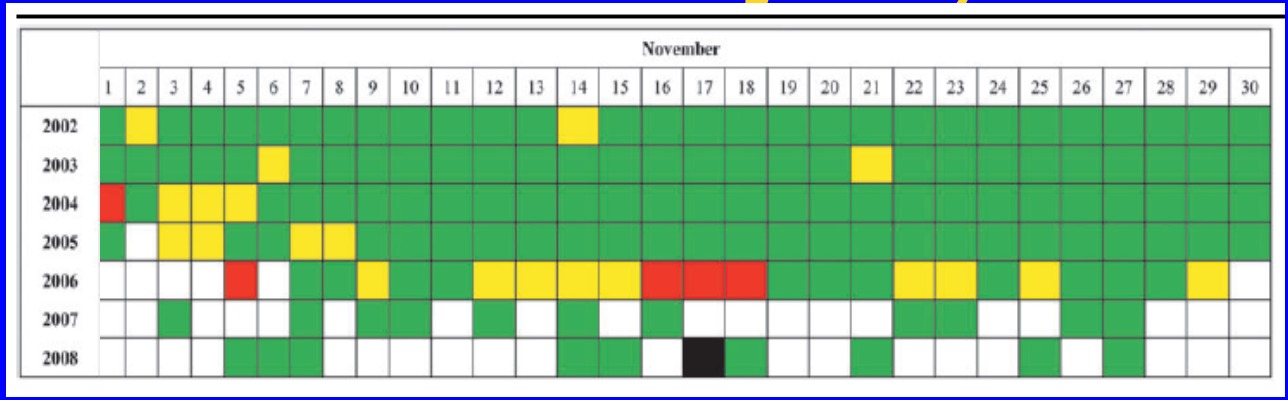


Vestfjord, Norway

University of St Andrews

FLOTEX 2006

Killer whales and sonar Vestfjord, Norway

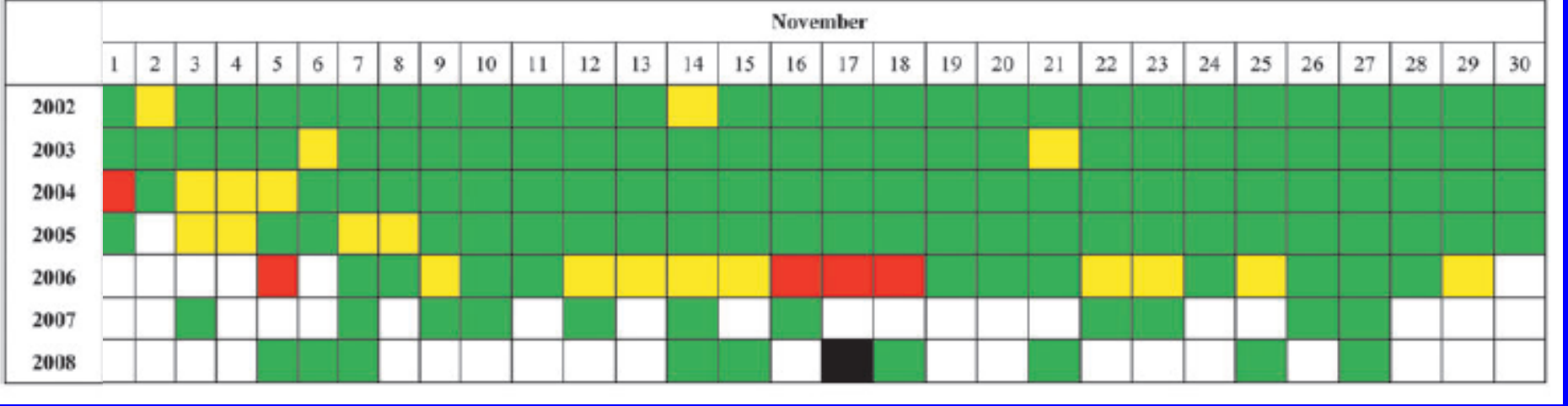


	"Sonar day"	"No-sonar day"
"No-whale day"		
"Whale day"		

Covariate	Effect	Data range	Deviance explained	d.f.	*p*-value
Herring	bs	0.02–2.2	57.2	3	0.001
Year	bs/f	2002–2007	—	—	—
Sonar	f	0–1	—	—	—
SonarType	f	0–3	6.5	3	0.1*
SonarLag	f	0–1	—	—	—
Weather	f	0–1	33.4	1	0.001
JulianDay	bs	298–334	23.3	3	0.001

Kuningas, Kvadsheim, Lam, Miller 2013, ICES J. Mar. Science

Killer whales and sonar Vestfjord, Norway



	"Sonar day"	*"No-sonar day"*
"No-whale day"		
"Whale day"		

Killer whales and sonar Vestfjord, Norway

Whale numbers affected by sonar on some days

BUT

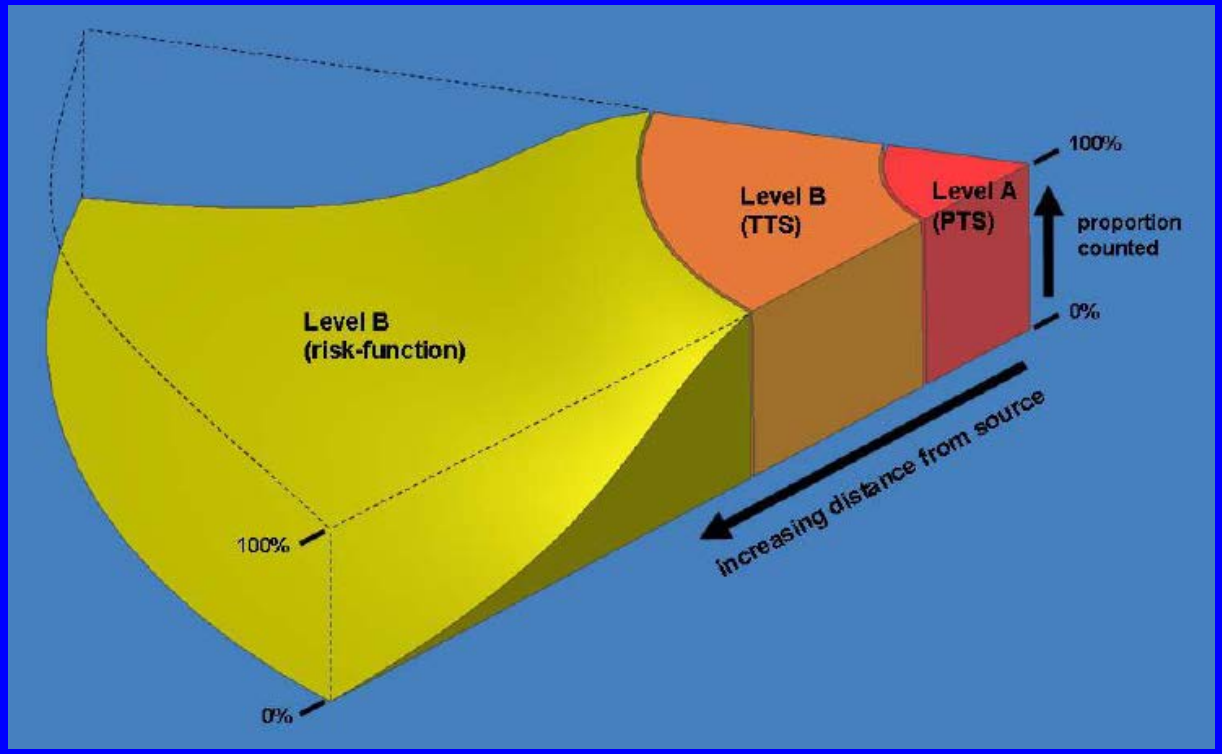
Herring affected whale numbers more strongly

3S Sonar-exposure experiments:

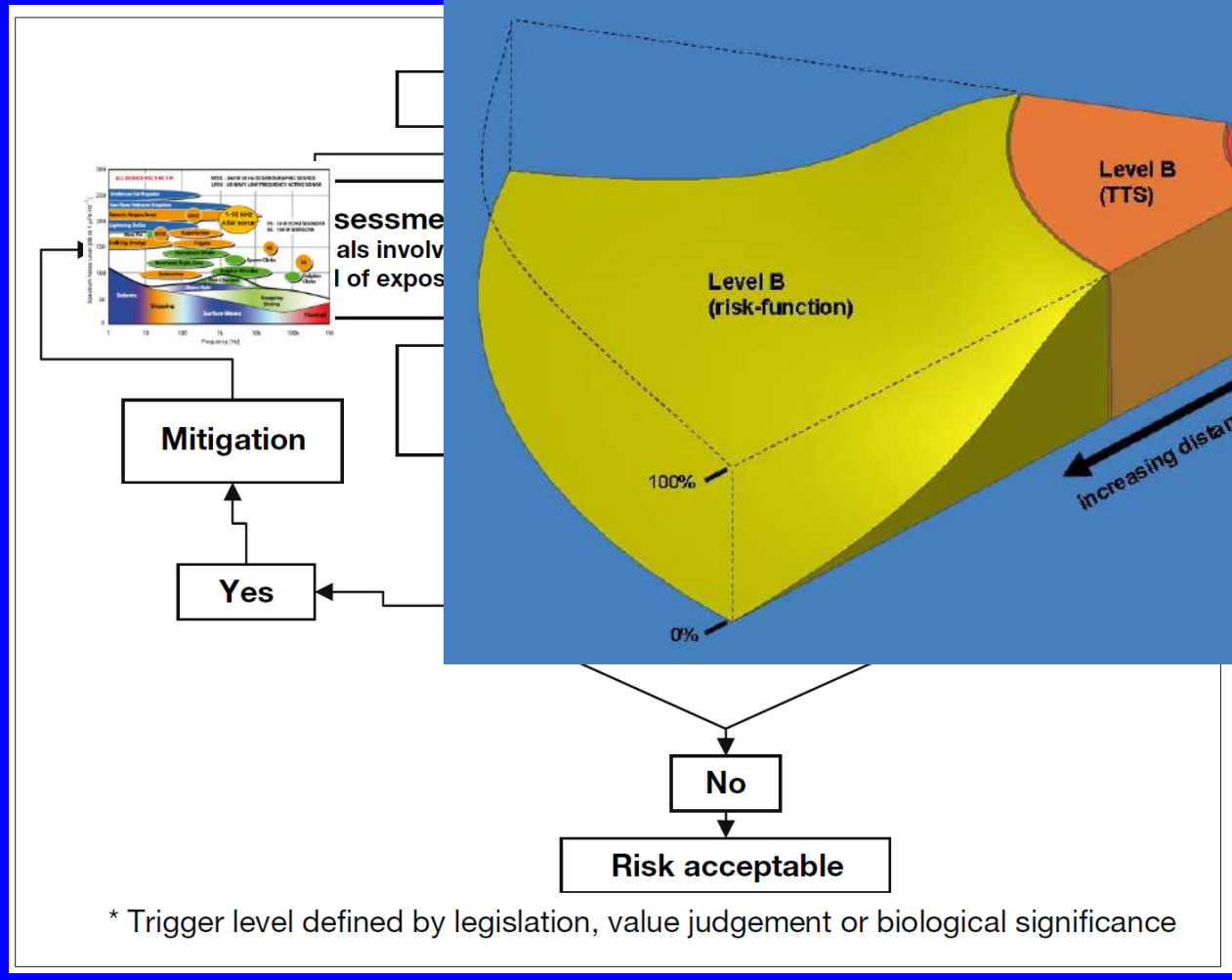
- directly test for sonar effects
- determine safety limits for sonar operations

US Navy approach

Hearing and behavior are treated separately

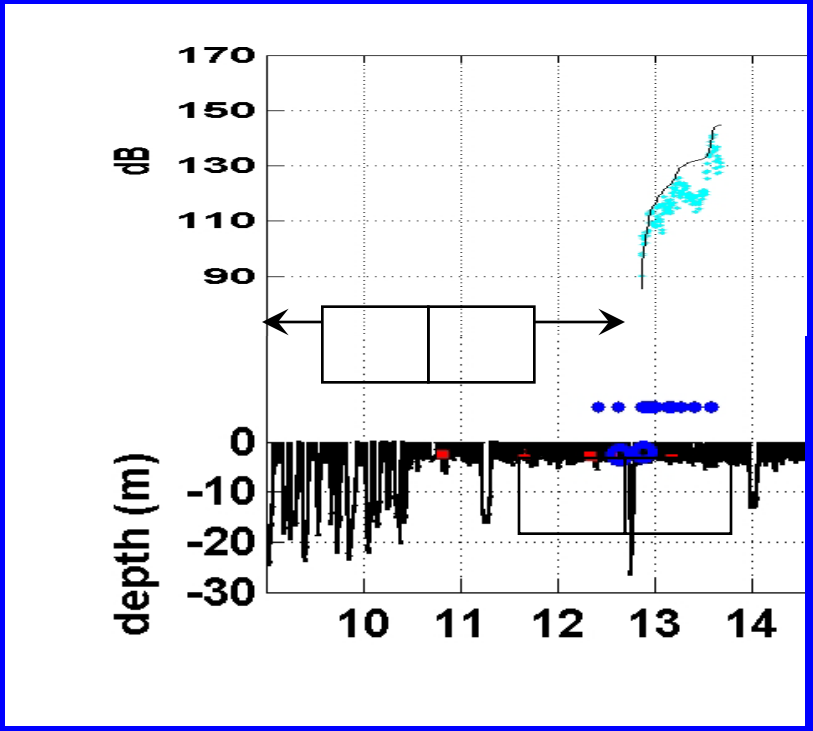


US Northwest Training and testing final EIS 2015


sessme
als involv
l of expos
Mitigation
Yes
No
Risk acceptable
Level B
(TTS)
Level A
(PTS)
100%
proportion
counted
0%
Level B
(risk-function)
100%
0%
increasing distance from source
* Trigger level defined by legislation, value judgement or biological significance

How to pursue statistical analyses?

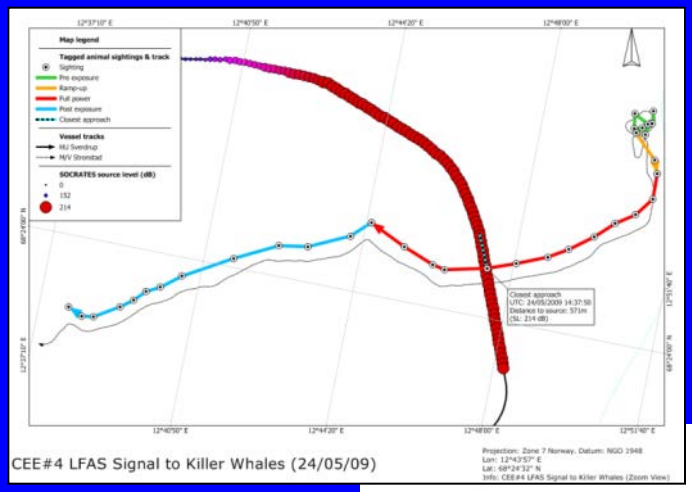
Assess the probability that the change occurred during the sonar exposure if it was not a reaction?



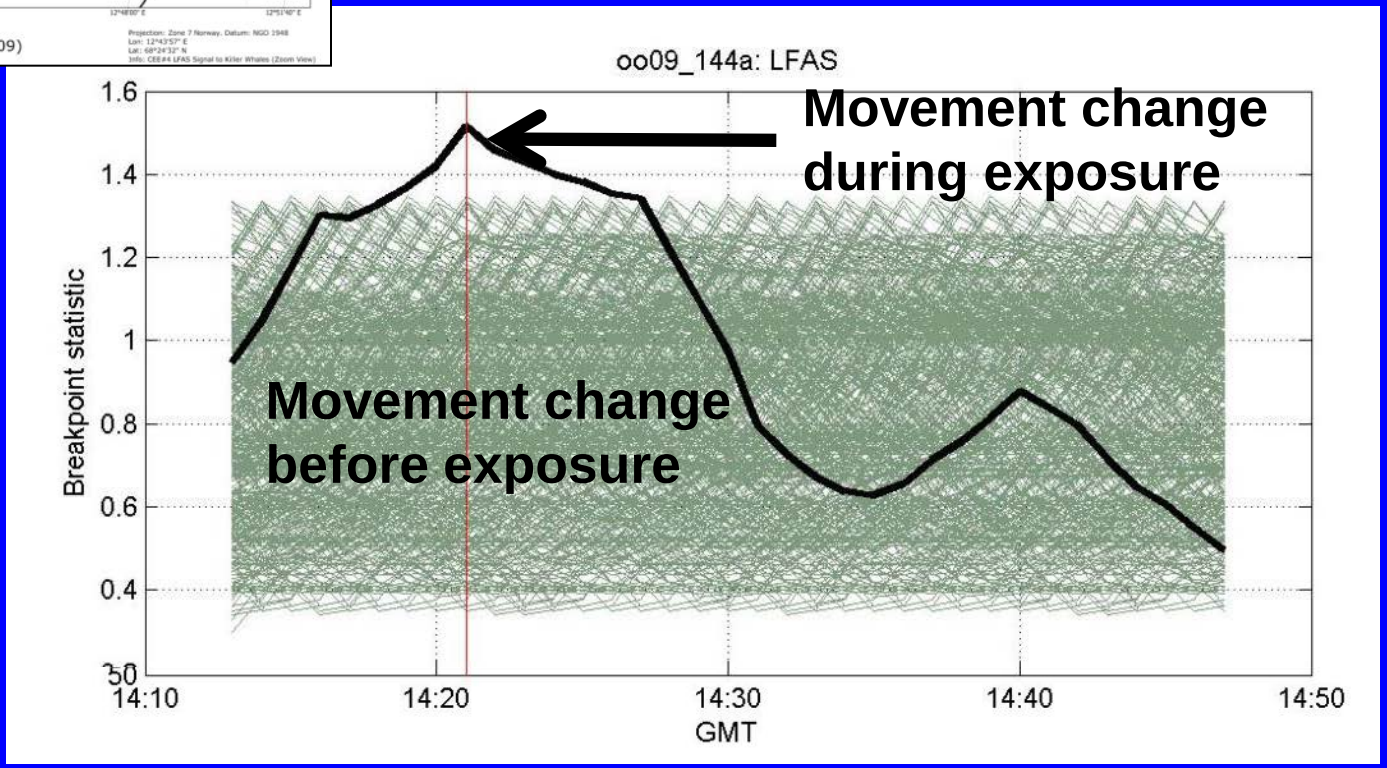
Randomization of exposure time within record to create a “null” distribution

use sliding window in pre-exposure period

Experiment with avoidance



3S-09 oo09_144a,b

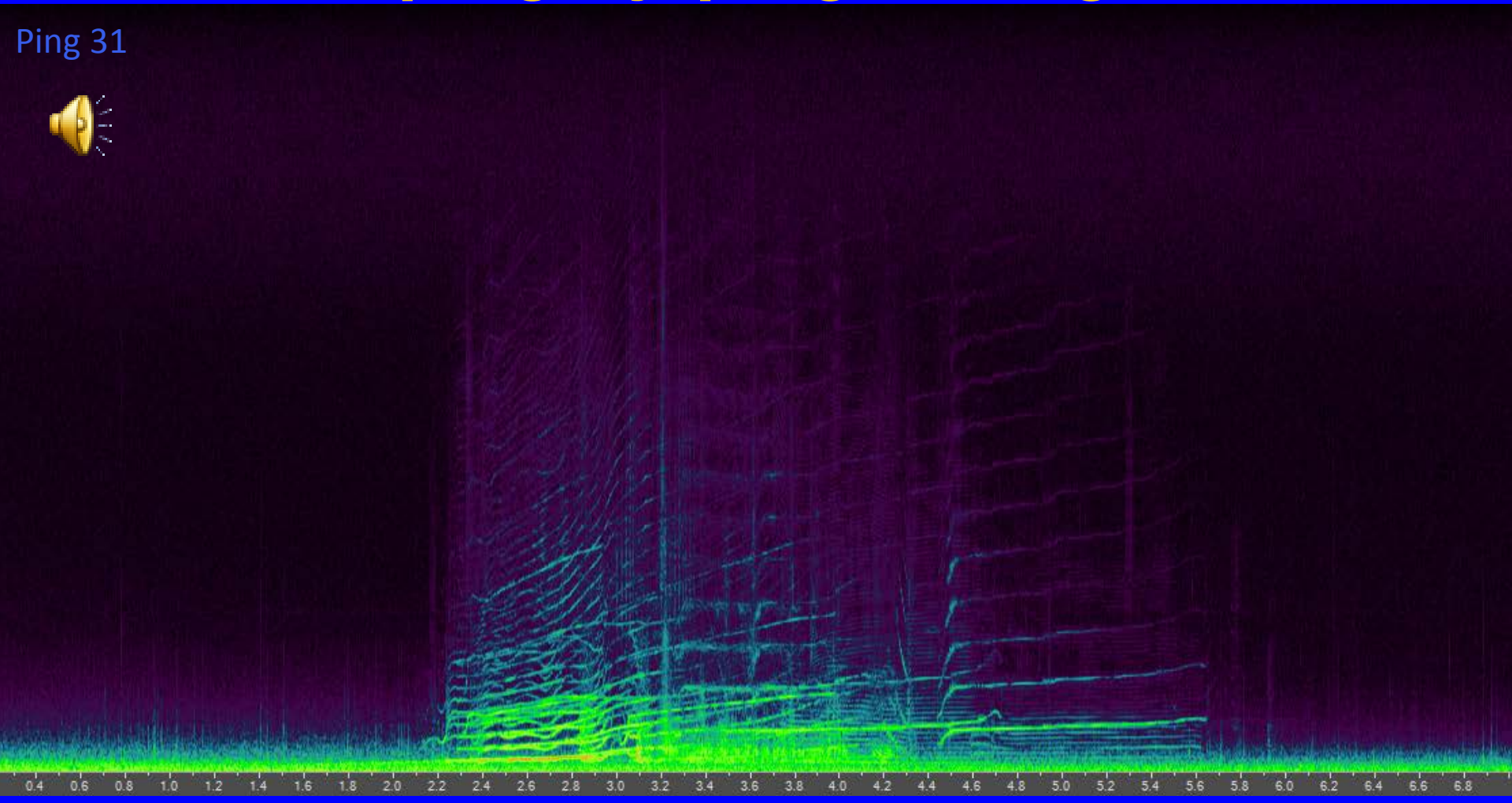


University of St Andrews

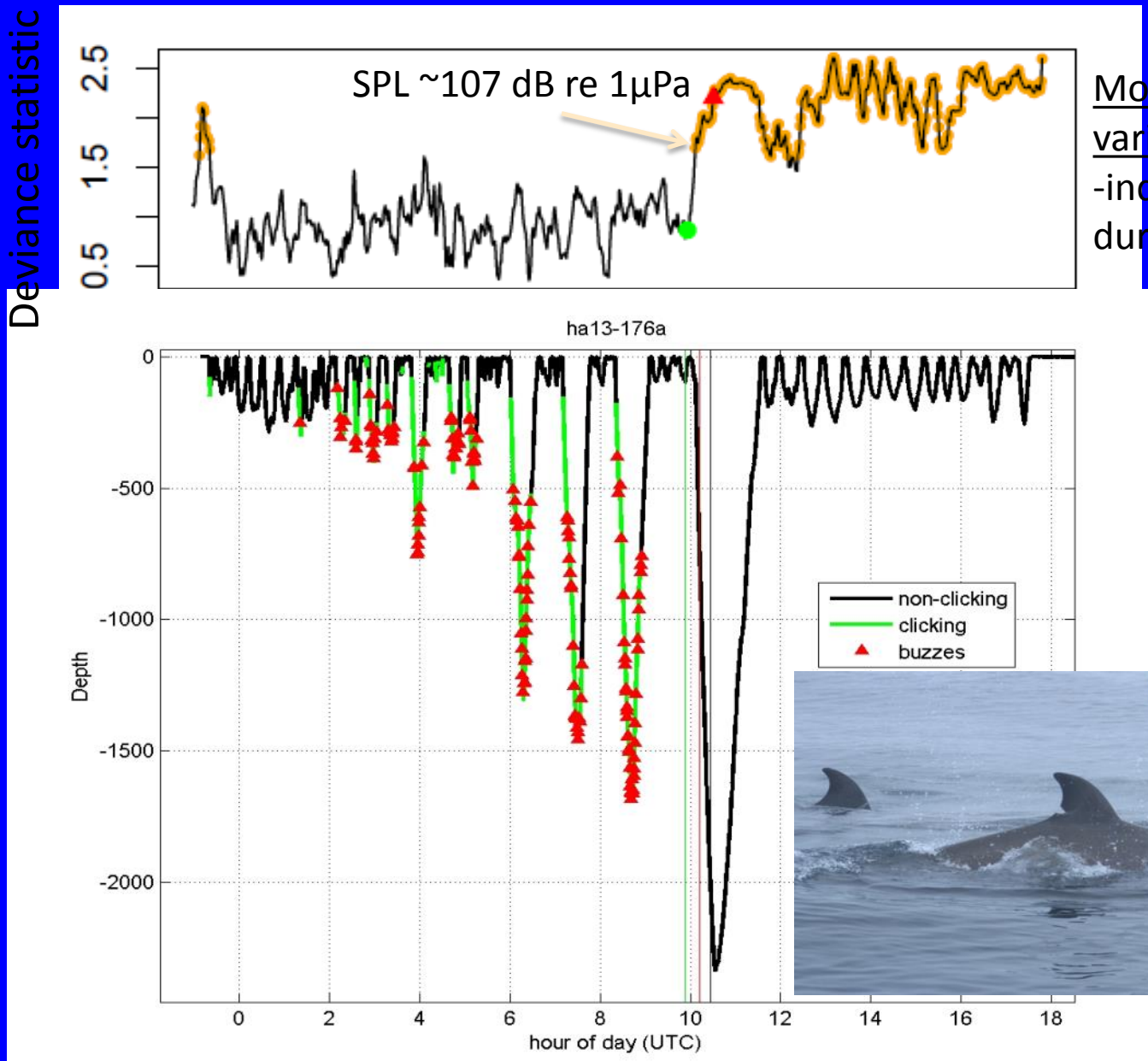
3S-09 oo09_144a,b

Killer Whale ping-by-ping calling

Ping 31



Bottlenose whale experiment: ha13_176a



Movement variables:
-indicate long-duration sonar effect

Censored Data Can be Used but Less Informative then Titrated

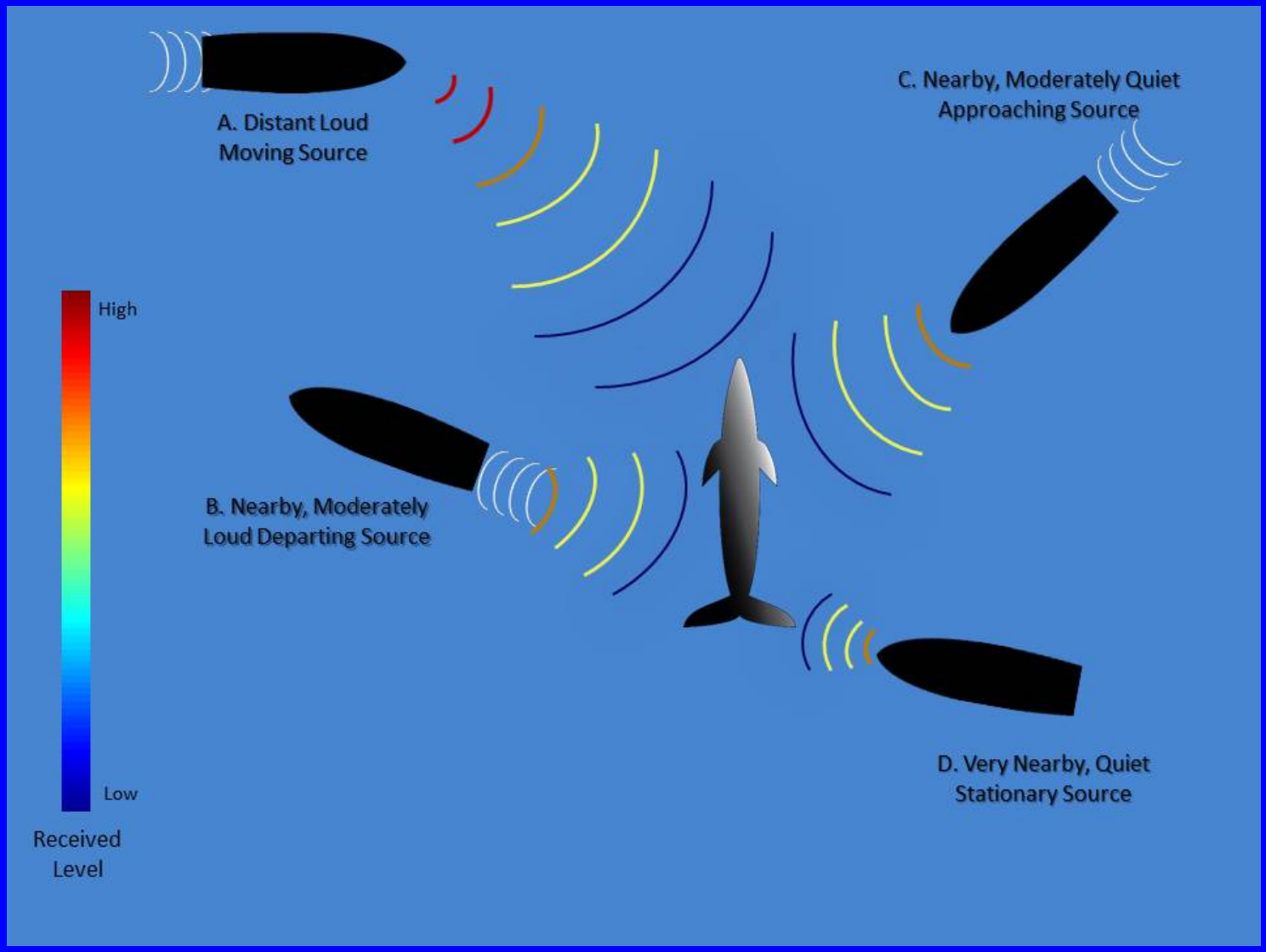
- If dose:escalation works correctly then you know the minumum exposure required to elicit response

- If animal responds on first ping, you know response threshold ≤ RL_{first}

- If animal never responds during escalation, you know response threshold > RL_{last}

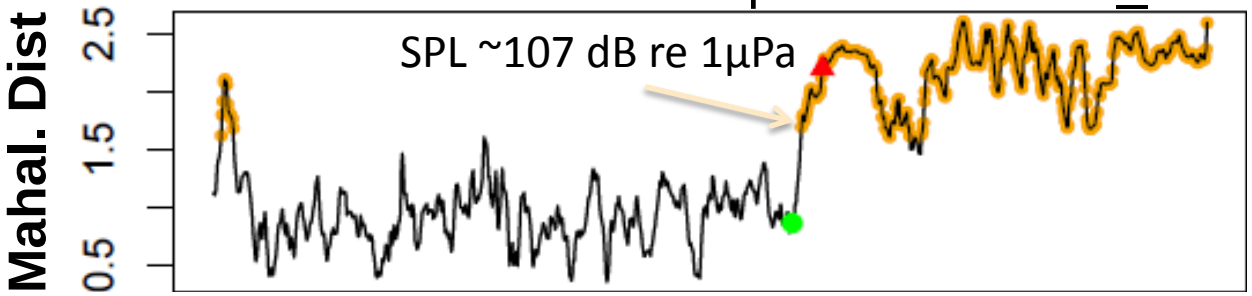
Min ⟵ Received Level ⟶ Max

Received SPL vs Distance

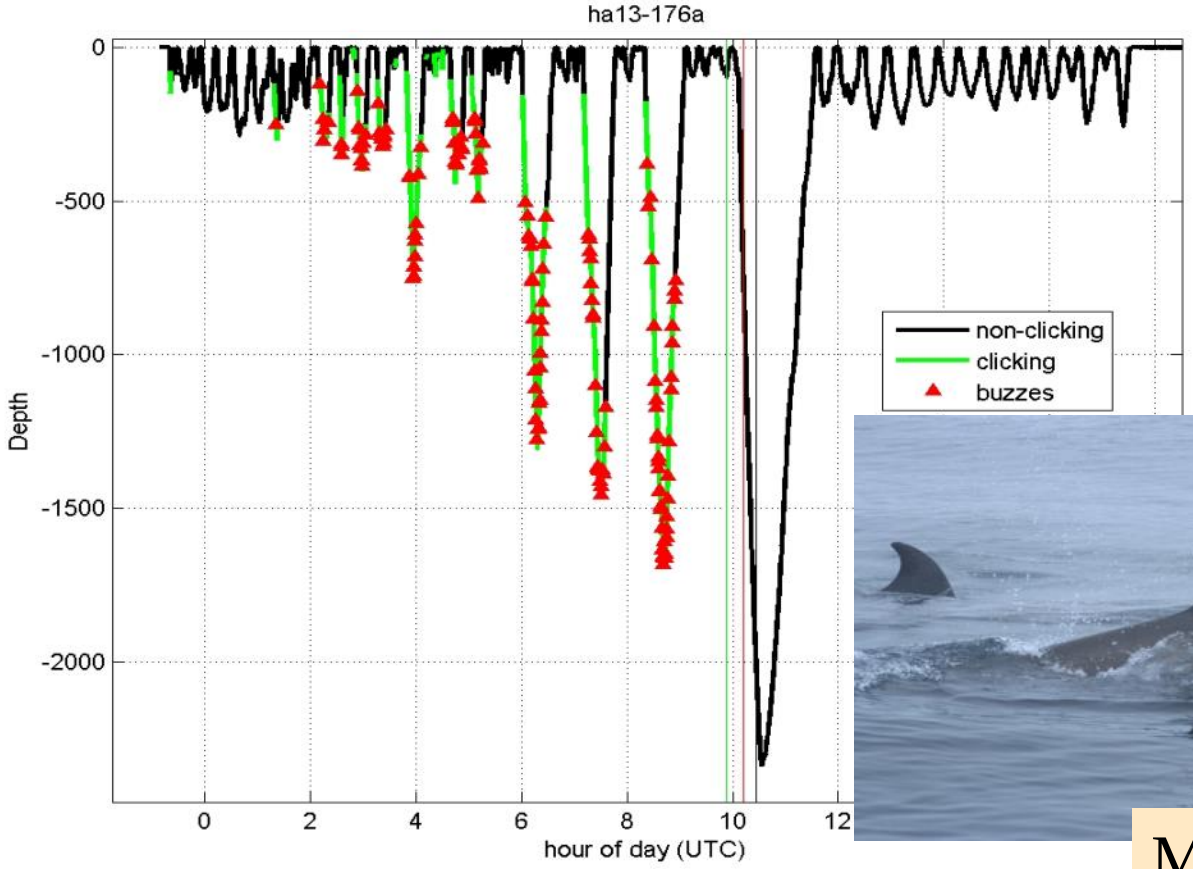


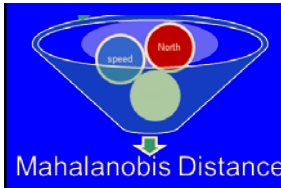
Break-point analysis:

Bottlenose whale experiment: ha13_176a



Movement data
-indicate long-duration sonar effect

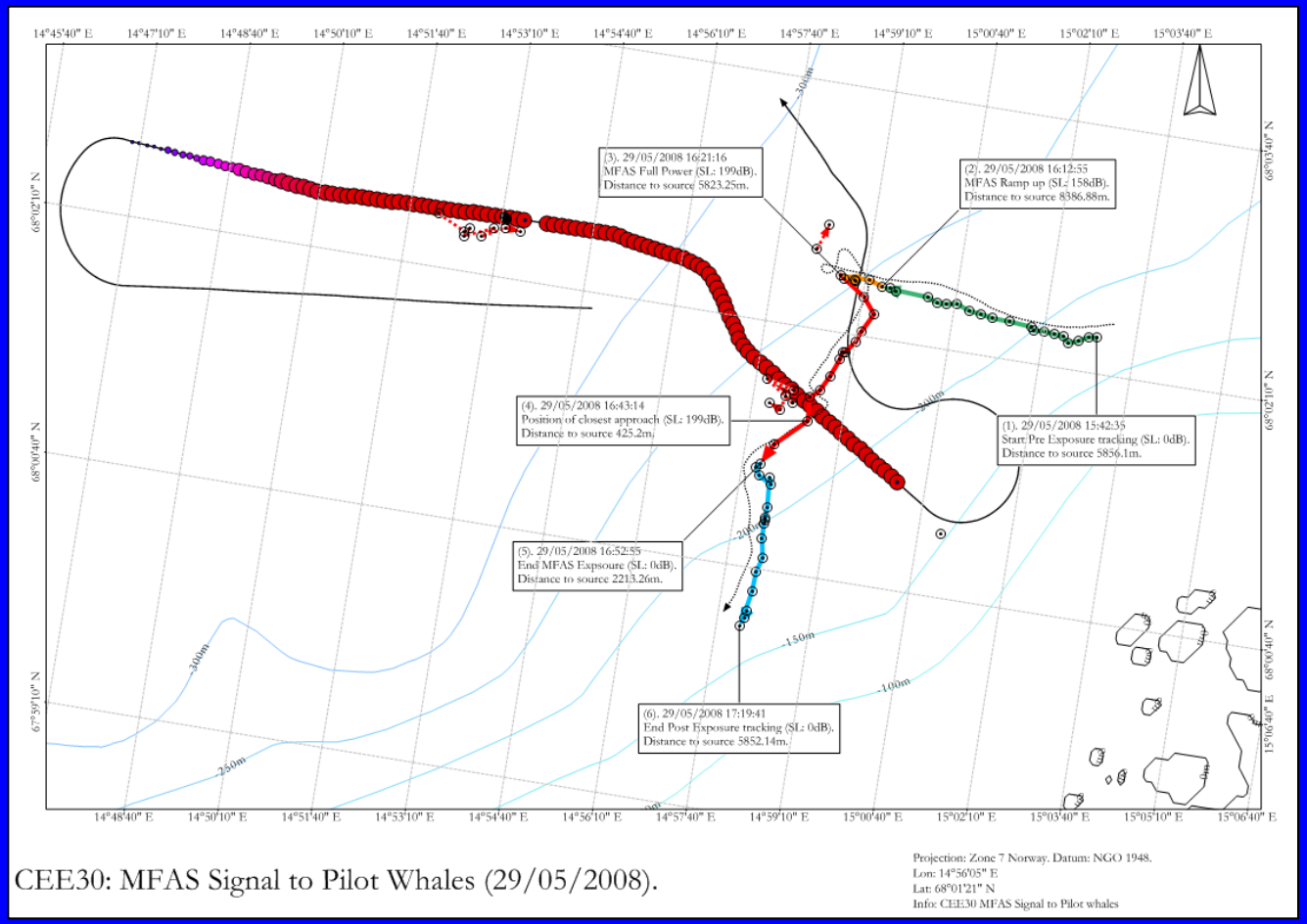




Miller et al., 2015

Expert-evaluation

Step 1: Was there an apparent response?



gm08_150c MFAS