Section A

Institution: University of St Andrews

Unit of Assessment: UoA 05: Biological Sciences

Title of case study: Improving management of the risk to cetaceans of US and European naval sonars.

Period when the underpinning research was undertaken: 2003 - 31 December 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Patrick Miller	Professor	01 October 2002 – present
Peter Tyack	Professor	12 September 2011 - present
John Harwood	Professor	01 February 1996 - present
Catriona Harris	Senior Research Fellow	01 August 2004 - present
Paul Wensveen	Research Fellow	01 June 2016 – 31 January 2017

Period when the claimed impact occurred: 2015 - 2019

Is this case study continued from a case study submitted in 2014? No

Section B

1. Summary of the impact

Research in the University of St Andrews (USTAN) School of Biology has estimated the exposure to sonar that causes specific behavioural responses in cetaceans (whales, dolphins and porpoises). Severe behavioural responses to naval sonar have resulted in hundreds of lethal cetacean strandings over the last decades, and millions of cetaceans are estimated, in US Navy environmental impact assessments, to be behaviourally harassed by sonar transmissions. Our studies provide key information on the effects of sonar on cetaceans, enabling navies to **effectively manage sonar use** in ways that meet environmental regulations and **reduce their environmental impacts**. Scientific information provided by USTAN has contributed to **updated operating and mitigation procedures** in allied Navies within NATO, including the USA, Netherlands, and Norway. No strandings have been linked to these new operating procedures, while approximately 100 whales stranded on the UK and Irish coasts in 2018 when naval sonar was operating outside of procedures informed by the USTAN research.

2. Underpinning research

Navies of the world have identified active sonar to be a key operational tool for national defence that cannot be replaced. Cetaceans also use sound and are at a particularly high risk of negative effects from sonars that transmit intense sounds into the ocean – including both physiological effects, such as hearing loss, and behavioural effects, such as avoidance, and disturbance that disrupts natural behaviour such as cessation of feeding.

Prior to USTAN research into this area (before 2006), sonar was known to have a range of consequences for cetaceans, from minor changes in behaviour to death from stranding or decompression syndrome. A lack of controlled experiments made it difficult to predict relationships between sonar exposure and the occurrence of non-lethal behavioural responses. Despite that science gap, national regulations required their navies to estimate environmental impacts and to gain permits to conduct activities. All NATO nations faced the same lack of information on how cetaceans respond to sonar, and on the possible effectiveness of mitigation procedures such as “ramp-up”, in which the source level of sonar is gradually increased when first turned on to give nearby animals time to move away. Key gaps in information included: what types of responses might animals exhibit, how severe might these responses be, and at what received sound level animals might respond? Prior to our research impact described herein, the US Navy used a predictive risk function in its 2013 Phase II Environmental Impact Statements (EIS) for cetaceans, which represented an educated estimate based on a suite of non-systematic observations (left side of Figure 1).

Key Research Findings: In 2006***,*** USTAN scientists developed and employed an experimental design that describes behavioural responses of cetaceans to escalating dosages of sound – enabling identification of the minimum level of sound that causes a response (**R1**). International collaborative projects, each with named principal investigators from USTAN, have carried out behavioural response studies (BRS), between 2006 and 2016, using this protocol to investigate behavioural responses of 10 free-ranging cetacean species (Blainville's beaked, Cuvier's beaked, Baird's beaked, northern bottlenose, sperm, killer, long-finned pilot, humpback, minke and blue whales) to Navy sonar signals. An associated USTAN-led project (between 2012 and 2015) focussed on developing a suite of statistical tools for quantitative analysis of BRS datasets. These tools have been used to identify change-points in time-series data from BRS experiments (e.g. **R2, R3**), describe behavioural changes in response to sonar (e.g. **R3, R4**), and relate responses to received sound exposure levels using exposure-response model methods that are similar to dose-response analyses in Phase-1 medical clinical trials (**R1**). For each species listed above, the BRS experiments and analytical tools have identified behavioural responses and the level of sound exposure associated with each response.

The results of these studies demonstrated high levels of variability in responsiveness across species. Beaked whales, which are most often involved in sonar-related strandings, exhibited strong behavioural responses, e.g. strong avoidance and cessation of foraging, indicating particular sensitivity of these species (**R2, R3, R4, R5**). Variability in responsiveness has also been demonstrated among individuals within less-responsive species (**R1, R6**), and the potential role of context in determining responsiveness. For example, some killer whales exhibited strong responses, such as separation of dependent young from their group, to low received levels of sonar, alongside a lack of response in other individuals exposed to higher levels (**R1**). The variable responsiveness among individuals was a key finding in determining the effectiveness of ramp-up, which depends critically on how responsive animals are, and how rapidly they move away from the sonar source (**R6**). The research demonstrated that a short duration ramp-up is appropriate to 'warn' nearby animals of the sound, with little expected benefit of a longer-duration ramp-up (**R6**), which has commonly been employed prior to our research.

3. References to the research (USTAN School of Biology staff are highlighted in **bold** in the text.)

The impact is based on a body of work consisting of more than 20 research publications of which the 6 most relevant / representative are listed below. These research publications were published in highly regarded peer-reviewed journals in the field. In addition to the publications, datasets have been made available to the US Navy, which has used them to implement their management methods. Publication R1 is included in the REF submission for UoA 05.

R1. **Miller, P. J. O.**, Antunes, R. N., **Wensveen, P. J**., Alves, A. C., Kvadsheim P. H., Kleivane L., Lam F. P. A., Ainslie M. A., **Tyack P. L.**, and Thomas, L. 2014. Dose–response relationships for the onset of avoidance of sonar by free-ranging killer whales (*Orcinus orca*). Journal of the Acoustical Society of America. 135, 975-993. DOI: 10.1121/1.4861346

R2. DeRuiter, S. L., Southall, B. L., Calambokidis, J., Zimmer, W. M. X., Sadykova, D., Falcone, E. A., Friedlaender, A. S., Joseph, J. E., Moretti, D., Schorr, G. S., Thomas, L., and **Tyack, P. L.** 2013 First direct measurements of behavioural responses by Cuvier's beaked whales to mid-frequency active sonar. Biology Letters. 9, 1-5. DOI: 10.1098/rsbl.2013.0223

R3. **Wensveen, P.**, Isojunno, S., Hansen, R., von Benda-Beckmann, A., Kleivane, L., van IJsselmuide, S., Lam, F. P., Kvadsheim, P. H., DeRuiter, S., Curé, C., Narazaki, T., **Tyack, P.**, and **Miller P**. 2019. Northern bottlenose whales in a pristine environment respond strongly to close and distant navy sonar signals. Proceedings of the Royal Society B. 286, 20182592. DOI: 10.1098/rspb.2018.2592

R4. Sivle, L. D., Kvadsheim, P. H., Curé, C., Isojunno, S., **Wensveen, P. J.**, Lam, F. P. A., Visser, F., Kleivane, L., **Tyack**, **P. L.**, **Harris, C. M.**, and **Miller**, **P. J. O.** 2015. Severity of expert-identified behavioural responses of humpback whale, minke whale, and northern bottlenose whale to naval sonar. Aquatic Mammals. 41, 469-502. DOI: 10.1578/AM.41.4.2015.469

R5. Moretti, D., Thomas, L., Marques, T., **Harwood**, **J.**, Dilley, A., Neales, B., Shaffer, J., McCarthy, E., New, L., Jarvis, S., and Morrissey, R. 2014. A risk function for behavioral disruption of Blainville's beaked whales (*Mesoplodon densirostris*) from mid-frequency active sonar. PLoS One. 9, e85064. DOI: 10.1371/journal.pone.0085064

R6. **Wensveen, P. J.**, Kvadsheim, P., Lam, F. P. A., von Benda-Beckmann, A. M., Sivle, S., Visser, F., Curé, C., **Tyack**, **P. L.**, and **Miller**, **P. J. O.** 2017. Lack of behavioural responses of humpback whales (*Megaptera novaeangliae*) indicate limited effectiveness of sonar mitigation. Journal of Experimental Biology. 220(22), 4150-4161. DOI: 10.242/jeb.161232

4. Details of the impact (USTAN School of Biology staff are highlighted in bold in the text.)

USTAN research (described in Section 2) has provided key information on the effects of sonar on cetaceans and has estimated the exposure that causes specific behavioural responses. This research has helped NATO navies to **effectively manage naval sonar use**, **update their operating and mitigation procedures**, and **reduce their environmental impacts**. In all the contributing studies, USTAN staff were principal investigators and were actively involved in securing funding, planning, data collection, data analysis and publications. Many collaborators, both internal and external to USTAN, were also involved in the research.

Enabling effective management of naval sonar use:

The research described in Section 2 has provided critical information for effective management of naval sonar use through integration into environmental assessments, regulations and operating procedures in multiple countries, as documented within USA and European impact assessment documents (**S1, S2**). Although environmental compliance laws differ by nation, most have regulations that require environmental assessment. For example, the US Navy is required to assess the environmental impact of naval activities between every 5 and 7 years and to request permits to "take" marine mammals, which means including behavioural harassment, injury, and lethal impact. For their most recent "phase III" round of environmental impact statements (EIS) (2017), the US Navy developed exposure-response functions (right side of Figure 1) for estimating the probability of behavioural response to different levels of sonar, using data provided by the BRS project teams (**R1, R2, R4, R5**) and using bespoke statistical models based on research conducted under the MOCHA project (e.g., **R1**) and provided by USTAN researchers. The director of the US Navy Environmental Readiness Divisions states, "*In developing these documents, the Navy thoroughly reviews and incorporates the "best available science" into its acoustic modeling and risk assessment analyses to characterize the environmental impacts of the proposed activities. Research conducted by the University of St Andrews contributed to the best available science utilized during the development of the Navy's Phase III "At-Sea" EIS/OEIS …… that enable the Navy to obtain permits authorizing continued training and testing on at-sea ranges*". (**S3**)

The US Navy, in the development of its EIS (**S1**, Section 3, Tables 3-3 to 3-7 therein, pp. 68, 71, 75, 78, 79), referenced USTAN research outputs (**R1, R2, R4, R5)** to derive exposure-response functions noting in the acknowledgements for Section 3.1.8: "*Exposure and behavioral response data for the 3S and BRS studies were also directly discussed with the researchers (***P. Miller**, **P. Wensveen**, P. Kvadsheim, F.P. Lam, B. Southall, J. Goldbogen, and J. Calambokidis*) …….. Finally, L. Thomas and* ***P. Wensveen*** *contributed significantly to the Bayesian methodology from which the Navy derived response functions*" (**S1**, p. 65).

In addition, **R1** led the US Navy to adopt exposure-response functions that allow for context-dependent responses at lower exposure levels for its Phase III EIS (**S1**). Figure 1 demonstrates the transition from simple exposure-response functions used in the US Navy Phase II EIS prior to the inclusion of USTAN research (left panel of Figure 1) to a more complex, data-driven function used for toothed-whales in the Phase III EIS (right panel of Figure 1). The US Navy also maintained a separate exposure-response function specifically for beaked whales, supported by the growing body of evidence from BRS that these species are highly sensitive to sonar (**R2, R5, S1, S3**).

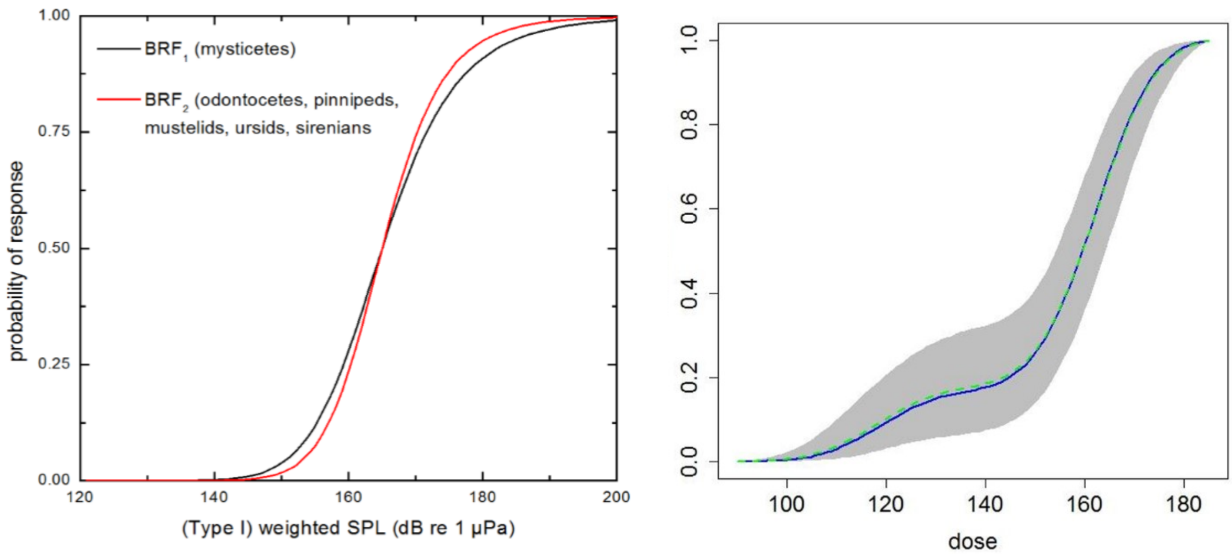

Figure 1: Left: Risk function used in the US Navy 2013 Phase II Environmental Impact Statement (EIS) before inclusion of USTAN research (taken from **S1**, Figure 3-1, p. 48). BRF refers to 'Behavioural Response Function'. Right: Risk function used in the US Navy 2018 Phase III EIS after inclusion of USTAN research (from **S1**, Figure 3-4, p. 70). "Dose" on the x-axis indicates Sound Pressure Level (dB re 1 µPa).

Updating of operating and mitigation procedures of European Navies: The Norwegian and The Netherlands Navies have changed specific operating procedures based on USTAN research to reduce the impact of sonar on cetaceans. These navies have used data published by USTAN to develop tools for planning sonar exercises and as real-time decision aids on the bridge of warships. Examples of these assessment tools include the Norwegian SONATE (**S4**) and The Netherlands SAKAMATA: "*Research conducted by biologists and analyzed by statisticians at the University of St Andrews has been used for the Royal Netherlands Navy regulations for responsible use of sonar systems, and in particular the risk-assessment tool in use on frigate of the Royal Netherlands Navy, SAKAMATA*." (**S5**, p. 2)

BRS results (**R1, R3, R4, R6**) have been critical for the Norwegian 'Instructions for sonar use' (**S6**): "*The integration of St Andrews research into our policy is most clearly evidenced by referring to the document 'Instruction for use of active sonar in Norwegian waters' … These guidelines are 'intended to minimize negative effects of active naval sonars on the marine environment'*." (**S4**, referring to **S6**). For example, the Norwegian Navy's guidance for planning of intense sonar exercises is based upon sound levels that have been shown by USTAN research to lead to behavioural effects (**R1, R3, R4**). In addition, effective planning of the time and place of sonar activities allows for evaluation of the presence of particularly sensitive animals, as identified by BRS studies (e.g., **R3, R4**). "*This section also contains specific recommendation to avoid intense sonar exercises in areas with high abundance of marine mammals, particularly feeding areas of beaked and sperm whales. This recommendation is informed by research of University of St Andrews which documented significant reductions in feeding for sperm whales and beaked whales due to sonar exposure*" (**S4**).

The key findings of **R6** and related research, which evaluated the efficacy of ramp-up as a mitigation procedure, were used to design the ramp-up procedures used by the Norwegian Navy: "*Research by the University of St Andrews within the 3S project [between 2015 and 2016] was particularly important in the design and testing of ramp-up procedures to give animals time to move away while reducing the impact of ramp-up on the sonar operation itself*." (**S4**), and The Netherlands Navy: "*the ramp-up scheme to be used by naval operators has been adapted based on outcomes of the analyses of 3S*") (**S5**, p. 2). Use of a shorter ramp-up period is easier for more navies to implement, without decreasing its positive impact on sensitive animals that move away from the sonar source.

In 2014, NATO established the Active Sonar Risk Mitigation Smart Defence Initiative "*to harmonize procedures designed to mitigate the risk of active sonar operations by NATO navies*" (**S5)**. This initiative led to "*recommended common mitigation procedures for the use of sonar within NATO operations, which was accepted as common NATO policy and published in June 2018*" (**S5**). This common NATO policy was based on contributions from NATO partners, including those with updated operating procedures based on USTAN research (**S5**).

Reduced environmental impact: The environmental benefits of the procedures used in planned NATO training exercises (as updated by USTAN research) are demonstrated by the ability of NATO to conduct large planned international naval operations without strandings, which contrasts against the death of a significant portion of a whale population likely caused by sonar operations that apparently did not follow these procedures. In 2018, NATO conducted a series of planned major naval exercises in beaked whale habitats with no known adverse impact on beaked whales. In contrast, the risks of operating powerful sound sources in the ocean without procedures that incorporate the latest research findings are illustrated by strandings of approximately 100 beaked whales off the Irish and Scottish coasts in 2018. These strandings coincided with a naval operation in the northeast Atlantic. Sonar signals were recorded and "*The Royal Navy were operational in that area at that time: UK Ministry of Defence*" (**S7: slide 9**). The whales that stranded had died at sea, some with evidence of injuries that have been associated with exposure to naval sonars (**S7: slide 8**). Data from the Scottish Marine Animal Stranding Scheme suggests "*Potentially this unusual mortality event involved 1,500-2,000 animals*" (**S7: slide 13**), mainly made up of Cuvier's beaked whale (**S7: slide 2**). This estimate constitutes approximately 20% of the Cuvier's beaked whale population in the northeast Atlantic (**S7: slide 13**).

5. Sources to corroborate the impact

S1. US Navy (2017) Criteria and Thresholds for US Navy Acoustic and Explosive Effects Analysis (Phase III); Data tables documenting USTAN research: Section 3, Tables 3-3 to 3-7. Dose-response functions: Section 3, Figures 3-1 and 3-4. Acknowledgements for Section 3.1.8: "Exposure and behavioral response data for the 3S and BRS studies were also directly discussed with the researchers (**P. Miller**, **P. Wensveen**, P. Kvadsheim, F.P. Lam, B. Southall, J. Goldbogen, and J. Calambokidis)...Finally, L. Thomas and **P. Wensveen** contributed significantly to the Bayesian methodology from which the Navy derived response functions").

S2. TNO report for Benchmark study comparing NATO procedures http://publications.tno.nl/publication/34623611/iRwoDP/TNO-2016-R10570.pdf

S3. Letter from US Navy Environmental Readiness division

S4. Letter from Norwegian Navy representative

S5. Letter from Netherlands Navy representative

S6. Wederwang, T (2015). Instruction for use of sonar in Norwegian Waters. In: Nordlund N and Kvadsheim P (2015). Operating procedures referred to in S4 are documented on pages 9-12.

S7. Brownlow et al (2019). Deep trouble: Investigation into an unprecedented number of beaked whale strandings, eastern Atlantic, July-October 2018. Presentation at the World Marine Mammal Conference, Barcelona Spain, 11 December 2019. Slides documenting statements: Slides 2, 9, 13.