NEED ADDRESSED: NEED TOPIC N-0207-19: IDENTIFICATION OF MONITORING PRIORITIES FOR STUDYING THE POPULATION CONSEQUENCES OF DISTURBANCE ON MARINE MAMMALS

Title: 'MSM4PCoD' – Marine Species Monitoring for the Population Consequences of Disturbance (LMR ID: 308)

Offeror: Cormac Booth (PI). SMRU Consulting, New Technology Centre, North Haugh, University of St Andrews, St Andrews, KY16 9SR, United Kingdom, +44-131-46-38-555, +44-1334-464-746, cgb@smruconsulting.com

Lead Organization Type: Private (profit).

Co-Investigators:
John Harwood, SMRU Consulting, University of St Andrews, UK
Len Thomas, CREEM, University of St Andrews, UK
Ursula Verfuss & Rachael Sinclair, SMRU Consulting, University of St Andrews, UK

Period of Performance: BASE: Sept 2019 – June 2020; OPTION: Sept 2020 – Dec 2023/24*

Financial POC: Nicole Stewart, Management Accountant, SOI Group Limited, New Technology Centre, North Haugh, ST Andrews, Fife, KY16 9SR, United Kingdom, Email: ns62@soigroup.co.uk, Tel: +44 (0)1334 464746

Technical Approach

Summary

Base: The overall objective of the 'MSM4PCoD' project is to review the US Navy Marine Species Monitoring (MSM) program to see how these efforts can be adapted to inform future Population Consequences of Disturbance (PCoD) analyses. However, in order for such a review to be fit for purpose for the MSM program, we propose to engage with relevant Navy stakeholders via a 2-day workshop in order to communicate the intent of 'MSM4PCOD', to review and refine the scope of a series of optional tasks (see below) and to ensure stakeholders buy-in for the project. This will be critical to the success of any future MSM4PCoD effort. As a standalone workshop, will also be valuable as a forum to discuss how PCoD might be informed by global Navy monitoring efforts.

Optional: If the workshop determines that the MSM4PCOD is a viable approach, we propose a series of tasks. The MSM4PCoD approach would be achieved by conducting a systematic review of monitoring efforts (using metadata, grey literature and published literature) carried out for deep diving cetacean and ESA-listed large whale species in specific regions. This review will explore the methods used, the effort conducted and the sample sizes generated for each approach. The results of this review will be amalgamated into a single database to provide a repository in which summary data can be housed and updated as new monitoring outputs are generated. Collating the data in this way will allow goals/recommendations to be assessed as new information becomes available for given species/variables and/or species/methods combinations. We will use the PCoD model outputs from PCoD+ and other related ONR-funded projects to define appropriate population characteristics that are suitable metrics for monitoring. We will use the knowledge gained from the data collation and review in a series of power analyses to assess the signal/noise properties of each population characteristic and the practicality of collecting appropriate data series. Specifically, we propose that power analyses will be used to explore what might be achieved in a PCoD analysis using the data already collected, and the levels of effort required for different approaches to inform PCoD in the future. The outputs of the above tasks will allow us to provide both quantitative and qualitative feedback for the Living Marine Resources (LMR) and MSM programs about the best way to apply PCoD models/monitoring in the future in order to build on the investment in this field over the past 15 years. In addition this project will assess how these recommendations can be efficiently incorporated into existing MSM projects.

Introduction

Between 2009 and 2015, a working group supported by ONR developed a mathematical framework for assessing PCoD. The PCoD framework outlines how disturbance may impact both the behavior and physiology of an individual, and how changes in these characteristics may affect that individual's vital rates either directly (an acute effect) or indirectly via its health (a chronic effect). To implement such frameworks for a species of interest requires substantial knowledge of foraging patterns, life-history schedules, and demographics. Therefore, it was essential to use well-studied species to validate the approach. The PCoD framework provides a conceptual framework which can be used to forecast a plausible range of outcomes given a specific set of input data. However, in data poor situations any forecasts have significant uncertainty associated with them. Given these uncertainties there is merit in identifying the data gaps that need to be filled in order to better parameterize the models. However it may take decades to fill these gaps and, in the meantime, undetected population declines may occur.

Typically, animal populations are monitored via surveys to determine population size or density. There are well established approaches for estimating the size of marine mammal populations – such as line-transect

surveys for cetaceans (e.g. Wade and Gerrodette 1993) or telemetry-corrected haulout counts for pinnipeds (e.g. Thompson and Harwood 1990). However, these are expensive and, particularly in the case of cetacean populations, tend to provide imprecise estimates because marine mammal populations are often spread over wide areas and individuals spend a lot of time submerged where they cannot be visually detected. Consequently, monitoring programs based on these approaches typically only have the power to detect large changes in abundance (Taylor et al. 2007, Jewell et al. 2012). Additionally, for long lived species, it can take a long time before changes in vital rates manifest themselves as changes in population size (Holmes & York 2003).

Holmes and York (2003) used time-varying matrix models of Steller sea lion (*Eumatopias jubatus*) populations to determine whether age-structure information could be used to detect changes in survival, fecundity and population status. Incorporating the 'juvenile fraction' (akin to the proportion of immatures) along with count data improved their ability to detect changes in demographic parameters. Booth, et al (2017) used existing PCoD models to determine that changes in certain demographic variables, such as the mother:calf ratio and proportion of immature animals, are strongly correlated with changes in abundance or population status. Therefore, such metrics, if monitored with high precision, can provide some early warning of future changes in abundance. However the same analysis revealed that there was a high risk of false positives (i.e. predicting a decline when there is none) if these variable were used on their own as early warning indicators. The study noted that capture-recapture and photogrammetry were likely to be the most useful approaches for monitoring population demography. PCoD models also predict changes in individual health in declining population, and Booth et al. (2017) concluded that remote tissue sampling, photogrammetry and individual tracking (e.g. using telemetry) were likely to be the most useful approaches for monitoring health variables in baleen whales and deep-diving cetaceans.

The US Navy has a broad apparatus via which marine mammal research and monitoring is conducted, from basic and applied research through to the dedicated Navy MSM Program. The program has four conceptual framework categories: Occurrence, Exposure, Response, and Consequences studies. These parallel the PCoD framework described in New et al. (2014), where Occurrence and Exposure are critical to the assessment of the numbers of animals being disturbed by an activity, Response is focused on the effect of disturbance via behavioral and physiological changes, and Consequences is concerned with how observed changes might ultimately impact population dynamics.

In this project, we aim to use the outcomes from the PCoD+ project and related ONR projects, dedicated reviews of MSM efforts to date, and power analysis approaches to evaluate the potential of the MSM Program to inform analyses of the effects of disturbance associated with Navy activities on marine mammal populations, and provide recommendations for how this might be achieved in practice.

Project Scope & Objectives

The overall objective of the 'MSM4PCoD' project is to evaluate the MSM Program through the lens of PCoD models to determine how its efforts might be used to inform PCoD analyses. This will be via a scoping workshop and this could be supplemented by four optional tasks:

- Scoping Workshop: Hold a 2 day workshop with Navy stakeholders to determine if/how the MSM program might be supplemented to inform PCoD analyses.
- Optional task 1: Review current and historical MSM projects and methodologies for priority areas and species and compile into a reference database.

- Optional task 2: Select suitable metrics for monitoring populations of deep diving odontocetes and large baleen whales using PCoD models that already exist or are currently in development.
- Optional task 3: Conduct power analyses to assess the power of these metrics to inform PCoD analyses when collected within existing MSM projects, and determine the effort required to increase this power.
- Optional task 4: Prepare a report that synthesizes the results of the previous tasks and provides recommendations for the feasibility of developing MSM for PCoD.

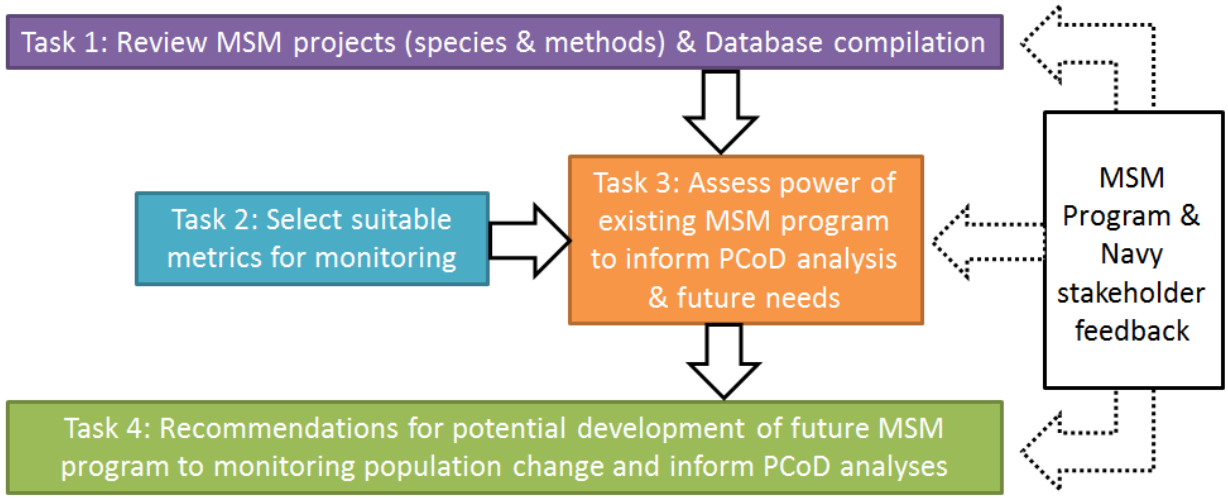

Figure 1 - Schematic indicating the workflow for the MSM4PCoD project and the scoping workshop and proposed liaison in optional tasks throughout the proposed project (white boxes on the right).

The timelines and milestones for the MSM4PCoD project are detailed in the 'Schedule/Milestones' section.

Base: Monitoring for PCoD: Scoping Workshop

It is critical to project success that Navy stakeholders from the MSM program are engaged in this project (see Figure 1). This is in order to ensure that the process we undertake is comprehensive and relevant to the MSM program and to ensure that the recommendations we propose are actionable. In order to better understand MSM and Navy viewpoints on the objectives of monitoring programs and to explore how monitoring for PCoD might be achieve to supplement or refine the comprehensive efforts that already exist, we propose to hold a scoping workshop with Navy stakeholders.

The objective of the workshop is to communicate the potential of a MSM4PCOD effort, present and discuss the scope – gaining key insight from Navy stakeholders to ultimately refine the scope of the optional tasks to ensure that they are as informative as possible to the MSM program and the wider Navy groups. We intend to invite representatives from OPNAV N45, ONR, LMR, NAVSEA, NAVAIR, USFF, PACFLT, SPAWAR, NAVFAC (LANT, PAC, SW, NW) and welcome guidance from LMR on other stakeholders who might attend.

We propose to hold this workshop in February or March 2020, to allow for sufficient time from project start-up to determine the most suitable window and location for all personnel. This is to maximize Navy stakeholder engagement in the workshop as it is critical to the success of the effort.

The output of the workshop would be a workshop report, summarizing discussions on how the MSM program might be supplemented to help inform PCoD analyses. If, following the workshop, there was

interest in the remaining options (see below), this workshop would help ensure the scope of work was fit for purpose going forward.

Optional Task 1: Marine Species Monitoring Review & Database

The objective of this Task is to evaluate how the Navy MSM Program can inform future PCoD analyses. This will include assessing the effort that has been conducted over the past 10-15 years of the Program. This Task has two distinct elements: 1) a review of MSM to date; and 2) the development of a database to collate relevant elements of monitoring.

Task 1.1: Review MSM to date for key species

This task will review the MSM effort conducted to date, focusing on studies conducted on deep diving odontocete and large baleen whale species listed on the Endangered Species Act (ESA) - see Table 1 - in (or close to) MSM program areas (spanning Atlantic, Gulf of Mexico, Southern California, Washington, Alaska, Hawaii, Guam/Marianas). For each study, the methods employed, the effort conducted, the species sampled, and the sample sizes obtained for different species/metrics and species/method combinations will be documented. Whilst the effort will be almost exclusively conducted by the project team specified in this proposal, we expect that this review may initially require some facilitation from Navy personnel, to provide access to the relevant datasets, metadata and contact with MSM practitioners (past and current).

This task will require engagement with Navy stakeholders within (and outwith) the MSM program. Therefore we intend to initiate discussions at the 2019 LMR In-Progress Review (IPR) with relevant personnel to discuss and agree a communications strategy that allows a two-way dialogue regarding scope of work, progress and facilitation of review elements (access to data, monitoring teams etc.).

We propose that given the broad range of expertise (across Navy departments, researchers with varying knowledge of priority species, study areas and methodologies employed) likely to be attending LMR IPR meetings, we request to hold a small 1 day workshop following the 2020 IPR meeting (i.e. at the end of a full year of effort on the project). To achieve this, we have included budget for 1 additional night stay for 9 marine mammal experts and 2 project team members to deliver this workshop. The objective of the workshop will be to present the findings to date of Task 1 and 2 and get feedback on the review to date from Navy stakeholders and method and species-specific technical experts.

Task 1.2: Develop a data repository in which the summary information for different regional MSM monitoring efforts can be collated.

The review described in Task 1.1 will only be possible if it is conducted within a sensible data collation framework. Given the need for such a framework, the logical step is to collate an overview of the data (species, methods, regions, sample sizes etc.) into a database to house the relevant information. Therefore, the intention is that this task will deliver a database (e.g. in Microsoft Access or Excel depending on Navy preference). This could also be regularly updated with new data as it becomes available. Going forward, MSM contractors could be requested to fill in a template so that future MSM efforts can be easily integrated into the database, allowing a continuous assessment of progress and setting of appropriate monitoring objectives. We are happy to work alongside existing metadata repositories as directed by Navy sponsors to ensure the format of the proposed database is aligned with existing efforts.

Table 1 - List of priority species considered in this project. All species are either captured as a 'deep diving species' or are ESA listed large whale (grey shading).

Species Name	Latin Name	Notes

Baird's Beaked Whale	*Berardius bairdii*	Deep diving species
Blainville's Beaked Whale	*Mesoplodon densirostris*	Deep diving species
Blue Whale	*Balaenoptera musculus*	ESA listed large whale
Bryde's Whale*	*Balaenoptera edeni*	ESA listed large whale
Cuvier's Beaked Whale **	*Ziphius cavirostris*	Deep diving species
False Killer Whale	*Pseudorca crassidens*	Deep diving species
Fin whale	*Balaenoptera physalus*	ESA listed large whale
Gervais' Beaked Whale	*Mesoplodon europaeus*	Deep diving species
Gray Whale	*Eschrichtius robustus*	ESA listed large whale
Humpback Whale	*Megaptera novaeangliae*	ESA listed large whale
Killer Whale	*Orcinus orca*	ESA listed large whale
Long-finned Pilot whale	*Globicephala melas*	Deep diving species
Melon-headed Whale	*Peponocephala electra*	Deep diving species
North Atlantic Right Whale	*Eubalaena glacialis*	ESA listed large whale
North Pacific Right Whale	*Eubalaena japonica*	ESA listed large whale
Pygmy Killer Whale	*Feresa attenuata*	Deep diving species
Pygmy Sperm Whale	*Kogia breviceps*	Deep diving species
Sei whale	*Balaenoptera borealis*	ESA listed large whale
Short-finned Pilot Whale	*Globicephala macrorhynchus*	Deep diving species
Sperm Whale‡	*Physeter macrocephalus*	Deep diving species
True's Beaked Whale	*Mesoplodon mirus*	Deep diving species

** - Gulf of Mexico subspecies*

*** - N.B. Also ESA petitioned species in Gulf of Mexico*

‡ *- Also ESA listed.*

Optional Task 2: Identification suitable monitoring metrics

The purpose of this task is to select appropriate metrics to be used in the analysis of what might be achieved with MSM for PCoD, providing a functional link between the review (Task 1) and power analyses (Task 3). The demographic parameters identified to date come from an analysis of outputs from the iPCoD model (King et al. 2015) and PCoD Lite projects (ONR award: N000141410406; Booth et al. (2016), Harwood and Booth (2016)) and were outlined in Booth et al. (2017). It is not intended that any new models will be developed in the MSM4PCoD project. Instead, it is intended that these metrics will come from the models developed within PCoD+ and ongoing ONR funded projects, particularly N000141812821 "Integrating information on displacement caused by mid-frequency active sonar and measurements of prey field into a population consequences of disturbance model for beaked whales".

The ONR-funded PCOD+ project developed bio-energetics based models for pilot whales (Hin et al. *in review*) and blue whales (Pirotta et al. 2018, Pirotta et al. in press) that provided benchmarks for assessing the potential population consequences of disturbance that causes lost feeding opportunities. In addition, this framework is currently being expanded to cover beaked whales as part of ONR award N000141812821. That project will result in PCoD models for two other deep diving species, Blainville's beaked whale and Cuvier's beaked whale. One of the outputs of that effort will be *"A detailed report describing the potential implications of MFAS-induced disturbance for beaked whale populations on US Navy ranges, and the likely effectiveness of different monitoring strategies."* These models will be used in combination with real world Navy disturbance scenarios, constructed as part of N000141812821, to identify population characteristics that might change as a result of disturbance and that are appropriate for monitoring on US Navy ranges.

The list of population characteristics that may be suitable for monitoring, together with their relationship to changes in broader responses (such as population density, and growth rate) will be passed to Task 3. Task

3 will then provide an assessment of the value and practicality of using these characteristics for monitoring purposes. As such, Task 2 provides the connection between Tasks 1 and 3.

Optional Task 3: Power analyses

To understand the potential for population change we need to consider information on long-term trends in population size and their demographic drivers. Power analyses are fundamental for conducting scientific research to ensure sample sizes are sufficiently large to allow detection of an effect. There are a number of approaches that can be used to investigate (a) whether trends are occurring through time, and (b) whether there is sufficient statistical power to detect a biologically significant trend in the data (Steidl and Thomas 2001, Thomas et al. 2004). However we are also interested in detecting sudden declines or increases, to be better understand the natural variations (and their drivers) but also enable adaptive management or mitigation (e.g. Durant et al. 2011). Assessing statistical power is a way of determining whether the uncertainty associated with estimates in a time series dataset is low enough to be able to detect a biologically significant trend, if one was present in the time series. One approach is to incorporate relevant covariates to improve power to detect changes (e.g. Gimenez et al. 2006). In a PCoD setting we are interested principally if whether MSM efforts to date have the power to inform PCoD analyses and to better understand what effort would be required for different species/method/variable combinations.

MSM efforts have been conducted for the past 15 years and so by using the outputs of Task 1 and 2 we will conduct a series of power analyses for a minimum of two priority case study species (likely one deep diving odontocete and one large whale species), as determined by the most suitable species from the MSM review. An initial set of analyses will determine the power to detect a long-term population decline or sudden decrease using the metrics from Task 2 and given the level of measurement or observation error associated with past monitoring efforts. Power depends on effect size (in this case magnitude of the long-term decline or sudden decrease), and hence an important early task is to develop a range of scenarios for what determines a biologically meaningful change – we propose to do this in consultation with the LMRAC, and also looking for guidance from the regulatory community. After the initial power analyses, we will develop a set of simulation scenarios to determine the amount and type of sampling effort that would be required for different approaches to inform PCoD in the future (for a deep diving species and a large baleen whale species – as determined by the results of Task 1 and 2).

These outputs will be combined with the outputs of Tasks 1 and 2 to generate a set of robust and practical recommendations for MSM to advance PCoD analyses (see Task 4).

Optional Task 4: Reporting & Dissemination

Recommendations report

Using the results generated as part of Tasks 1, 2 and 3, we will deliver a report summarizing the assessment process undertaken, the current state of knowledge and MSM effort for each of the priority species and areas (considering the utilized methodologies). This report will also provide qualitative and quantitative recommendations for LMR and MSM programs on how, given the past 10-15 years of effort, monitoring can inform PCoD. This will include an exploration (with Navy feedback) of how feasible and actionable incorporating these recommendations into existing MSM projects is, in the current situation.

This will be delivered along with the MSM database (Task 1) and a dedicated ‘helpfile’ describing the structure and contents. This guidance document can aid users in interpreting and using the database going forward and allow for future updates of the database as more data are collected.

Manuscript

Using the results generated as part of tasks 2 and 3 (guided by learning from Task 1), we will prepare at least one manuscript describing the methods undertaken in the selection of the most suitable metrics for monitoring for PCoD identified for one or more MSM species case studies (i.e. likely one deep diving odontocete and one large baleen whale species – guided by Task 1). The manuscript(s) will also present the results of power analyses conducted to highlight what can be achieved via existing and/or a bespoke 'early warning' monitoring program. Manuscript(s) will be submitted to international peer reviewed journals under an open access policy.

See 'Products and Deliverables' below for further details.

Optional Task 5: Digitization and Integration of MSM database (OPTIONAL)

As noted above, a key element of this project is the review of existing MSM efforts to understand how they might inform PCoD analyses. This will be achieved via the collation of MSM project metadata for different priority species/methods/variable combinations for LMR priority areas. This isolated effort may be improved by digitization and integration of the database into an online platform, such as the OBIS-SEAMAP information system (http://seamap.env.duke.edu/)(Halpin et al. 2006). Integrating the MSM metadata into a spatially referenced format and platform will improve access to and understanding of the efforts conducted to date. It will also help identify reference studies that might provide useful information for understanding the causes of any observed changes, and provide a template that can be used to streamline and focus future data collection efforts (both by LMR/MSM and the wider stakeholder community) so that they can inform PCoD analyses.

The integration of the MSM4PCoD effort at the end of 2022 would deliver a 'snapshot' in time which captures the MSM effort conducted over the past 15 years up to the end of 2022. Such an integration with OBIS SEAMAP could be maintained on a 2-5 year cycle (or as required) if funds are made available. If this option is selected for - we will document the process to ensure it is repeatable and engage with Navy stakeholders from the MSM program to confirm the initial digitization and integration into OBIS-SEAMAP is 'fit for purpose' and useful for the Navy. It will involve liaison with the OBIS-SEAMAP project team and MSM personnel to employ the most suitable approach to the integration of the proposed MSM4PCoD database. We have budgeted for a face-to-face meeting with OBIS-SEAMAP personnel at Duke Marine Laboratory in 2023.

Project Governance

Base: The proposed Scoping Workshop will be organized by Dr. Cormac Booth (SMRU Consulting), who will be the point of contact for the proposed project. As project PI, he will coordinate with LMR personnel to ensure the workshop plans are fit for purpose. Booth will be supported in workshop preparations (both logistical and scientific) by Rachael Sinclair (who was involved in the 'Monitoring Priorities' review as part of the PCoD+ project) and by Prof. Len Thomas, who has been integral to a number of PCoD and population monitoring efforts, both for the US Navy and the wider scientific community. The team will also be supported by Prof. John Harwood in a review capacity. Many of this team are also slated to be involved in the optional tasks and therefore if funded, will allow for a streamlined transition into the main proposed MSM4PCOD effort.

Optional tasks: The project will be led by Cormac Booth (SMRU Consulting), who will be the point of contact for the proposed options and will be responsible for the project management. As project PI, he will coordinate all the scientific elements of the proposal, including the review and development of a MSM database (Optional Task 1). Booth will be supported in these review and development tasks by Ursula Verfuss and Rachael Plunkett, who has experience in species reviews and database development from previous ONR and IOGP Sound and Marine Life JIP projects. John Harwood will coordinate Optional Task 2 and liaise with PIs Booth and Thomas to ensure this Task provides an effective link between Optional Task 1 (led by Booth) and the power analyses (Optional Task 3, led by Thomas).

This project does not involve any dedicated field efforts. However, a key component of the project is the review of MSM monitoring. Therefore, gaining access to relevant datasets from past efforts (to understand methods used, sample sizes etc.) will be particularly important. This may require support and facilitation by Navy personnel to provide introductions and access. This has already been discussed and agreed with Anu Kumar, Joel Bell, Chip Johnson and Robert Uyeyama.

Task 2 uses the outputs of models developed (and conclusions drawn) from within the PCoD+ project (concluding in 2019) to inform the most appropriate metrics for power analyses (Task 3). Whilst additional models are not required to achieve Task 2 and 3, we have included a small budget to ensure we have the most complete set of monitoring metrics for the priority species. Therefore, we propose to further advance the power analyses (Task 3) by exploring other suitable models that have been developed recently by other researcher for priority species (e.g. sperm whales (Farmer et al. 2018), humpback whale - in development by the Costa Lab). To achieve this we will engage with ONR to understand if any other efforts are underway which could be utilized in the MSM4PCoD. We will offer data analysis, methods development and co-authorship in relevant papers in exchange for access to models and their outputs. For models where developers prefer not to make the model directly available, but to collaborate with the MSM4PCoD team, there is a small budget to facilitate their involvement – the only additional funding requested is for running models to detect suitable supplemental metrics (to complement those identified via PCoD+ and ONR award N000141812821 – see Task 2), i.e. aligned with our objectives, when such model analyses have not yet been done or is not funded in any other way.

SMRU Consulting will provide a central point for collating, summarizing and evaluating the Navy MSM efforts to date using a systematic comparative approach. The project will be conducted via distinct tasks allocated to specific team members. Each team member will be responsible to the project manager for completing their individual tasks.

Engagement with Navy personnel

It is critical to project success that Navy stakeholders from the MSM program are engaged in this project (see Figure 1). This is in order to ensure that the process we undertake is comprehensive and relevant to the MSM program and to ensure that the recommendations we propose are actionable. We intend to liaise throughout the project via email and conference call as required by the Navy. In addition, we will present at the LMR IPR meetings in each year of the project (as requested). Following the 2021 LMR IPR meeting, we propose to hold a dedicated 1 day workshop to present the MSM-relevant outputs of PCoD+, the review to date in order to obtain feedback and guidance from Navy personnel to ensure the projected outputs will be usable for the Navy. It is intended meeting will also feature LMR funded marine mammal scientists who can help provide some feedback on monitoring method and/or species-specific issues. In order to ensure there are multiple opportunities to obtain feedback from the Navy stakeholders, we have included funds to present a progress update at the 2022 MSM Monitoring Technical Review meeting. We have assumed that

this will be a joint meeting of Pacific and Atlantic Fleets, but if separate meetings are held in that year, we will attend both, with funding for the second coming from internal sources. This presentation (or these presentations) will provide a further opportunity to engage directly with the MSM program stakeholders. If it is helpful, we are also happy to provide feedback via conference call or updates via webinar.

Principal Investigator's and Key Team Members' Related Experience

Cormac Booth, Len Thomas and John Harwood have been heavily involved in the development and application of the PCAD/PCoD framework over the past decade. Cormac Booth has most recently been PI and PM on the 'PCoD+' and 'PCoD Lite' projects (N000141612858 and N000141410406 respectively) carried out past reviews and specifically developed approaches to effectively monitor marine mammals to identify the early warning of population change (Booth et al. 2017). John Harwood has been a driving force in the development of modelling approaches for the assessment of the potential effects of Navy sonar on marine mammals. Similarly Len Thomas has been advancing statistical methods to better predict the effects of anthropogenic impacts, trends in monitoring populations, as well as power to detect trends. Harwood and Thomas were members of the 'Committee on the Assessment of the Cumulative Effects of Anthropogenic Stressors on Marine Mammals' and authors of National Academies of Sciences and Medicine (2017). The members of the project team have collaborated extensively in the past and have co-authored many reports and papers in this topic area. We have included nominal funds to subcontract relevant PCoD model developers to supplement the models identified for Task 2. These might include Vincent Hin, Enrico Pirotta, Nick Farmer and Dan Costa (and colleagues) and will be explored further on project award.

Below we outline the project team, their project role and years of experience (YOE). Please see the Appendix for project team CVs.

Name	Role	Organization	Location	YOE
Cormac Booth, PhD.	PI & PM	SMRU Consulting	Helsinki, Finland	20
Len Thomas, PhD.	Co-PI	Univ. St Andrews	St Andrews, UK	28
John Harwood, PhD.	Co-PI	SMRU Consulting	St Andrews, UK	48
Ursula Verfuss, PhD.	Supporting Scientist	SMRU Consulting	St Andrews, UK	20
Rachael Sinclair, MRes.	Supporting Scientist	SMRU Consulting	St Andrews, UK	8

EMR/DART

SMRU Consulting is a UK company and a wholly owned subsidiary of the University of St Andrews. As we are based in the UK we do not have an Experience Modification Rate (EMR) or Days Away, Restricted and Transferred (DART) rate. SMRU Consulting's health and safety policy is appended to this document. Combined and Employer's liability and Professional Indemnity insurance policy documents are available here: https://smrumarine.box.com/s/3t2t4dyfonn7z6hjrmavd0z6l3ab0axm

Navy Benefits

As part of the permitting process under the Marine Mammal Protection Act and the Endangered Species Act, the Office of Protected Resources is required to determine whether or not a proposed activity will cause negligible impact to the animal species or stocks inhabiting the area. The overall approach of the Navy MSM Program has to date been primarily focused on Occurrence, Exposure and Response' elements

but less so on the Consequences of Disturbance, which is concerned with how such changes might impact upon health, vital rates and ultimately population dynamics. Conventionally, marine mammal populations are monitored via visual or acoustic surveys to determine population size or density. However, these are expensive and typically insensitive methods for detecting changes at a population level. We will assess the monitoring conducted to date to understand its power to detect changes in the populations studied with the ultimate goal of monitoring for PCoD. This will result in a set of practical recommendations of how PCoD elements could be incorporated into existing MSM efforts. This will have the potential benefit of developing and targeting Navy 'Consequences' monitoring to the species and populations which are best studied for identifying PCoD. In addition, two key areas of the LMR program that could be further advanced are the 'Improved Collection and Processing of Protected Species Data in Areas of Navy Interest' (via focused monitoring informed by these tasks herein) and 'Monitoring and Mitigation Technology Demonstrations' (via the understanding of which methods are most appropriate, practical and ready (or in need of further development for priority species/areas). To ensure maximum relevance, we will liaise closely with, where appropriate, representatives of the Navy offices overseeing the monitoring efforts.

Schedule/Milestones

This scoping workshop (base) project will run between Q4 2019 and Q2 2020 (Figure 2a). The optional proposal task package (1-4), if funded, would start in Q4 2020 and be completed by December 31 2023 (Figure 2b). We have proposed an additional optional task that, if selected, would run between January and December 2024.

	2019			2020					
Project Phase	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
Contracting									
Workshop preparations									
Scoping workshop (date TBD)									
Workshop report									
In Progress Review Meeting									

Figure 2a - Timeline for the 'MSM4PCoD' Scoping Workshop, broken down by month.

	2020	2021				2022				2023				2024			
Project Phase	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Contracting																	
T1.1: MSM review																	
T1.2: Database development																	
T2: Modelling-Monitoring Feedback																	
T3: Power analysis - Retrospective																	
T3: Power analysis - Future																	
T4: Reporting: Recommendations																	
*T5: MSM Digitization & Integration**																	
In Progress Review Meeting																	

Figure 3b - Timeline for the optional 'MSM4PCoD', broken down by quarter. * denotes optional task. Effort in 2024 is dependent on the optional Task 5 being exercised.

Base: The proposed Scoping Workshop effort will start in Q4 of 2019 with presentation of the workshop objectives and approach at the LMR in-progress review meeting. This will also provide an opportunity to directly engage with the many relevant Navy personnel and to help establish a strong working relationship with them. Between Q4 2019 and Q1 2020 we will identify the most suitable time window and meeting location for the workshop. We have initially proposed San Diego and late February or early March 2020 as

a suitable location and timing (in order to maximize the likelihood of Navy stakeholder attendance at the workshop). We welcome any feedback on more suitable locations/timings.

Options: The proposed MSM4PCoD project will start in Q4 of 2020 in order to finalize contracts and attend the LMR IPR meeting to kick-off the full effort. Main project work will commence in January 2020 with the start of the MSM review and scoping the development of the database (Optional Task 1). In Q3 of 2021 the selection of metrics for power analysis will commence (Optional Task 2), reviewing the work completed within PCoD+ and reviewing the modelling as part of ONR award N000141812821. In Q4 of 2021, the power analysis work will ramp up (Optional Task 3), as the review and metric selection phases become better developed. Power analyses will developed throughout 2022 and completed in 2023. Following stakeholder feedback we will prepare a technical report on recommendations/guidance on the practical steps that could be taken to monitor for PCoD within the existing MSM program. If this timeline is not suitable to the MSM program, we welcome feedback and can explore what interim reporting can be delivered earlier in the process.

As highlighted above, feedback to Navy stakeholders throughout the project is critical to success. If the optional parts of the proposed MSM4PCoD project are funded, we have proposed the following feedback milestones to ensure further engagement across Navy stakeholders:

- Q4 2020 – LMR IPR Meeting (Project Startup)
- Q4 2021 – LMR IPR Meeting + dedicated 1 day MSM4PCoD workshop
- Q2/Q3 2022 – Presentation of MSM4PCoD project progress to Atlantic/Pacific Fleet monitoring meeting. Timing TBD.
- Q4 2022 – LMR IPR Meeting: Progress update.
- Q4 2023 – LMR IPR Meeting: Core proposal completion.

We also have suggested that webinars/conference calls during the project can provide an effective means to obtain feedback from the MSM program.

Product Implementation

Products and Deliverables:

Base: The main deliverable of the Scoping Workshop will be a workshop report detailing the discussions and key outcomes of the workshop, in particular with that result in changes to the scope of a potential MSM4PCoD project (see Options).

Options:

1. MSM Database reviewing monitoring carried out to date on priority species in priority regions that might inform PCoD analyses.
    a. Delivered in spreadsheet format (unless format specified).
    b. Guidance document for MSM database.
2. Report on approach undertaken along with recommendations on how PCoD models/monitoring can be practically applied to existing MSM efforts.

3. Manuscript(s) describing the results of Task 2 and 3 power analyses for one or two MSM case studies (manuscripts will be submitted to international peer reviewed journals under an open access policy)

.Implementation Requirements:

The intended end user of the products is primarily the Navy MSM program and the Navy environmental compliance community but it is expected that they will also be of value to the wider scientific community. We intend that there will be many opportunities for feedback (if required) to ensure project plans and outputs are fit for purpose to the MSM program. We intend that transition of results will be straightforward, as the outputs (e.g. in database, recommendations report) will be based on quantitative results. Planned publication(s) describing case studies based on the products and deliverables will help transition the results to the wider community. The database described will be delivered with a guidance document to aid its translation and uptake by the Navy MSM program and their contractors.

Technical Risks:

This project is generally a low risk because no dedicated data collection is required for project success. The main technical risk to this project is that if we are unable to obtain sufficient access to the data from MSM contractors/surveyors collected as part of the program, which could limit the quality of the power analyses and therefore hinder the project team's ability to provide robust qualitative and quantitative recommendations for future monitoring for PCoD. However, support and facilitation by Navy personnel to provide introductions and access has already been discussed and agreed with Anu Kumar, Joel Bell, Chip Johnson and Robert Uyeyama, therefore this is considered a low risk.

References

Booth, C., C. Donovan, R. Plunkett, and J. Harwood. 2016. Using an interim PCoD protocol to assess the effects of disturbance associated with US Navy exercises on marine mammal populations Final Report.

Booth, C. G., R. Plunkett, and J. Harwood. 2017. Identifying Monitoring Priorities for Population Consequences of Disturbance. Office of Naval Research – Marine Mammal & Biology program.

Durant, S. M., M. E. Craft, R. Hilborn, S. Bashir, J. Hando, and L. Thomas. 2011. Long-term trends in carnivore abundance using distance sampling in Serengeti National Park, Tanzania. Journal of Applied Ecology **48**:1490-1500.

Farmer, N. A., D. P. Noren, E. M. Fougères, A. Machernis, and K. Baker. 2018. Resilience of the endangered sperm whale Physeter macrocephalus to foraging disturbance in the Gulf of Mexico, USA: a bioenergetic approach. Marine Ecology Progress Series **589**:241-261.

Gimenez, O., C. Crainiceanu, C. Barbraud, S. Jenouvrier, and B. J. J. B. Morgan. 2006. Semiparametric regression in capture–recapture modeling. **62**:691-698.

Halpin, P., A. J. Read, B. Best, K. Hyrenbach, E. Fujioka, M. Coyne, L. B. Crowder, S. Freeman, and C. Spoerri. 2006. OBIS-SEAMAP: developing a biogeographic research data commons for the ecological studies of marine mammals, seabirds, and sea turtles. Marine Ecology Progress Series **316**:239-246.

Harwood, J., and C. Booth. 2016. The application of an interim PCoD (PCoD Lite) protocol and its extension to other marine mammal populations and sites. Final Report to the US Office of Naval Research.

Hin, V., J. Harwood, and A. M. de roos. in review. Bio-energetic modeling of medium-sized cetaceans shows high sensitivity to disturbance in seasons of low resource supply Ecological Applications **TBC**:TBC.

Holmes, E., and A. York. 2003. Using age structure to detect impacts on threatened populations: a case study with Steller sea lions. Conservation Biology **17**:1794-1806.

Jewell, R., L. Thomas, C. M. Harris, K. Kaschner, R. Wiff, P. S. Hammond, and N. J. Quick. 2012. Global analysis of cetacean line-transect surveys: detecting trends in cetacean density. Marine Ecology Progress Series **453**:227-240.

King, S. L., R. S. Schick, C. Donovan, C. G. Booth, M. Burgman, L. Thomas, and J. Harwood. 2015. An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution **6**:1150-1158.

National Academies of Sciences, E., and Medicine. 2017. Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals. National Academies Press.

New, L. F., J. S. Clark, D. P. Costa, E. Fleishman, M. Hindell, T. Klanjšček, D. Lusseau, S. Kraus, C. McMahon, and P. Robinson. 2014. Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. Marine Ecology Progress Series **496**:99-108.

Pirotta, E., M. Mangel, D. P. Costa, J. A. Goldbogen, J. Harwood, V. Hin, L. M. Irvine, B. R. Mate, E. A. McHuron, D. M. Palacios, L. Schwarz, and L. F. New. in press. Anthropogenic disturbance in a changing environment: modelling lifetime reproductive success to predict the consequences of multiple stressors on a migratory population. Oikos **TBD**.

Pirotta, E., M. Mangel, D. P. Costa, B. Mate, J. A. Goldbogen, D. M. Palacios, L. A. Hückstädt, E. A. McHuron, L. Schwarz, and L. New. 2018. A Dynamic State Model of Migratory Behavior and Physiology to Assess the Consequences of Environmental Variation and Anthropogenic Disturbance on Marine Vertebrates. The American Naturalist **191**:E000-E000.

Steidl, R. J., and L. Thomas. 2001. Power analysis and experimental design. Design and analysis of ecological experiments:14-36.

Taylor, B. L., M. Martinez, T. Gerrodette, J. Barlow, and Y. N. Hrovat. 2007. Lessons from monitoring trends in abundance of marine mammals. Marine Mammal Science **23**:157-175.

Thomas, L., K. Burnham, and S. Buckland. 2004. Temporal inferences from distance sampling surveys. Advanced distance sampling:71-107.

Thompson, P. M., and J. Harwood. 1990. Methods for estimating the population size of common seals, Phoca vitulina. Journal of Applied Ecology:924-938.

Wade, P. R., and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. Report of the international Whaling Commission **43**.

Appendix – Project Team Curriculum Vitaes

Name:	**Dr Cormac Booth**	**Tel:**	+44-131-4638555
	B.Sc (Hons), M.Sc, Ph.D	**Mobile:**	+358-40-321-9235
D.O.B	4 December 1980	**Email:**	cgb@smruconsulting.com
Nationality:	British		
Academic Training/ Education:	**2006-'10** Uni. of St Andrews: *PhD: Variation in distribution and habitat preference of harbour porpoises west of Scotland* **2003-'04** Uni. of Aberdeen : *Masters of Research: Marine and Fisheries Science* **1998-'01** Uni. of Wales, Aberystwyth: *BSc Hons: Marine and Freshwater Biology*		
Current Position:	**Principal Scientist & Director of Business Development, SMRU Consulting 2010-current** Lead scientist and project manager for multiple projects involving investigating the potential impacts of marine developments marine mammal species. He is the Project Manager and contributing scientist on a number of interim Population Consequences of Disturbance (PCOD) projects. Principal investigator, co-investigator or Project Manager on numerous research projects totalling > £3 million since 2012.		
Career History:	Research Consultant – JNCC / SMRU, University of St Andrews. **2010** Research Assistant: - CREEM / SMRU, University of St Andrews. **2005 - 2006** Scientific Manager – The Odyssey. Ocean Alliance **2004 - 2005** Acoustic Analyst – Scripps Institute of Oceanography **2001 - 2002**		
Skills & Areas of Expertise:	Project Management, Statistical analysis (R – GEEs, GAMs, GLMs, bootstrapping, data processing), Visual surveying & PAM monitoring, Databases development (MS Access); Word processing (MS Word); Spreadsheets (MS Excel), MMO, GIS (Manifold & ArcGIS), Acoustic analysis (MATLAB), Photo Identification projects.		
Key Experience:	Cormac Booth has been working in the field of marine mammal biology since 2000, both in the UK and abroad, in the laboratory and in the field. He has extensive experience in marine mammal biology, statistics and acoustics (in particular static and towed passive acoustic monitoring techniques and robust modelling approaches). Cormac has developed unique PAM mitigation approaches used on UK marine development sites and analysed extensive acoustic datasets. He has been the Principal Investigator and/or Project Manager for the interim **Population Consequences of Disturbance (PCoD) framework** project, and numerous PCoD projects for the UK, Canadian, Dutch & USA regulatory bodies and the Office of Naval Research. He has also managed projects spanning a range of sectors and expertise and coordinated teams of diverse expertise to complete objectives. His expertise and experience span: • **Assessing anthropogenic impacts on marine mammals**: Via working on the initial development, application and evolution of the interim PCOD framework – investigating how the potential impacts of disturbance can be robustly assessed. • **Distribution and Ecology of Cetaceans:** A range of habitat modelling and GIS techniques and conducting visual and towed-acoustic, line-transect surveys to study habitat preferences and distribution of harbour porpoise. • **Marine Mammal Monitoring & Mitigation:** Prior to, and during his time with SMRU Consulting, Cormac has worked on several projects developing suitable monitoring and mitigation methods to meet regulatory standards and enabling industry to develop sustainably. He is the scientist responsible for the delivery of several commercial projects involving the use of PAM to monitor cetaceans. Also has extensive experience of conducting and analysing the data generated from different marine mammal monitoring and survey approaches.		
Client Experience:	**Europe:** The Crown Estate, Forth Crossing Bridge Constructors, Marine Current Turbines, Minesto UK Ltd, Scottish Power Renewables, Tidal Energy Ltd, SeaGreen Wind Energy Ltd, Vattenfall, CEFAS, Moray Offshore Renewables Limited, Beatrice Offshore Wind Limited, RWE Innogy, BioConsult SH, IBL Umweltplanung.		

	DECC, Shell (UK) Ltd, Shell (Angola) Ltd, TNO, Aquatera, Cromarty Firth Port Authority, GoBe, Statkraft, EDPR, Mainstream RP, Scottish Natural Heritage, Marine Scotland, Natural England, WWF UK, JNCC. **North America:** US Navy Office of Naval Resources, NOAA, National Marine Fisheries Service, DFO Canada, Port of Vancouver, USFW, IOGP Sound & Marine Life Joint Industry Program, FORCE, Acadia University, Pacific Northwest National Laboratory.
Key Projects	Population Consequences of Disturbance models – Project manager and PI/Co-PI for a series of projects involving the development of PCoD models (clients include: UK regulators and SNCBs; Office of Naval Research; Netherlands Min. Environment & NOAA.) AVADECAF: Assessing the viability of DECAF approaches for long term oil and gas fields. Deepwater Horizon (DWH) Natural Resources Damage Assessment – Supported NOAA in assessing the long term consequences of the DWH spill on bottlenose dolphins and other Gulf of Mexico species. Expert elicitation – Developed a number of expert elicitations for marine mammal species (clients include: NOAA, US Fish and Wildlife, US Navy Office of Naval Research).
References:	Pirotta, E., **Booth, C.G.**, D. P. Costa, E. Fleishman, S. D. Kraus, D. Lusseau, D. Moretti, L. F. New, R. S. Schick, and L. K. Schwarz. 2018. Understanding the population consequences of disturbance. Ecology and Evolution. Thomas, L., **Booth, C.G.,** Rosel, PE., Hohn, A., Litz, J. & Schwacke, LH. (2017). Where were they from? Modelling the source stock of dolphins stranded after the Deepwater Horizon oil spill using genetic and stable isotope data. Endangered Species Research Vol. 33: 253-264. **Booth, C.G.**, Oedekoven, C.S., Gillespie, D., Macaulay, J., Plunkett, R, Joy, R., Harris, D., Wood, J., Marques, T.A., Marshall, L., Verfuss, U.K., Tyack, P. Johnson, M., & Thomas, L. 2017. Assessing the Viability of Density Estimation for Cetaceans from Passive Acoustic Fixed Sensors throughout the Life Cycle of an Offshore E&P Field Development. Report number: SMRUC-OGP-2017-001. Submitted to IOGP Sound and Marine Life Joint Industry Programme (Unpublished). **Booth, C.G.**, Plunkett, R & Harwood, J. 2017. Identifying Monitoring Priorities for Population Consequences of Disturbance – Interim Report. Report Code SMRUC-ONR-2017-017, submitted to the Office of Naval Research – Marine Mammal & Biology program, Nov 2017 (unpublished). **Booth, C.G.,** Harwood, J., Plunkett, R., Mendes, S. & Walker, R. (2017). Using the Interim PCoD framework to assess the potential impacts of offshore wind developments in Eastern English Waters on harbour porpoises in the North Sea. Natural England Joint Report, Number 024 York. **Booth, C.G.** (2016). The Challenge of Using Passive Acoustic Monitoring in High Energy Environments: UK Tidal Environments and Other Case Studies. Popper, A.N. and A. Hawkins. (Eds), The Effects of Noise on Aquatic Life II. Springer, New York **Booth, C.G**, Donovan, C., Plunkett, R & Harwood, J. 2016. Using an interim PCoD protocol to assess the effects of disturbance associated with us navy exercises on marine mammal populations: Final Report. Report code SMRUC-ONR-2016-004, submitted to the Office of Naval Research – Marine Mammal & Biology program, February 2016 (unpublished). Harwood, J. & **Booth, C.G.** (2016). The application of an interim PCoD (PCoD Lite) protocol and its extension to other marine mammal populations and sites. Final Report. Report code SMRUC-ONR-2016-004, submitted to the Office of Naval Research – Marine Mammal & Biology program, February 2016 (unpublished). Donovan, C., Harwood, J, King, S., **Booth, C.G.**, Caneco, B., & Walker, C. (2016). Expert elicitation methods in quantifying the consequences of acoustic disturbance from offshore renewable energy developments. In: Popper A.N., Hawkins A.D. (eds) Effects of Noise on Aquatic Life II. Advances in Experimental Medicine and Biology 875, DOI 10.1007/978-1-4939-2981-8_27. Springer, New York King, S. L., Schick, R. S., Donovan, C., **Booth, C. G.**, Burgman, M., Thomas, L., & Harwood, J. (2015). An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution doi:10.1111/2041-210X.12411 Harwood, J.S., S. King, C. Donovan, L. Thomas, R. Schick, **Booth, C.G.,** D. Costa, E. Fleishman, S. Kraus, D. Lusseau, L. New, and L. Schwarz. (2006) Understanding the population- level consequences of acoustic disturbance (PCAD) for marine mammals. In: Popper A.N., Hawkins A.D. (eds) Effects of Noise on Aquatic Life II. Advances in Experimental Medicine and Biology 875, DOI 10.1007/978-1-4939-2981-8_27. Springer, New York **Booth C.G.**, Embling C., Gordon J., Calderan S.V., Hammond P.S. 2013. Habitat preferences and distribution of the harbour porpoise (Phocoena phocoena) west of Scotland. Marine Ecology-Progress Series 478:273-285. **Booth, C. G. 2010.** Impacts of Commercial Aquaculture Acoustic Devices on harbour porpoises west of Scotland. Chapter of PhD Thesis. Department of Biology. Scottish Oceans Institute. University of St Andrews.

Name:	**Dr Ursula Verfuß**	**Tel:**	+44 (0)1334 466011
Date of Birth:	16th December 1968	**Email:**	ukv@smruconsulting.com

Nationality:	***German***		
Academic Training/ Education:	*2009*	University of Tübingen, Germany	**PhD Animal Physiology** Excellent. The echolocation behaviour of harbour porpoises (*Phocoena phocoena*)
	1996	University of Tübingen, Germany	**Graduate Study (Diploma)** Excellent. Foraging and echolocation behaviour of an Amazon River dolphin (*Inia geoffrensis*) in captivity.
	1991	University of Münster, Germany	**Basic Study Biology (Diploma)** Excellent.
Current Appointment:	**Principal Scientist, SMRU Consulting 2018-current** **Senior Scientist, SMRU Consulting 2012-2018** Lead scientist and project manager for projects involving the effects of renewable energy development on marine mammals. Provide specialist input into EIA's and provide data and advice for mitigation studies relating to impacts to marine mammals.		
Career History:	German associate of EU-Life+ project BIAS: Baltic Sea Information on the Acoustic Soundscape (through itap GmbH, Germany) 2012-2016 Freelance Biologist 2011-2012 Scientist, German Oceanographic Museum, Stralsund, Germany 2001-2010 Internship, Kewalo Basin Marine Mammal Laboratory, Univ. of Hawaii 1993		
Key Skills:	Acoustic data acquisition hardware handling; Acoustic data acquisition and analysis software (Dasylab, MATLAB, Adobe audition, Avisoft, SONA PC, PAMGUARD, T-POD.exe, C-POD.exe); Video analysis software; MS Office, MS Access; SigmaPlot, MS Visual Basic.NET (basics), Adobe Photoshop Lightroom.		
Key Experience:	21 years' experience studying and working within the marine mammal field. A wide range of practical, analytical and management skills developed through involvement with many European projects. • Extensive experience in underwater acoustics and bioacoustics, including passive acoustic monitoring (using various devices), of marine mammals throughout northern European waters. • Team leader of the Harbour porpoise research team at the German Oceanographic Museum, Stralsund, Germany. • Scientific advisor to the "Standard Investigation of the impacts of offshore wind turbines on the marine environment" (StUK 3, StUK 4) for the German Federal Maritime and Hydrographic Agency. • Scientific contributor for international agreements on cetacean conservation (ASCOBANS, HELCOM, ICES) • Organisation of several workshops and conferences, including an international symposium "Towards an environmentally sound offshore wind energy deployment" in January 2012. • Nine years board member of the European Cetacean Society.		
Key Projects:	Autonomous - review of autonomous platforms and sensors for marine mammal detection Low Vis – Low visibility real-time monitoring techniques review. Assessing the benefit of noise reduction measures during offshore wind farm construction on harbour porpoises, WWF UK AMPOD – Investigations of the compatibility of application and analysis methods with regard to the acoustic monitoring of harbour porpoises. AIDA – Assessment of the compatibility of two different passive acoustic monitoring devices.		

	Post consent monitoring review - comprehensive review of UK offshore wind farm post consent monitoring, leading the marine mammal section.
Publications / Reports:	**Verfuss, U.K.**, Aniceto, A.S., Harris, D.V., Gillespie, D., Fielding, S., Jiménez, G., Johnston, P., Sinclair, R.R., Sivertsen, A., Solbø, S.A., Storvold, R., Biuw, M., Wyatt, R. (2019). A review of unmanned vehicles for the detection and monitoring of marine fauna. Marine Pollution Bulletin. Volume 140, 2019, Pages 17-29. **Verfuss, U. K**., D. Gillespie, J. Gordon, T. A. Marques, B. Miller, R. Plunkett, J. A. Theriault, D. J. Tollit, D. P. Zitterbart, P. Hubert and L. Thomas (2018). "Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys." Marine Pollution Bulletin 126: 1-18. **Verfuss, U. K.**, R. Plunkett, C. G. Booth and J. Harwood (2016). Assessing the benefit of noise reduction measures during offshore wind farm construction on harbour porpoises, WWF-UK. **Verfuss, U.**, Sparling, C & Plunkett, R. (2017). Thanet Extension Offshore Wind Farm: Marine Mammal Piling Noise Impact Assessment. Draft 1 submitted to GoBe Consultants Ltd and Vattenfall Wind Power Ltd, August 2017. **Verfuss U. K.,** Aniceto, A. S., Biuw, M., Fielding, S. Gillespie, D., Harris, D., Jimenez, G., Johnston, P., Plunkett, R., Sivertsen, A., Solbø, A., Storvold, R. And Wyatt, R. (2016). Literature Review: Understanding The Current State Of Autonomous Technologies To Improve/Expand Observation And Detection Of Marine Species. Report Number SMRUC-OGP-2015-015 Provided To IOGP, February, 2016 (Unpublished). **Verfuss UK**, Gillespie D, Gordon J, Marques T, Miller B, Plunkett R, Theriault J, Tollit D, Zitterbart DP, Hubert P, & Thomas L. (2015). Low Visibility Real-Time Monitoring Techniques Review. Report Number SMRUM-OGP-2015-002 Provided To IOGP, November 2015 (Unpublished). **Verfuß, U**., Sparling, C., Arnot., C., Judd, A. and Coyle, M. (2013) Review of offshore wind farm impact monitoring and noise mitigation measures with regards to marine mammals. Invited talk at the StUKplus Conference: Five Years of Ecological research at alpha ventus – Challenges, Results and Perspectives. 30-31 October 2013, Berlin. Diederichs, A., Nehls, G., Dähne, M., Adler, S., Koschinski, S., and **Verfuß, U.**, (2008). Methodologies for measuring and assessing potential changes in marine mammal behaviour, abundance or distribution arising from the construction, operation and decommissioning of offshore windfarms. COWRIE Ltd.

Surname:	**SINCLAIR** (formerly Plunkett)	**Tel:**	01334 466 012
First name(s):	Rachael, Robin	**Email:**	rrs@smruconsulting.com
	BSc (Hons), MRes	**DoB:**	17/02/1988

Education:

2011 University of St Andrews **MRes Marine Mammal Science**
Thesis: Habitat use of the South Abaco Island bottlenose dolphin community.
2010 University of Aberdeen **BSc (Hons) Marine Biology**
First Class Honours and winner of the Rixon Award for best honours year marine biologist.
Thesis: Does the exploitation of immature fish contribute to the sustainability of fish stocks?

Current Appointment:

Senior Scientist, SMRU Consulting
Current
Associate Scientist, SMRU Consulting 2015 - 2018
Project Scientist, SMRU Consulting 2013 - 2015

Career History:

Research Assistant – Lighthouse Field Station, Aberdeen University 2012 - 2013

Research Assistant – CMRG, Massey University NZ 2011 - 2012

Contracted Responder – Oiled Wildlife Response Team, NZ 2011

Skills & Areas of Expertise:

Marine mammal spatial distribution and habitat use, GIS, marine mammal behaviour, photo-identification, data analysis, WordPress, Adobe Illustrator and Photoshop, computer skills.

Key Experience:

Rachael has been working in the field of marine mammal science for eight years. She has two years experience conducting visual marine mammal surveys investigating the impacts of swim-with-dolphin tourism and on a long term bottlenose dolphin photo-ID project. Since joining the SMRU Consulting Europe team she has experienced a range of consultancy work for various industries and sectors including offshore renewables, offshore civil engineering and oil and gas. Rachael has conducted a wide array of industry funded project work including the production of Environmental Statements and supporting documents, collision risk modelling, population modelling and survey design and coordination.

- Production of and input into baseline characterisation, noise impact assessments, ES chapters, habitats regulations assessments, shadow EPS assessments and marine mammal monitoring protocols for offshore wind farms. EIA experience for Dounreay Tri, Thanet Extension, Moray West, Hornsea Three, Seagreen Phase 1 and Hornsea Four.
- Analytical work including collision risk modelling for tidal devices and population trajectory modelling using the iPCoD model for offshore wind farms, cumulative assessments and tidal device collision impacts.
- Main GIS specialist at SMRU Consulting.
- Visual marine mammal survey projects including designing surveys and protocols, acting as survey co-ordinator and analysing and reporting data.
- Involved in designing and implementing a novel photographic geo-referencing technique to obtain more accurate sighting location data during land based vantage point surveys at the Skerries tidal array site.
- Experienced in identifying marine mammal species from digital still images obtained during aerial surveys.
- Experience on various PAM projects conducting analysis of data for baseline site characterisation and underwater noise monitoring during construction works.
- Trained in spatial modelling methods for correlated data and distance sampling.

Publications/ Reports:	Hornsea Project Four Offshore Wind Farm. EIA: Scoping Report, Chapter 6.5 Marine Mammals. October 2018. Seagreen Alpha and Bravo. EIA Report Volume I, Chapter 10 - Marine Mammals. September 2018. Moray West Offshore Wind Farm. EIA Report Volume 2, Chapter 9 – Marine Mammals. July 2018. Moray West Offshore Wind Farm. EIA Report Volume 4, Technical Appendix 9.1 – Marine Mammal Baseline Characterisation Report. July 2018. Thanet Extension Offshore Wind Farm. Environmental Statement Volume 2, Chapter 7 – Marine Mammals. June 2018. **Plunkett, R**. (2017). Seal Telemetry Data in Relation to the Hornsea 3 Project. Report Number SMRUC-RPS-2017-008, Submitted To RPS, March 2017. Sparling, C. & **Plunkett, R.** (2017). Predicting population change under different scenarios of population parameters and mortality rates. Report Submitted to Tidal Lagoon Swansea Bay. Sparling, C., Cook, A., Thompson, D., Smout, S., Tollit, D., Verfuss, U., **Plunkett, R**., Wood, J., Brookes, K., Bennet, F., Morris, C., Stringell, T. & Smith, K. (2017). Acceptable thresholds of change: how much is too much? A review of the population assessment of impacts on marine mammals. Submitted to NRW, April 2017. Sparling, CE. & **Plunkett. R.** (2016). Tidal Lagoon Swansea Bay – Monitoring and mitigation review and feasibility report. Report number SMRUC-TLP-2016-010 provided to Tidal Lagoon Swansea Bay, August, 2016. **Plunkett, R.,** Sparling, CE., Russell, DJF., Moss, S. & Hastie, GD. (2016). Race Bank Offshore Wind Farm Harbour Seal Telemetry Study: Interim Report #1 – Fieldwork Report. Report Number SMRUC-DON-2016-014 Provided To Dong Energy, November 2016. Verfuss, UK., **Plunkett, R**., Booth, CG. & Harwood, J. (2016). Assessing the Benefit of Noise Reduction Measures During Offshore Wind Farm Construction on Harbour Porpoises. Report Number SMRUC-WWF-2016-008 Provided To WWF UK, June, 2016. Verfuss U. K., Aniceto, A. S., Biuw, M., Fielding, S. Gillespie, D., Harris, D., Jimenez, G., Johnston, P., **Plunkett, R.**, Sivertsen, A., Solbø, A., Storvold, R. And Wyatt, R. 2016. Literature Review: Understanding The Current State Of Autonomous Technologies To Improve/Expand Observation And Detection Of Marine Species. Report Number SMRUC-OGP-2015-015 Provided To IOGP, February, 2016. **Plunkett, R**; Booth, CG. & Sparling, CE. (2015). Tidal Lagoon West Cumbria: Review Of Marine Mammal Baseline Information and Recommendations For Marine Mammal Monitoring. SMRUC-TLP-2015-009 and SMRUC-TLP-2015-023, Submitted To Tidal Lagoon Power, December 2015. Verfuss UK, Gillespie D, Gordon J, Marques T, Miller B, **Plunkett R**, Theriault J, Tollit D, Zitterbart DP, Hubert P, & Thomas L. 2015. Low Visibility Real-Time Monitoring Techniques Review. Report Number SMRUM-OGP-2015-002 Provided To IOGP, November 2015. Sparling, C., **Plunkett, R**., Gordon, J. & Gotz, T. (2015). The Use Of Acoustic Deterrents For The Mitigation Of Injury To Marine Mammals During Pile Driving For Offshore Wind Farm Construction. SMRUC-TCT-2015-006, Submitted To The Carbon Trust, June August 2015. Booth, C.G., Sparling, C.E., **Plunkett, R**., Scott-Hayward, L. & Rexstad, E. Collision Risk Simulation Modelling: Marine Mammals And Deep Green Device At Holyhead Deep. Report Number SMRUM-MIN-2015-005 provided To Minesto UK Ltd, March 2015. **Plunkett, R**, Sparling, C. & Kidney, D. Anglesey Skerries Marine Mammal Monitoring: Land Based Vantage Point Survey trial. Report Number SMRUM-MCT-2014-012 Provided To MCT, November, 2014. Booth, C.G., **Plunkett, R.** & Verfuβ, U. K. Interim Marine Mammal And Noise Monitoring At Invergordon Report. Report Number SMRUL-AFF- 2014-003 Provided To Affric Ltd, May 2014.

JOHN HARWOOD

Curriculum Vitae

Current Post: Professor, School of Biology, University of St Andrews
Institute: Centre for Research into Ecological and Environmental Modelling,
University of St Andrews,
St Andrews, Fife KY16 8LB, UK
E-mail: jh17@st-andrews.ac.uk
Date of birth: 14 April 1949
Education: B.Sc. (Hons) Class 1, Zoology. University College London 1970
Ph.D., Zoology. University of Western Ontario, Canada 1975.
Career: Director, NERC Sea Mammal Research Unit 1978-1996.
Fellow of St Edmund's College, Cambridge 1990-1996.
Director, Centre for Research into Ecological and Environmental Modelling, 2004 - 2009
Professor, University of St Andrews 1996-present

RESEARCH INTERESTS

Application of risk analysis to conservation and management. Population biology of vertebrates, particularly the dynamics of small populations. Management of marine mammals. Prof Harwood has been actively involved in the development of the Populations Consequences of Disturbance (PCoD) framework for the last decade. He was co-chair of the ONR Working Groups on PCoD and a member of the National Academies of Sciences Committee on the Assessment of the Cumulative Effects of Anthropogenic Stressors on Marine Mammals

Recent Publications:

Refereed journals:

Pirotta, E, Booth, CG , Costa, DP, Fleishman, E, Kraus, SD, Lusseau, D, Moretti, D, New, LF, Schick, RS, Schwarz, LK, Simmons, SE, Thomas, L, Tyack, PL, Weise, MJ, Wells, RS & Harwood, J 2018 Understanding the population consequences of disturbance. *Ecology and Evolution*. DOI: 10.1002/ece3.4458

Donovan, CR, Harris, CM, Milazzo, L, Harwood, J, Marshall, L & Williams, R 2017. *A simulation approach to assessing environmental risk of sound exposure to marine mammals* *Ecology and Evolution*, vol. 7, no. 7, pp. 2101-2111. DOI: 10.1002/ece3.2699

Tyack, PL, Bailey, H, Crocker, D, Estes, JE, Francis, CD, Harwood, J, Schwacke, L, Thomas, LJ & Wartzok, D 2017. *Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals*. National Academies Press, Washington DC. DOI: 10.17226/23479

Fleishman, E, Costa, DP, Harwood, J, Kraus, S, Moretti, D, New, LF, Schick, RS, Schwarz, LK, Simmons, SE, Thomas, L & Wells, RS 2016, Monitoring population-level responses of marine mammals to human activities. *Marine Mammal Science*, 10.1111/mms.12310

King, S.L., Schick, R.S., Donovan, C., Booth, C.G., Burgman, M., Thomas, L. & Harwood, J. 2015. An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution doi: 10.1111/2041-210X.12411

Pirotta, E., Harwood, J., Thompson, P.M., New, L., Cheney, B., Arso, M., Hammond, P.S., Donovan, C., & Lusseau, D. 2015. Predicting the effects of human developments on individual dolphins to understand potential long-term population consequences. Proc. R. Soc. B 282: 20152109. http://dx.doi.org/10.1098/rspb.2015.2109

Wiff, R., Barrientos, M.A., Milessi, A.C., Quiroz, J.C., & Harwood, J. 2015. Modelling production per unit of food consumed in fish populations. Journal of Theoretical Biology 365, 67–75.

Klimova, A., Phillips, C., Fietz, K., Olsen, M., Harwood, J., Amos, W. & Hoffman, J. 2014. Global population structure and demographic history of the grey seal. Molecular Ecology 23(16), 3999–4017. doi: 10.1111/mec.12850

Pirotta, E., New, L., Harwood, J., & Lusseau, D. 2014. Activities, motivations and disturbance: An agent-based model of bottlenose dolphin behavioral dynamics and interactions with tourism in Doubtful Sound, New Zealand. Ecological Modelling, 282, 44–58. doi:10.1016/j.ecolmodel.2014.03.009

Moretti, D., L. Thomas, T. Marques, J. Harwood, A. Dilley, B. Neales, J. Shaffer, E. McCarthy, L. New, S. Jarvis and R. Morrissey. 2014. A risk function for behavioral disruption of Blainville's beaked whales (Mesoplodon densirostris) from mid-frequency active sonar. PLoS ONE 9(1): e85064.

New, L.F, J.S. Clark, D.P. Costa, E. Fleishman, M.A. Hindell, T. Klanjcek, D. Lusseau, S. Kraus, C.R. McMahon, P.W. Robinson, R.S. Schick, L.K. Schwarz, S.E. Simmons, L. Thomas, P. Tyack and J. Harwood. 2014. Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. Marine Ecology Progress Series. 496, 99-108

Smout, S. C., Rindorf, A., Hammond, P. S., Harwood, J. & Matthiopoulos, J. 2014 Modelling Prey Consumption by UK Grey Seals. ICES Journal of Marine Science 71(1): 81-89.

Harris, D., L. Matias, L., Thomas, J. Harwood and W.F. Geissler. 2013. Applying distance sampling to fin whale calls recorded by single seismic instruments in the northeast Atlantic. J. Acoustical Society of America 134, 5, 3522.

New, L.F., J. Harwood, L. Thomas, C. Donovan, J.S. Clark, G. Hastie, P.M. Thompson, B. Cheney, L. Scott-Hayward and D. Lusseau. 2013. Modelling the biological significance of behavioural change in coastal bottlenose dolphins in response to disturbance. Functional Ecology 27: 314-322.

Schick, R.S., L.F. New, L. Thomas, D.P. Costa, M.A. Hindell, C.R. McMahon, P.W. Robinson, S.E. Simmons, M. Thums, J. Harwood and J.S. Clark. 2013. Estimating resource acquisition and at-sea body condition of a marine predator. Journal of Animal Ecology 82: 1300-1315.

Len Thomas

Director, Centre for Research in Ecological and Environmental Modelling
The Observatory, Buchanan Gardens, University of St Andrews, St Andrews, Scotland KY16 9LZ
Tel: (0)1334 461801 Email: len.thomas@st-andrews.ac.uk Web: lenthomas.org

CAREER HISTORY:

2017-present	**Professor of Statistics** University of St Andrews, Scotland
2010-2017	**Reader in Statistics**; **Director of CREEM** since 2014 University of St Andrews, Scotland
2005-2010	**UK Research Council Academic Fellow in Mathematics and Statistics** University of St Andrews, Scotland
2001-2005	**Senior Research Fellow in Mathematics and Statistics** University of St Andrews, Scotland
1997-2001	**Research Fellow in Mathematics and Statistics** University of St Andrews, Scotland

EDUCATION:

1997	**PhD in Forestry**, University of British Columbia, Canada. Thesis entitled 'Evaluation of statistical methods for estimating long-term population change from extensive wildlife surveys'.
1991	**MSc (Distinction) in Biological Computation**, University of York, U.K.
1990	**BSc (Hons.) in Animal and Plant Sciences**, Class 2:1, University of Sheffield, U.K.

RESEARCH SUPPORT:

Principal investigator, co-investigator or contractor on numerous research projects totalling >UK8.0 million. Major projects (>UK£150K) since 2010 (amounts are just Univ. St Andrews' component):

2010-2015	LATTE: Linking Acoustic Tests and Tagging using statistical Estimation. US Office of Naval Research (ONR). £412K.
2010-2013	Extending our capability to determine distribution and abundance of marine mammals from line transect data. ONR. £455K
2011-2014	Cheap DECAF (Density Estimation for Cetaceans from Acoustic Fixed sensors). ONR. £218K
2012-2015	Statistical tools for fitting models of the Population Consequence of Disturbance. ONR. £288K.
2012-2016	MOCHA: Multi-study Ocean Acoustics Human Effects Analysis. ONR. £852K
2014-2018	LSD: Large Scale Density estimation of blue and fin whales. ONR. £187.

2015-2018	AFFOGATO: A framework for ocean glider abundance estimation. ONR. £305.
2015-2019	DECAF-TEA: Density Estimation for Cetaceans from Fixed passive acoustics in Testing and Evaluation Areas. £214. LMR.
2017-2021	Denmod: Working group for advancement of density surface modelling. LMR £448K
2018-2019	CARMMHA: Consortium for Advanced Research on Marine Mammal Health Assessment. Gulf of Mexico Research Institute. £214K
2018-2021	Double MOCHA: Phase II Multi-study Ocean acoustic Human effects Analysis. ONR. £524K
2019-2020	Analytical methods to support the development of noise exposure criteria for behavioral response. LMR £153K.

RESEARCH OUTPUTS:

103 papers in peer-reviewed journals; 3 books (one an edited volume); 85 other publications and tech. reports; >70 external seminars and conference talks since 2006. Selected publications:

Harris, C.M., L. Thomas, E.A. Falcone, J. Hildebrand, D. Houser, P.H. Kvadsheim, F.P.A. Lam, P.J.O. Miller, D.J. Moretti, A.J. Read, H. Slabbekoorn, B.L. Southall, P.L. Tyack, D. Wartzok, and V.M. Janik. 2018. Marine mammals and sonar: dose-response studies, the risk-disturbance hypothesis and the role of exposure context. Journal of Applied Ecology 55: 396-404.

Pirotta, E., C. Booth, D. Costa, E. Fleishman, S. Kraus, D. Lusseau, D. Moretti, L.F. New, R. Schick, L. Schwarz, S. Simmons, L. Thomas, P. Tyack, M. Weise, R. Wells and J. Harwood. 2018. Understanding the population consequences of disturbance. Ecology and Evolution 8: 9934-9946.

National Academies of Sciences, Engineering, and Medicine. 2017. Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals. Washington, DC: The National Academies press. Preprint available at http://dx.doi.org/10.17226/23479

Taylor, B.L., L. Rojas-Brancho, J. Moore, A. Jaramillo-Legorreta, J.M. ver Hoef, G. Cardenas-Hinojosa, E. Nieto-Garcia, J. Barlow, T. Gerrodette, N. Tregenza, L. Thomas and P.S. Hammond. 2017. Extinction is Imminent for Mexico's Endemic Porpoise Unless Fishery Bycatch is Eliminated. Conservation Letters 10: 588–595.

Schwacke, L.H., L. Thomas, R.S. Wells, W.E. McFee, A.A. Hahn, K.D. Mullin, E.S. Zolman, B.M. Quigley, T.K. Rowles and J.H. Schwacke. 2017. An age-, sex- and class-structured population model for estimating nearshore common bottlenose dolphin injury following the Deepwater Horizon oil spill. Endangered Species Research 33: 265-279.

Fleishman, E., D.P. Costa, J. Harwood, S. Kraus, D. Moretti, L.F. New, R.S. Schick, L.K. Schwarz, S.E. Simmons, L. Thomas and R.S. Wells. 2016. Monitoring population-level responses of marine mammals to human activities. Marine Mammal Science 32: 1004-1021.

Thomas, L., C.G. Booth, P.E. Rosel, A. Hohn, J. Litz and L.H. Schwacke. Where were they from? Modelling the source stock of dolphins stranded after the Deepwater Horizon oil spill using genetic and stable isotope data. 2017. Endangered Species Research 33: 253-264.

Borchers, D.L., B.C. Stevenson, D. Kidney, L. Thomas, T.A. Marques. 2015. A unifying model for capture-recapture and distance sampling surveys of wildlife populations. 2015. Journal of the American Statistical Association 110: 195-204.

King, S.L., R.S. Schick, C. Donovan, C.G. Booth, M. Burgman, L. Thomas and J. Harwood. 2015. An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution 6: 1150-1158.

Miller, D.L. and L. Thomas. 2015. Mixture models for distance sampling detection functions. PLOS One 10(3): e0118726.

Newman, K., S.T. Buckland, B. King, D.R. Borchers, D.L. Cole, P. Besbeas, O. Gimenez and L. Thomas. 2014. Modelling Population Dynamics: Model Formulation, Fitting and Assessment using State-Space Methods. Springer Series: Methods in Statistical Ecology, 215p.

Marques, T.A, L. Thomas, S.W. Martin, D.K. Mellinger, J.A. Ward, D.J. Moretti, D. Harris and P.L. Tyack. 2013. Estimating animal population density using passive acoustics. Biological Reviews 88: 287-309.

McClintock, B.T., R. King, L. Thomas, J. Matthiopoulos, B.J. McConnell, J.M. Morales. 2012. A general modeling framework for animal movement and migration using multi-state random walks. Ecological Monographs 82:335-349.

Thomas, L., S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop, T.A. Marques and K.P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5-14.

Thomas, L., S.T. Buckland, K.B. Newman and J. Harwood. 2005. A unified framework for modelling wildlife population dynamics. Australian and New Zealand Journal of Statistics 47: 19-34.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers & L. Thomas (editors). 2004. Advanced Distance Sampling. Oxford University Press.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers & L. Thomas. 2001. Introduction to Distance Sampling. Oxford University Press.