SMRU Consulting

understand ♦ assess ♦ mitigate

Identifying monitoring priorities for Population Consequences of Disturbance - Interim Report

As part of the project: 'PCoD+ - Developing widely-applicable models of the population consequences of disturbance (PCoD)'

Authors:	Cormac Booth, Rachael Plunkett & John Harwood
Report Code:	SMRUC-ONR-2017-017
Date:	6th November 2017

This report is to be cited as: 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Report Code SMRUC-ONR-2017-017, submitted to the Office of Naval Research – Marine Mammal & Biology program, Nov 2017 (unpublished).

This work was sponsored by the Office of Naval Research: Marine Mammal Biology Program, under award N000141612858

1 Contents

2 Table of Figures

3 Table of Tables

Executive Summary

The Population Consequences of Disturbance (PCoD) framework provides a conceptual framework which can be used to forecast a plausible range of population-level outcomes given a specific set of input data. To implement such frameworks for a species of interest requires significant baseline knowledge of foraging patterns, life-history, and demographic parameters. However, for many marine mammal populations, current knowledge is lacking and such 'data poor' situations mean that any such 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 parameterise the models. However it may take decades to fill these gaps and, in the meantime, undetected population declines may occur. In this report we focus on identifying methods for monitoring populations that are subject to disturbance that may also provide insights into the processes through which disturbance may affect these populations. In addition, we aim to identify priorities for monitoring to inform future PCoD analysis of the potential effects of Navy activities on marine mammal populations. Therefore, our ultimate objective is to identify a suite of variables that can provide information on changes in demography or health, together with the methodologies that can be used to measure these variables.

To identify and address the knowledge gaps highlighted above, we conducted a comprehensive survey of the literature to identify suitable response variables which could be monitored using established survey techniques or techniques that are currently in development. Following the initial literature review, we held a workshop with a small number of experts on monitoring approaches to develop this list further and to identify the current state of utility and feasibility of the different approaches for Navy relevant marine mammal species groups. This report summarises the results of the literature review, and the outputs from the workshop. In addition, we explore the methods and/or techniques required to collect appropriate datasets and the feasibility of using them to monitor different species and populations (section 2) with sufficient precision to avoid false positive results (i.e. results that suggest a population is in decline when it is not). Therefore, using existing PCoD benchmark models, we explore the potential for different demographic parameters to provide early warning indicators of population decline and explore the potential to detect change and limit the proportion of false positive results (section 3). In order to realistically assess what methods might be feasible to conduct, it was considered crucial to assess the monitoring infrastructure that currently exists. As such, we also summarize US Navy marine mammal monitoring in terms of the approaches already in use, the platforms for research available (e.g. vessels, aerial, fixed sensors etc.) and species/populations which are currently (or have recently been) monitored (section 4). Building from this foundation, we assess the potential for current monitoring practice to inform a PCoD analysis (section 5.3) using the lessons learned from the literature review and sensitivity analysis phases.

Using existing PCoD models, we determined that changes in certain demographic variables are strongly correlated with changes in abundance or population status, and can therefore provide some early warning of future changes in abundance. In particular, the proportion of immature animals in a population might provide a reasonable early indicator of population decline. We also explored the ratio of mothers to calves/pups but determined that there was a high risk of false positives (i.e. predicting a decline when there is none). We observed that demographic parameters tend to be most commonly estimated from monitoring using established approaches such as visual surveys and capture-recapture. In addition, both vertical and lateral photogrammetry appear to be viable methods to determine important demographic parameters. Monitoring body condition might be a suitable approach to identify 'unhealthy' animals (though determining causation may be difficult) and is a particularly attractive route for monitoring PCoD and a range of methods are in development to explore this topic area. In general, monitoring individual health and physiological variables was determined to be important in informing elements of the PCoD framework, primarily via photogrammetry, remote tissue sampling, direct

handling and individual tracking approaches. The continued development of remote tissue sample libraries and analytical approaches to improve our understanding of stress response, physiology and –omics fields is critical. Additionally, it is important to continue the use (and development) of PAM techniques to monitor cetacean populations to better understand the relative and absolute indices that can be derived to inform PCoD.

We recommend that, where possible, monitoring programs are developed to specifically inform future PCoD analyses, which requires a clear set of objectives regarding the purpose of the monitoring. Monitoring programs should be identified which can provide reference or control populations against which observed patterns can be compared.

We have highlighted that, where possible, the integration of new technologies into existing Fleet/SYSCOM monitoring efforts might provide significant added value. The inclusion of novel approaches into monitoring programs where infrastructure exists means a cost-effective increase in what can be achieved by a given program.

1 Introduction

1.1 An Introduction to the PCoD conceptual framework

Between 2009 and 2015, a working group supported by ONR developed a mathematical framework for assessing the population consequences of disturbance (PCoD). The initial framework, shown in Figure 1, is based on a conceptual model drawn up by a National Research Council committee on Characterizing Biologically Significant Marine Mammal Behavior (National Research Council 2005) and was focused exclusively on acoustic disturbance.

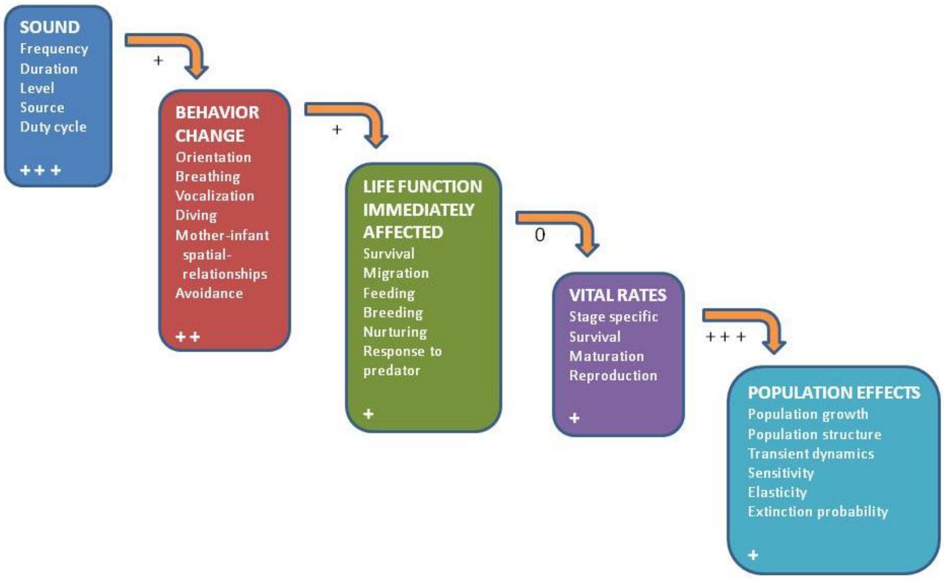

Figure 1 - The Population Consequences of Acoustic Disturbance (PCAD) framework developed by the National Research Council's (NRC) panel on the biologically significant effects of noise. After Figure 3.1 in NRC (2005). The number of + signs indicates the panel's evaluation of the level of scientific knowledge about the links between boxes, 0 indicates no knowledge.

The initial framework was expanded by the ONR working group to consider forms of disturbance other than noise, and to address the impact of disturbance on physiology as well as behaviour. The updated framework is shown below (Figure 2), and described in more detail in New et al. (2014) and National Academies of Sciences and Medicine (2017). The PCoD framework outlines how disturbance may impact both the behaviour 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). A key component of this framework is an assessment of the health of individuals. A variety of health indices, including allostatic load, energy stores, immune status, organ status, stress levels, contaminant burden, and parasite load, may be used. Appropriate health indices integrate the potential effects of physiological and behavioral responses to multiple stressors on fitness over a time scale that is longer than the duration of the responses themselves but shorter than the response time of vital rates. Such indices can provide early indicators of risk of reduced survival and reproduction before an actual alteration in these rates and can increase understanding of the mechanisms by which disturbance affects fitness.

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 ONR working group considered four case studies that spanned the range of marine mammal taxonomic groups and reproductive strategies, and for which there were large, robust dataset. The resulting publications explore how changes in behavior (in response to disturbance) could affect adult female energy reserves and the implications of this for fertility and/or survival (adult or offspring) in elephant seals (*Mirounga* spp.)(Schick et al. 2013b, New et al. 2014, Costa et al. 2016, Schwarz et al. 2016), bottlenose dolphins (*Tursiops truncatus*)(New et al. 2013a, Pirotta et al. 2015, Schwarz et al. 2016), North Atlantic right whales (*Eubalaena glacialis*)(Schick et al. 2013a, Rolland et al. 2016) and beaked whales (Order *Ziphiidae*)(New et al. 2013b).

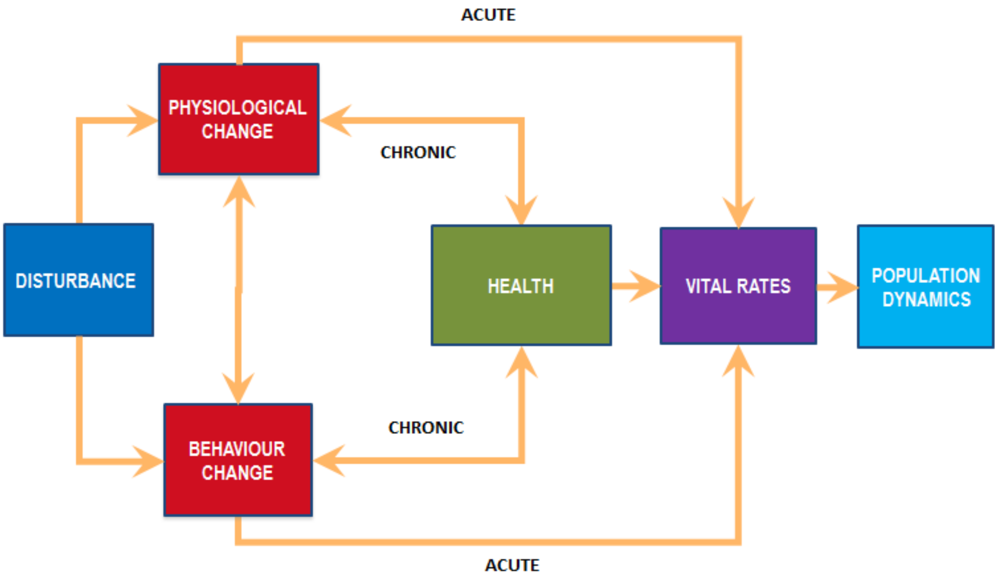

Figure 2 - The PCoD framework for modelling the population consequences of disturbance developed by the ONR working group on PCAD (modified from Figure 4 of New et al. (2014)).

In its description of the PCAD framework (Figure 1), the National Research Council (2005) highlighted how well specific variables (i.e. those in each box) could be measured and how well understood the transfer functions between each box were. During the same time that the ONR working group was developing the model framework described above, a wide range of Navy funded efforts (summarised in Harris and Thomas 2015, Popper and Hawkins 2016, Southall et al. 2016) have improved our understanding of the extent and scale over which marine mammals are exposed to Navy activities and how individuals respond to exposure. Whilst these studies were not explicitly designed to fit into the PCoD framework, they nevertheless provide important jigsaw pieces, developing our knowledge base of potential effects of exposure to Navy activity on marine mammal species. However, most of these efforts have addressed the transfer function on the left-hand side of the PCoD framework, which are concerned with 'disturbance' and 'physiological and behavioural changes' at an individual level and improving knowledge on the causal mechanisms of responses to exposure (e.g. Ellison et al. 2013).

In addition a number of studies have explored links between health and vital rates (e.g. fertility and survival) in marine mammals populations where the body condition of individual animals can be measured directly This work includes studies of the relationship between foraging success and body condition (Schick et al. 2013b) and between body condition and pup survival in elephant seals (New et al. 2014), studies of the links between physiological indicators, health and reproductive success in bottlenose dolphins following the Deepwater Horizon oil spill (Schwacke et al. 2013, Lane et al. 2015, Schwacke et al. 2017), and studies of blood chemistry in stranded and wild caught harbour seals (Greig et al. 2010). In addition, sightings history and visual health assessments of North Atlantic right whales have been used in a Bayesian hierarchical framework to estimate health status, demography and population status (e.g. Schick et al. 2013a, Rolland et al. 2016). Although it has proved possible to develop full PCoD models for a number of marine mammal species (King et al. 2015, van Beest et al. 2015, Booth et al. 2016, Harwood and Booth 2016, Nabe-Nielsen and Harwood 2016, Tollit et al.

2016), the paucity of data on the transfer functions in the centre and right-hand sides of the PCoD framework, that describe how disturbance impacts health and vital rates and how changes in health affects vital rates (and thus population dynamics) remains a major challenge to the development of more models.

1.2 Monitoring marine mammal populations

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, as noted above, 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 parameterise the models. However it may take decades to fill these gaps and, in the meantime, undetected population declines may occur. In this report we focus on identifying methods for monitoring populations subject to disturbance that may also provide insights into the processes through which disturbance may affect these populations. Typically, animal populations are monitored via surveys to determine population size or density. Whilst there are well established approaches – 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) - for estimating the size of marine mammal populations, 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 spend a lot of time submerged where they cannot be sighted. Consequently, monitoring programs based on these approaches typically only have the power to detect the drastic declines (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. There may, therefore, be merit in monitoring demographic variables and indicators of individual health (detailed in Chapter 7 of National Academies of Sciences and Medicine 2017) rather than population size. The National Academies report highlights the need to identify variables that can provide an early warning of population decline. It notes that monitoring demographic variables might allow for early detection of population level effects, and that monitoring health indicators may help to identify some of the drivers of changes in these variables

In order to properly assess what is feasible in terms of monitoring programs designed to identify PCoD, it is crucial to consider the monitoring infrastructure that currently exists. This infrastructure is summarised below and described in detail in section 4.

1.3 US Navy marine mammal research and monitoring

The US Navy has a broad apparatus via which marine mammal research and monitoring is conducted. The Office of Naval Research (ONR) Marine Mammal Biology program "*supports basic and applied research and technology development related to understanding the effects of sound on marine mammals, including physiological, behavioural, ecological effects and population-level effects*." (ONR 2017). The Living Marine Resources (LMR) program is responsible for funding applied research demonstrate and validate (DEMVAL) research efforts to help transition this science (where appropriate) into Navy compliance monitoring, for which the Navy Marine Species Monitoring program oversees. These monitoring programs support Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA) authorizations. A schematic of how US Navy funded research and monitoring is captured under each program is shown below (Figure 3).

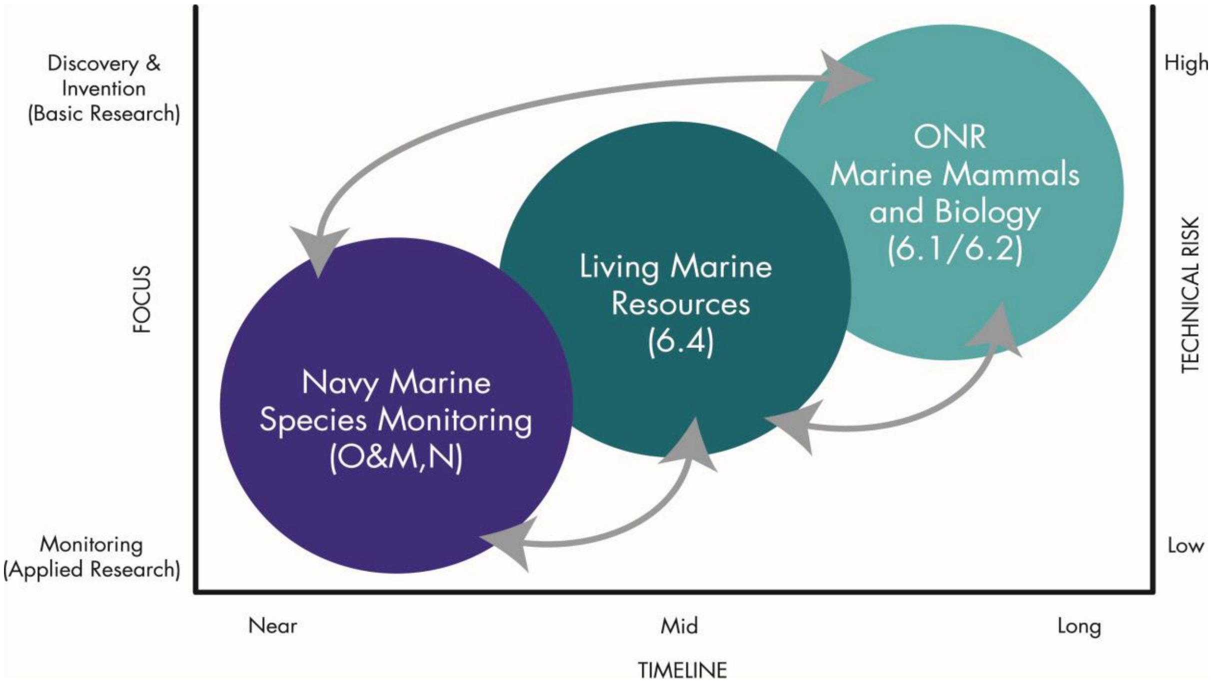

Figure 3 – Overview of how ONR, LMR and Navy Marine Species Monitoring research and monitoring efforts can be viewed in the context of readiness ('timeline'), focus and technical risk.

The overall approach of Navy Marine Species Monitoring for both Atlantic and Pacific range complexes is captured in four conceptual framework categories (DoN 2016a, b):

*"**Occurrence** – gathers basic information on the presence and diversity of species that occur in a Navy range or area of proposed training activity; information by patterns of habitat use, population structure, density, abundance, and behavioral ecology (e.g., feeding, mating, migrating).*

***Exposure** – examines Navy training activities including where, when, and how often sources are being used, types and properties of generated sounds, and sound propagation to determine received levels and other metrics. Exposure and occurrence information may be coupled to estimate number of individuals from each population that are exposed to specific sound levels.*

***Response** – investigates how animals react to exposure across spatial (e.g., changes in habitat) and temporal (short-term, medium-term, and long-term) scales, behavioral and social interactions. The findings on responses may be useful in refining exposure estimates.*

***Consequences** – considers species occurrence and habitat use cumulatively to determine long-term impacts of exposure and responses. These investigations include evaluating long-term impacts on distribution, behavior, social groups, and foraging success and their effects to fitness through reproduction, growth, and survival."*

- DoN (2016a)

With these categories in mind, it is clear that parallels can be drawn to the PCoD framework described in New et al. (2014), where 'Occurrence' and 'Exposure' are integral to the assessment of numbers of animals disturbed, 'Response' captures the link between disturbance and behavioral and physiological changes, and 'Consequences' is concerned with how such changes might impact upon health, vital rates and ultimately population dynamics. The monitoring program is overseen by a steering committee (with a Strategic Planning Process) which develops broad intermediate scientific objectives (ISOs) and monitoring questions under each of the categories above.

In the context of this project, our aim was identify variables and methods that could inform future PCoD analysis of the effects of Navy activities on marine mammals. Here we identify a suite of suitable methods that could provide this information as part of existing Navy monitoring programs using either established survey techniques or techniques that require further development.

1.4 Report intention and structure

To address the knowledge gaps highlighted above, we conducted a comprehensive survey of the literature to identify suitable response variables which could be monitored using established survey techniques or techniques that are currently in development. Following the initial review, we held a workshop with a small number of experts on monitoring approaches to develop this list further.

This report summarises the results of the literature review, and the outputs from the workshop. In addition we explore the methods and/or techniques required to collect appropriate datasets and the feasibility of using them to monitoring different species and populations (section 2). Using existing PCoD models, we explore the potential utility of different demographic parameters to provide early warning indicators of population decline (section 3). We also summarize US Navy marine mammal monitoring (section 4) and assess the potential for current monitoring practice to inform a PCoD analysis (section 5.3) using the lessons learned from the literature review and sensitivity analysis phases. We conclude the report with recommendations for how to inform future PCoD analysis of the effects of Navy activities on relevant marine mammal populations (section 6).

2 Review of monitoring methods & variables to inform PCoD

2.1 Background

Fleishman et al. (2016) identified four elements that should be included in the design and implementation of a monitoring program to investigate the potential effects of human activity on marine mammal behavior and physiology, and the population-level consequences of any behavioral and physiological changes. Those elements are: develop a set of mechanistic hypotheses that outline why a given activity might be expected to have measurable effects; define a set of biologically meaningful effects; select appropriate response variables for monitoring; and specify a temporal sequence of monitoring. We investigate how this approach could be used in the design of monitoring program for marine mammals on Navy ranges so that they could inform PCoD models. Specifically, we focused on identifying suitable response variables and appropriate methods (considering available platforms, feasibility, and the relative cost and precision of different approaches) for monitoring these response variables. This section presents the literature review and integrates its conclusions with the outputs from the workshop held with the project team and invited experts (see Appendix – section 7.1 for further details).

2.2 Considerations for a PCoD monitoring program

It is important to consider at an early design stage how the characteristics of a monitoring program will affect our ability to measure the response variables of interest. For example, even if a particular response variable has the potential to provide an early warning of unacceptable population change, it will be of limited value if it cannot be monitored practically or with sufficient precision.

Here we outline some of the key steps involved in designing or augmenting a monitoring program (Figure 4). As noted above, simply monitoring population density or abundance is unlikely to provide an early warning of population decline because of the relatively low precision associated with most density estimates. However, there may be situations, for example where there is a small resident population, when population size can be estimated as or more precisely than any other variable.

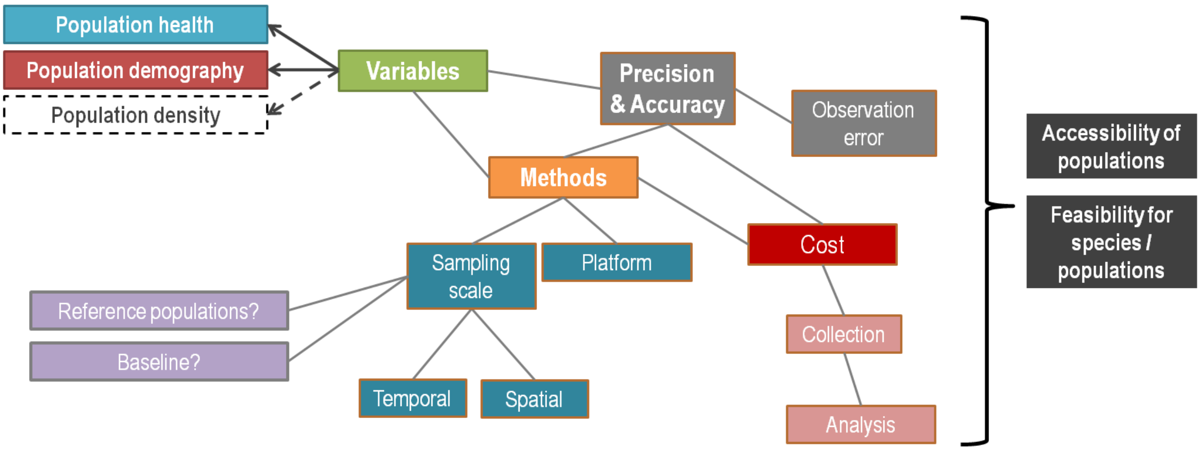

Figure 4 – Schematic of elements to be considered in monitoring program for identifying variables that be collected practically and might inform future PCoD analyses of the effects of Navy activities on marine mammals.

Our ultimate objective is to identify a suite of variables that can provide information on changes in demography or health, together with the methodologies that can be used to measure these variables. This involved an assessment of the temporal and spatial scale of sampling required to achieve a sample size that is appropriate for robust estimation. In addition, the availability of suitable platforms (e.g. vessel, air, land-based) for data collection and the costs of data collection and analysis need to be considered. Critically, it must be possible to measure or estimate the chosen response variables with sufficient precision to detect change and limit the proportion of false positive results (i.e. results that suggest a population is in decline when it is not). These will be dictated by a species or population's life-history, its behavior (e.g. migratory or resident) and its distribution (e.g. wide-ranging or local) and the survey methodologies that are currently available or in development. These elements are explored in subsequent sections.

2.3 Methods for assessing suitability of variables and methods

Using the results from the literature search and the workshop exercises (section 7.1), we identified a set of currently available and developing methodologies for monitoring demographic variables and individual health that are reviewed in section 2.4. At the workshop, we agreed to follow a multiple lines of evidence (LoE) approach (e.g. Ross 2000, Amidan et al. 2015) to assess the value of these methodologies for monitoring marine mammal populations. This involved making a judgement on the feasibility and the utility of each methodology for following marine mammal groups (see Appendix 7.1.2 for details):

- Deep-diving cetaceans
- Baleen whales
- Coastal dolphins and porpoises
- Oceanic dolphins
- Land-breeding pinnipeds
- Ice-breeding pinnipeds

Here 'feasibility' captured the readiness of the methodology for use in a monitoring program, the likelihood that it could be applied to each marine mammal group, and its potential for collecting demographic / health information as new analytical techniques become available. It should be recognised that feasibility was assessed on a relative scale for each class of response variable, so that a feasibility score of 3 applied to a methodology for measuring demographic variables cannot be equated directly with a score of 3 applied to a methodology for monitoring health measures. 'Utility' captured the number of demographic variables and/or health measures that could be monitored with a specific method. For the 'Feasibility-Utility' assessments (sections 2.5.1.3 and 2.5.2.3) experts also ranked the demographic variables in terms of their potential value as early warning indicators and these ranks were used to weight the value of variables (as not variables are equally valuable in informing demography or health). Following the workshop, we developed a similar value ranking index (not reviewed by the health experts but following the approach undertaken by demography experts in the workshop) for health variables. The ranking combined an assessment of the current feasibility of collecting information on each variable and how informative the variable was likely to be in a health monitoring context (see Appendix 7.1.1 for details) and this was used to weight as described above.

2.4 Review of monitoring methodologies

Here we review the methods categories that the experts selected and describe their use in informing PCoD analyses. In section 2.5, we present the outputs of the workshop and subsequent analyses to explore the feasibility and utility of each approach.

2.4.1 Hands-on assessment: capture-release, live stranding & necropsies

Hands-on assessment of marine mammals can be conducted on live animals that have been caught and then released, on live or dead stranded animals, or bycaught animals. The demographic variables that can be estimated from hands-on assessments include age at sexual maturity and age at first pregnancy, sex ratio, and survival and pregnancy/inter-birth-interval rates. For example, whether or not an animal is pregnant can be assessed using ultrasound, hormone analysis or physical examination of sex organs (e.g. Kjeld et al. 2006, Galatius et al. 2013, Kellar et al. 2013, Wells et al. 2014). Ultrasound has also been used to measure blubber thickness in stranded/bycaught small delphinids (Joblon et al. 2014) and in live baleen whales, specifically North Atlantic right whales and Southern right whales (*Eubalaena australis*)(Moore et al. 2001, Miller et al. 2011, Miller et al. 2012a, Nousek-McGregor et al. 2013). Serum, urine and blubber sampling as part of hands-on assessments can also provide a wide range of omics biomarkers, immune function markers and hormone measurements. A comprehensive review of the methods used to obtain reproductive information (e.g. reproductive hormones such as progesterone and also including stress hormones (e.g. cortisol)) from hands-on assessment of free-living or dead cetaceans can be found in Mello and Oliveira (2016). The age of individual animals can be estimated from growth layers in teeth (e.g. dolphin species, Hohn and Fernandez 1999, pinnipeds, Blundell and Pendleton 2008) or earplugs (e.g. baleen whales, Trumble et al. 2013), and from fatty acid concentration in blubber (e.g. odontocetes, Koopman et al. 2003, Herman et al. 2008).

Hands-on assessments of live animals are often performed as part of capture-release or individual-tracking studies (see section 2.4.6). Hall et al. (2010) provides a comprehensive review of possible approaches and outputs of health assessments that are made as part of these studies. For example in the Sarasota Dolphin Research Program individual bottlenose dolphins have been captured since the 1980's to conduct health assessments and to obtain demographic data such as sex ratio, age structure, pregnancy rates, survival rates and age at maturity (Wells and Scott 1990, Wells et al. 2004). Serum samples and ultrasound have been used to assess physiological state and pregnancy status respectively in pinnipeds captured for individual-tracking studies (e.g. Roletto 1993, Mellish et al. 2004, Mellish et al. 2006, Greig et al. 2010).

Similar information can be collected from hands-on studies of animals found dead or stranded but still alive. However, these samples may not be representative of the healthy population. In addition, deep diving cetaceans and oceanic dolphins are less likely to be available for this kind of sampling than other marine mammal groups because they wash ashore less frequently than coastal species. Even when a stranded carcass is available, its suitability to provide information on demographic and health variables will depend on its level of decomposition. The sample sizes obtained from hands-on assessments of stranded animals are usually small, but larger samples may be available from bycaught animals and animals harvested for subsistence or during culls.

2.4.2 Remote tissue sampling

Tissue samples may be collected remotely using biopsy darts and from blows and faeces. Biopsy samples of blubber can be analyzed to obtain data on sex ratios, reproductive hormones and wax/sterol esters or fatty acids to estimate the age/stage class of the population and many of the hormone and markers highlighted in section 2.4.1.

Remote sampling methods have been used to measure reproductive hormone levels in blubber samples from delphinid species (e.g. Kellar et al. 2009, Trego et al. 2013), baleen whales (e.g. bowhead whales, Kellar et al. 2013, humpback whales, Vu et al. 2015) and deep diving cetaceans such as sperm whales (Sinclair et al. 2015). Biopsy samples have been obtained during several US Navy marine mammal monitoring programs, for example: the baseline vessel monitoring at the East Coast Range complexes (Foley et al. 2016b), humpback whale monitoring in the mid-Atlantic (Aschettino et al. 2016), the mid-Atlantic continental shelf break cetacean study (HDR 2016) and during the study of the occurrence, ecology and behaviour of deep diving odontocetes at Cape Hatteras (Foley et al. 2016a).

Sampling the blow from respiring animals is a non-invasive method that can be used to assess the reproductive status of individual animals based on their hormone levels. For example, testosterone and progesterone levels have been measured in blow samples from humpback, northern right, northern bottlenose, long-finned pilot (*Globicephalus melas*) and sperm whales (e.g. Hogg et al. 2009, Dunstan et al. 2012, Hunt et al. 2013, Thompson et al. 2014). Blow samples can be obtained from sample receptacles attached to cantilever poles which are positioned above the blowhole of the animal, but this requires very close proximity of vessels to the target animal. Remote options are now becoming more widely available with the use of drones which can be used to collect samples in difficult or sensitive locations (e.g. the Snotbot, Bennett et al. 2015). It can be difficult to collect samples in this way from fast moving species, and environmental factors, such as sea state and wind speed, can affect the likelihood of successful sampling. This approach is at a relatively early stage of development and, for most species groups, further research is required to confirm its utility and the accuracy with which reproductive status can be assessed.

Faecal sampling is an established, non-invasive technique for monitoring the health of pinnipeds (Harvey 1989, Fossi et al. 1997, Trites and Joy 2005, Deagle and Tollit 2007), killer whales (Hanson et al. 2010, Ford et al. 2011, Ayres et al. 2012)and baleen whale species (reviewed in Hunt et al. 2013). From these faecal samples it is possible to obtain measures of a number of physiological markers including stress hormones, reproductive hormones, thyroid hormone metabolites (as indicators of nutritional stress), gut microflora (including parasite load), exposure to toxins, prey DNA and faecal hormone metabolites (to assess acute vs chronic stress markers). As with blow sampling, there is still a need for further work to validate these approaches and to understand how measurements obtained from faecal samples compare with those obtained via biopsy.

2.4.3 Visual and acoustic surveys

Visual and acoustic survey approaches have been well developed over the past few decades as a means to monitor marine mammal populations. Their utility has been explored separately below.

2.4.3.1 Visual surveys

Visual surveys of marine mammal abundance can be conducted from aerial, vessel or land based platforms. This survey data can be used to estimate marine mammal density using standard techniques. However, once they have been sighted, individuals can often be categorised into stage classes, such as adult, juvenile and calf based on their size, colouration and associations with other individuals. For example, the pigmentation/coloration patterns of Atlantic spotted dolphins (*Stenella frontalis*) (Herzing 1997); Pantropical spotted dolphins (*Stenella attenuata*) (Perrin 1970, Perrin et al. 1976) and white-beaked dolphins (*Lagenorhynchus albirostris*) (Bertulli et al. 2016) have been shown to change as they develop through different age/stage classes. This can provide information on the stage- or age-structure of the population, as well as on mother-calf ratios (e.g. Indopacific bottlenose dolphins, Kogi et al. 2004, bowhead whales, Koski et al. 2008, bottlenose dolphins, Currey et al. 2009, grey whales, Perryman et al. 2010).

A number of other features, such as the presence of rake marks and epidermal lesions on individual animals, which may be useful for health assessment and can be detected during visual surveys. However, these are best documented using photographs, and the use of visual surveys to collect this information is discussed under Photogrammetry (Section 2.4.5)

2.4.3.2 Acoustic surveys

Acoustic surveys are usually conducted using some form of Passive Acoustic Monitoring (PAM). PAM relies on detecting the sounds produced by marine mammals. It is best developed for cetaceans but it has been successfully used for pinnipeds. Data from PAM has been used extensively to estimate marine mammal density (e.g. McDonald and Fox (1999), Mellinger and Barlow (2003), Mellinger et al. (2007), (Marques et al. 2009, Mellinger et al. 2011, Mellinger and Heimlich 2013)). Therefore PAM provides a means by which local density or abundance estimates can be made. Acoustic index counts – i.e. detection rates can provide a relative densities or density indices. However the utility of such variables in providing specific information on population demography is generally quite limited (and subject to a wide range of potential biases and little is known about the contextual information that might result in changes in cue production rates and availability biases (which heavily impact detection rates). Furthermore, currently little is known about how vocal repertoire of marine mammals vary with age or stage and there is a paucity of information on the sounds calves/pups/juveniles might produce and therefore PAM is unlikely to provide information on stage structure. However, a number of other methods to estimate such variables (i.e. investigating stage structure) are presented elsewhere in section 2.4.

A key strength of PAM approaches is that they can be used to monitor species occurrence and to estimate density. This has been successfully demonstrated in a range of studies. PAM surveys are routinely conducted using towed hydrophones deployed from vessels (Barlow and Taylor 2005, Gillespie et al. 2005, Gillespie et al. 2010, Barlow et al. 2013) and, more recently, from gliders and other autonomous mobile platforms (Baumgartner and Fratantoni 2008, Klinck et al. 2012, Baumgartner et al. 2013). However in these approaches the number of animals detected is often limited by the length of time that a suitable towing platform is available. Fixed PAM installations allow for cost-effective long-term monitoring over limited spatial extents. These installations can generate significant sample sizes, and thereby increase the ability to detect trends (Gerrodette et al. 2011). The Density Estimation from Fixed Acoustic Sensors (DECAF) studies used this approach with data from fixed hydrophone arrays on US Navy ranges. Data from the Atlantic Undersea Test and Evaluation Center (AUTEC) was used to estimate density of Blainville's beaked whale (Marques et al. 2009, Kusel et al. 2011) and sperm whales (Ward et al., 2011). Data from the Pacific Missile Range Facility (PMRF) were used to estimate minke whales density (Marques et al. 2012, Martin et al. 2013). Density estimates for a number of other baleen whale species have also been made using similar approaches (Harris 2012, Harris et al. 2013). In addition, on AUTEC it has been used to explore beaked whale density before, during and after Navy exercises (e.g. McCarthy et al. 2011) and to develop dose-response relationships (Moretti et al. 2014). Furthermore, Moretti (in prep) has used PAM data collected on AUTEC to explore changes in beaked whale density over time, independent of Navy activity.

2.4.4 Capture-recapture

Capture-recapture (also known as mark-recapture) is a technique that can be used to estimate population size, and survival and immigration rates for a wide range of marine mammal species. It involves 'capturing' and marking a group of individuals, returning them to the population and allowing for complete mixing before subsequent samples are obtained. Historically, animals were marked by attaching individually numbered tags, but now natural marks and genetic samples are routinely used to identify individuals uniquely. Once an animal is marked it can be followed through its life providing information on age at independence and at maturity (for animals tagged as calves), and inter-birth interval (see Table 1 for a complete list of demographic variables that can be measured using information from capture-recapture studies).

Photo-identification (photo-ID) is a common method for 'capturing' animals that can be identified from their markings. This method involves taking photographs of individual animals and comparing these to a catalogue of known identified animals. Studies on coastal and oceanic dolphins have used the scratches and nicks on dorsal fins (e.g. bottlenose dolphins, Wells and Scott 1990), or the dorsal fin shape and saddle patch markings of killer whales (e.g. Kuningas et al. 2014) to identify individuals. Capture-recapture techniques have been used extensively in coastal bottlenose dolphins to derive a range of demographic variables (Hansen and Wells 1996, Norman et al. 2004, De Wet 2013, Schwacke et al. 2013, Fair et al. 2014). Studies on baleen whales have used fluke patterns (e.g. humpback whales, Gabriele et al. 2017), patterns of calluses and crenulations (e.g. southern right whales, Carroll et al. 2011) and patterns of pigmentation, scarring and barnacles (e.g. grey whales, Yakovlev and Tyurneva 2005). Deep diving cetaceans can be identified using nicks and marks on the trailing edge of flukes (e.g. sperm whales, Matthews et al. 2001) and patterns of scars (e.g. beaked whales, Ballardini et al. 2005, Falcone et al. 2009), and pinnipeds can be identified uniquely using their pelage patterns (e.g. harbour seals, Cordes and Thompson 2015, ringed seals, Zhelezniakov et al. 2015). Other method of capture have been employed. For example, genetic tagging (using genotyping in capture recapture) has been most extensively explored in baleen whales (Palsbøll et al. 1997, Calambokidis et al. 2001, Stevick et al. 2004, Lukacs and Burnham 2005, Wiig et al. 2011). Telemetry data has also been used for harbour seals (Ries et al. 1998, McConnell et al. 2004).

For those species or age groups that do not have sufficient identifiable markings it is possible to permanently mark individuals using branding methods (hot irons or freeze branding) or by clipping dorsal fins. Non-permanent methods of marking animals includes capturing individual animals and marking them with dyes or paints, attaching flipper tags or shaving patches of fur in seals. These methods are the least effective for long-term studies as there is the risk of mark loss which will affect the re-sighting rate. Dyes and paints are often used for shorter term studies such as tracking grey seal pups from birth to first moult (e.g. Büche and Stubbings 2016).

From a catalogue of known individuals (such as those in comprehensive photo-ID studies), abundance can be estimated using a capture matrix of well-marked individuals and software packages such as CAPTURE and MARK[1]. Photo-ID provides a permanent record of the individuals seen which can be cross validated whenever necessary. Depending on the species of interest, photographs can be obtained during ship-based, aerial, or land-based surveys. However all of these have the potential to disturb the target animals because the photographer must get close enough to obtain good quality photographs. Photo-ID has been used to obtain demographic data from a number of US Navy marine mammal monitoring programs. For example, studies of pinnipeds in Chesapeake Bay (Rees et al. 2016) and Narragansett Bay (Moll et al. 2016), bottlenose dolphins near Panama City (Balmer et al. 2015) and studies of mid-Atlantic humpback whales (Aschettino et al. 2016).

One drawback of photo-ID based capture-recapture is collection and post-processing of photographs can be very time consuming, even for relatively small, resident populations. These challenges are likely to increase as population size and range increase. For example, the Sarasota Dolphin Research Program has been conducting photo-ID studies since 1970 (Wells 2014) to provide information on the population size, survival rate, fecundity rate and age at maturity (e.g. Wells and Scott 1990, Rosel et al. 2011, Bassos-Hull et al. 2013, Wells 2014).. This has required at least 10 surveys per month, year round. For example, 126 days of surveys were conducted between November 2009 and October 2010, resulting in 970 group sightings of 3,437 dolphins (including re-sighted animals). All of these sightings had to be verified and matched to individuals in the catalogue[2]. Similarly, a long-term study of a bottlenose dolphin population of ~200 animals in the Moray Firth has required a 1 day survey each week throughout the summer. A total of 13,403 photographs were taken during the 20 surveys conducted in 2015, each of which was graded for quality and the individuals matched to the existing catalogue by two independent analysts (Graham et al. 2016).

As with many other variables, it is important collect a long time series for photo-ID datasets. In order to obtain reliable estimates of survival rates, surveys must be repeated over multiple years. Where these data are available, they can be used as a baseline against which during- and post-disturbance rates can be compared in order to assess if disturbance activities have caused a change in the survival and fecundity rates of the population of interest. Data collected during capture-recapture studies can also be used to derive information on habitat usage (depending on sampling effort).

2.4.5 Photogrammetry

Photogrammetry or videogrammetry (henceforth collectively referred to as 'photogrammetry') is a non-invasive method to measure the size of animals. We explore other photographic methods like photo-identification in the capture-release section (2.4.4). Morphometric measurements can provide data on individual body condition. In addition, it may be possible to determine age or stage class from body length estimates, particularly for large whales (where whaling data can be used to determine the necessary relationship) and delphinids/porpoises (where data from stranded or bycaught animals and pigmentation can be used).

[1] http://www.phidot.org/software/mark/

[2] http://www.sarasotadolphin.org/dolphin-population-monitoring-program-2009-2010/

Photogrammetry has been used to measure the size and body condition for all species groups, including sperm whales (Dawson et al. 1995), blue whales (e.g. Durban et al. 2016), North Atlantic and Southern right whales (Pettis et al. 2004, Christiansen et al. in review), humpback whales (e.g. Christiansen et al. 2016, Mason 2017), grey whales (Bradford et al. 2012), killer whales (e.g. Fearnbach et al. 2015), common dolphins (e.g.Perryman and Lynn 1993), spinner dolphins (Karczmarski et al. 2005), grey and harbour seals (e.g. Pomeroy et al. 2015), Weddell seals (*Leptonychotes wedellii*) (Ireland 2004), Galapagos sea lions (Meise et al. 2014) and Hawaiian monk seals (McFadden et al. 2006). It has also been assessed for its potential to identify pregnancy state in large baleen whale species (Perryman and Lynn 2002, Miller et al. 2011, Miller et al. 2012a).

The simplest form of photogrammetry used in marine mammal surveys is single-camera photogrammetry where photos are taken from vessels, aircraft or land of individual animals and some form of scale indicator such as a known size object. Aerial single-camera photogrammetry is becoming common in marine mammal surveys. Drones or manned aircraft are flown above animals, and a vessel of known size is included in the images to act as a scale. An extension of this method is stereo-photogrammetry which involves simultaneously taking photos from two cameras of known separation distance. This method does not require a scale to be present in the image.

Parallel-laser photogrammetry involves mounting dual lasers onto the camera system. The laser dots in the resulting photographs can be used as a scale in order to obtain morphometric measurements (e.g. Durban and Parsons 2006). For example, the dorsal fin length of some dolphin species can be used as a predictor of total body length; therefore, if images are obtained of the dorsal fin and the two laser dots, the length of the dorsal fin can be measured from the images and the total body length can be estimated. This has been demonstrated in Hector's dolphins (*Cephalorhynchus hectori*) (Webster et al. 2010) and spinner dolphins (*Stenella longirostris*) (Karczmarski et al. 2005). In Moray Firth bottlenose dolphins (in the UK), calf length has been shown to be significantly correlated with survival through the first winter (pers. comm. Barbara Cheney); therefore there is the potential for body size measurements to provide an estimate of calf survival rates. Parallel-laser photogrammetry can also provide data on body condition if the images are taken from above to give both length and width measurements.

3D photogrammetry uses photos of individual animals taken from multiple angles. A 3D model of the animal is then constructed using software such as Photomodeler Pro® and this model can be used to estimate the animal's dimensions, condition and mass. This method has been successfully used for pinnipeds (e.g. Stellar sea lions, Waite et al. 2007, Southern elephant seals, Postma et al. 2013) on land. It is more challenging to obtain photos from multiple angles for animals that are wholly or partially submerged.

The ONR Marine Mammals and Biology Program funded photogrammetry studies to assess the condition and growth of Blainville's beaked whales in the Bahamas. This project was successful in splitting animals into stage classes according to morphometry (Claridge et al. 2017). Ongoing work includes ONR funded studies on the use of photogrammetry to assess body condition and bioenergetics to assess population consequences of disturbance (Christiansen et al. 2016, Christiansen 2017, Christiansen et al. in review). This work has been conducted on humpback, minke and right whales to date, and Phase II might additionally include bowhead and grey whales. In addition, efforts are currently underway to validate lateral and aerial measurements obtained via photogrammetry and to understand how food intake can impact blubber topography, mass and resulting measurements (Noren, S.R. pers. comm.). Both studies have potential for informing studies investigating PCoD.

Photographic information has also been widely used, most prominently for North Atlantic and Southern right whales (Pettis et al. 2004, Christiansen et al. in review) to provide information on individual health. A number of visible indicators (reviewed by Hall et al. (2010) have been used for this purpose. These include rake marks and epidermal lesions (Thompson and Hammond 1992, Hughes-Hanks et al. 2005, Van Bressem et al. 2009), and the shape of the post-nuchal (Gryzbek 2013, Reed et al. 2015) and scapular depressions (e.g. Bradford et al. 2012). Rolland et al. (2007) used a combination of information from visual indicators and faecal sampling (to assess parasite load) to provide a single health metric for individual North Atlantic right whales. This information was then analyzed in a Bayesian framework to explore the links between health metrics, vital rates and population status (Schick et al. 2013a, Rolland et al. 2016).

2.4.6 Individual tracking

Telemetry has been used to study the movements of cetacean and pinniped species over both short (Johnson and Tyack 2003, Miller et al. 2012c, DeRuiter et al. 2013), intermediate (Mate et al. 2016) and longer time scales (Mate et al. 2000, Mate et al. 2007, Peterson et al. 2012, Hindell et al. 2016). These studies have also provided information on residency patterns and activity budgets (e.g. McConnell et al. 2004, Aarts et al. 2008, Patterson et al. 2010, Laidre and Heide-Jorgensen 2012, McClintock et al. 2012, McClintock et al. 2013). A key development in the use of telemetry for assessing individual health is the study of dive behavior - particularly 'drift dives' (Biuw et al. 2003, Biuw et al. 2007) - to provide information on changes in the buoyancy of individuals over time. This has been used to derive a measure of body density in elephant seals (Aoki et al. 2011, Miller et al. 2012b, New et al. 2014), fur seals (Costa et al. 1989, Page et al. 2005) and Northern bottlenose whales (*Hyperoodon ampullatus*)(Miller et al. 2016) and is currently being explored for humpback, blue and long-finned pilot whales (Miller *pers. comm*). In some cases it is possible to correlate buoyancy with pregnancy (e.g. Crocker et al. 1997). Telemetry data have also been used to explore how disturbance may impact animals energetically (Costa 2012, New et al. 2014, Costa et al. 2016) and this remains a promising area of PCoD model development. Future developments of ARGOS telemetry include the ability to estimate body condition and transmit via satellite to allow longitudinal monitoring of condition over a period of months (Miller et al. 2017 project).

2.5 Workshop Outputs

2.5.1 Demographic Variables and Methods

2.5.1.1 Utility

Using the LoE approach, the main methods suitable for collecting information on demographic variables were identified and a list of suitable response variables was developed. These are presented below (Table 1). Here we present those without specific consideration of species feasibility. The exercise highlighted that methods involving capture-recapture of individual animals (e.g. photo-identification – photo-ID) were suitable for the collection of information on a wide range of demographic variables, particularly population age- and stage-structure. In addition capture-recapture methods can provide information on stage-specific survival rates, reproductive rate, inter-calf interval, age at first reproduction, length of offspring dependence and the proportion of immature (i.e. pre-reproductive) animals in the population. The same methods can also provide estimates of population size for small, resident populations, which can be reliably sampled each year. A number of the same variables can also be estimated from species that are suitable for hands-on assessment (primarily pinnipeds and coastal delphinid populations (e.g. Costa 1987, Wells et al. 2004, Mellish et al. 2006, Weijs et al. 2009, Schwacke et al. 2013). Samples collected from necropsies or live-stranding can also provide information on a number of demographic variables, as can biopsy, blow or faecal samples that can be collected remotely.

2.5.1.2 Feasibility

The experts next assessed the overall feasibility of collecting demographic data for each species group using these methodologies. This assessment is summarised in Table 2.

For deep-diving cetaceans, capture-recapture methods (e.g. photo-ID), acoustic surveys and photogrammetric approaches were considered to be the most feasible for collecting data on demographic variables. Hands-on assessments and necropsy were considered to be the least feasible due to the low probability that animals could be handled live, the limited utility of sampling from dead animals and the low likelihood of generating sufficient sample sizes with this approach. Feasibility scores for baleen whales were similar to those for deep-diving cetaceans. The key difference was that visual surveys and remote sampling were considered to be more feasible, given the greater amount of time that these animals spend at the surface.

For coastal dolphin and porpoise species most of the methods were considered to be feasible. The only exceptions to this was acoustic surveys, where distinguishing the vocalisation of different species is challenging Most of the methods were considered to be less feasible for oceanic dolphin species, although visual and acoustic surveys, and obtaining remote tissue samples were considered to be similarly feasible. Hands-on assessments, strandings and necropsy all scored low (though the value of necropsy samples from by-caught animals was highlighted). It was noteworthy that capture-recapture methods were considered infeasible for this species group, because of the difficulties in collecting photo-ID data and the likely low recapture rate for these wide ranging species.

For pinnipeds, most methods were considered suitable for obtaining demographic information. In some cases this was specifically due to the ease of sampling animals whilst they are hauled out and the ease with which animals can be tagged. Acoustic surveys were considered infeasible for land-breeding pinnipeds, and the value of conducting visual acoustic surveys for ice-breeding seals was considered to be low.

Table 1 – Summary of methods suitable for collection of information on demographic variables (note Individual Tracking was not included as it was determined not to be suitable for monitoring demographic variables in isolation (only when used with capture-recapture approaches) (see Table 2)).

Category	Variable \ Method	Hands-on assessment	Necropsy / Stranding	Visual Surveys	Acoustic Surveys	Capture-recapture	Photogrammetry	Biopsy / Blow
Demographic Variables	lifetime reproductive output	X	X			X		
	stage specific survival rates	X	X			X		X
	abundance index				X			
	recruitment (female # recruited)					X		
	Proportion of immatures	X	X			X	X	
	age structure	X	X			X	X	X
	size/stage structure*	X		X		X	X	
	age at first reproduction / age of sexual maturity	X	X			X		X
	probability of giving birth to a viable calf	X				X		X
	birth mass, mass at weaning	X					X	
	ratio of 1 year olds: all dependent offspring	X				X	X	
	sex ratio	X		X		X		X
	pregnancy rate	X				X	X	X
	birth rate (post-birth pulse)	X		X		X	X	
	inter-birth interval	X	X			X		
	length of offspring dependence	X	X			X		X
	age of senescence	X				X		
Contextual Variables	density dependence			X	X	X		
	demographic stochasticity for small N			X		X		
	environmental variability- direct	X		X	X	X		
	environmental variability- proxy	X	X					X
	geographic range			X	X	X		X
	immigration/emigration					X		
	social structure							

* provided context is known

Table 2 - Experts' assessment of the feasibility of collecting information on demographic variables for each species group using the methodologies in Table 1. Key: 0 - Not feasible to collect or analyze such data within five years; 1 - Feasible to collect data or analyze samples within five years, but no plans to do so; 2 - Sufficient results for reviewing response variable estimation expected within five years; 3 - Method can be used to estimate demographic variables.

Method	Deep diving cetaceans	Baleen whales	Coastal dolphins & porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds
Hands-on assessment	0 to 1*	1 to 2*	3	1 to 2**	3	2 to 3***
Visual Surveys	1 to 2	3	3	2	3	1 to 2
Acoustic Surveys	3	3	1 to 2	1 to 2	0	1 to 2
Capture-recapture	3	3	3	1	3	3
Photogrammetry	2 to 3	3	3	2 to 3	3	2 to 3
Remote Tissue Sampling	1 to 2	3	2 to 3	2 to 3	3ǂ	2 to 3
Individual tracking (tagging & focal follow)	0	0	0	0	0	0

* only if necropsy/stranding; **: 2 – if bycaught; ***: 2- if hunted; ǂ - 3 if hands-on

2.5.1.3 Feasibility-Utility Assessments

We assessed which methods had the best combination of feasibility and utility for each species group by plotting their utility scores (the number of variables that could be estimated under favourable conditions) and their feasibility scores.

For deep-diving cetaceans (Figure 5) and baleen whales (Figure 6), capture-recapture methods, remote tissue sampling (via biopsy) and photogrammetry had the highest Feasibility-Utility scores (those in the upper right of Figure 5). Acoustic surveys were also determined to be a practical approach to deriving local density estimates. For coastal delphinid and porpoise species capture-recapture, hands-on assessment, photogrammetry and biopsy sampling had the highest combined scores (Figure 7) but visual surveys were also considered feasible (but with lower utility). For oceanic dolphin species (Figure 8) few methods had a high feasibility score but biopsy sampling, visual surveys and photogrammetry appear to be the most promising methods (though experts noted that hands-on assessment (for by-caught animals) yielded valuable information though subject to biases). Most methods had a high combined score for monitoring demographic variables in pinnipeds (Figure 9 and 10), Capture-recapture and hands-on assessments had the highest combined scores, with photogrammetry, remote tissue sampling and visual surveys also considered feasible.

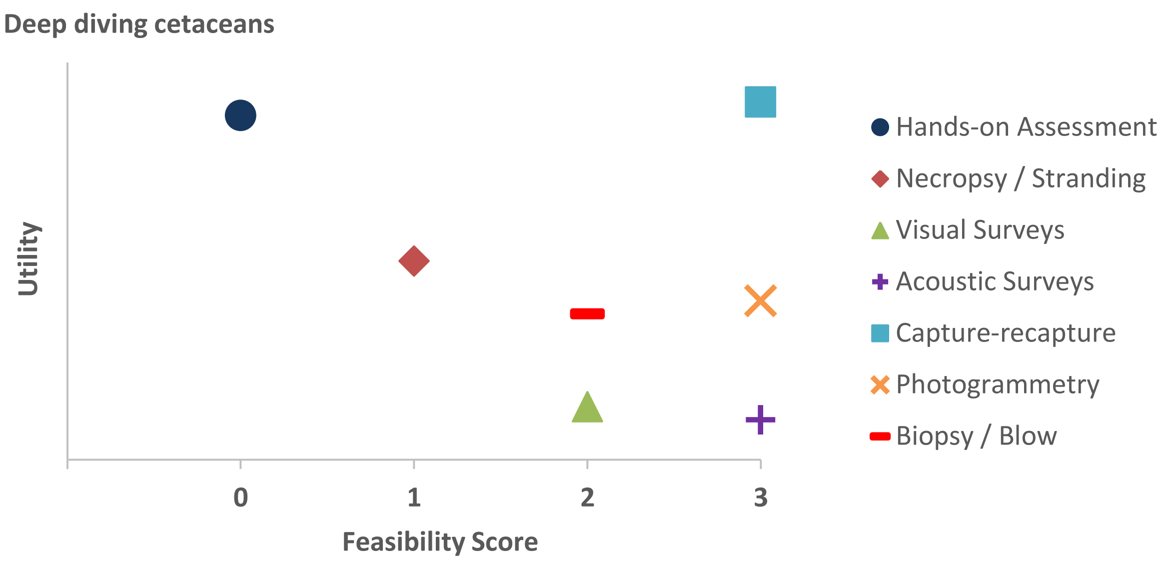

Figure 5 – Feasibility-Utility plot for methods to monitor demographic variables for populations of deep diving cetaceans. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

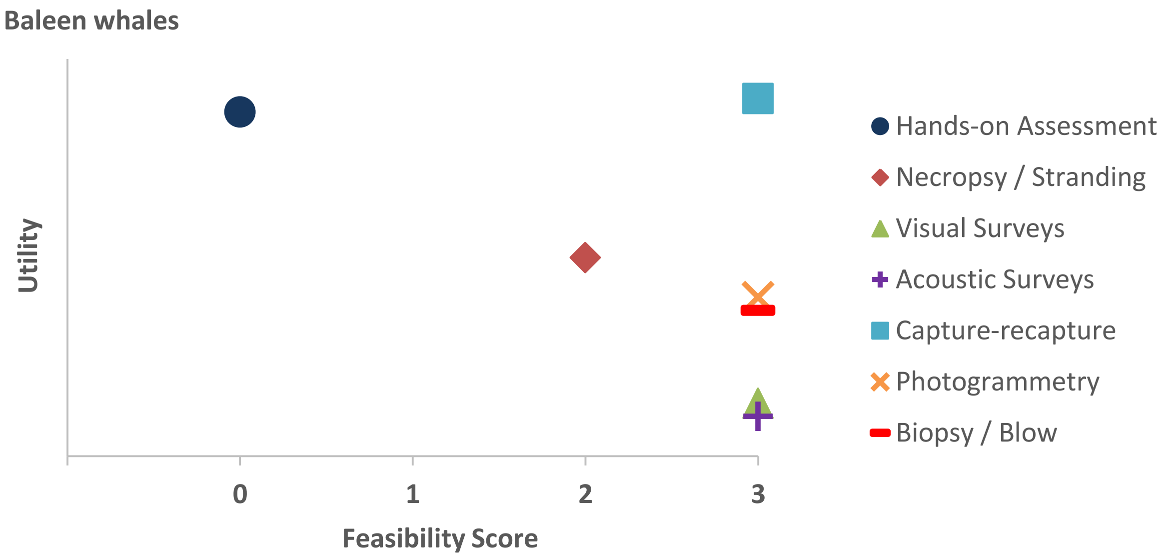

Figure 6 - Feasibility-Utility plot for methods to monitor demographic variables for populations of baleen whales. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

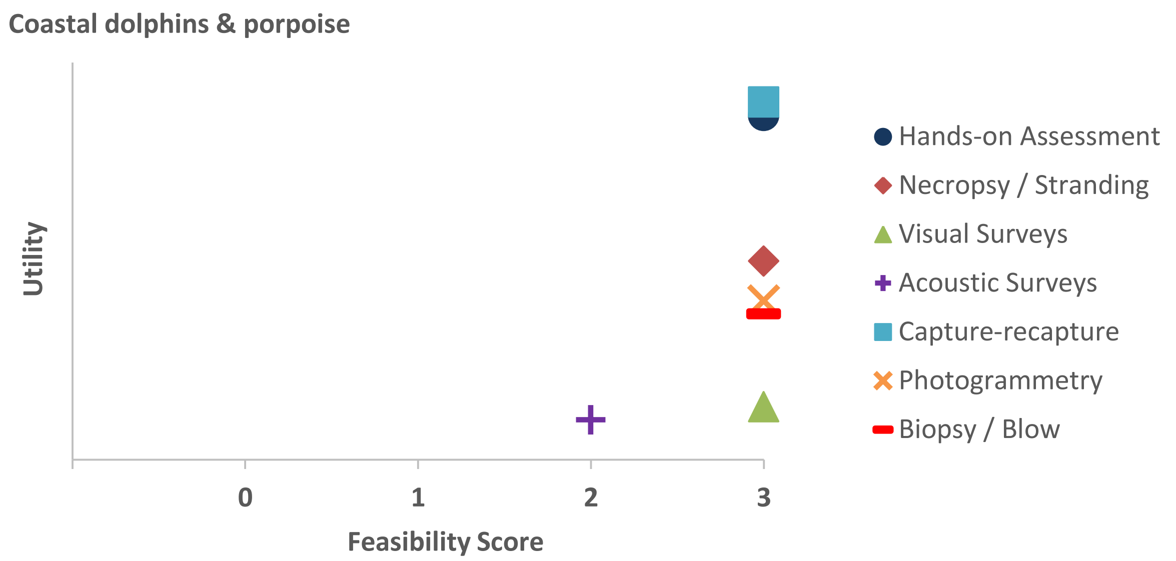

Figure 7 - Feasibility-Utility plot for methods to monitor demographic variables for populations of coastal dolphins and porpoises. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

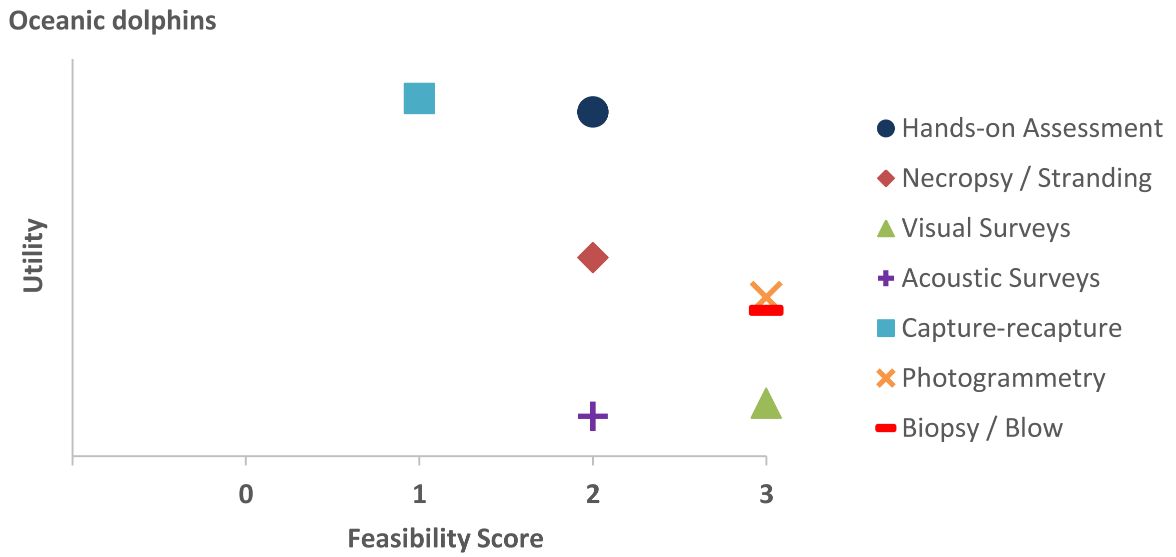

Figure 8 - Feasibility-Utility plot for methods to monitor demographic variables for populations of oceanic dolphins. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

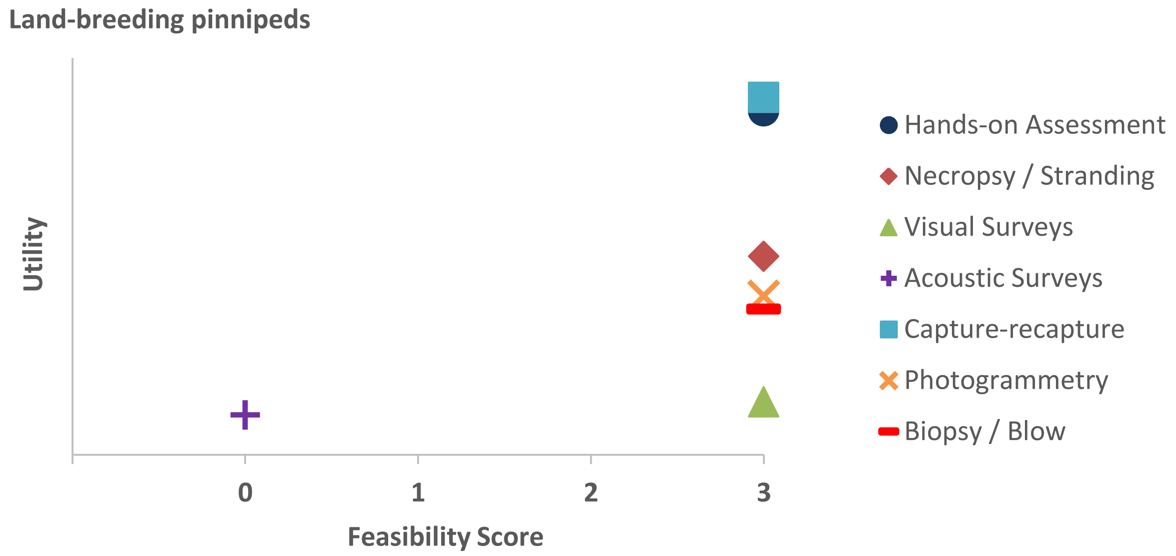

Figure 9 - Feasibility-Utility plot for methods to monitor demographic variables for populations of land-breeding pinnipeds. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

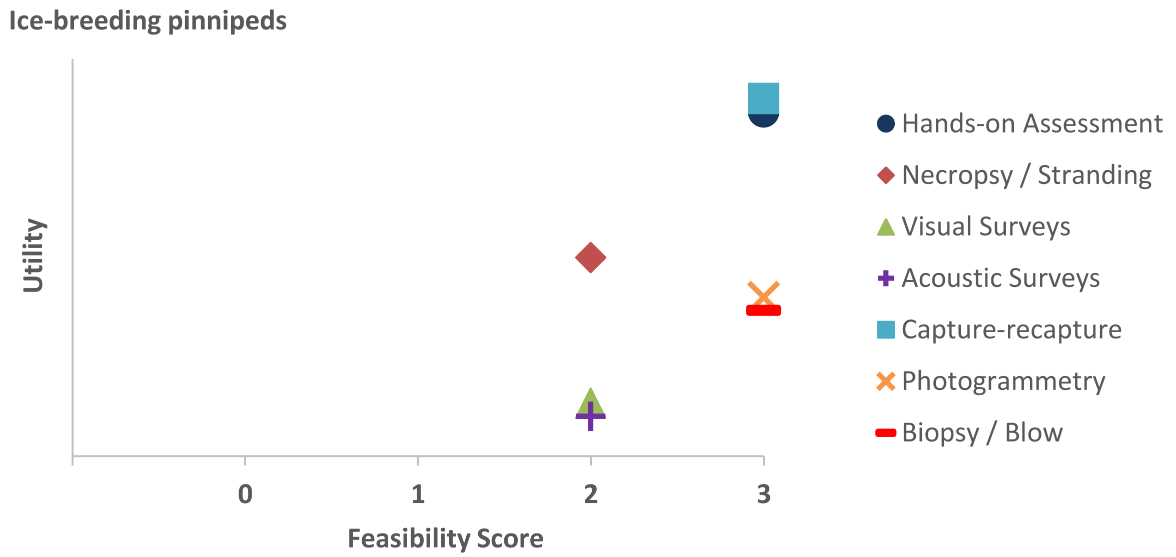

Figure 10 - Feasibility-Utility plot for methods to monitor demographic variables for populations of ice-breeding pinnipeds. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

2.5.2 Health Variables and Methods

The same LoE approach was undertaken for individual health measures. This exercise highlighted the importance of collecting life history and environmental information to provide a context for the interpretation of observed differences in health measures between individuals and populations. Experts also noted that their assessment of feasibility and utility was made on the assumption that adequate and representative samples can be obtained and that there is a high prevalence of exposure to disturbance and that disturbance has a reasonably high severity of impact. In addition, the experts noted that although most of the methods were still at an exploratory stage, health measures were a fundamental component of the PCoD framework. This future capability was reflected in the feasibility scores. They also noted that more research was required to develop the methods and to relate changes in the health measures to the levels of disturbance experienced by individuals. Therefore the scores should be considered as a best case assessment of the current feasibility and utility of the methods that were reviewed.

2.5.2.1 Utility

Table 3 list the methods that are currently available or in development, and the health measures and contextual information which they can be used to collect. As was the case with demographic variables, this Table does not address the feasibility of applying the methods to different species groups. This is addressed in section 2.4.2.2 and the individual methods are described in more detail in sections 2.4.1-2.4.6. Hands-on sampling – either as part of a capture-release program, or from dead or live-stranded individuals - was likely to provide information on the largest number of health measures, although there may be biases in the resulting estimates because of unrepresentative sampling. Capture-release can only be used with smaller cetaceans and pinnipeds, but it has been widely used in these species for hands-on health assessments. Remote tissue sampling from biopsies, blows or faeces, and individual tracking (via telemetry) can provide information on a suite of health measures, including stress indicators (e.g. stress hormones, omics markers of chronic stress), levels of reproductive hormones, body condition indices and immune function markers. Remote sampling techniques do not require handling of the animal and therefore have applications for a wider range of marine mammal species. Photo-identification and photogrammetric methods were identified as a useful, non-invasive approach to collect information on variables such as body condition (e.g. post-nuchal/scapular depression, parasite load/lesions, morphometrics etc.). Tagging can provide information on foraging success and body condition via dive behavior, particularly for species which perform drift dives.

2.5.2.2 Feasibility

The experts also evaluated the feasibility of assessing individual health in different species groups (Appendix 7.1.2) using the methods identified in Table 3. The results are summarised in Table 4.

For deep-diving cetaceans, capture-recapture methods (e.g. photo-ID), remote tissue sampling from biopsy, electronic tagging and photogrammetric approaches had the highest feasibility scores. As was the case for demographic variables, hands-on assessments and necropsy were considered to be the least feasible. Feasibility scores for baleen whales were similar to those of deep-diving cetaceans. The key difference was that collecting faecal and blow samples were more feasible for these species because they spend more time at the surface. Remote tissue samples and necropsy were considered to be the most feasible methods for coastal dolphins and porpoises. Capture-release, photogrammetry, telemetry and visual and acoustic survey techniques were also considered to be currently (or soon) feasible. For oceanic dolphin species, obtaining remote tissue samples was considered to be feasible, and photogrammetric methods were thought likely to yield information on body condition. Necropsy was considered to be a feasible method if dolphins were bycaught in fisheries.

Most methods were considered feasible for assessing the health of pinnipeds because animals are accessible for sampling/handling whilst they are on land/ice. It is feasible to assess body condition but not pregnancy using photogrammetry. For the latter hands-on assessment using ultrasound was considered the most feasible method.

Table 3 – Summary of methods suitable for collection of information on specific variables on individual health.

Method / Variable	Hands-on Assessment						Remote Tissue Sampling			Surveys	
	Ultrasound	Serum sampling	Necropsy / Live Stranding	Capture-recapture	Photogrammetry	Ind. Tracking	Biopsy	Blow	Faeces	Visual	Acoustics
body condition index	X		X		X						
body mass index	X		X		X						
body shape			X		X						
% lipid and lipid composition (including fatty acid profile)			X				X				
lipid mass	X		X								
buoyancy changes (drift dive)						X					
post-nuchal depression			X	X	X						
scapular depression			X	X	X						
morphometrics			X	X	X						
total mass	X		X		X				X		
rake marks			X	X	X						
parasite load		X	X	X	X				X		
lesions			X	X	X						
levels of stress hormones		X					X	X	X		
omics markers of chronic stress		X					X	X	X		
levels of reproductive hormones		X					X	X	X		
pup mass at birth											
pup mass at weaning											
progesterone level during stage of pregnancy		X					X	X	X		
oxidative stress damage		X					X				
redox potential		X					X				
DNA damage (oxidative stress, adducts)		X					X		X		
prevalence of infectious disease (immunity indicator)		X						X			
stable isotope ratios			X				X				

Method / Variable	Hands-on Assessment						Remote Tissue Sampling			Surveys	
	Ultrasound	Serum sampling	Necropsy / Live Stranding	Capture-recapture	Photogrammetry	Ind. Tracking	Biopsy	Blow	Faeces	Visual	Acoustics
prevalence of organ damage (respiratory disease)		X	X				X				
immune function markers		X					X	X			
contaminant/toxin load		X	X				X	X	X		
activity budgets						X					X
habitat use				X		X				X	
changes in site usage				X		X				X	
foraging success				X		X				X	
proportion of foraging bouts						X					
patch utilization				X		X				X	
echolocation rates/unit area						X					X
SNR for echolocation signals						X					X
overall call rates						X					X
advertisement or display behavior											X
SNR for social calls											X
change in movement patterns				X		X					
ovulation rate			X								
implantation success			X								
birth rate			X	X						X	

Table 4 - Experts' assessment of the feasibility of collecting information on health for each species group using the methodologies in Table 3. Key: NA –this method is not currently appropriate for collecting information for this species group; 0 - Not feasible to collect or analyze such data within five years; 1 - Feasible to collect data or analyze samples within five years, but no plans to do so; 2 - Sufficient results for reviewing response variable estimation expected within five years; 3 - Method can be used to provide health measures.

Method	Deep diving cetaceans	Baleen whales	Coastal dolphins & porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds
Hands-on assessment	0 to 1	1 to 2	2	1*	3	3
Capture-recapture	2 to 3	3	2	1 to 2	3	3
Photogrammetry	2 to 3	3	2	1 to 2	3	3
Individual Tracking	2 to 3	2	2	0 to 1	3	3
Biopsy sampling	2 to 3	3	3	3	2 to 3ǂ	2 to 3ǂ
Blow sampling	1	2	0 to 1	0 to 1	NA	NA
Faecal sampling	1 to 2	2	1	1	3	3
Visual Survey	2	3	2	1	1 to 2	1 to 2
Acoustic Surveys	1 to 2	2	2	1 to 2	2	2

* - if bycaught; ǂ - 2 if remotely sampled, 3 - if done hands-on.

2.5.2.3 Feasibility-Utility Assessments

We determined which methods have the best combination of feasibility and utility for each species groups by plotting the number of parameters that could be derived from a method against its feasibility score (Figure 11-Figure 15).

For deep-diving cetaceans (Figure 11) and baleen whales (Figure 12), biopsy sampling, photogrammetry and capture-recapture approaches and individual tracking had the highest combined scores. For coastal dolphins and porpoises biopsy sampling had the highest combined scores (Figures 13 and 14). Most of the methods assessed here had high combined scores for all pinnipeds (Figure 15)(scores were the same for both land and ice-breeding pinnipeds), in particular hands-on assessment.

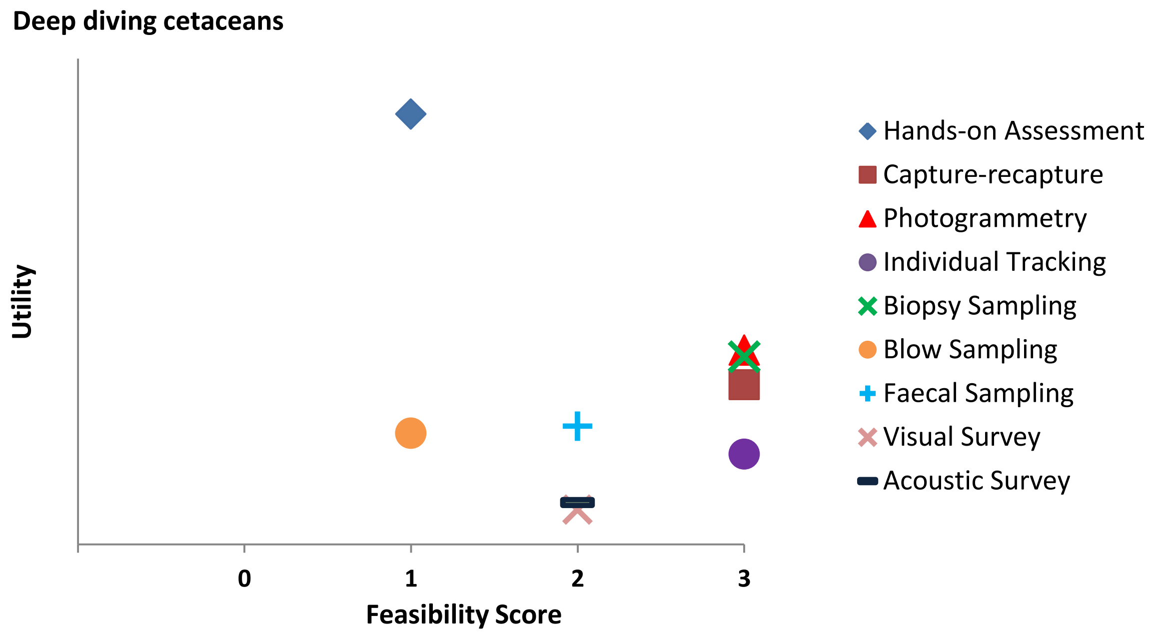

Figure 11 - Feasibility-Utility plot for methods to monitor health outcomes for populations of deep diving cetaceans. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

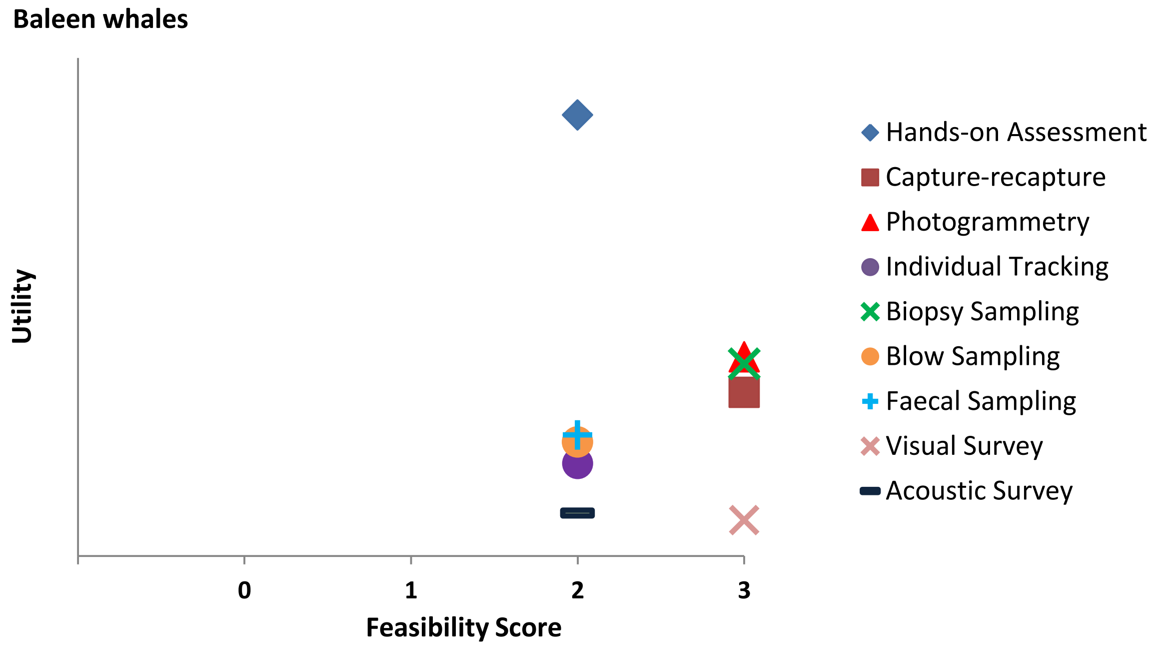

Figure 12 - Feasibility-Utility plot for methods to monitor health outcomes for populations of baleen whales. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

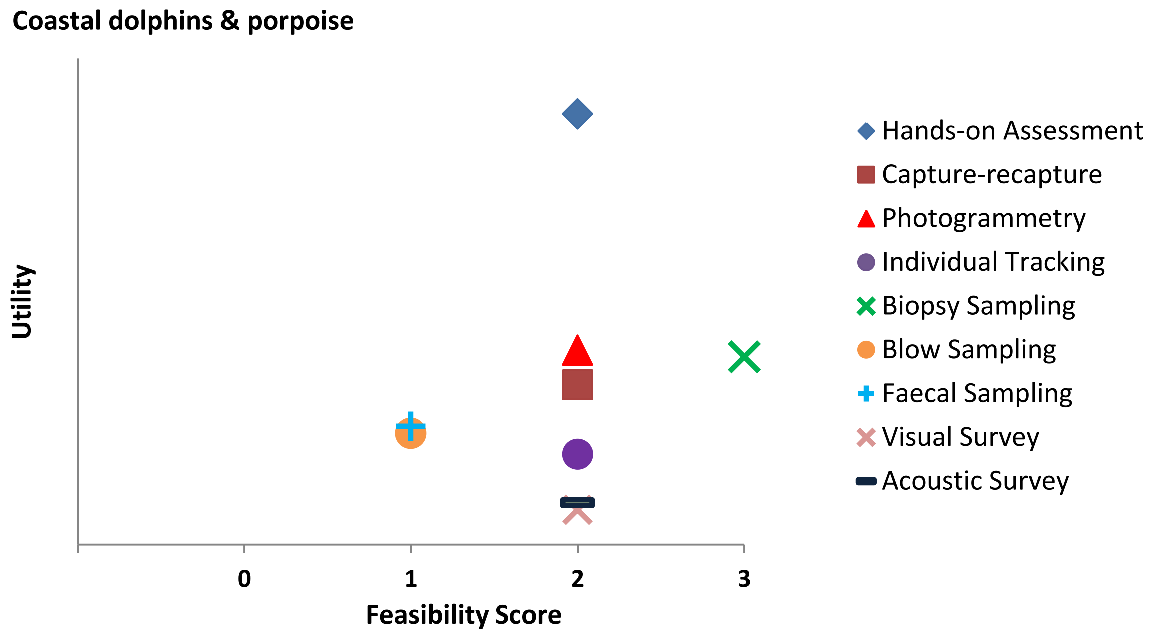

Figure 13 - Feasibility-Utility plot for methods to monitor health outcomes for populations of coastal dolphins and porpoises. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

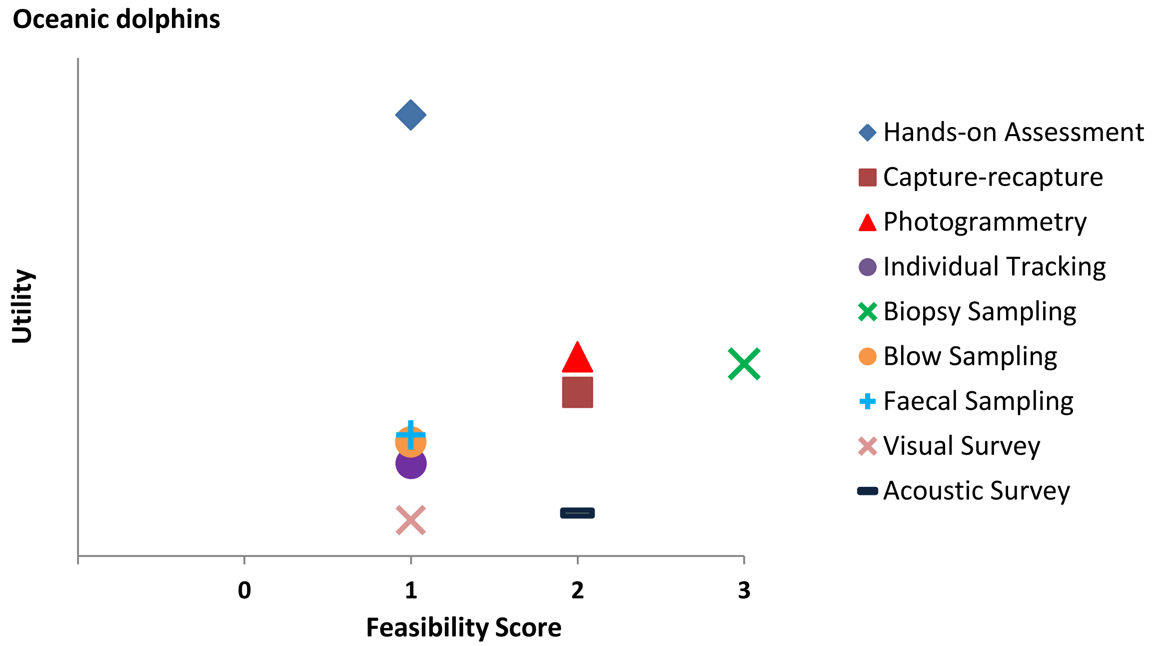

Figure 14 - Feasibility-Utility plot for methods to monitor health outcomes for populations of oceanic dolphins. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

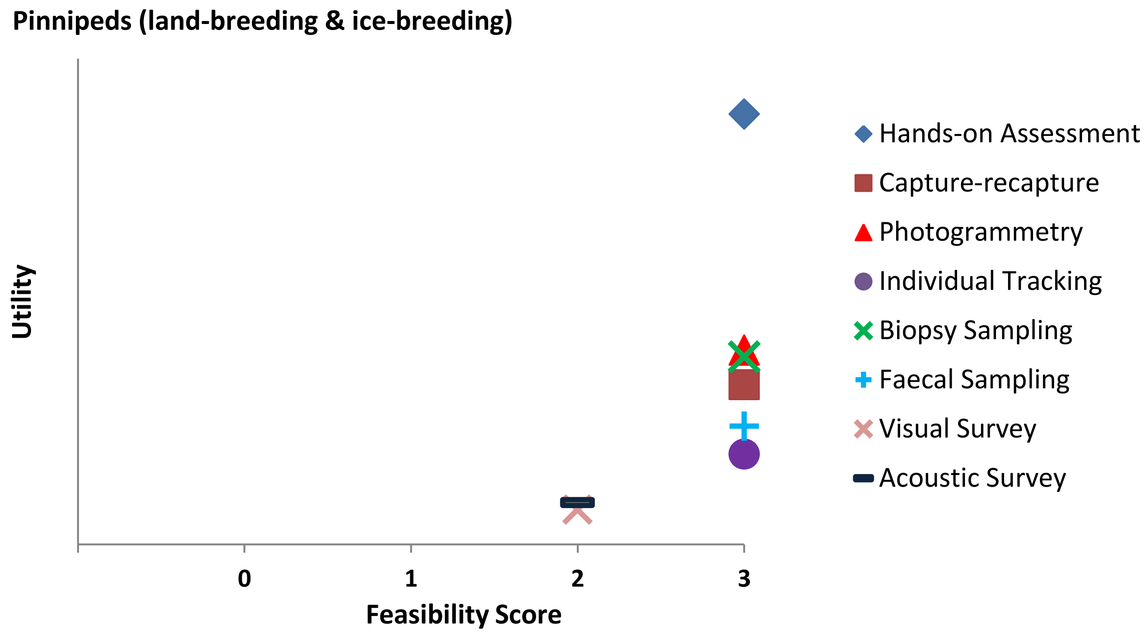

Figure 15 - Feasibility-Utility plot for methods to monitor health outcomes for populations of all pinnipeds. Feasibility indicates which methods are most practicable for this species group (higher score = greater feasibility) and Utility Score indicates the weighted number of variables that might be measured using a given technique. Methods with the best combination of scores appear in the upper, right-hand side of the figure.

2.6 Monitoring in practice

Here we are primarily focused on detecting early warning signals of decline in marine mammal populations. In order to be confident of detecting any such signals with sufficient precision (and low false positive rate). In addition we need to consider how data are to be collected, including appropriate platforms, sampling scales and collecting baselines/control/reference information – all of which have cost implications for any monitoring program. Here we discuss some of the key elements to be further considered when designing or augmenting monitoring programs for informing PCoD analyses.

2.6.1 Precision

In order to detect changes over time in demographic variables or health measures, it is imperative to have reliable estimates of the precision with which these variables have been measured. Information on levels of uncertainty is also a fundamental component of PCoD models. From our review, we determined that information on precision is limited for many of the methodologies that we considered. The main exception was for the estimates of demographic variables that have come from capture-recapture analyses. For example, Graham et al. (2016) calculated that the 95% confidence interval for their estimate of apparent survival for the Moray Firth bottlenose dolphin population was 0.93-0.96. In addition, a number of studies that have used photo-ID as the basis for capture-recapture analysis have explored the source of errors (e.g. incorrect identification) and their effect on estimation of abundance (Stevick et al. 2001). Other studies (reviewed in Pollock 2002) have explored the value of including covariates to improve precision and the use of information from auxiliary studies to improve estimates of recapture probability (e.g. Hewitt et al. 2010).

Most photogrammetry studies reviewed provided estimates of measurement error that were around 1-3%. Measurement error was even lower in the most recent papers which was attributed to improvements in the photographic equipment used (Christiansen et al. 2016, Mason 2017) A number of papers have described how to minimise biases in photogrammetric sampling (Koski et al. 2006, Koski et al. 2009, Koski et al. 2013). The sources of error in photogrammetry can mean it is challenging to quantify overall error in such techniques (and these will be experiment specific). For example, the posture (or orientation) of animals, the turbidity of the water, the altitude of the camera, weather conditions and observer error (e.g. in measuring from photographs whether done automatically or manually) can all contribute to error around a single measurement. But such issues are not exclusive to photogrammetry – and each of these can be explored and quantified with an appropriate experimental set-up (e.g. Webster et al. 2010, Christiansen et al. in review).

Many of the methods that involve quantification of hormone levels (e.g. laboratory approaches) also provide error estimates. For example, Clark et al. (2016) calculated CVs of 12-15% for their estimates of progesterone concentration in blubber. Other studies have reported CVs of 4-13% for measurements of cortisol concentration in serum and 6-17% for concentrations in blubber.

2.6.2 Sampling scale

2.6.2.1 Spatial

In the design of a monitoring program, it is crucial to consider the temporal and spatial scale of sampling for the variables of interest. The scales feasible for monitoring programs will vary depending on the variable, method, species of interest and overall objectives of the monitoring. The National Academies of Sciences and Medicine (2017) highlights that our ability to sample animals to obtain information on variables depends upon the ranging patterns of species interest. In particular, they outlined four ranging groups;

- Accessible resident populations.
- Animals that can be sampled on land.
- Species that have large ranges but are accessible at certain times of year or during migrations
- Open ocean species.

Accessible resident populations provide potentially cost effective opportunities to study both demographic and individual health variables (Schwacke et al. 2013, Wells 2014). These populations tend to small and well-defined, aiding assessments and reducing uncertainty but it is unclear how representative learning from these types of populations will be to species as a whole. Nonetheless they represent the best opportunities to advance our knowledge. Animals that can be sampled on land are limited to pinniped species but represent excellent opportunities to conduct hands-on assessments, capture-recapture and tissue sampling and obtain detailed information on specific individuals (and - for certain methods - colonies as a whole). Lessons learned from pinniped research may provide useful insights in species with similar life-history traits/reproductive strategies. Marine mammal species accessible at certain points of the year provide similar study opportunities as described above – but they are limited to the narrow sampling windows. Depending on the species, these may only provide a snapshot at a particular stage (e.g. during migrations, on foraging or breeding sites). The study of open ocean species remains the most challenging group as it is hard to conduct long term studies cost effectively. Furthermore, many 'open-ocean' species populations are not geographically isolated providing a challenge to obtain precise estimates – but in data poor situations, it is important to develop a foundation of knowledge (even if estimates are imprecise). As noted above studying stage-structure may be feasible for open ocean species and the value of such an approach is explored further below (section 3).

2.6.2.2 Temporal

The temporal scale over which sampling is conducted should be assessed in light with the objectives of the study. In many cases sampling is focused on times of year when conditions at sea are best. Depending on the variable of interest, it may be possible to focus sampling on a specific temporal period within the year.

We explored the sampling involved in capture-recapture studies above – highlighting the labour-intensive nature of this approach. Other methods may not require such intensive sampling – for example the use of photogrammetry for determining age/stage structure could be conducted less intensively (assuming sufficient effort to obtain a representative population sample). As noted above, certain methods, such as PAM can provide long term monitoring of local population trends – whilst this is unlikely to provide early warning signs; it remains an important source of contextual information. In addition, methods like electronic tagging can provide useful medium and long term sampling throughout the year and reproductive cycle.

2.6.2.3 Baselines, Controls and References populations

In order to detect changes in potential demography or health variables to inform future PCoD analysis of the effects of Navy activities on relevant marine mammal populations, it is crucial to have contextual information to help us understand the drivers of change. For individual health variables, it's important to understand the natural variability of individuals & populations under 'normal' conditions – against which relevant populations can be compared. Such a baseline is ideal, but in practice very challenging to detect as this should be collected in the absence of stressors – but in most cases we lack knowledge of how the current state of a population to aid the understand the patterns in observed data and determine the causes. For example, measures of body condition have been considered as a potential variable for considering health of individuals. However, where animals are identified to be in 'poor' conditions, this could be representative of a poor quality environment (a region or period), exposure to a stressor or indicative of sampling a population close to carrying capacity where competition for resources is high (e.g. Estes et al. 2009). Where possible, identifying suitable reference populations against which focal populations can be compared can provide value.

In reality, it will be necessary to understand the stressors affecting reference populations as few 'pristine' environments remain. For example, Claridge (2013) monitored demographic variables of Blainville's beaked whales on the Navy range at AUTEC and nearby (~170 km away) Abaco (where sonar exposure is limited) and observed differences in abundance, recruitment and stage-structure. Initially, this might suggests that sonar exposure is a driver of these changes. However, Benoit-Bird (2017) monitored the prey resources and relative qualities of the different environments (within AUTEC and on Abaco) and identified that these are significantly different (both spatially and vertically in the water column) and highlighting that Abaco may support a more "energy-efficient food web" than AUTEC. Similar explorations of difference in beaked whale habitat quality have been carried out on SOCAL range and identified that environment quality varies significantly across the region (Benoit-Bird et al. 2016).

Therefore, one solution is collection of auxiliary datasets may provide useful contextual information and inclusion of covariates in analyses For example, incorporation of information on quality of environment or prey resources should be considered as they may elucidate observed patterns and aid the assessment of the effects of Navy activities (versus other potential stressors). This could be achieved by exploring the utility of indices which have been correlated with success of different trophic levels - such as the North Atlantic Oscillation (Drinkwater et al.

2003, Greene and Pershing 2003) or El Niño Southern Oscillation (Tershy et al. 1991, Wilson et al. 2001), or using site specific prey resource mapping to provide context to observed patterns (e.g. Friedlaender et al. 2016).

3 Sensitivity analyses for 'early warnings'

3.1 Methods for assessing potential for early warnings

In this section we evaluate whether monitoring population variables, other than population density, can provide an early warning that a population is declining. To do this, we used a series of population models developed using the outputs of expert elicitations in which experts were asked to predict the potential effects of different levels of disturbance on the vital rates (individual survival and fertility) of marine mammals. We focused on populations of harbour porpoise, bottlenose dolphin and Blainville's beaked whale that have different life history strategies and that are exposed to different types of disturbance. The harbour porpoise and bottlenose dolphin population models were based on studies of the effects of noise associated with the construction of offshore wind farms in the North Sea (King et al. 2015). The Blainville's beaked whale model was based on studies of the effects of sonars used in Navy exercises at the Atlantic Undersea Training and Evaluation Center in the Bahamas (Moretti et al. 2014, Booth et al. 2016, Harwood and Booth 2016). We investigated the sensitivity of the following demographic variables to changes in vital rates that might be caused by disturbance:

- the ratio of calves to mature females immediately before the breeding season;
- the proportion of immature animals in the population.

The first of these variables will be sensitive to changes in fertility and calf survival; the second will be sensitive to changes in juvenile survival as well as fertility and calf survival.

3.2 Models used

Details of the expert elicitation process we used can be found in Booth et al. (2016), and Donovan et al. (2016). In all the expert elicitations we asked the experts for their best estimates of the number of days of disturbance that would be required to have any effect on survival or fertility, the maximum likely effect of disturbance on these vital rates, and the number of days of disturbance that would be required to have this maximum effect. We also asked them for an estimate of the uncertainty they associated with these values. This information allowed us to construct a set of response functions of the form shown in Figure 16a for each expert. The opinions of all the experts were combined to provide a probability density surface for these functions, which was summarised as a heat map (Figure 16b). In order to investigate the potential effects of a particular disturbance activity on a population, we obtained the views of many hundreds of "virtual" experts by sampling at random from these density surfaces.

The functions from each virtual expert were incorporated into a stage-structured population model of the kind described in King et al. (2015) in order to investigate their implications for population dynamics.

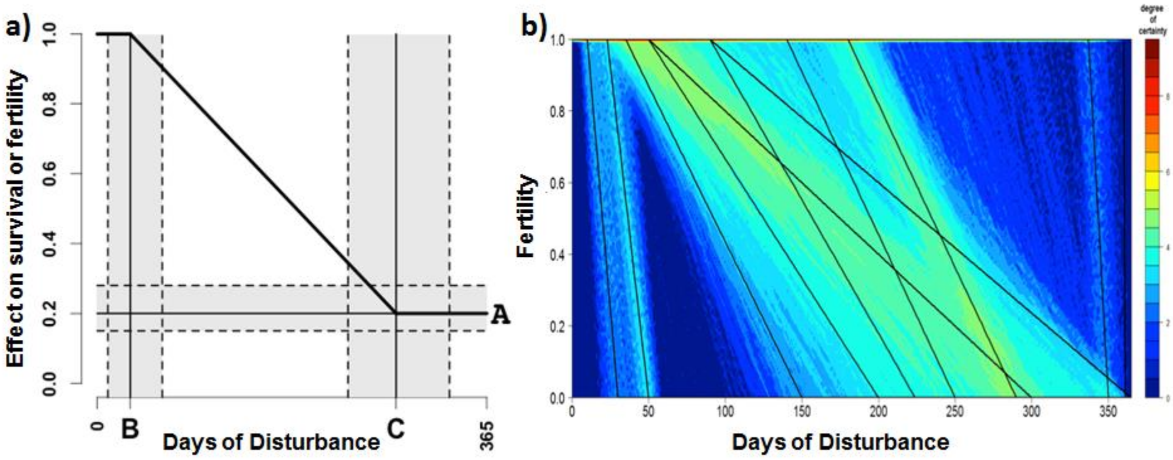

Figure 16 – a): Response function used in the expert elicitation relating number of days of disturbance experienced by an individual marine mammal and the effect of this disturbance on its fertility. A = maximum effect of disturbance on fertility, B=number of days of disturbance required before disturbance has any effect, C = number of days of disturbance required to have the maximum effect. Shaded areas indicate the uncertainty associated with each parameter value. b): Example probability density surface derived from the responses of multiple experts. The likely probability of a given value is represented by its colour, with dark blue representing a low probability and yellow representing a high probability. Black lines indicate the "best" response function proposed by each expert.

For the simulated harbour porpoise populations we investigated the effect of disturbance occurring over 10 years on a population of 10,000 animals. For bottlenose dolphins we investigated the effect of a similar disturbance on a population of 200 animals. In both cases we examined the population consequences of the response functions predicted by 500 virtual experts, and compared the values of the two demographic variables at various times during the first 10 years with the overall predicted decline in population size to the maximum decline in population size. Initially, we only accounted for variation between the opinions of the different virtual experts. However, environmental variation will also affect the value of the two demographic variables we chose to examine. We therefore re-ran the harbour porpoise simulations allowing survival and fertility to vary from year to year using experts' predictions of the level of this variability (see King et al. 2015). For the bottlenose dolphin population we also took account of demographic stochasticity (the chance variation in survival and fertility between individuals which can affect the dynamics of small populations).

Beaked whales on Navy testing ranges are likely to be subject to the same pattern of disturbance over many years. For the Blainville's beaked whale example, we therefore examined the implications of 500 virtual experts' predictions of the effect of 44 days of disturbance each year for the long-term growth rate of a population. We then compared these long-term growth rates with the ratio of calves to adult females and the proportion of immature animals in the population as indicated by the stable age distribution associated with this long-term growth rate. We also calculated estimated values for these demographic variables that would be obtained from samples of 1,000 or 100 individuals from a large population.

3.3 Results

3.3.1 Harbour porpoise

Figure 17 shows the effects of 10 years of disturbance on a population of 10,000 animals as predicted by 10 (of 500) virtual experts. The mean predicted reduction in population size as a result of disturbance was 30%.

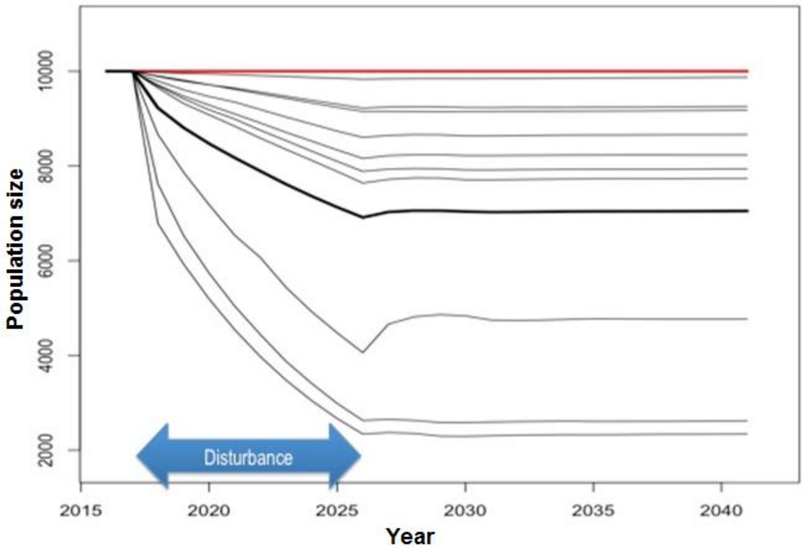

Figure 17 - Effect of disturbance over 10 years on a population of harbour porpoises, as predicted by 10 virtual experts. The red line shows the predicted changes in the absence of disturbance and the thick black line shows the mean of all 500 virtual experts' predictions.

Figure 18a shows the relationship between the maximum reduction in population size recorded in a particular simulation and the ratio of calves to mature females in the third year of disturbance, equivalent to 2019 in Figure 17. Figure 18b shows the same relationship for the proportion of immature animals in year 5 (equivalent to 2021 - we chose a later date than that used for the calf to mature female ratio to allow time for the effects of disturbance on fertility and calf survival to be influence the proportion of immature animals). Although there was a good correlation between the pairs of values, there are some clear outliers in Figure 18a, where a large reduction in population size was not matched by a change in the ratio of calves to mature females. These outliers correspond to the opinions of a small number of virtual experts who predicted that disturbance would have a large effect on juvenile survival, but very little effect on fertility or calf survival.

Figure 18 overestimates the power of these two demographic characteristic to provide an early warning of population decline because it does not account for the effects of environmental variation, which will also affect the stage-structure of the population. Figure 19 shows some examples of expert predictions which include the effects of environmental variation, and Figure 20 shows the relationship between maximum population decline and the two demographic variables when environmental variation was included in the simulations. The predictive power of the demographic variables is much reduced.

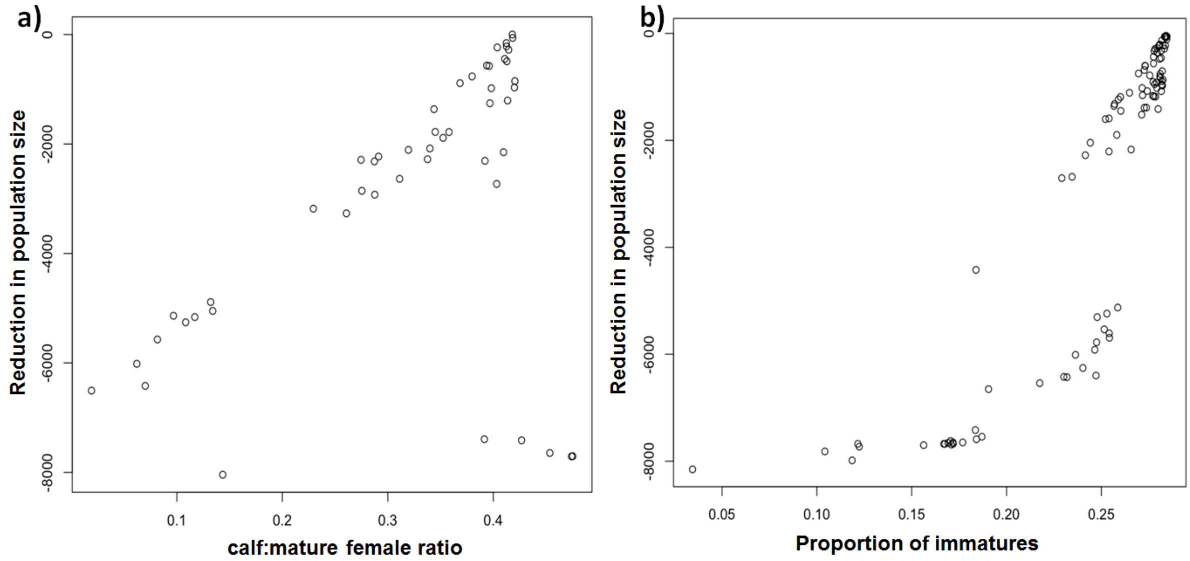

Figure 18 - Relationship between the maximum predicted reduction in harbour porpoise population size and (a) the ratio of calves to mature females in year 3, and (b) the proportion of immature animals in year 5.

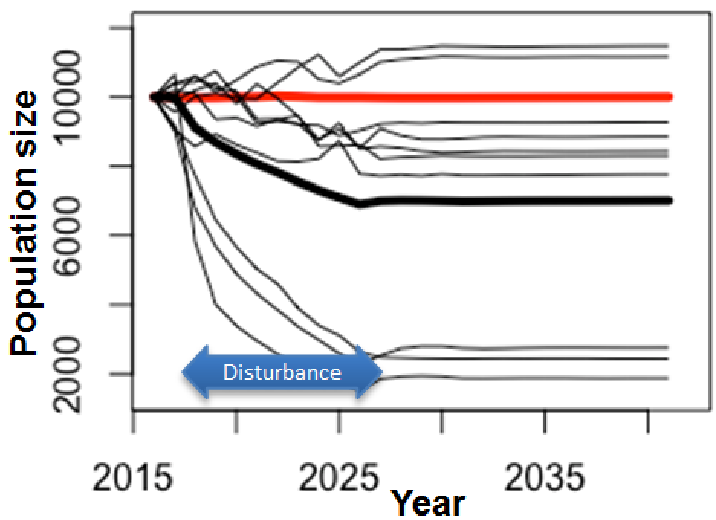

Figure 19 - Effect of disturbance over 10 years on a population of harbour porpoises, as predicted by 10 virtual experts, including the effects of environmental stochasticity. The red line shows the predicted changes in the absence of disturbance and the thick black line shows the mean of all 500 virtual experts' predictions.

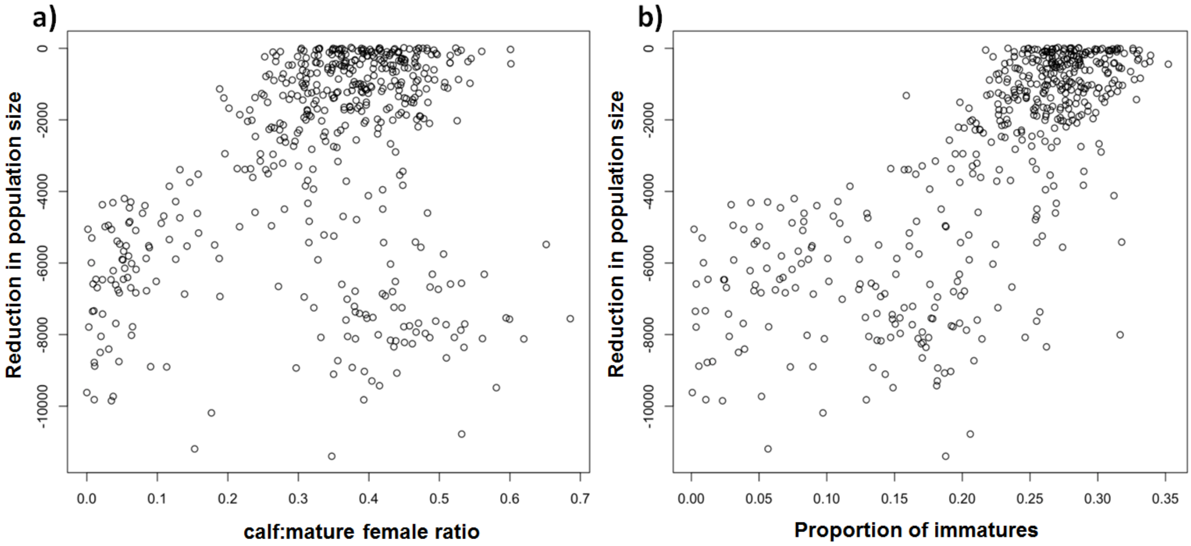

Figure 20 - Relationship between the maximum predicted reduction in harbour porpoise population size and (a) the ratio of calves to mature females in year 3, (b) the proportion of immature animals in year 5 when environmental variation was included in the simulations.

3.3.2 Bottlenose dolphins

Figure 21 shows the effects of 10 years of disturbance on a population of 200 animals as predicted by 10 virtual experts, including the effects of environmental variation and demographic stochasticity. The mean predicted reduction in population size as a result of disturbance was 33%.

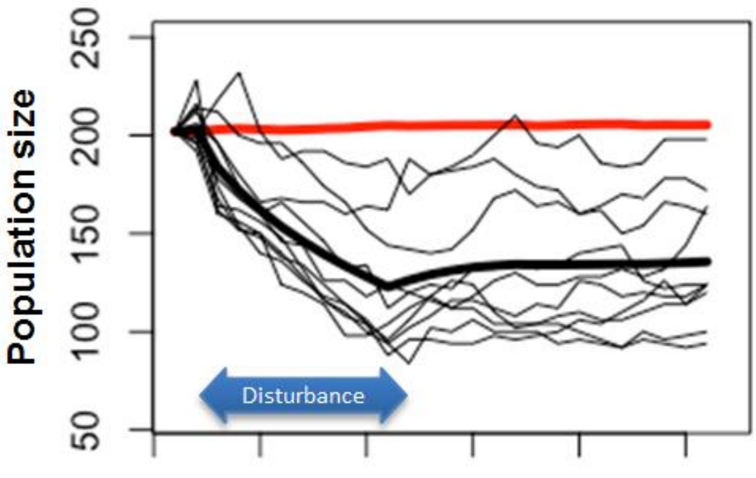

Figure 21 - Effect of disturbance over 10 years on a population of bottlenose dolphins, as predicted by 10 virtual experts, including the effects of environmental variation and demographic stochasticity. The red line shows the predicted changes in the absence of disturbance and the thick black line shows the mean of all 500 virtual experts' predictions.

Figure 22a shows the relationship between the maximum reduction in population size recorded in a particular simulation and the mean ratio of calves to mature females in the first 3 years of disturbance, and Figure 22b shows the same relationship for the proportion of immature animals in year 5 (equivalent to 2021). The mean ratio of calves to mature females over 3 years was used rather than the value from a single year because of the small population size and low fertility rate for bottlenose dolphins, which resulted in large variations in the predicted number of calves born each year. Although there is a clear correlation between the pairs of values, there is a lot of variability with a wide range of values of the demographic variables corresponding to specific predicted reduction in population size.

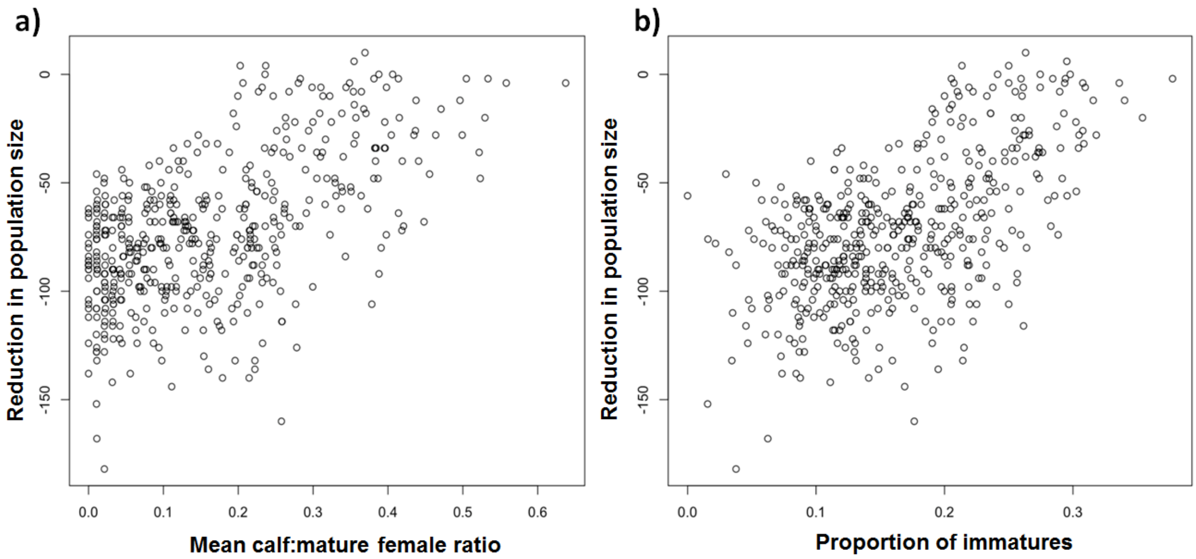

Figure 22 - Relationship between the maximum predicted reduction in bottlenose dolphin population size and (a) the average ratio of calves to mature females in the first 3 years of disturbance, (b) the proportion of immature animals in year 5 when environmental variation and demographic stochasticity was included in the simulations.

3.3.3 Blainville's beaked whales

For the Blainville's beaked whale model, we incorporated experts' predictions of the effects of 44 days of disturbance from Navy exercises on a population with the same demographic rates as those observed by Claridge (2013) for an undisturbed population in the Bahamas. These effects resulted in a reduction of between 0% and 6% in the predicted population growth rate. As expected, the ratio of calves to mature females and the proportion of immature animals derived from the stable stage structure for the disturbed population were both very reliable predictors of long-term population growth rate. However, these values are not presented here as in practice it would be impossible to estimate the two critical demographic variables with the kind of precision that is provided by the stable stage structure. These relationships were less reliable if estimates of the demographic parameters were based on a sample of 1,000 individuals (Figure 23a & b), and appear to be of limited value if the sample was only 100 individuals (Figure 23c & d).

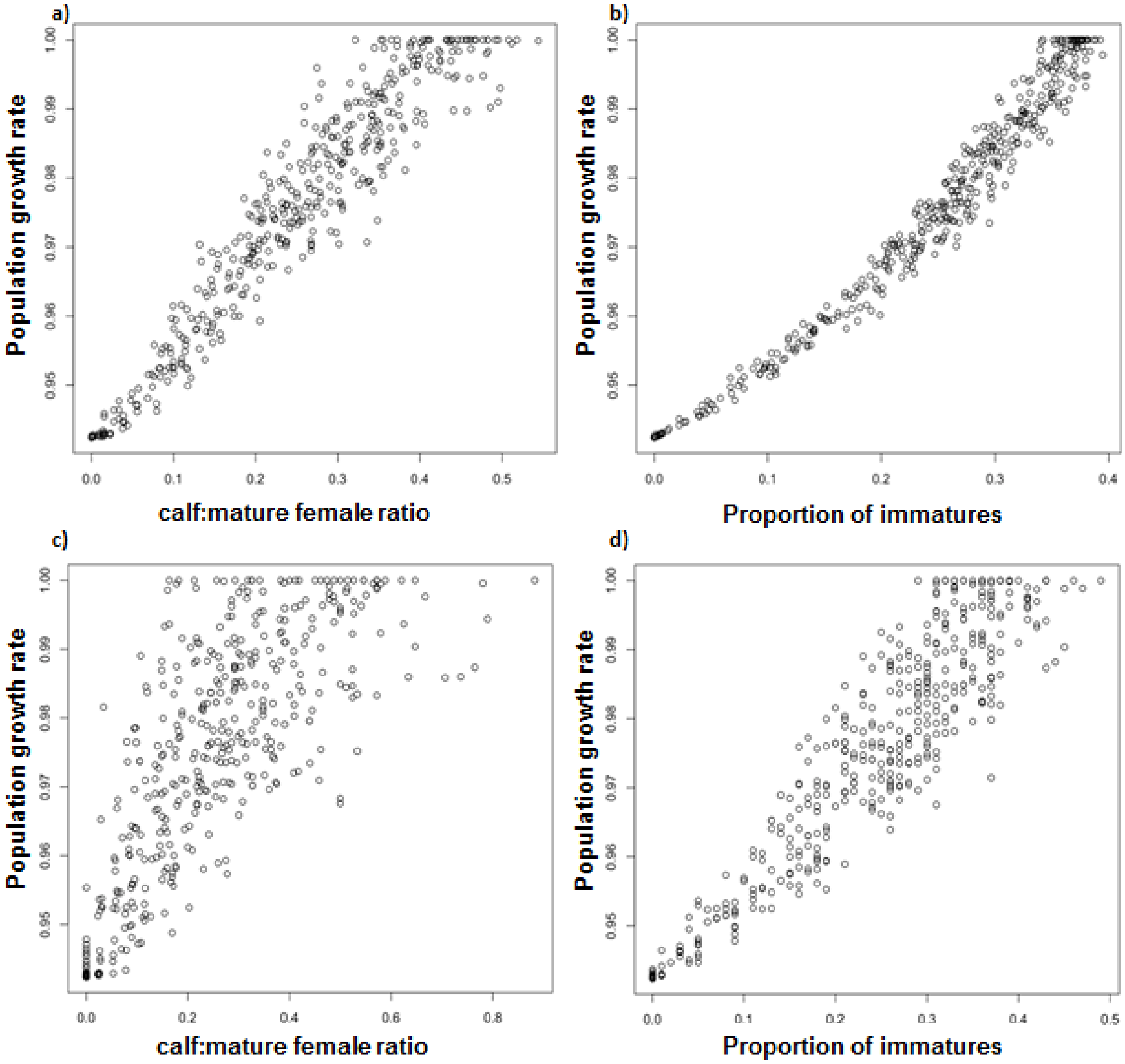

Figure 23 - Relationship between the long term growth rate of a Blainville's beaked whale population and (a) the ratio of calves to mature females estimated from a random sample of 1,000 animals, (b) the proportion of immature animals estimated from a random sample of 1,000 animals (c) the ratio of calves to mature females estimated from a random sample of 100 animals, (d) the proportion of immature animals estimated from a random sample of 100 animals.

4 Navy Monitoring of Marine Mammal Populations

In previous sections we have explored the feasibility and utility of different monitoring approaches to inform PCoD analyses. Here we summarise current Navy marine mammal monitoring and highlight some of the research being conducted to advance different techniques that might be informative in the future.

4.1 Fleet/SYSCOM monitoring program

We've reviewed the monitoring reports collated on the Navy Marine Species Monitoring pages, which hosts comprehensive reports on efforts undertaken in support of environmental compliance for training and testing activities on various range complexes and testing ranges around the world (http://www.navymarinespeciesmonitoring.us/).

Here we explored the monitoring undertaken in the two regions – Atlantic and Pacific (summarised in Figure 24)(see Appendix 7.2).

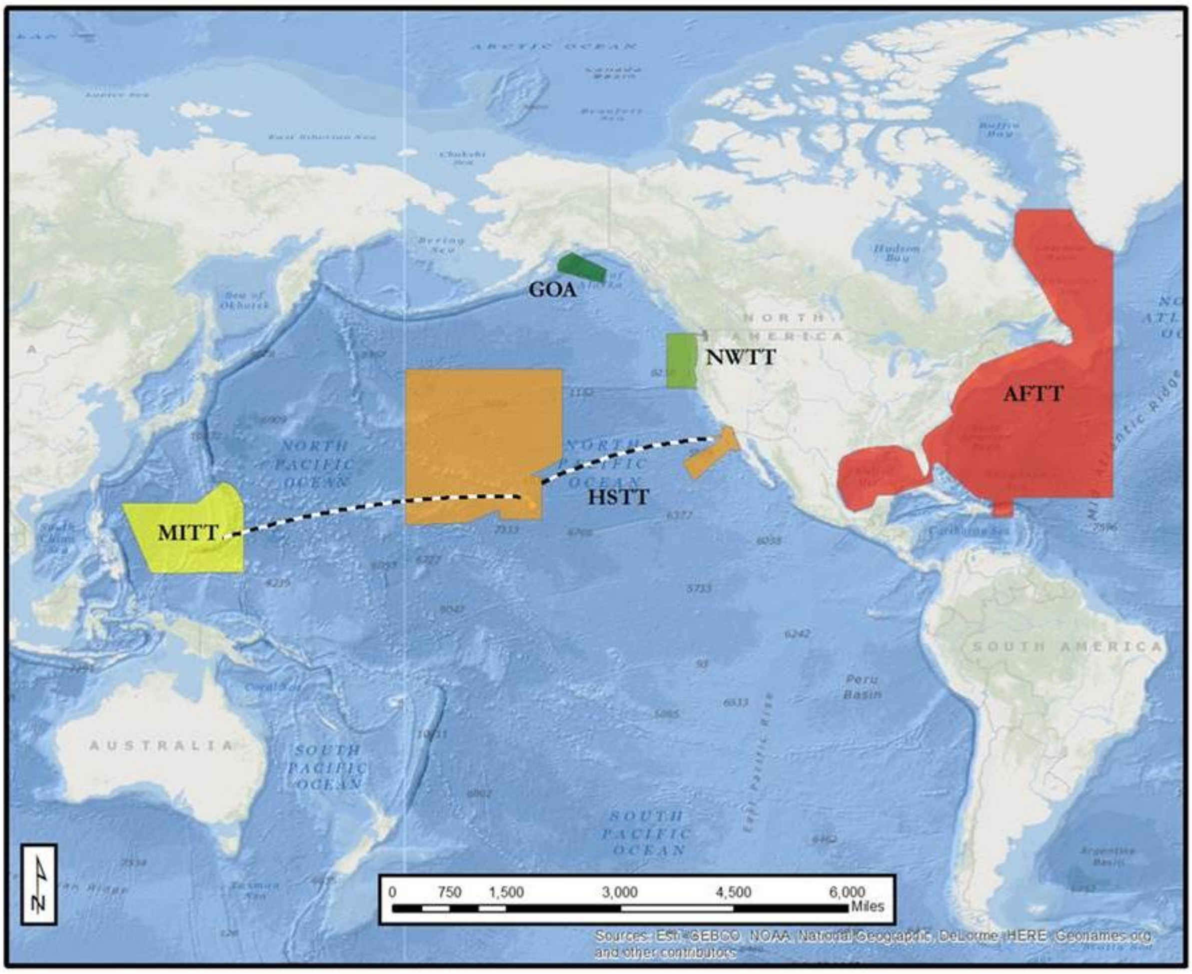

Figure 24 - Summary of US Navy Fleet Test and Training sites in the Atlantic & Pacific regions.

We reviewed the monitoring across the range complexes to identify the methods, species of interest and platforms used in current efforts and framed those in the context of the assessments in section 2. Below provides an overview of the monitoring efforts conducted between 2012-2016 which determined a wide range of monitoring efforts have been conducted across the different ranges, with different species foci (dictated by region) and a suite of different methods and platforms utilised (Table 5). A full detailed summary of monitoring efforts is provided in Appendix 7.2. In section 1.3 we highlighted the approach to monitoring as framed in 4 conceptual frameworks, Occurrence, Exposure, Response and Consequences. The bulk of the efforts to date have been under the Occurrence category, but in more recent years an increasing shift towards monitoring to support assessments of Exposure and Response.

4.1.1 Atlantic

Across the Atlantic ranges, all species groups except for the ice-breeding pinnipeds were studied (as expected given the locations of range complexes). Within the Virginia Capes (VACAPES), Cherry Point and (CHPT) and

Jacksonville (JAX) range complexes, the majority of effort was focused on most cetacean species, though deep diving species were the focus on VACAPES (McAlarney et al. 2014, Foley et al. 2016a, Foley et al. 2016b, Hodge et al. 2016). The main methods employed on these ranges were visual and acoustic surveys, where photo-ID effort was integrated into the visual survey effort (McAlarney et al. 2014, Foley et al. 2016b, Hodge et al. 2016). In addition on the VACAPES and JAX ranges individual tracking was conducted either by satellite tagging or individual focal follow methods. On the VACAPES range, remote tissue samples were also collected by biopsy approaches (Aschettino et al. 2016). A wide range of platforms for monitoring were utilised, with land-based, vessel-based, aerial and PAM surveys all being conducted (McAlarney et al. 2014, Foley et al. 2016b, Hodge et al. 2016, Rees et al. 2016).

Land-based visual (haulout) surveys of pinnipeds were conducted on the Narragansett Range Complex and mouth of in the Chesapeake Bay, and coastal dolphin species (bottlenose dolphin) are the focus at a testing location near the Patuxent River (via vessel-based visual, acoustic and photo-ID surveys) (Moll et al. 2016, Richlen et al. 2016).

At AUTEC the Fleet-level efforts focused on the use of the hydrophone array deployed there and localised vessel based efforts, using PAM methods to monitor density of beaked whales (Moretti et al. 2016). Photo-ID and tagging of animals has also been carried out. Whilst beaked whales are typically the focal species there, coastal and oceanic dolphin species also occur and are studied there. On the Naval Surface Warfare Center (Balmer et al. 2015), efforts have focused on vessel-based surveys of coastal and oceanic dolphin species. The main methods undertaken there have been visual surveys and photo-identification with biopsy sampling also undertaken.

4.1.2 Pacific

Across the Pacific ranges ranges, all species groups have been surveyed during Fleet monitoring efforts. In the Northwest Training and Testing range study area (NWTT) efforts have focused on coastal delphinid and porpoise species (particularly southern Resident killer whales) and baleen whales though deep-diving cetaceans and pinnipeds have also been monitored. The predominant methods have been PAM surveys along with visual surveys, remote tissue sampling, capture-recapture and tracking efforts all undertaken (Mate 2013, Debich et al. 2014, Trickey et al. 2015, Smultea et al. 2017).

In the Mariana Islands Training and Testing study area (MITT) monitoring has focused on all species of marine mammals and sea turtles to establish baseline occurrence, habitat use and population.. Remote tissue sample, capture-recapture surveys and individual tracking have all been undertaken, with the focus of effort on visual and acoustic surveys from all platforms (Hill M.C. et al. 2013, Oleson 2014, Norris et al. 2017). The same is true in the Hawaii-Southern California Training and Testing (HSTT) study area (which includes Southern California (SOCAL), Hawaii (HRC), SOAR and Pacific Missile Range Facility) (HSTT), most species groups have been monitored, with the focus on deep-divers and baleen whales with a range of approaches undertaken by the majority of monitoring via either visual surveys, capture-recapture, photo-ID, tagging, genetics, and PAM (Baird et al. 2011, Littnan and Wilson 2011, Mobley et al. 2012, Martin et al. 2013, Baumann-Pickering et al. 2016, Henderson et al. 2016, Mate et al. 2017, Schorr et al. 2017a).

In the Gulf of Alaska Temporary Maritime Activities Area (GOA TMAA), only baleen whales and deep diving cetacean species have been monitored, almost exclusively via vessel based and fixed PAM efforts (Department of the Navy 2014, Rone et al. 2014, Rice et al. 2015).

Table 5 - Summary of the Navy Monitoring studies conducted between 2012 and 2016, outlining the focus species, monitoring types, geographic areas where conducted and platforms used. X denotes which species were studied, the survey method and platform used. Green shading indicates the primary groups / methods / platforms of the monitoring conducted. A full table is presented in Table 10 in Appendix 7.2.

	Species Group						Method							Platform			
Region	Deep diving cetaceans	Baleen whales	Coastal dolphins & porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands-on assessment	Remote Tissue Sampling	Visual surveys	Acoustic surveys	Capture-recapture	Photogrammetry	Individual Tracking	Land	Aerial	Vessel	PAM
Virginia Capes (VACAPES)	X	X	X	X	X			X	X	X	X		X	X	X	X	X
Cherry Point (CHPT)	X	X	X	X				X	X	X	X				X	X	X
Jacksonville (JAX)		X	X	X				X	X	X	X		X		X	X	X
Narragansett Complex					X				X					X			
Chesapeake Bay (NAS PAX)			X						X	X					X		X
Atlantic Undersea Test and Evaluation Centre (AUTEC)	X		X	X					X	X	X		X				X
Naval Surface Warfare Centre, Panama City Division (NSWC PCD)			X	X				X	X		X					X	
Northwest (NWTT)	X	X	X		X			X	X	X	X		X	X	X	X	X
Mariana Islands (MITT)	X	X	X	X				X	X	X	X		X	X	X	X	X
Hawaii-Southern California Training & Testing (SOCAL/SOAR/HRC/PMRF)	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X
Gulf of Alaska (GOA TMAA)	X	X								X						X	X

4.2 Exploratory (ONR) and applied research (LMR) efforts

The US Navy marine mammal research program includes an extensive program of basic research and exploratory development at the Office of Naval Research, as well as the Navy's Living Marine Resources applied research program. We reviewed the available ONR and LMR annual reports to assess how the methods described above (section 2) are currently being developed or validated which may in the future provide essential jigsaw pieces for the larger PCoD picture. Recently a number of other PCoD modelling efforts, advancing energetics-based approaches (Costa 2015, Christiansen 2017) and different species groups including beaked whales, baleen whales and oceanic dolphins (Costa 2015, Schwacke and Wells 2015, Williams 2015, Aguilar de Soto et al. 2016 project, Williams et al. 2016 project, Christiansen 2017, Moretti et al. 2017).

Due to the breadth of studies of research funded by ONR and LMR - we have focused on highlighting the studies which fit into the Response and Consequences categories of (middle and right-side of the PCoD framework). This is not to downplay the importance of determining the occurrence and exposure of animals – but focussing on those topics that can be used to improve our knowledge of important variables or methods to be further developed to inform future PCoD analysis of the effects of Navy activities on relevant marine mammal populations.

A number of research projects have employed photo-ID data collection methods and utilised capture-recapture techniques to learn more about population structure and demographic rates (e.g. Aguilar et al. 2013, Moretti et al. 2017, Schorr et al. 2017b). Other efforts have explored the power of photo-identification surveys to inform demographic variables – which can be extremely informative in helping assess or design the feasibility of such photo-ID surveys in generating robust estimates for different species and populations (e.g. Moore et al. 2017). Photogrammetry is an approach that has been widely used for marine mammals (section 2.4.5) but has not yet been heavily utilised in Navy monitoring (as the techniques have been under development). However recent and current projects have been useful in assessing the viability of approaches in providing suitable demographic variable estimates (e.g. determining age class - as in Claridge et al. 2017) and as a means to assess body condition and/or pregnancy status (Noren 2016 project, Christiansen 2017) .

Improving knowledge of the physiological and stress responses of marine mammals is a key area of development. For marine mammals, this area is less developed than in terrestrial systems – but significant advances are being made, exploring what can be gleaned in different species and sampling media (Champagne and Houser 2015, Lusseau 2015, Atkinson 2017, Calambokidis 2017, Crocker et al. 2017, Houser 2017, Kellar and Durban 2017, Lusseau 2017, Romano 2017, Trumble and Usenko 2017) . New tools are also being developed to monitor physiology of animals (e.g. Ponganis 2015, Ponganis and McDonald 2015, Williams 2015, Fahlman et al. 2016 project, Madsen and van der Hoop 2016 project, McDonald et al. 2016 project)). A key area for future development will be establishes linking changes in health variables (e.g. body condition, stress markers) and vital rates.

Recent ONR and LMR (and other) funded efforts have developed the utility of PAM approaches for marine mammal monitoring (Miksis-Olds et al. 2017). A key advance in this area is the development of DECAF tools to allow the estimation of density of animals from acoustic detections and has shown promise in monitoring PAM-suitable populations (i.e. those which reliably vocalise and for which the site-specific vocal behaviour is well understood and classifiable). This is already an established monitoring technique, but developing hardware and software (e.g. classifiers (for correct detection of species) (Lammers 2017, Oswald and Yack 2017) and localisation (Arranz et al. 2016 project, Nosal 2016 project)(which can improve detection functions used in DECAF) and tools (e.g. DECAF TEA) are advancing this topic area. Specific key advances are in the development of approaches for distinguishing the vocalisation of delphinid species (which in the past has been extremely challenging)(Oswald and Yack 2014, Oswald and Yack 2017).

Finally, the ONR Integrated Ecosystem Research topic is providing key multidisciplinary efforts which broaden the research view to incorporate important contextual variables that when combined with focused marine mammal efforts have the potential to improve our power to detect behavioral and/or physiological changes and examine causation (e.g. combining the results of Claridge 2013, Benoit-Bird 2017 to better understand observed patterns in beaked whale populations)

5 Discussion

This study explored the current state of knowledge of methods and variables to be used to inform PCoD analyses of the potential effects of Navy activities on marine mammal populations. Using a combination of literature review (section 2.4) and expert workshops (section 2.5) we identified a set of currently available and developing methodologies for monitoring demographic and health variables suitable for this purpose and, via sensitivity analyses (section 3), explored the demographic variables capable of detecting early warning signs of population decline. Here we discuss those results in the context of current (section 4) and future potential Navy monitoring and research efforts to explore feasible next steps in inform future PCoD analyses.

5.1 Review and Workshop Outputs

The literature review and expert workshops identified that there are a range of marine mammal monitoring approaches which can be employed, and variables for which data can be collected, in order to inform PCoD analyses. In general, demographic variables were typically determined to be collected using established approaches. Monitoring health has a wide range of possible approaches and has significant potential to elucidate the pathways between disturbance and changes in vital rates; however most methods require further exploration and validation to better identify their utility for monitoring PCoD in different species groups.

Monitoring of demographic variables is most commonly achieved via capture-recapture techniques (most commonly using photo-identification, though genetic and electronic tagging methods have also been used in this way) and can provide information on stage-specific survival rates and estimates of fertility. Such approaches are labor intensive but remain the most established and robust approach to monitor population demography and therefore one of the best potential ways to identify early warnings of declines (sections 3 & 5.2). Photo-identification also provides a means by which health variables such as body condition can be assessed (e.g. post-nuchal and scapular depressions and other visual health assessments). Photogrammetric methods were identified to be both feasible and useful in informing both demographic (e.g. stage-class to infer proportion of immatures in the population) and health variables (e.g. body condition metrics). In addition they have been widely used over the past decade to study marine mammals. Therefore, integration of such techniques into Navy monitoring programs is likely to be feasible, particularly in cases where vessels are the primary monitoring platform. Development and validation of standardised approaches and technologies (UAVs, improved resolution lens etc.) are likely to advance the utility of this field in estimating health and demographic variables. Monitoring body condition is likely the most direct means by which the links between health and vital rates can be determined.

Remote tissue sampling, either via established techniques like biopsy sampling or novel approaches (e.g. blow and faecal sampling) have been demonstrated to have value for monitoring health variables (e.g. % lipid in blubber, stress and reproductive hormones), but also for providing information on demographic parameters (e.g. sex ratios, pregnancy status of individuals etc.). In addition, hands-on assessments – either using captive animals, for small cetaceans or pinnipeds in accessible locations or from strandings/bycatch – can provide a suite of useful measurements for a range of health and demographic variables. However it should be considered how generalizable results will be for other populations or individuals within the same population (e.g. sampling bias for animals easier to catch and handle and/or those likely to be bycaught or strand/wash ashore). Nonetheless, remote and direct sampling of animals has provided significant advances in our understanding of health indicators, including physiological and stress markers, and this is an area that shows great promise for monitoring health and requires further effort in the future.

In general for health variables, there are a wide range of promising developments in this field and further research is required to improve our understanding of the natural variability (e.g. species/life-history specific fluctuations) of specific health variables, how they change in response to chronic or acute stressors, and the causal pathways and 'knock-on' effects on vital rates. This is certainly an area for continued exploration as our understanding of physiology, stress response and –omics in marine mammals develops.

For PAM methods, the current utility of these approaches for determining demography or health are limited, however tools for estimating density of vocal species are well established and provides a means to cost-effectively monitor population trends (e.g. Moretti in prep). These approaches are continually being expanded to overcome key obstacles for the implementation of DECAF (e.g. Olmstead et al. 2010, Helble et al. 2013, Helble et al. 2015, Roch et al. 2017). These include developing and validating detection and classification capacity for challenging PAM species (e.g. oceanic dolphins), improving localisation capabilities (to help improve detection function estimation) and understanding the variability of call rates under natural conditions and when exposed to Navy activities.

5.2 Sensitivity Analysis

The sensitivity analysis simulation results described above (section 3) indicate that monitoring the ratio of calves to mature females, or the proportion of immature animals in a population, may provide an early warning of an imminent decline in population size for a population exposed to episodic disturbance, and they may indicate that a population subject to regular disturbance is declining. However, such a monitoring approach may generate a high proportion of “false positive” outputs, where the monitored characteristic implies a substantial population decline, but the actual decline is much smaller.

We examined the likely effectiveness of a monitoring program based on one or other of the two demographic variables to provide an early warning of a potential population reduction of 40% or more by the end of the period of disturbance. For the harbour porpoise populations, the proportion of immature animals in the population fell below 0.2 in year 5 in 147 (29%) of the 500 simulations. In 90% of the simulations in which this early warning signal was detected, the population had declined by more than 40% by the end of the disturbance period. However, 19% of the simulations in which the population declined by more than 40% were not identified using this early warning indicator. It was not possible to identify an early warning threshold for the ratio of calves to mature females that did not involve a high risk of false positive values. For example, a calf to mature female ratio of 0.4 in year 3 occurred in 58% of the simulations in which the population declined by more than 40%, but in 25% of the simulations in which the ratio fell below 0.4 the actual population decline was less than 10% and the overall false positive rate was 64%. Similar results were obtained for bottlenose dolphins: early warning thresholds occurred in a high proportion of the simulations in which there was a population decline of at least 40% also had a high false positive rate (45-50%). In general, these results suggest that the ratio of calves to mature females may be problematic as an early warning indicator as it has a high false positive rate, but that the proportion of immature animals in the population might be more robust to this issue. Assessing multiple demographic parameters is likely to strengthen our ability to minimise false positives.

Results from the Blainville’s beaked whale analysis was more encouraging. For example, the ratio of calves to mature females, and the proportion of immature animals in a sample of 100 animals was less than 0.2 in all the cases in which experts predicted a population growth rate less than 0.95 (i.e. an annual decline in abundance of 5% or more). The overall false positive rate, in terms of predicting a decline of at least 5%, was 47% in the case of the calf to mature female ratio, and 59% for the proportion of immature animals. However, the long-term growth rate was low (less than 0.97) in 95% of the cases in which the proportion of immatures was less than 0.2. In practice, it is rare for as many as 100 beaked whales to be detected in a population survey, and even rarer for these individuals to be under observation long enough for them to be classified into a stage class (e.g. some beaked whale species, e.g. Cuvier’s, are challenging to distinguish into stage class). However, it may be possible to obtain more reliable estimates when the population of concern is small and, over time, almost all of the individuals in the population can be classified into an appropriate stage, as was the case for the study of beaked whales in the Bahamas (Claridge 2013). In addition, it may be relatively straightforward to monitor these two demographic variables in a range of other species, like many oceanic dolphins or baleen whales (on foraging/breeding grounds), that form large aggregations that can be photographed. As such, monitoring techniques which can provide estimates of these demographic variables (e.g. surveys, aerial photogrammetry or vessel-based laser photogrammetry) should be considered for such species groups.

Although we have tried to account for a number of sources of uncertainty in these analyses, we have not accounted for observer error. That is, we have assumed that observers can assign individual cetaceans into one of the three stages (calf, immature, mature female) without error. Although it should be possible to identify mother/calf pairs with relative certainty (the exception being in cases where alloparental care occurs), it will be much more difficult to distinguish calves from immature animals when they are not accompanied by their mothers, and to distinguish mature females without calves from immature animals. This additional uncertainty will increase the false positive rate and reduce the reliability of the demographic variables as early warning indicators.

5.3 Advancing marine mammal monitoring for informing PCoD

We reviewed the recent and current Navy range monitoring programs and the efforts to develop and/or validate methods/techniques coming online in section 4. The current monitoring program is expansive, covering a wide range of habitats, species groups and methodologies and, as noted above, has most recently focused on monitoring the occurrence, exposure and response elements of the Navy's monitoring framework (DoN 2016b, a). Efforts could be made to expand programs to include where 'Consequences' monitoring can be comprehensively integrated without compromising Occurrence- /Exposure- /Response-focused objectives.

We highlighted in section 2 and 3 the methods that had the highest feasibility and utility scores. In summary, for monitoring population demography in baleen whales and deep-diving cetaceans: capture-recapture, remote tissue sampling and photogrammetry had the highest scores and therefore were considered most useful. For delphinids and porpoises: capture-recapture, hands-on assessment, remote tissue sampling and (lateral laser) photogrammetry had the highest scores and therefore were considered most useful. Most approaches were determined as useful for monitoring PCoD in pinniped species.
In summarising monitoring for health variables, capture-recapture, individual tracking (e.g. telemetry), remote tissue sampling and (vertical) photogrammetry had the highest scores and therefore were considered the most useful methods for baleen whale and deep-diving cetacean species. For delphinids and porpoises remote tissue sampling was identified as the most suitable and ready approach. Many methods were considered valuable in informing PCoD analysis for pinnipeds, in particular hands-on assessment.

Based on the review of Fleet/SYSCOM monitoring conducted, photo-ID and biopsy monitoring are typically conducted as secondary efforts as part of monitoring – usually visual surveys. That is, in general photo-ID is conducted as an add-on to existing programs – i.e. during visual surveys and tagging efforts. In recent Fleet/SYSCOM monitoring (see Table 5) vessel-based surveys have been conducted on all of the ranges. In any monitoring program, the largest cost element will be the platform (i.e. vessel or airplane) required and thus maximising monitoring effort by including photo-ID and photogrammetry effort represents a cost effective addition. Given the broad range of studies using photo-ID and remote tissue sampling, a logical step would be to assess the amount of photo-ID and biopsy effort conducted to date (e.g. number of sightings/photographs/samples) to explore what could be feasible in an expanded monitoring program achieved by promoting capture-recapture and remote tissue sampling. This might be achieved by a desk-based review and power analysis of sample sizes for different populations monitored to explore what is available for informing PCoD analyses (i.e. what power might we expect given effort to date) and for specific case studies be assessed in a workshop setting to determine best recommendations for future research and/or expansion of effort and/or analyses of existing datasets.

In section 2 and 3, vertical and lateral photogrammetric methods were identified here to be both feasible and useful in informing both demographic and health variables (e.g. body condition) and have been widely employed over the past decade to study marine mammals. However these are yet to be utilised in Fleet/SYSCOM monitoring programs (as methods are under development). Based on the available literature, and current ONR/Navy investments, the methods could be considered for further development and validation (i.e. through ONR and LMR) for populations of interest (e.g. as in Claridge et al. 2017 on Blainville's beaked whales on AUTEC and at Abaco) or for direct integration into Navy monitoring program (e.g. for baleen whales – see section 2.4.5) with the objective of providing stage-specific information to determine the proportion of immatures in a population and/or assessments of body condition. In addition, as noted above and in the sensitivity analysis – this might be a viable approach for sampling Navy relevant species groups such as oceanic dolphins which occur in large aggregations for which it is otherwise challenging to determine demographic parameters. Studies of drift diving using electronic tags have been useful in providing estimates of body condition and this area is currently being actively studied (Miller et al. 2017 project).

In addition to the suggested path to further develop Navy monitoring and research to inform PCoD analyses, it is important to stress the value in continuing PAM studies which are valuable to continue to provide population level monitoring and which continue to be developed to improve understanding and reduce uncertainties in density estimation. Similarly, there is a pressing need to continue to develop physiological and stress topic areas (including –omics). Initial efforts have yielded promising results and improving our understanding of physiological and stress responses will be critical to understanding pathways between disturbance and effects on vital rates in PCoD.

5.4 Caveats and Limitations

There are important considerations in any monitoring program with the objective of informing PCoD analyses. Here we note some of the potential challenges to be considered in any 'population-level' and/or individual health monitoring. The items covered here do not span the entire range of issues likely to be encountered across all species and populations, but highlight potential considerations.

For marine mammal populations, it can be challenging to identify an appropriate unit of assessment. As our ultimate objective is to determine early warnings of a population decline, we have to consider what our 'population' of animals is. This is often determined by the animals which can be accessed and sampled and many 'local' populations that are not genetically or demographically isolated which could be considered a single population. Furthermore, local population size is affected by local demographic parameters but also by emigration and immigration and, because immigration rates can vary spatially, monitoring trends in local population size alone may not differentiate healthy and unhealthy populations. For example, if disturbance negatively affects reproduction or survival, local population parameters (e.g. size/demography) might still be maintained by immigration of individuals from other populations. In such an instance, local issues may not be reflected in overall population trends until problems become severe. As such, where possible and feasible, consideration of what the sampled 'population' represents and identification of any sampling biases should be made.

In general, we've highlighted the value of monitoring demographic and health variables in providing an early warning of a population decline. In the context of Navy activities or any other anthropogenic stressor, when assessing causal links of observed 'warning signals' we must consider that demography and health metrics like body condition are subject to natural variation and can be impacted by density dependent factors. For example, animals in a healthy population may be in poor condition if the population is close to its carrying capacity and there is high competition for resources. Another example would be when monitoring levels of lipid reserves, that the lipid reserves of even 'undisturbed' females in a 'healthy' condition are likely to fluctuate dramatically over a single reproductive cycle (between pregnant-lactating-resting phases) and therefore understanding where a female is in this cycle will be critical contextual information. In some visual assessment variables, such as rake marks, there may also be confounding factors (if used a direct indicators of health), for example a healthy male in good body condition may carry a lot of rake marks because it engages in frequent male:male interactions, and not because they are in poor condition. As such, contextual information must be considered in order to fully inform any PCoD monitoring and analyses.

6 Conclusions & Recommendations

6.1 Conclusions

The ultimate objective of this study was to identify a suite of variables that can provide information on changes in demography or health, together with the methodologies that can be used to measure such variables.

Using existing PCoD models, we identified that changes in demographic variables are strongly correlated with changes in abundance or population status, and can provide some early warning of future changes in abundance. In particular, the proportion of immature animals in a population (via assessments of stage-structure) might provide a reasonable early indicator of population decline. We also explored the ratio of mothers to calves/pups (as this is one of the most easily measured variables available) but determined that there was a high risk of false positives (i.e. predicting a decline when there is none). However, we note that the probability of failing to detect a large decline may be high if only one characteristic is monitored. In general, we consider that the value of monitoring of any of these (or other) variables will depend on the precision with which they can be measured, and the practicality and cost of this monitoring.

There are a number of other scientific considerations (as opposed to the logistical ones of cost and practicality) in how to conduct a monitoring program to inform PCoD analyses or identify early warning signs of future changes in abundance. These include (but are not limited to) consideration of how to obtain a representative sample of populations (e.g. avoiding sampling biases of animals that easier to 'sample'), determining an appropriate (and feasible) unit of assessment and developing an understanding the 'local' population (which may not be genetically or demographically isolated) being monitored. There a number of other potential limitations which should be considered (section 5.4).

In terms of appropriate methodologies to employ in PCoD monitoring, we observed that demographic parameters tend to be most commonly estimated from monitoring using established approaches such as visual surveys and capture-recapture. In addition, both vertical and lateral (e.g. laser-) photogrammetry could be used as methods to help determine important demographic parameters such as the proportion of immature animals in a population (informed via assignment of individuals into stage structure) or, if the population life-history is well-understood, pregnancy rate (vertical photogrammetry only). Monitoring body condition might provide a way to identify unhealthy animals (though there might be many potential causes) and is a particularly attractive route for monitoring PCoD and a range of methods are in development to explore this topic area. In general, monitoring individual health and physiological variables was determined to have significant potential (see Table 3) primarily via photogrammetry, remote tissue sampling, direct handling and individual tracking approaches. However, other than body condition metrics (which have a direct theoretical link to fitness), the methods for the collection of other health variables (including stress and reproductive hormones, and -omics) still had significant uncertainty around them, and thus it is critical that they are further developed and validated for different species (and reproductive strategies) so that their potential of informing PCoD analysis is fulfilled. As part of this validation, it is important that we understand the natural variability and vulnerable species/life-history stages to aid focused PCoD monitoring studies.

6.2 Recommendations

This study has highlighted the current and future potential of a range of methods to collect important data in informing PCoD analyses. We outline specific recommendations for how existing Fleet/SYSCOM monitoring programs might be augmented if informing PCoD analysis were a key objective and highlight the methodologies for development to advance our ability to identify early warnings of future changes in abundance. Critically, any augmentations must start with a clear set of objectives regarding the purpose of the monitoring.

We recommend that, where possible, monitoring programs are developed to specifically inform future PCoD analyses. This could include photogrammetric techniques to help in assessments of body condition and in the estimation of demographic parameters. Specifically, the use of lateral laser-photogrammetry and photo-ID could provide valuable information on the stage structure of oceanic dolphin species. Similarly, vertical photogrammetry can provide estimates of body condition and stage structure and provide information on pregnancy, maternal investment etc., particularly for baleen whales and beaked whales. It is important to continue efforts where capture-recapture studies (e.g. photo-ID) have been undertaken (where viable sample sizes are achieved). These provide estimates of survival rate and fertility and additionally there is significant value in continuing longitudinal studies to understand natural variations and contextualize observed patterns. Continuing to develop remote tissue sample libraries to facilitate learning in stress response, physiology and –omics fields is critical to understanding pathways between disturbance and effects on vital rates in PCoD. Additionally, it is important to continue the use (and development) of PAM techniques to monitor cetacean populations to better understand the relative and absolute indices that can be derived to inform PCoD.

Where possible, monitoring programs should be identified which can provide reference or control populations against which observed patterns can be compared. Similarly, multidisciplinary studies which provide important contextual information (e.g. environmental quality – such as Benoit-Bird 2017) to help inform PCoD studies and establish (or dismiss) potential causes are extremely valuable.

In particular, it is beneficial to use approaches where more than one variable can be measured. For example, remote tissue sampling yields a sample (whether it is fecal, blow, serum or blubber) that can be used in multiple analyses. Similarly, the use of vertical photogrammetry could theoretically provide visual assessments of health, estimates of body condition metrics (depending on species), age/class/stage structure (e.g. mother:calf/pup ratio, proportion of immatures in population etc.) and can also be used with capture-recapture approaches to estimate demographic parameters. As highlighted above, the probability of failing to detect a large decline may be lowered if more than one characteristic is monitored and there is added value in maximising what can be achieved for a given approach.

We have highlighted that, where possible, the integration of new technologies into existing Fleet/SYSCOM monitoring efforts might provide significant added value. The inclusion of novel approaches into monitoring programs where infrastructure exists means a cost-effective increase in what can be achieved by a given program. For example, the inclusion of vertical or lateral laser-photogrammetry, or remote tissue sampling into an existing vessel-based effort could be valuable. The cost per sample would be moderate given the existing infrastructure in place. Similarly, in the future, as new technology develops and is validated (e.g. estimates of body condition remotely sampled and telemetered from tags), these can be incorporated into appropriate monitoring efforts.

Given the amount of effort conducted over the past 10 years as part of Fleet/SYSCOM monitoring efforts (see Table 10), if one has not yet been conducted, there would be merit in an assessment of the data collected to date to determine what might be achieved in a PCoD analysis. Such a retrospective assessment could be particularly informative in terms of setting appropriate monitoring objectives. This could include a review of effort conducted to date, sample sizes obtained for different species/variables and species/method-specific power analyses to determine the levels of effort required to collect sample sizes to inform future PCoD analyses. Depending on data availability, an exploratory meta-analysis of existing data might be what has been observed in past monitoring.

This report has indicated that whilst there are existing monitoring approaches that can be considered ready for use now, there are large array of promising avenues for future research to inform PCoD. In section 2.5 we highlighted methods for different species groups by their utility (i.e. the number of valuable parameters that can be collected) and feasibility (i.e. how readily data can be collected for the group using a specific method). Much of our focus has been on approaches with the highest feasibility given the current state of science. However many topic areas, particularly relating to health, had high utility scores. We would recommend that methods with high utility, but moderate or lower feasibility be further developed as they likely hold significant potential in informing future PCoD analyses. In particular, there is a need to continue to develop stress response, and –omics fields as they are likely to yield important 'jigsaw pieces' in our understanding of the pathways linking disturbance and effects on vital rates and crucially, provide the earliest possible warnings.

6.3 Future work within PCoD+

This project represents one of five tasks within the PCoD+ project. We plan to utilize efforts from other tasks (e.g. the development of a Decision Tree framework) to help further development monitoring priorities for PCoD+ through to project conclusion in summer 2019. In addition, between now and then, we intend to utilize modelling efforts in Task 3 – Benchmark Models' to continue to explore whether there are health variables (e.g. body condition metrics, physiological variables) which can be assessed for their utility as in section 3 here. This will also capitalize on work conducted under the Sound and Marine Life Joint Industry Program-funded project "A Bioenergetic Model to Estimate the Population Consequences of Disturbance" (PI Costa). It is intended that this and planned effort will be presented at a focused PCoD Monitoring Priorities workshop in spring 2019.

7 Appendices

7.1 Workshop Details

The workshop was held in Santa Cruz, CA over two full days on Tuesday 28th February and Wednesday 1st March 2017. Here, we provide a brief summary of the objectives of the workshop, the process undertaken. The outputs are discussed above. The workshop attendees are shown in Table 6. We'd like to acknowledge the input of each of the attendees in developing inputs for the Feasibility-Utility plots and discussions on how to advance monitoring priorities for PCoD.

Table 6- Attendees of the Identifying Monitoring Priorities for PCoD Workshop.

Personnel	Affiliation	Role
Cormac Booth	SMRU Consulting	Project Team
John Harwood	SMRU Consulting & University of St Andrews	
Len Thomas	CREEM, University of St Andrews	
Catriona Harris	CREEM, University of St Andrews	
Dan Costa	Costa Lab, University of California, Santa Cruz	
Lisa Schwarz	Costa Lab, University of California, Santa Cruz	
Brandon Southall	Southall Environmental Associates	Science Advisory Panel
Andy Read	Read Lab, Duke University	
Sam Simmons	Marine Mammal Commission	
Lori Schwacke	National Marine Mammal Foundation	
Andre de Roos	University of Amsterdam	
Mike Weise	Office of Naval Research	
Anurag Kumar	NAVFAC	
Barb Taylor	Southwest Fisheries Science Center, NOAA	Invited Experts
Dan Crocker	Sonoma State University	
Nick Kellar	Southwest Fisheries Science Center, NOAA	
Shawn Noren	Williams Lab, University of California, Santa Cruz	
Frances Gulland	The Marine Mammal Center	
Jeff Moore	Southwest Fisheries Science Center, NOAA	

The workshop began with a series of presentations from Cormac Booth, John Harwood, members of the project team and invited Science Advisory Panel members providing background information on PCoD in general, and developing efforts within the PCoD+ project. Those initial presentations are outlined below (Table 7).

Table 7 – Presentations made at the Identifying Monitoring Priorities Workshop in spring 2017.

Presenter	Title
Cormac Booth	Introduction to PCoD+ and workshop
John Harwood	An overview of PCoD efforts to date and setting scene
Lisa Schwarz	Summary of JIP funded research exploring links between health and vital rates
Brandon Southall	Overview of new Noise Criteria Severity Scales
Anurag Kumar	Overview of U.S. Navy Marine Mammal Compliance and Monitoring Program
Cormac Booth	Identifying Monitoring Priorities for PCoD: Literature Review

John Harwood	Identifying Monitoring Priorities for PCoD: Sensitivity Analysis

Each of the presentations was delivered in an open question and answer format, allowing free discussion among participants and thorough exploration of the different topics being presented. Following presentations and discussions arising, the workshop participants broke into breakout groups (one for demographic variables, another for Individual health) to explore suitable variables and methods to inform a future PCoD analysis (Table 8).

The invited experts participated in exercises to develop an expanded list of variables and methods, building on those from the literature review. In particular, they explored the feasibility and utility of each approach/variable for different marine mammal species groups adopting a 'strengths of lines of evidence' approach. Discussions and exercises were guided with input from the project team. The approach undertaken and results of these exercises are presented in section 2.

Table 8 - Breakout groups to explore suitable variables and methods to inform future PCoD analysis. Project Team shown with *.

Demography	Individual health measures
Cormac Booth*	Len Thomas*
John Harwood*	Dan Costa*
Lisa Schwarz*	Shawn Noren
Barb Taylor	Nick Kellar
Andy Read	Dan Crocker
Jeff Moore	Mike Weise
Anurag Kumar	Lori Schwacke
Sam Simmons	Frances Gulland
Andre de Roos	Brandon Southall

As described in section 2, the experts at the workshop adopted a multiple Lines of Evidence approach as part of the assessment of the feasibility of different methodologies for different marine mammal species groups. Below we describe the general groupings, lines of evidence and contextual information considered in the assessments.

7.1.1 Lines of Evidence

Response variables were defined for this exercise as: 'assuming that you have robust data on the response variable that show a difference from an expected value consistent with disturbance then, based on the current state of knowledge, how useful would you rate this response variable as a means of detecting a non-negligible impact' where negligible impact was defined as: 'an impact resulting from a specified activity that cannot be reasonably expected to, and is not reasonably likely to, affect the species or stock through effects on annual rates of recruitment or survival'.

For each species group, each method was coded as follows: '-': Not applicable; this method is not useful for RV estimation for this stock/species; 0: Not feasible to collect or analyze data within five years; 1: Feasible to collect data or analyze samples within five years, but no plans to do so; 2: Sufficient results for reviewing RV estimation expected within five years; 3: Method can be used to estimate variables of interest for assessing population consequences.

Initially, for each species, response variables LoE were coded as following: 0: this response variable is not informative or potentially misleading; 1: Weak; this RV must be combined with multiple additional response variables; 2: Moderate; this response variable must be combined with at least one other response variable and 3: Strong; this RV can be used alone to warrant concern for negative population consequences.

Following workshop breakout groups, it was determined these LoE rules did not exactly fit and the following approach was adapted, building off the initial assessments and discussions. 'Feasibility' capturing the readiness of the methodology for use in a monitoring program, the likelihood that it could be applied to each marine mammal group and its potential for collecting demographic / health information as new analytical techniques become available. It should be recognised that feasibility was assessed on a relative scale for each class of response variable, so that a feasibility score of 3 applied to a methodology for measuring demographic variables cannot be equated directly with a score of 3 applied to a methodology for monitoring health measures. In the workshop response variables were initially assessed 'Utility' captured the number of demographic variables and/or health measures that could be monitored with a specific method (see 'weighting' below).

The demographics group also developed a ranking combining an assessment of the feasibility of collecting information on each variable and how informative the variable was likely to be in a monitoring context (0 – not feasible; 1 – low feasibility and importance; 2 – medium feasibility and importance; 3 – high feasibility, importance and already currently being collected). The health value ranking used for weighting was developed following the workshop and followed the same approach. These scores were attributed to each variable and were used to weight the variables in calculating overall 'Utility' for a method in the Feasibility-Utility assessments (high importance variables contributed a larger score to the total Utility score (y-axis in Figure 5-Figure 15).

7.1.2 Species Groupings

Below are the approximate species groupings considered for a range of marine mammals species (

Table 9). The species presented are those included in datasets provided to OBIS-SEAMAP from Navy monitoring efforts. We note that no ice-breeding seal species were included in those datasets. They have been included in the report for completion.

Table 9 - Species groupings in Feasibility-Utility assessments. Where there is an *, this indicates where species might be moved to another category depending on the habitat and movement patterns of a specific population (e.g. killer whales might be considered coastal or oceanic, depending on population).

Species Group	Common Name	Scientific Name
Deep diving cetacean	Baird's Beaked Whale	Berardius bairdii
	Short-finned Pilot Whale	Globicephala macrorhynchus
	Pygmy Sperm Whale	Kogia breviceps
	Blainville's Beaked Whale	Mesoplodon densirostris
	Gervais' Beaked Whale	Mesoplodon europaeus
	True's Beaked Whale	Mesoplodon mirus
	Sperm Whale	Physeter macrocephalus
	Cuvier's Beaked Whale	Ziphius cavirostris
	Pygmy Killer Whale	Feresa attenuata
	Melon-headed Whale	Peponocephala electra
Baleen whale	Minke Whale	Balaenoptera acutorostrata
	Sei Whale	Balaenoptera borealis
	Bryde's whale	Balaenoptera brydei
	Eden's whale	Balaenoptera edeni
	Blue Whale	Balaenoptera musculus
	Fin Whale	Balaenoptera physalus
	Gray Whale	Eschrichtius robustus
	North Atlantic Right Whale	Eubalaena glacialis
	Humpback Whale	Megaptera novaeangliae
Coastal dolphins & porpoise	Harbor Porpoise*	Phocoena phocoena
	Dall's Porpoise	Phocoenoides dalli
	Risso's Dolphin*	Grampus griseus
	Bottlenose Dolphin*	Tursiops truncatus
	Killer Whale*	Orcinus orca
Oceanic dolphins	Long-beaked Common Dolphin	Delphinus capensis
	Short-beaked Common Dolphin	Delphinus delphis
	Fraser's Dolphin	Lagenodelphis hosei
	Pacific White-sided Dolphin	Lagenorhynchus obliquidens
	Northern Right Whale Dolphin	Lissodelphis borealis
	False Killer Whale	Pseudorca crassidens
	Pantropical Spotted Dolphin	Stenella attenuata
	Clymene Dolphin	Stenella clymene
	Striped Dolphin	Stenella coeruleoalba
	Atlantic Spotted Dolphin	Stenella frontalis
	Spinner Dolphin	Stenella longirostris
	Rough-toothed Dolphin	Steno bredanensis
Land-breeding pinnipeds	Steller Sea Lion	Eumetopias jubatus
	Hawaiian Monk Seal	Monachus schauinslandi
	Harbor Seal	Phoca vitulina
	California Sealion	Zalophus californianus
	Northern Fur Seal	Callorhinus ursinus
	Northern Elephant Seal	Mirounga angustirostris

7.2 Summary of US Navy marine mammal monitoring programs

Table 10 - Summary of the recent and current US Navy marine mammal monitoring programmes and publications (i.e. there is some duplication) summarising the species group of interest, the survey platform and survey method employed. AUTEC = Atlantic Undersea Test and Evaluation Centre, CHPT = Cherry Point, GOA TMAA = Gulf of Alaska Temporary Maritime Activities Area, HSTT = Hawaii-Southern California Training & Testing (includes HRC (Hawaii Range Complex), SOCAL (Southern California), SOAR (Southern California Anti-Submarine Warfare Range) & PMRF (Pacific Missile Range Facility)), JAX = Jacksonville, MINEX = Mine Exercise, MITT = Mariana Islands Range, NAS PAX = Chesapeake Bay, NSWC PCD = Naval Surface Warfare Centre, Panama City Division, NWTT = Northwest Training Range, VACAPES = Virginia Capes.

			Species Group						Method							Platform			
Region	Project Title	Location	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
ATLANTIC	Autonomous Real-Time Passive Acoustic Monitoring of Baleen Whales for Mitigating Interactions with Naval Activities	Gulf of Maine		X								X							X
	Seal Tagging and Tracking in Virginia	VACAPES					X			X			X		X	X			
	Acoustic Monitoring and Evaluation of Tursiops Response to MINEX Training activities	VACAPES			X	X						X							X
	Deep Diving Odontocete Behaviour and Spatial Use	VACAPES	X		X	X				X	X	X	X		X			X	X
	VACAPES Continental Shelf Break Cetacean Study	VACAPES	X	X						X	X		X		X			X	
	Mid-Atlantic Humpback Whale Monitoring	VACAPES		X						X	X		X		X			X	
	Haul-Out Counts and Photo-Identification of Pinnipeds in Chesapeake Bay, Virginia	VACAPES					X				X		X			X			

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Sperm whale (Physeter macrocephalus) presence and behavior off the mid-Atlantic states of North Carolina and Virginia from 2011 to 2016.	VACAPES	X								X						X		
	Hidden Markov models reveal complexity in the diving behaviour of short-finned pilot whales. -	VACAPES	X									X			X				X
	Diving behavior of Cuvier's beaked whales (Ziphius cavirostris) off Cape Hatteras, North Carolina.	VACAPES	X												X				
	Multi-scale behavioral response studies of cetaceans and MFAS along the US East Coast.	VACAPES	X									X			X				X
	Year-round presence of beaked whales off Cape Hatteras North Carolina.	VACAPES	X								X						X		
	Effects of duty-cycled passive acoustic recordings on detecting the presence of beaked whales in the northwest Atlantic.	VACAPES	X									X							X
	Baseline Monitoring for Marine Mammals in the East Coast Range Complexes (passive acoustics)	VACAPES & JAX	X	X	X	X						X							X
	Baseline Monitoring for Marine Mammals in the East Coast Range Complexes (aerial surveys)	VACAPES & JAX	X	X	X	X					X						X		
	Baseline Monitoring for Marine Mammals in the East Coast Range Complexes (vessel surveys)	VACAPES, CHPT & JAX	X	X	X	X				X	X		X		X			X	
	Passive Acoustic Monitoring for North Atlantic Right Whales off Cape Hatteras, North Carolina	CHPT		X								X							X
	Tagging and Tracking of Endangered North Atlantic Right Whales in Florida Waters	JAX		X							X				X			X	

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Patterns of occurrence and marine mammal acoustic behavior in relation to Navy sonar activity off Jacksonville, Florida.	JAX	X	X	X	X						X							X
	Haul-Out Counts and Photo-Identification of Pinnipeds in Narragansett Bay, RI	Narragansett Bay					X				X		X			X			
	NAS Patuxent River Marine Species Surveys	NAS PAX			X	X					X	X	X				X		X
	Bottlenose Dolphin Occurrence in Estuarine and Coastal Waters near Panama City, Florida	NSWC PCD			X					X	X		X					X	
	Acoustic monitoring of dolphin occurrence and activity in a MINEX training range.	MINEX			X							X							X
	Response by coastal dolphins to naval mine exercise (MINEX) training activities off Virginia Beach, USA.	MINEX			X							X							X
	Acoustic differentiation of Shiho- and Naisa-type short-finned pilot whales in the Pacific Ocean.	Pacific Coast	X									X							X
	The development of an intermediate-duration tag to characterize the diving behavior of large whales.	Gulf of California		X											X			X	
	Sound source measurements from pile driving	all East Coast										X							X
	Source levels and spectral characteristics of sound produced during pile driving at US East Coast Navy installations.	all East Coast										X							X
	Fin whale song variation in the southeast and middle Atlantic.	Atlantic coast		X								X							X

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Modelling the Offshore Distribution of Southern Resident Killer Whales in the Pacific Northwest	NWTT			X							X			X				X
	Marine Mammal Density Surveys in the Pacific Northwest (Inland Puget Sound)	NWTT			X		X				X						X		
	Pacific Northwest Pinniped Satellite Tracking	NWTT					X								X	X			
	Puget Sound aerial pinniped haulout surveys	NWTT	X								X						X		
	Passive acoustic monitoring NWTRC 2011-2012 -	NWTT	X	X	X	X						X							X
	Offshore gray whale tagging in the Pacific NW	NWTT		X											X			X	
	Summary of tag deployments on cetaceans off WA - May 2010 - May 2013	NWTT	X	X	X	X									X			X	
	Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2012-2013	NWTT	X	X	X	X						X							X
	Seasonality of NW killer whale calls TM558	NWTT			X							X							X
	Passive monitoring NWTRC TM557	NWTT	X	X	X	X						X							X
	Combining SRKW Tagging Acoustic Sighting Data	NWTT			X							X			X				X
PACIFIC	Harbor porpoise (Phocoena phocoena) recovery in the inland waters of Washington: estimates of density and abundance from aerial surveys, 2013-2015	NWTT			X						X						X		

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Small vessel visual surveys	MITT	X	X	X	X				X	X	X	X		X			X	
	Acoustic analysis of High-frequency Acoustic Recording Package data	MITT	X	X	X	X						X							X
	Pilot study for shore-based surveys	MITT	X	X	X						X					X			
	Autonomous glider passive acoustic monitoring of marine mammals in the Mariana Islands Ranch Complex	MITT	X	X	X	X						X							X
	Pilot study for shore based humpback surveys	MITT		X						X	X		X		X	X		X	
	cetacean surveys in Guam, the commonwealth of the northern marianas islads and the high-seas	MITT	X	X	X	X				X	X	X	X					X	
	Deployment of Ecological Acoustic Recorders in the Mariana Islands Range Complex (MIRC)	MITT	X	X	X	X						X							X
	Acoustic Data from the Mariana Islands Sea Turtle and Cetacean Survey (MISTCS)	MITT	X	X	X	X						X							X
	Analysis of long-term acoustic datasets from the Mariana Islands Range Complex (MIRC)	MITT	X	X	X	X						X							X
	Passive Acoustic Monitoring Of Marine Mammals Using Gliders	MITT	X	X	X	X						X							X
	Estimation of minke whale abundance from an acoustic line transect survey of the Mariana Islands. -	MITT		X								X						X	X
	Five decades of marine megafauna surveys from Micronesia.	MITT			X	X					X						X		

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Dwarf sperm whale (Kogia sima) echolocation clicks from Guam (Western North Pacific Ocean).	MITT	X								X	X						X	X
	A complex baleen whale call recorded in the Mariana Trench Marine National Monument.	MITT		X								X							X
	Mid-frequency active sonar and beaked whale acoustic activity in the Northern Mariana Islands.	MITT	X									X							X
	Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaii Range Complex	HRC	X	X	X	X					X						X		
	Habitat Use and Behavioral Monitoring of Hawaiian Monk Seals	HRC					X								X	X			
	Movements and Spatial Use of Satellite-tagged Odontocetes in the Western Main Hawaiian Islands	HRC	X		X	X							X		X				
	The characteristics of dolphin clicks compared across recording depths and instruments.	HRC			X	X						X							X
	Inter and intra specific variation in echolocation signals among odontocete species in Hawaii, the northwest Atlantic and the temperate Pacific.	HRC	X		X	X						X							X
	Beaked whale species occurrence in the central Pacific and their relation to oceanographic features.	HRC & MITT	X									X							X
	Central and western Pacific blue whale song and occurrence.	HRC & MITT		X								X							X
	Long-term Trends in Abundance of Marine Mammals at PMRF	PMRF	X	X		X						X							X
	Estimation of Received Levels of MFAS on Marine Mammals at PMRF	PMRF	X	X		X				X	X	X	X		X				X

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Behavioural Response of Marine Mammals to Navy Training and Testing at PMRF	PMRF	X	X		X				X	X	X	X		X			X	X
	Navy Civilian Marine Mammal Observers On MFAS Ships In Offshore Waters of the Hawaii Range Complex	PMRF	X	X	X	X					X							X	
	Swim track kinematics and calling behavior attributed to Bryde's whales on the Navy's Pacific Missile Range Facility	PMRF		X								X							X
	Occurrence and habitat use of foraging Blainville's beaked whales (Mesoplodon densirostris) on a U.S. Navy range in Hawaii	PMRF	X									X							X
	Impacts of U.S. Navy training events on Blainville's beaked whale (Mesoplodon densirostris) foraging dives in Hawaiian waters.	PMRF	X									X							X
	Opportunistic behavioral-response studies of baleen whales in response to US Navy sonar training off Kauai, Hawaii.	PMRF		X								X							X
	Blue And Fin Whale Satellite Tagging	SOCAL & NWTT		X						X	X		X		X			X	
	Marine mammal sightings during CalCOFI cruises	SOCAL	X	X	X	X													
	Cuvier's Beaked Whale Impact Assessment at the Southern California Offshore Antisubmarine Warfare Range (SOAR)	SOAR & SOCAL	X								X	X	X		X				X
	Cuvier's Beaked Whale, Blue Whale, and Fin Whale Impact Assessments at Non-Instrumented Range Locations in the SOCAL Range Complex	SOCAL	X	X							X	X	X		X				X

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
	Marine Mammal Observers on DDGs	SOCAL	X	X	X	X					X							X	
	Mixed-species associations of marine mammals in the Southern California Bight, with emphasis on Risso's dolphins (Grampus griseus)	SOCAL				X					X						X		
	Cetacean mother-calf behavior observed from a small aircraft off Southern California.	SOCAL		X	X						X						X		
	Blue whale (Balaenoptera musculus) behavior and group dynamics as observed from an aircraft off southern California.	SOCAL		X							X						X		
	Assessing 'observer effects' from a research aircraft on behavior of three Delphinidae species (Grampus griseus, Delphinus delphis,and Orcinus orca).	SOCAL			X	X					X				X		X		
	Gulf of Alaska Line-Transect Survey (GOALS) II: Marine Mammal Occurrence in the Temporary Maritime Activities Area	GOA TMAA	X	X	X	X					X	X	X		X			X	X
	Passive Acoustic Monitoring of Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area using Autonomous Gliders	GOA TMAA		X	X	X						X							X
	Passive Acoustic Monitoring of Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area using Bottom-Mounted Passive Acoustic Devices	GOA TMAA	X	X								X							X
	Abundance and distribution of cetaceans in the Gulf of Alaska.	GOA TMAA	X	X	X	X					X							X	

			Species Group						Method							Platform			
Region	**Project Title**	**Location**	Deep diving cetaceans	Baleen whales	Coastal dolphins and porpoise	Oceanic dolphins	Land-breeding pinnipeds	Ice-breeding pinnipeds	Hands on Assessment	Remote Tissue Sampling	Visual Survey	Acoustic Survey	Capture-recapture	Photogrammetry	Individual tracking	Land	Aerial	Vessel	PAM
Various/Other	Marine mammal passive acoustics applied to the monitoring of long-term trends in beaked whale abundance and to the derivation of a behavioral risk function for exposure to mid-frequency active sonar.	AUTEC, PMRF, SOCAL	X									X							X
	Calls of North Atlantic right whales Eubalaena glacialis contain information on individual identity and age class.	Various		X								X							X
	Echolocation behavior of endangered fish-eating killer whales (Orcinus orca) recorded from digital acoustic recording tags (DTAGs): Insight into subsurface foraging activity.	Various			X										X			X	
	Does depth matter? Investigating the effect of recording depth on delphinid whistle characteristics and classifier performance.	Various			X	X						X							X
	Long-term monitoring of cetaceans using autonomous acoustic recording packages	Various	X	X	X	X						X							X
	Baleen whale responses to a high frequency active pinger: Implications for upper frequency hearing limits.	Australia		X											X			X	

8 References

Aarts, G., M. MacKenzie, B. McConnell, M. Fedak, and J. Matthiopoulos. 2008. Estimating space-use and habitat preference from wildlife telemetry data. Ecography **31**:140-160.

Aguilar de Soto, N., E. Carroll, and P. Hammond. 2016 project. Assessing resilience of beaked whale populations to human impacts: Population structure and genetic diversity in impacted and semi-pristine areas. Current ONR funded project.

Aguilar, N., C. Reyes, A. Schiav, and P. S. Hammond. 2013. Population Parameters of Blainville´s and Cuvier´s Beaked Whales. 2013 Marine Mammal & Biology Program Review.

Amidan, B. G., A. M. Venzin, and L. M. Bramer. 2015. Multiple Lines of Evidence. Pacific Northwest National Lab.(PNNL), Richland, WA (United States).

Aoki, K., Y. Y. Watanabe, D. E. Crocker, P. W. Robinson, M. Biuw, D. P. Costa, N. Miyazaki, M. A. Fedak, and P. J. O. Miller. 2011. Northern elephant seals adjust gliding and stroking patterns with changes in buoyancy: validation of at-sea metrics of body density. Journal of Experimental Biology **214**:2973-2987.

Arranz, P., N. Aguilar de Soto, T. Marques, L. Thomas, and M. Johnson. 2016 project. Estimating beaked whale density from passive acoustic recordings. Current ONR funded project.

Aschettino, J. M., D. Engelhaupt, A. Engelhaupt, and R. M. 2016. Mid-Atlantic Humpback Whale Monitoring, Virginia Beach, Virginia: 2015/16 Annual Progress Report. Final Report., Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract Nos. N62470-10-3011, Task Orders 03 and 54, and N62470-15-8006, Task Order 13, issued to HDR Inc., Virginia Beach, Virginia. 30 August 2016.

Atkinson, S. 2017. Development and Validation of Techniques for the Detection of Pregnancy and Stress in Large Whales. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Ayres, K. L., R. K. Booth, J. A. Hempelmann, K. L. Koski, C. K. Emmons, R. W. Baird, K. Balcomb-Bartok, M. B. Hanson, M. J. Ford, and S. K. Wasser. 2012. Distinguishing the impacts of inadequate prey and vessel traffic on an endangered killer whale (Orcinus orca) population. PLoS ONE **7**:e36842.

Baird, R., G. S. Schorr, D. Webster, S. Mahaffy, J. Aschettino, and T. Cullins. 2011. Movements and spatial use of satellite tagged odontocetes in the western main Hawaiian Islands: results of field work undertaken off O'ahu in October 2010 and Kaua'i in February 2011. Prepared for: CNO(N45), Washington, D.C. NPS-OC-11-006CR.

Ballardini, M., T. Pusser, and B. Nani. 2005. Photo-identification of Cuvier's beaked whale (*Ziphius cavirostris*) in the Northern Ligurian Sea. Pages 2-7 *in* 19 th Annual Conference of the European Cetacean Society. La Rochelle, France. April.

Balmer, B., B. Quigley, T. Speakman, G. Ylitalo, E. Zolman, and L. Schwacke. 2015. Study of Bottlenose Dolphin Occurrence in St. Andrew Bay, Florida and Coastal Waters Near the Naval Surface Warfare Center, Panama City Division Testing Range. MOA-2015-029/9087.

Barlow, J., and B. L. Taylor. 2005. Estimates of sperm whale abundance in the northeastern temperate Pacific from a combined acoustic and visual survey. Marine Mammal Science **21**:429-445.

Barlow, J., P. L. Tyack, M. P. Johnson, R. W. Baird, G. S. Schorr, R. D. Andrews, and N. Aguilar de Soto. 2013. Trackline and point detection probabilities for acoustic surveys of Cuvier's and Blainville's beaked whales. Journal of the Acoustical Society of America **134**:2486-2496.

Bassos-Hull, K., R. M. Perrtree, C. C. Shepard, S. Schilling, A. A. Barleycorn, J. B. Allen, B. C. Balmer, W. E. Pine, and R. S. Wells. 2013. Long-term site fidelity and seasonal abundance estimates of common bottlenose dolphins (*Tursiops truncatus*) along the southwest coast of Florida and responses to natural perturbations. J. Cetacean Res. Manage **13**:19-30.

Baumann-Pickering, S., A. Simonis, J. S. Trickey, M. A. Roch, and E. M. Oleson. 2016. Beaked whale species occurrence in the central Pacific and their relation to oceanographic features. J. Acoust. Soc. Am., Vol. 140, No. 4, Pt. 2, October 2016.

Baumgartner, M. F., and D. M. Fratantoni. 2008. Diel periodicity in both sei whale vocalization rates and the vertical migration of their copepod prey observed from ocean gliders. Limnology and Oceanography **53**:2197-2209.

Baumgartner, M. F., D. M. Fratantoni, T. P. Hurst, M. W. Brown, T. V. Cole, S. M. Van Parijs, and M. Johnson. 2013. Real-time reporting of baleen whale passive acoustic detections from ocean gliders. The Journal of the Acoustical Society of America **134**:1814-1823.

Bennett, A., V. Preston, J. Woo, S. Chandra, D. Diggins, R. Chapman, Z. Wang, M. Rush, L. Lye, and M. Tieu. 2015. Autonomous vehicles for remote sample collection in difficult conditions: Enabling remote sample collection by marine biologists. Pages 1-6 *in* Technologies for Practical Robot Applications (TePRA), 2015 IEEE International Conference on. IEEE.

Benoit-Bird, K. J. 2017. Linking deep-water prey fields with odontocete population structure and behavior. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017. Office of Naval Research, Arlington, VA.

Benoit-Bird, K. J., B. L. Southall, and M. A. Moline. 2016. Predator-guided sampling reveals biotic structure in the bathypelagic. Page 20152457 *in* Proc. R. Soc. B. The Royal Society.

Bertulli, C. G., A. Galatius, C. C. Kinze, M. H. Rasmussen, W. Keener, and M. A. Webber. 2016. Color patterns in white-beaked dolphins (*Lagenorhynchus albirostris*) from Iceland. Marine Mammal Science **32**:1072-1098.

Biuw, M., L. Boehme, C. Guinet, M. Hindell, D. Costa, J.-B. Charrassin, F. Roquet, F. Bailleul, M. Meredith, and S. Thorpe. 2007. Variations in behavior and condition of a Southern Ocean top predator in relation to in situ oceanographic conditions. Proceedings of the National Academy of Sciences **104**:13705-13710.

Biuw, M., B. McConnell, C. J. Bradshaw, H. Burton, and M. Fedak. 2003. Blubber and buoyancy: monitoring the body condition of free-ranging seals using simple dive characteristics. Journal of Experimental Biology **206**:3405-3423.

Blundell, G. M., and G. W. Pendleton. 2008. Estimating age of harbor seals (*Phoca vitulina*) with incisor teeth and morphometrics. Marine Mammal Science **24**:577-590.

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.

Bradford, A. L., D. W. Weller, A. E. Punt, Y. V. Ivashchenko, A. M. Burdin, G. R. VanBlaricom, and R. L. Brownell Jr. 2012. Leaner leviathans: body condition variation in a critically endangered whale population. Journal of mammalogy **93**:251-266.

Büche, B., and E. Stubbings. 2016. Grey Seal Breeding Census Skomer Island 2015. Wildlife Trust of South and West Wales.

Calambokidis, J. 2017. Behavioral and physiological response of baleen whales to ships and ship noise. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Calambokidis, J., G. H. Steiger, J. M. Straley, L. M. Herman, S. Cerchio, D. R. Salden, U. R. Jorge, J. K. Jacobsen, O. V. Ziegesar, and K. C. Balcomb. 2001. Movements and population structure of humpback whales in the North Pacific. Marine Mammal Science **17**:769-794.

Carroll, E., N. Patenaude, S. Childerhouse, S. Kraus, R. Fewster, and C. Baker. 2011. Abundance of the New Zealand subantarctic southern right whale population estimated from photo-identification and genotype mark-recapture. Marine Biology **158**:2565-2575.

Champagne, C., and D. Houser. 2015. Stress Hormones and their Regulation in a Captive Dolphin Population. Award Number: N000141310770.

Christiansen, F. 2017. Developing a bioenergetic model for baleen whales to assess population consequences of disturbance – Phase 1. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Christiansen, F., A. M. Dujon, K. R. Sprogis, J. P. Y. Arnould, and L. Bejder. 2016. Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales. Ecosphere **7**.

Christiansen, F., F. Vivier, C. Charlton, R. Ward, A. Amerson, S. Burnell, and L. Bejder. in review. Maternal body size and condition determine calf growth rates in Southern right whales. Marine Ecology Progress Series **XX**:XX-XX.

Claridge, D., C. Dunn, J. Durban, H. Fearnbach, and W. Perryman. 2017. Photogrammetry with an Unmanned Aerial System to Assess Body Condition and Growth of Blainville's Beaked Whales. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017. Office of Naval Research.

Claridge, D. E. 2013. Population ecology of Blainville's beaked whales (*Mesoplodon densirostris*). University of St Andrews.

Clark, C. T., A. H. Fleming, J. Calambokidis, N. M. Kellar, C. D. Allen, K. N. Catelani, M. Robbins, N. E. Beaulieu, D. Steel, and J. T. Harvey. 2016. Heavy with child? Pregnancy status and stable isotope ratios as determined from biopsies of humpback whales. Conservation Physiology **4**:1-13.

Cordes, L. S., and P. M. Thompson. 2015. Mark-resight estimates of seasonal variation in harbor seal abundance and site fidelity. Population Ecology **57**:467-472.

Costa, D. 2015. Development of the PCAD Model to Assess Biological Significance of Acoustic Disturbance. Award Number: N00014-13-1-0134.

Costa, D. P. 1987. Isotopic methods for quantifying material and energy intake of free-ranging marine mammals. Approaches to marine mammal energetics **1**:43-66.

Costa, D. P. 2012. A bioenergetics approach to developing a population consequences of acoustic disturbance model. Pages 423-426 The Effects of Noise on Aquatic Life. Springer.

Costa, D. P., J. P. Croxall, and C. D. Duck. 1989. Foraging energetics of antartic fur seals in relation to changes in prey availability. Ecology **70**:596-606.

Costa, D. P., L. Schwarz, P. Robinson, R. S. Schick, P. A. Morris, R. Condit, D. E. Crocker, and A. M. Kilpatrick. 2016. A bioenergetics approach to understanding the population consequences of disturbance: Elephant seals as a model system. Pages 161-169 The Effects of Noise on Aquatic Life II. Springer.

Crocker, D. E., B. J. L. Boeuf, and D. P. Costa. 1997. Drift diving in female northern elephant seals: implications for food processing. Canadian journal of zoology **75**:27-39.

Crocker, D. E., D. S. Houser, D. M. Janz, N. M. Kellar, and J. F. Cockrem. 2017. Variability of hormonal stress markers and stress responses in a large cross-sectional sample of elephant seals / Physiological impacts of variation in hormonal stress markers and stress responses in a large cross-sectional sample of elephant seals. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Currey, R. J., S. M. Dawson, E. Slooten, K. Schneider, D. Lusseau, O. J. Boisseau, P. Haase, and J. A. Williams. 2009. Survival rates for a declining population of bottlenose dolphins in Doubtful Sound, New Zealand: an information theoretic approach to assessing the role of human impacts. Aquatic Conservation: Marine and Freshwater Ecosystems **19**:658-670.

De Wet, M. 2013. A systematic health assessment of two dolphin species by-caught in shark nets off the KwaZulu-Natal coast, South Africa. University of Pretoria.

Deagle, B. E., and D. J. Tollit. 2007. Quantitative analysis of prey DNA in pinniped faeces: potential to estimate diet composition? Conservation Genetics **8**:743-747.

Debich, A. J., S. Baumann-Pickering, A. Širović, J. Hildebrand, A. Alldredge, R. Gottlieb, S. Herbert, S. Johnson, L. Roche, B. Thayre, J. S. Trickey, and S. M. Wiggins. 2014. Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2012-2013. Marine Physical Laboratory Scripps Institution of Oceanography University of California San Diego.

Department of the Navy. 2014. Marine species monitoring for the US Navy's Gulf of Alaska Temporary Maritime Activitiers Area - Annual Report 2014. US Pacific Fleet, Pearl Harbour, HI.

DeRuiter, S. L., I. L. Boyd, D. E. Claridge, C. W. Clark, C. Gagnon, B. L. Southall, and P. L. Tyack. 2013. Delphinid whistle production and call matching during playback of simulated military sonar. Marine Mammal Science **29**:E46-E59.

DoN. 2016a. 2015 U.S. Navy Annual Marine Species Monitoring Report for the Pacific: A Multi-Range Complex Monitoring Report for Hawaii-Southern California Training and Testing (HSTT), Mariana Islands Training and Testing (MITT), Northwest Training and Testing (NWTT), and the Gulf of Alaska Temporary Maritime Activities Area (GOA TMAA).

DoN. 2016b. Marine Species Monitoring Report for the U.S. Navy's Atlantic Fleet Training and Testing (AFTT) – 2015 Annual Report., U.S. Fleet Forces Command, Norfolk, Virginia.

Donovan, C., J. Harwood, S. King, C. Booth, B. Caneco, and C. Walker. 2016. Expert elicitation methods in quantifying the consequences of acoustic disturbance from offshore renewable energy developments. Pages 231-237 The Effects of Noise on Aquatic Life II. Springer.

Drinkwater, K. F., A. Belgrano, A. Borja, A. Conversi, M. Edwards, C. H. Greene, G. Ottersen, A. J. Pershing, and H. Walker. 2003. The response of marine ecosystems to climate variability associated with the North Atlantic Oscillation. Wiley Online Library.

Dunstan, J., A. Gledhell, A. Hall, P. Miller, and C. Ramp. 2012. Quantification of the hormones progesterone and cortisol in whale breath samples using novel, non-invasive sampling and analysis with highly-sensitive ACQUITY UPLC and Xevo TQ-S. Waters Application Note: Waters Corporation, Milford, MA, USA.

Durban, J., and K. Parsons. 2006. Laser-metrics of free-ranging killer whales. Marine Mammal Science **22**:735-743.

Durban, J. W., M. J. Moore, G. Chiang, L. S. Hickmott, A. Bocconcelli, G. Howes, P. A. Bahamonde, W. L. Perryman, and D. J. LeRoi. 2016. Photogrammetry of blue whales with an unmanned hexacopter. Marine Mammal Science **32**:1510-1515.

Ellison, W. T., B. L. Southall, C. W. Clark, and A. S. Frankel. 2013. A new context-based approach to assess marine mammal behavioral responses to anthropogenic souns. Conservation Biology **26**:21-28.

Estes, J., D. Doak, A. Springer, and T. Williams. 2009. Causes and consequences of marine mammal population declines in southwest Alaska: a food-web perspective. Philosophical Transactions of the Royal Society of London B: Biological Sciences **364**:1647-1658.

Fahlman, A., S. Miedler, D. Garcia-Parraga, L. Marti-Bonmati, and M. Brodsky. 2016 project. Cardiorespiratory physiology in the bottlenose dolphin and harbor porpoise before and after breath-holding and exercise. Current ONR funded project.

Fair, P. A., A. M. Schaefer, T. A. Romano, G. D. Bossart, S. V. Lamb, and J. S. Reif. 2014. Stress response of wild bottlenose dolphins (Tursiops truncatus) during capture–release health assessment studies. General and Comparative Endocrinology **206**:203-212.

Falcone, E. A., G. S. Schorr, A. B. Douglas, J. Calambokidis, E. Henderson, M. F. McKenna, J. Hildebrand, and D. Moretti. 2009. Sighting characteristics and photo-identification of Cuvier's beaked whales (*Ziphius cavirostris*) near San Clemente Island, California: a key area for beaked whales and the military? Marine Biology **156**:2631-2640.

Fearnbach, H., J. Durban, D. Ellifrit, and K. Balcomb. 2015. Individual-based photogrammetric measures of length, growth and shape to infer body condition and reproductive status of southern resident killer whales.

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

Foley, H. J., N. J. Quick, D. M. Waples, Z. T. Swaim, and R. A.J. 2016a. Deep Divers and Satellite Tagging Project in the Virginia Capes OPAREA–Cape Hatteras, North Carolina: 2015 Annual Progress Report. . Prepared for United States Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract Nos. N62470-10-3011 (TO) 48 and N62470-15-D-8006 (TO 07) issued to HDR, Inc., Virginia Beach, Virginia. 12 February 2016.

Foley, H. J., D. M. Waples, L. J. Pallin, K. W. Urian, Z. T. Swaim, and A. J. Read. 2016b. Small Vessel Surveys for Protected Species in Navy OPAREAs off the U.S. Atlantic Coast: 2015 Annual Progress Report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract Nos. N62470-10-3011, Task Order 49 and N62470-15-D-8006, Task Order 04, issued to HDR, Inc., Virginia Beach, Virginia. 12 February 2016.

Ford, M. J., M. B. Hanson, J. A. Hempelmann, K. L. Ayres, C. K. Emmons, G. S. Schorr, R. W. Baird, K. C. Balcomb, S. K. Wasser, and K. M. Parsons. 2011. Inferred paternity and male reproductive success in a killer whale (*Orcinus orca*) population. Journal of Heredity **102**:537-553.

Fossi, M., L. Marsili, M. Junin, H. Castello, J. Lorenzani, S. Casini, C. Savelli, and C. Leonzio. 1997. Use of nondestructive biomarkers and residue analysis to assess the health status of endangered species of pinnipeds in the south-west Atlantic. Marine pollution bulletin **34**:157-162.

Friedlaender, A., E. Hazen, J. Goldbogen, A. Stimpert, J. Calambokidis, and B. Southall. 2016. Prey-mediated behavioral responses of feeding blue whales in controlled sound exposure experiments. Ecological Applications **26**:1075-1085.

Gabriele, C. M., J. L. Neilson, J. M. Straley, C. S. Baker, J. A. Cedarleaf, and J. F. Saracco. 2017. Natural history, population dynamics, and habitat use of humpback whales over 30 years on an Alaska feeding ground. Ecosphere **8**.

Galatius, A., O. E. Jansen, and C. C. Kinze. 2013. Parameters of growth and reproduction of white-beaked dolphins (*Lagenorhynchus albirostris*) from the North Sea. Marine Mammal Science **29**:348-355.

Gillespie, D., P. Berggren, S. Brown, I. Kuklik, C. Lacey, T. Lewis, J. Matthews, R. McLanaghan, A. Moscrop, and N. Tregenza. 2005. Relative abundance of harbour porpoises (*Phocoena phocoena*) from acoustic and visual surveys of the Baltic Sea and adjacent waters during 2001 and 2002. J. Cetacean. Res. Manage **7**:51-57.

Gillespie, D., R. Leaper, J. Gordon, and K. Macleod. 2010. An integrated data collection system for line transect surveys. J Cetacean Res Manage **11**:217-227.

Graham, I. M., B. Cheney, R. C. Hewitt, L. S. Cordes, G. D. Hastie, D. J. F. Russell, M. Arso Civil, P. S. Hammond, and P. M. Thompson. 2016. Strategic Regional Pre-Construction Marine Mammal Monitoring Programme Annual Report 2016. University of Aberdeen.

Greene, C. H., and A. J. Pershing. 2003. The flip-side of the North Atlantic Oscillation and modal shifts in slope-water circulation patterns. Limnology and Oceanography **48**:319-322.

Greig, D. J., F. M. D. Gulland, C. A. Rios, and A. J. Hall. 2010. Hematology and Serum Chemistry in Stranded and Wild-Caught Harbor Seals in Central California: Reference Intervals, Predictors of Survival, and Parameters Affecting Blood Variables. Journal of Wildlife Diseases **46**:1172-1184.

Gryzbek, M. K. 2013. A Visual Body Condition Index for Bottlenose Dolphins (*Tursiops truncatus*).

Hall, A. J., F. M. Gulland, J. A. Hammond, L. H. Schwacke, I. Boyd, W. Bowen, and S. Iverson. 2010. Epidemiology, disease, and health assessment. Marine mammal ecology and conservation. Oxford University Press, New York, NY:144-164.

Hansen, L. J., and R. S. Wells. 1996. Bottlenose dolphin health assessment: Field report on sampling near Beaufort, North Carolina, during July, 1995. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Charleston Laboratory.

Hanson, M. B., R. W. Baird, J. K. Ford, J. Hempelmann-Halos, D. M. Van Doornik, J. R. Candy, C. K. Emmons, G. S. Schorr, B. Gisborne, and K. L. Ayres. 2010. Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. Endangered Species Research **11**:69-82.

Harris, C. M., and L. Thomas. 2015. Status and future of research on the behavioural responses of marine mammals to US Navy sonar.

Harris, D., L. Matias, L. Thomas, J. Harwood, and W. H. Geissler. 2013. Applying distance sampling to fin whale calls recorded by single seismic instruments in the northeast Atlantic. Journal of the Acoustical Society of America **134**:3522-3535.

Harris, D. V. 2012. Estimating whale abundance using sparse hydrophone arrays. University of St Andrews.

Harvey, J. 1989. Assessment of errors associated with harbour seal (*Phoca vitulina*) faecal sampling. Journal of Zoology **219**:101-111.

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.

HDR. 2016. Work Plan: VACAPES Outer Continental Shelf Cetacean Study. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8066 Task Order 35, issued to HDR Inc., Virginia Beach, Virginia. 26 October 2016.

Helble, T. A., G. L. D'Spain, G. S. Campbell, and J. A. Hildebrand. 2013. Calibrating passive acoustic monitoring: correcting humpback whale call detections for site-specific and time-dependent environmental characteristics. The Journal of the Acoustical Society of America **134**:EL400-EL406.

Helble, T. A., G. R. Ierley, G. L. D'Spain, and S. W. Martin. 2015. Automated acoustic localization and call association for vocalizing humpback whales on the Navy's Pacific Missile Range Facility. The Journal of the Acoustical Society of America **137**:11-21.

Henderson, E. E., S. W. Martin, R. Manzano-Roth, and B. M. Matsuyama. 2016. Occurrence and habitat use of foraging Blainville's beaked whales (Mesoplodon densirostris) on a US Navy range in Hawaii. Aquatic Mammals **42**:549.

Herman, D. P., C. O. Matkin, G. M. Ylitalo, J. W. Durban, M. B. Hanson, M. E. Dahlheim, J. M. Straley, P. R. Wade, K. L. Tilbury, and R. H. Boyer. 2008. Assessing age distributions of killer whale Orcinus orca populations from the composition of endogenous fatty acids in their outer blubber layers. Marine Ecology Progress Series **372**:289-302.

Herzing, D. L. 1997. The life history of free-ranging Atlantic spotted dolphins (*Stenella frontalis*): age classes, color phases, and female reproduction. Marine Mammal Science **13**:576-595.

Hewitt, D. A., E. C. Janney, B. S. Hayes, and R. S. Shively. 2010. Improving inferences from fisheries capture-recapture studies through remote detection of PIT tags. Fisheries **35**:217-231.

Hill M.C., A. D. Ligon, M. H. Deakos, A. C. Ü, A. J. Milette-Winfree, and E. M. Oleson. 2013. Cetacean Surveys of Guam and CNMI Waters: May – July, 2012: Including Individual PhotoIdentification of Pilot Whales, Spinner Dolphins and Bottlenose Dolphins (2010-2012). Prepared for the U.S. Pacific Fleet Environmental Readiness Office. PIFSC Data Report DR-13-001. 40pp.

Hindell, M. A., C. R. McMahon, M. N. Bester, L. Boehme, D. Costa, M. A. Fedak, C. Guinet, L. Herraiz-Borreguero, R. G. Harcourt, and L. Huckstadt. 2016. Circumpolar habitat use in the southern elephant seal: implications for foraging success and population trajectories. Ecosphere **7**.

Hodge, L., J. Stanistreet, and A. Read. 2016. Annual Report 2015: Passive Acoustic Monitoring for Marine Mammals off Virginia, North Carolina, and Florida Using High-frequency Acoustic Recording Packages. Draft Report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract Nos. N62470-15-D-3011, Task Order 51 and N2470-15-D-8006, Task Order 06 issued to HDR, Inc., Virginia Beach, Virginia. February 2016.

Hogg, C., T. Rogers, A. Shorter, K. Barton, P. Miller, and D. Nowacek. 2009. Determination of steroid hormones in whale blow: It is possible. Marine Mammal Science **25**:605-618.

Hohn, A. A., and S. Fernandez. 1999. Biases in dolphin age structure due to age estimation technique. Marine Mammal Science **15**:1124-1132.

Houser, D. 2017. Variability of hormonal stress markers collected from a managed dolphin population. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Hughes-Hanks, J., L. Rickard, C. Panuska, J. Saucier, T. O'hara, L. Dehn, and R. Rolland. 2005. Prevalence of Cryptosporidium spp. and Giardia spp. in five marine mammal species. Journal of Parasitology **91**:1225-1228.

Hunt, K. E., M. J. Moore, R. M. Rolland, N. M. Kellar, A. J. Hall, J. Kershaw, S. A. Raverty, C. E. Davis, L. C. Yeates, and D. A. Fauquier. 2013. Overcoming the challenges of studying conservation physiology in large whales: a review of available methods. Conservation Physiology **1**:cot006.

Ireland, D. S. 2004. Mass estimation of Weddell seals through photogrammetry. Montana State University-Bozeman, College of Letters & Science.

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.

Joblon, M. J., M. A. Pokras, B. Morse, C. T. Harry, K. S. Rose, S. M. Sharp, M. E. Niemeyer, K. M. Patchett, W. B. Sharp, and M. J. Moore. 2014. Body condition scoring system for delphinids based on short-beaked common dolphins (Delphinus delphis). J Mar Anim Ecol **7**:5-13.

Johnson, M. P., and P. L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. IEEE Journal of Oceanic Engineering **28**:3-12.

Karczmarski, L., B. Würsig, G. Gailey, K. W. Larson, and C. Vanderlip. 2005. Spinner dolphins in a remote Hawaiian atoll: social grouping and population structure. Behavioral Ecology **16**:675-685.

Kellar, N. M., and J. Durban. 2017. Assessing beaked whale reproduction and stress response relative to sonar activity at the Atlantic Undersea Test and Evaluation Center (AUTEC). 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Kellar, N. M., J. Keliher, M. L. Trego, K. N. Catelani, C. Hanns, J. C. George, and C. Rosa. 2013. Variation of bowhead whale progesterone concentrations across demographic groups and sample matrices. Endangered Species Research **22**:61-72.

Kellar, N. M., M. L. Trego, C. I. Marks, S. J. Chivers, K. Danil, and F. I. Archer. 2009. Blubber testosterone: A potential marker of male reproductive status in short-beaked common dolphins. Marine Mammal Science **25**:507-522.

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.

Kjeld, M., Ö. Ólafsson, G. A. Víkingsson, and J. Sigurjónsson. 2006. Sex hormones and reproductive status of the North Atlantic fin whales (*Balaenoptera physalus*) during the feeding season. Aquatic Mammals **32**:75.

Klinck, H., D. K. Mellinger, K. Klinck, N. M. Bogue, J. C. Luby, W. A. Jump, G. B. Shilling, T. Litchendorf, A. S. Wood, and G. S. Schorr. 2012. Near-real-time acoustic monitoring of beaked whales and other cetaceans using a Seaglider™. PLoS One **7**:e36128.

Kogi, K., T. Hishii, A. Imamura, T. Iwatani, and K. M. Dudzinski. 2004. Demographic Parameters Of Indo-Pacific Bottlenose Dolphins (*Tursiops aduncus*) Around Mikura Island, Japan. Marine Mammal Science **20**:510-526.

Koopman, H. N., S. J. Iverson, and A. Read. 2003. High concentrations of isovaleric acid in the fats of odontocetes: variation and patterns of accumulation in blubber vs. stability in the melon. Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology **173**:247-261.

Koski, W., D. Rugh, A. Punt, and J. Zeh. 2006. An approach to minimise bias in estimation of the length-frequency distribution of bowhead whales (Balaena mysticetus) from aerial photogrammetric data. Journal of Cetacean Research and Management **8**:45.

Koski, W., J. Zeh, and J. George. 2008. A calf index for monitoring reproductive success in the Bering-Chukchi-Beaufort Seas bowhead whale (Balaena mysticetus) population. J. Cetacean Res. Manage **10**:99-106.

Koski, W. R., T. Allen, D. Ireland, G. Buck, P. R. Smith, A. M. Macrander, M. A. Halick, C. Rushing, D. J. Sliwa, and T. L. McDonald. 2009. Evaluation of an unmanned airborne system for monitoring marine mammals. Aquatic Mammals **35**:347.

Koski, W. R., T. A. Thomas, D. W. Funk, and A. M. Macrander. 2013. Marine mammal sightings by analysts of digital imagery versus aerial surveyors: a preliminary comparison. Journal of Unmanned Vehicle Systems **1**:25-40.

Kuningas, S., T. Similä, and P. S. Hammond. 2014. Population size, survival and reproductive rates of northern Norwegian killer whales (Orcinus orca) in 1986–2003. Journal of the Marine Biological Association of the United Kingdom **94**:1277-1291.

Kusel, E. T., D. K. Mellinger, L. Thomas, T. A. Marques, D. Moretti, and J. Ward. 2011. Cetacean population density estimation from single fixed sensors using passive acoustics. Journal of the Acoustical Society of America **129**:3610-3622.

Laidre, K. L., and M. P. Heide-Jorgensen. 2012. Spring partitioning of Disko Bay, West Greenland, by Arctic and Subarctic baleen whales. ICES Journal of Marine Science **69**:1226-1233.

Lammers, M. 2017. Does depth matter? Examining factors that could influence the acoustic identification of odontocete species on bottom-moored recorders. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Lane, S. M., C. R. Smith, J. Mitchell, B. C. Balmer, K. P. Barry, T. McDonald, C. S. Mori, P. E. Rosel, T. K. Rowles, and T. R. Speakman. 2015. Reproductive outcome and survival of common bottlenose dolphins sampled in Barataria Bay, Louisiana, USA, following the Deepwater Horizon oil spill. Page 20151944 *in* Proc. R. Soc. B. The Royal Society.

Littnan, C., and K. Wilson. 2011. APPENDIX M. Habitat Use and Behavioral Monitoring of Hawaiian Monk Seals in Proximity to the Navy Hawaii Range Complex. Report Period: August 2010-July 2011. National Marine Fisheries Service Permit No. 10137 To Take Protected Species For Scientific Research And Enhancement Purposes.

Lukacs, P. M., and K. P. Burnham. 2005. Review of capture–recapture methods applicable to noninvasive genetic sampling. Molecular Ecology **14**:3909-3919.

Lusseau, D. 2015. Understanding the Onset of Health Impacts Caused by Disturbances. Award Number: N000141512377.

Lusseau, D. 2017. The Health Black Box in PCoD: Understanding the Onset of Health Impacts Caused by Disturbance. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Madsen, P., and J. van der Hoop. 2016 project. RATE: Respiratory Acoustics To estimate Energy. Current ONR funded project.

Marques, T. A., L. Thomas, S. W. Martin, D. K. Mellinger, S. Jarvis, R. P. Morrissey, C. A. Ciminello, and N. DiMarzio. 2012. Spatially explicit capture-recapture methods to estimate minke whale density from data collected at bottom-mounted hydrophones. Journal of Ornithology **152**:S445-S455.

Marques, T. A., L. Thomas, J. Ward, N. DiMarzio, and P. L. Tyack. 2009. Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainvilleɘs beaked whales. The Journal of the Acoustical Society of America **125**:1982-1994.

Martin, S. W., T. A. Marques, L. Thomas, R. P. Morrissey, S. Jarvis, N. DiMarzio, D. Moretti, and D. K. Mellinger. 2013. Estimating minke whale (*Balaenoptera acutorostrata*) boing sound density using passive acoustic sensors. Marine Mammal Science **29**:142-158.

Mason, E. 2017. Quantifying photogrammetric accuracy for measuring humpback whales using Unmanned Aerial Systems.

Mate, B. 2013. Offshore Gray Whale Satellite Tagging in the Pacific Northwest. Prepared for Commander, U.S. Pacific Fleet, Pearl Harbor, Hawaii. Submitted to Naval Facilities Engineering Command Northwest (NAVFAC NW), Silverdale, WA 98315-1101, under Contract # N62470-
10-D-3011, issued to HDR Inc., San Diego, California 92123. 18 June 2013.

Mate, B., R. Mesecar, and B. Lagerquist. 2007. The evolution of satellite-monitored radio tags for large whales: one laboratory's experience. Deep-Sea Res Part II **54**.

Mate, B. R., L. M. Irvine, and D. M. Palacios. 2016. The development of an intermediate-duration tag to characterize the diving behavior of large whales. Ecology and evolution:n/a-n/a.

Mate, B. R., G. K. Krutzikowsky, and M. H. Winson. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration. Can J Zool **78**.

Mate, B. R., D. Palacios, C. Baker, B. Lagerquist, L. Irvine, T. Follett, D. Steel, C. Hayslip, and M. Winsor. 2017. Baleen Whale Tagging in Support of Marine Mammal Monitoring Across Multiple Navy Training Areas. Preliminary Report. Prepared for Commander, U.S. Pacific Fleet. Submitted to Naval Facilities Engineering Command Pacific, Pearl Harbor, Hawaii under Contract No. N62470-15-8006 (FZN1) issued to HDR, Inc., San Diego, California. January 2017.

Matthews, J., L. Steiner, and J. Gordon. 2001. Mark-recapture analysis of sperm whale (*Physeter macrocephalus*) photo-id data from the Azores (1987-1995). Journal of Cetacean Research and Management **3**:219-226.

McAlarney, R., E. Cummings, B. McLellan, and A. Pabst. 2014. Protected Species Monitoring in the Virginia Capes OPAREA Cape Hatteras, North Carolina January 2013 – December 2013.

McCarthy, E., D. Moretti, L. Thomas, N. DiMarzio, R. Morrissey, S. Jarvis, J. Ward, A. Izzi, and A. Dilley. 2011. Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multiship exercises with mid-frequency sonar. Marine Mammal Science **27**:E206-E226.

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

McClintock, B. T., D. J. F. Russell, J. Matthiopoulos, and R. King. 2013. Combining individual animal movement and ancillary biotelemetry data to investigate population-level activity budgets. Ecology **94**:838-849.

McConnell, B., R. Beaton, E. Bryant, C. Hunter, P. Lovell, and A. Hall. 2004. Phoning home-A new GSM mobile phone telemetry system to collect mark-recapture data. Marine Mammal Science **20**:274-283.

McDonald, B. I., M. Johnson, and N. Aguilar de Soto. 2016 project. Heart rate logging in deep diving toothed whales: A new tool for assessing responses to disturbance. Current ONR funded project.

McDonald, M. A., and C. G. Fox. 1999. Passive acoustic methods applied to fin whale population density estimation. The Journal of the Acoustical Society of America **105**:2643-2651.

McFadden, K. W., G. A. Worthy, and T. E. Lacher Jr. 2006. Photogrammetric estimates of size and mass in Hawaiian monk seals (Monachus schauinslandi). Aquatic Mammals **32**:31.

Meise, K., B. Mueller, B. Zein, and F. Trillmich. 2014. Applicability of single-camera photogrammetry to determine body dimensions of pinnipeds: Galapagos sea lions as an example. PLoS One **9**:e101197.

Mellinger, D. K., and J. Barlow. 2003. Future Directions for Acoustic Marine Mammal Surveys: Stock Assessment and Habitat Use: Report of a Workshop Held in La Jolla, California, 20-22 November 2002. US Department of Commerce, National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory.

Mellinger, D. K., and S. L. Heimlich. 2013. Introduction to the special issue on methods for marine mammal passive acoustics. Journal of the Acoustical Society of America **134**:2381-2382.

Mellinger, D. K., S. W. Martin, R. P. Morrissey, L. Thomas, and J. J. Yosco. 2011. A method for detecting whistles, moans, and other frequency contour sounds. Journal of the Acoustical Society of America **129**:4055-4061.

Mellinger, D. K., K. M. Stafford, S. Moore, R. P. Dziak, and H. Matsumoto. 2007. Fixed passive acoustic observation methods for cetaceans. Oceanography **20**:36.

Mellish, J.-A. E., D. G. Calkins, D. R. Christen, M. Horning, L. D. Rea, and S. K. Atkinson. 2006. Temporary captivity as a research tool: comprehensive study of wild pinnipeds under controlled conditions. Aquatic Mammals **32**:58.

Mellish, J.-A. E., P. A. Tuomi, and M. Horning. 2004. Assessment of ultrasound imaging as a noninvasive measure of blubber thickness in pinnipeds. Journal of Zoo and Wildlife Medicine **35**:116-118.

Mello, D. M. D., and C. A. Oliveira. 2016. Biological matrices for sampling free-ranging cetaceans and the implications of their use for reproductive endocrine monitoring. Mammal Review **46**:77-91.

Miksis-Olds, J., L. Thomas, and D. Harris. 2017. Large Scale Density estimation of blue and fin whales (LSD). 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Miller, C. A., P. B. Best, W. L. Perryman, M. F. Baumgartner, and M. J. Moore. 2012a. Body shape changes associated with reproductive status, nutritive condition and growth in right whales Eubalaena glacialis and E. australis. Marine Ecology Progress Series **459**:135-156.

Miller, C. A., D. Reeb, P. B. Best, A. R. Knowlton, M. W. Brown, and M. J. Moore. 2011. Blubber thickness in right whales Eubalaena glacialis and Eubalaena australis related with reproduction, life history status and prey abundance. Marine Ecology Progress Series **438**:267-283.

Miller, P., T. Narazaki, S. Isojunno, K. Aoki, S. Smout, and K. Sato. 2016. Body density and diving gas volume of the northern bottlenose whale (Hyperoodon ampullatus). Journal of Experimental Biology **219**:2458-2468.

Miller, P. J., M. Biuw, Y. Y. Watanabe, D. Thompson, and M. A. Fedak. 2012b. Sink fast and swim harder! Round-trip cost-of-transport for buoyant divers. Journal of Experimental Biology **215**:3622-3630.

Miller, P. J. O., M. Fedak, and P. Lovell. 2017 project. On-board calculation and telemetry of the body condition of individual marine mammals. Current ONR funded project.

Miller, P. J. O., P. H. Kvadsheim, F. P. A. Lam, P. J. Wensveen, R. Antunes, A. C. Alves, F. Visser, L. Kleivane, P. L. Tyack, and L. D. Sivle. 2012c. The Severity of Behavioral Changes Observed During Experimental Exposures of Killer (*Orcinus orca*), Long-Finned Pilot (*Globicephala melas*), and Sperm (*Physeter macrocephalus*) Whales to Naval Sonar. Aquatic Mammals **38**:362-401.

Mobley, J. R., M. A. Smultea, C. E. Bacon, and A. S. Frankel. 2012. Preliminary Report: Aerial Survey Monitoring for Marine Mammals and Sea Turtles in the Hawaii Range Complex-- Summary of Focal Follow Analysis for 2008-2012 SCC Events: Preliminary Report. Prepared for Commander, U.S. Pacific Fleet, Pearl Harbor, Hawaii. Submitted to Naval Facilities Engineering Command Pacific (NAVFAC), EV2 Environmental Planning, Pearl Harbor, Hawaii 96860-3134,

under Contract # N62470-10-D-3011, issued to HDR Inc., San Diego, California 92123. 11 June 2013.

Moll, T. E., J. S. Krumholz, G. H. Mitchell, C. G. Tompsett, T. E. Vars, and Z. D. Singer-Leavitt. 2016. Haul-out Counts and Photo-Identification of Pinnipeds in Narragansett Bay, Rhode Island: 2015/16 Annual Progress Report. Prepared for U.S. Fleet Forces Command, Norfolk, Virginia. December 2016. .

Moore, J., J. Barlow, A. Curtis, E. Falcone, G. Schorr, and D. Moretti. 2017. A Power Analysis and Recommended Study Design to Directly Detect Population-level Consequences of Acoustic Disturbance. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Moore, M., C. Miller, M. Morss, R. Arthur, W. Lange, K. Prada, M. Marx, and E. Frey. 2001. Ultrasonic measurement of blubber thickness in right whales. Journal of Cetacean Research and Management (Special Issue) **2**:301-309.

Moretti, D. in prep. Determining the effect of Mid-Frequency Active (MFA) sonar on fitness of Blainville’s beaked whales (Mesoplodondensirostris) in the Tongue of the Ocean. University of St Andrews.

Moretti, D., D. Claridge, and J. Durban. 2016. Marine Mammal Monitoring on Navy Ranges 2015 Summary Report.

Moretti, D., L. Thomas, J. Harwood, and E. A. Falcone. 2017. A Population Consequence of Acoustic Disturbance Model for Cuvier's beaked whale (*Ziphius cavirostris*) in Southern California. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

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

Nabe-Nielsen, J., and J. Harwood. 2016. Comparison of the iPCoD and DEPONS models for modelling population consequences of noise on harbour porpoises.

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

National Research Council. 2005. Marine mammal populations and ocean noise: determining when noise causes biologically significant effects. 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.

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. 2013a. Modelling the biological significance of behavioural change in coastal bottlenose dolphins in response to disturbance. Functional Ecology **27**:314-322.

New, L. F., D. J. Moretti, S. K. Hooker, D. P. Costa, and S. E. Simmons. 2013b. Using Energetic Models to Investigate the Survival and Reproduction of Beaked Whales (family Ziphiidae). PLoS One **8**.

Noren, S. 2016 project. Development of an index to measure the body condition of free-ranging cetaceans. Current ONR funded project.

Norman, S., R. Hobbs, J. Foster, J. Schroeder, and F. Townsend. 2004. A review of animal and human health concerns during capture-release, handling and tagging of odontocetes. Journal of Cetacean Research and Management **6**:53-62.

Norris, T. F., K. J. Dunleavy, T. M. Yack, and E. L. Ferguson. 2017. Estimation of minke whale abundance from an acoustic line transect survey of the Mariana Islands. Marine Mammal Science **33**:574-592.

Nosal, E. 2016 project. Single sensor and compact array localization methods. Current ONR funded project.

Nousek-McGregor, A. E., C. A. Miller, M. J. Moore, and D. P. Nowacek. 2013. Effects of body condition on buoyancy in endangered North Atlantic right whales. Physiological and Biochemical Zoology **87**:160-171.

Oleson, E. M. 2014. Interim Progress Report: Analysis of long-term acoustic datasets from MIRC. NOAA-NMFS-PIFSC-13-008.

Olmstead, T. J., M. A. Roch, P. Hursky, M. B. Porter, H. Klinck, D. K. Mellinger, T. Helble, S. S. Wiggins, G. L. D'Spain, and J. A. Hildebrand. 2010. Autonomous underwater glider based embedded real-time marine mammal detection and classification. The Journal of the Acoustical Society of America **127**:1971-1971.

ONR. 2017. Marine Mammals and Biology Program Website: https://www.onr.navy.mil/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology.

Oswald, J., and T. M. Yack. 2017. Development of automated whistle and click classifiers for odontocete species in the western Atlantic and Temperate Pacific Oceans and the waters surrounding the Hawaiian Islands. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Oswald, J. N., and T. M. Yack. 2014. Development of Automated Whistle and Click Classifiers for Odontocete Species in the Northwest Atlantic Ocean and the Waters Surrounding the Hawaiian Islands. DTIC Document.

Page, B., J. McKenzie, M. A. Hindell, and S. D. Goldsworthy. 2005. Drift dives by male New Zealand fur seals (Arctocephalus forsteri). Canadian journal of zoology **83**:293-300.

Palsbøll, P. J., J. Allen, M. Berube, P. J. Clapham, T. P. Feddersen, P. S. Hammond, R. R. Hudson, H. Jørgensen, S. Katona, and A. H. Larsen. 1997. Genetic tagging of humpback whales. Nature **388**:767-769.

Patterson, T. A., B. J. McConnell, M. A. Fedak, M. V. Bravington, and M. A. Hindell. 2010. Using GPS data to evaluate the accuracy of state-space methods for correction of Argos satellite telemetry error. Ecology **91**:273-285.

Perrin, W. 1970. Color pattern of Eastern Pacific spotted porpoise (Stenella-graffmani Lonnberg (Cetacea, Delphinidae). Zoologica-New York **54**:135-149.

Perrin, W. F., J. M. Coe, and J. R. Zweifel. 1976. Growth and reproduction of the spotted porpoise, Stenella attenuata, in the offshore eastern tropical Pacific. Fishery Bulletin **74**:229-269.

Perryman, W. L., and M. S. Lynn. 1993. Identification of geographic forms of common dolphin (Delphinus delphis) from aerial photogrammetry. Marine Mammal Science **9**:119-137.

Perryman, W. L., and M. S. Lynn. 2002. Evaluation of nutritive condition and reproductive status of migrating gray whales (Eschrichtius robustus) based on analysis of photogrammetric data. Journal of Cetacean Research and Management **4**:155-164.

Perryman, W. L., S. B. Reilly, and R. A. Rowlett. 2010. Results of surveys of northbound gray whale calves 2001-2009 and examination of the full sixteen years series of estimates from the Piedras Blancas Light Station. Rep. Intl. Whaling Commission, Scientific Committee. SC/62/BRG1.

Peterson, S. H., M. M. Lance, S. J. Jeffries, and A. Acevedo-Gutiérrez. 2012. Long distance movements and disjunct spatial use of harbor seals (Phoca vitulina) in the inland waters of the Pacific Northwest. PLoS One **7**:e39046.

Pettis, H. M., R. M. Rolland, P. K. Hamilton, S. Brault, A. R. Knowlton, and S. D. Kraus. 2004. Visual health assessment of North Atlantic right whales (Eubalaena glacialis) using photographs. Canadian journal of zoology **82**:8-19.

Pirotta, E., J. Harwood, P. M. Thompson, L. New, B. Cheney, M. Arso, P. S. Hammond, C. Donovan, and D. Lusseau. 2015. Predicting the effects of human developments on individual dolphins to understand potential long-term population consequences. Page 20152109 *in* Proc. R. Soc. B. The Royal Society.

Pollock, K. H. 2002. The use of auxiliary variables in capture-recapture modelling: an overview. Journal of Applied Statistics **29**:85-102.

Pomeroy, P., L. O'connor, and P. Davies. 2015. Assessing use of and reaction to unmanned aerial systems in gray and harbor seals during breeding and molt in the UK 1. Journal of Unmanned Vehicle Systems **3**:102-113.

Ponganis, P. 2015. Blood Oxygen Conservation in Diving Sea Lions: How Low Does Oxygen Really Go? , ONR MMB Award Number: N000141410404.

Ponganis, P., and B. I. McDonald. 2015. Deep-Diving California Sea Lions: Are they pushing their physiological limit? , ONR MMB Award Number: N000141210633.

Popper, A. N., and A. Hawkins. 2016. The effects of noise on aquatic life II. Springer.

Postma, M., M. N. Bester, and P. N. De Bruyn. 2013. Spatial variation in female southern elephant seal mass change assessed by an accurate non-invasive photogrammetry method. Antarctic Science **25**:731-740.

Reed, L., K. McHugh, and R. S. Wells. 2015. Post-Nuchal Depression as an Indicator of Health in Bottlenose Dolphins (Tursiops truncatus).

Rees, D. R., J. D.V., and B. A. Bartlett. 2016. Haul-out Counts and Photo-Identification of Pinnipeds in Chesapeake Bay, Virginia: 2015/16 Annual Progress Report. Final Report., Prepared for U.S. Fleet Forces Command, Norfolk, Virginia. 15 November 2016.

Rice, A. C., S. Baumann-Pickering, A. Širović, J. Hildebrand, A. Brewer, A. Debich, S. Herbert, B. Thayre, J. Trickey, and S. Wiggins. 2015. Passive Acoustic Monitoring for Marine Mammals in the Gulf of Alaska Temporary Maritime Activities Area 2014-2015., Marine Physical Laboratory, Scripps Institution of Oceanography. MPL TM 600. 58 p.

Richlen, M., T. Keenan-Bateman, E. Cummings, R. McAlarney, W. McLellan, D. A. Pabst, J. Aschettino, A. Engelhaupt, and D. Engelhaupt. 2016. Occurrence, Distribution, and Density of Protected Marine Species in the Chesapeake Bay near NAS PAX: 2015 Annual Progress Report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command (NAVFAC) Atlantic, Norfolk, Virginia, under Contract No. N62470-10-3011, Task Order 55, issued to HDR Inc., Virginia Beach, Virginia. 01 March 2016.

Ries, E., I. Traut, P. Paffen, and P. Goedhart. 1998. Diving patterns of harbour seals (Phoca vitulina) in the Wadden Sea, the Netherlands and Germany, as indicated by VHF telemetry. Oceanographic Literature Review **9**:1637.

Roch, M. A., P. Miller, T. A. Helble, S. Baumann-Pickering, and A. Širović. 2017. Organizing metadata from passive acoustic localizations of marine animals. The Journal of the Acoustical Society of America **141**:3605-3605.

Roletto, J. 1993. Hematology and serum chemistry values for clinically healthy and sick pinnipeds. Journal of Zoo and Wildlife Medicine:145-157.

Rolland, R. M., P. K. Hamilton, S. D. Kraus, B. Davenport, R. M. Gillett, and S. K. Wasser. 2007. Faecal sampling using detection dogs to study reproduction and health in North Atlantic right whales (Euhalaena glacialis). Journal of Cetacean Research and Management **8**:121.

Rolland, R. M., R. S. Schick, H. M. Pettis, A. R. Knowlton, P. K. Hamilton, J. S. Clark, and S. D. Kraus. 2016. Health of North Atlantic right whales Eubalaena glacialis over three decades: From individual health to demographic and population health trends. Marine Ecology Progress Series **542**:265-282.

Romano, A. 2017. Investigation of the Molecular Response in Blood and Skin of Belugas in Response to "Stressors" to Aid in Assessing the Impact of Environmental and Anthropogenic Challenges on Health. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Rone, B., A. Douglas, T. Yack, A. Zerbini, T. Norris, E. Ferguson, and J. Calambokidis. 2014. Report For The Gulf Of Alaska Line-Transect Survey (Goals) II: Marine Mammal Occurrence In The Temporary Maritime Activities Area (TMAA). In fulfillment of Contract No. N62470-10-D-3011 Task Order 0022 from HDR Environmental, Operations and Construction, Inc.

Rosel, P., K. Mullin, L. Garrison, L. Schwacke, J. Adams, B. C. Balmer, P. Conn, M. Conroy, T. Eguchi, A. Gorgone, A. Hohn, M. Mazzoil, C. Schwarz, C. Sinclair, T. Speakman, K. Urian, N. Vollmer, P. Wade, R. Wells, and E. Zolman. 2011. Photo-Identification Capture-Mark-Recapture Techniques For Estimating Abundance Of Bay, Sound And Estuary Populations Of Bottlenose Dolphins Along The U.S. East Coast And Gulf Of Mexico: A Workshop Report. NOAA Technical Memorandum NMFS-SEFSC-621.

Ross, P. S. 2000. Marine mammals as sentinels in ecological risk assessment. Human and Ecological Risk Assessment **6**:29-46.

Schick, R. S., S. D. Kraus, R. M. Rolland, A. R. Knowlton, P. K. Hamilton, H. M. Pettis, R. D. Kenney, and J. S. Clark. 2013a. Using hierarchical Bayes to understand movement, health, and survival in the endangered North Atlantic right whale. PLoS One **8**:e64166.

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, and J. Harwood. 2013b. Estimating resource acquisition and at-sea body condition of a marine predator. Journal of Animal Ecology **82**:1300-1315.

Schorr, G., E. Falcone, B. Rone, and E. Keene. 2017a. Distribution and demographics of Cuvier's beaked whales in the Southern California Bight. . Annual Report to the US Navy Pacific Fleet Integrated Comprehensive Monitoring Program, Award No. N66604-14- C-0145. 15p.

Schorr, G. S., E. A. Falcone, and B. Rone. 2017b. Movements and diving behavior of beaked whales in Monterey Bay, CA: A comparative study site in the California Current Ecosystem. 2017 Marine Mammal & Biology Program Review, Book of Abstracts 20-24 March 2017.

Schwacke, L., L. Thomas, R. Wells, W. McFee, Hohn AA, M. KD, Z. ES, Q. BM, R. TK, and S. JH. 2017. Quantifying injury to common bottlenose dolphins from the Deepwater Horizon oil spill using an age-, sexand class-structured population model. Endang Species Res **33**:265-279.

Schwacke, L., and R. Wells. 2015. The Bottlenose Dolphin (Tursiops truncatus) as a Model to Understand Variation in Stress and Reproductive Hormone Measures in Relation to Sampling Matrix, Demographics, and Environmental Factors. ONR MMB Award Numbers: N0001413IP20004, N0001412IP20053, N0001411IP20085, & N000141110542.

Schwacke, L. H., C. R. Smith, F. I. Townsend, R. S. Wells, L. B. Hart, B. C. Balmer, T. K. Collier, S. De Guise, M. M. Fry, and L. J. Guillette Jr. 2013. Health of common bottlenose dolphins (Tursiops truncatus) in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. Environmental Science & Technology **48**:93-103.

Schwarz, L. K., E. McHuron, M. Mangel, R. S. Wells, and D. P. Costa. 2016. Stochastic dynamic programming: An approach for modelling the population consequences of disturbance due to lost foraging opportunities. Page 040004 *in* Proceedings of Meetings on Acoustics 4ENAL. ASA.

Sinclair, C., J. Sinclair, E. Zolman, A. Martinez, B. Balmer, and K. Barry. 2015. Remote biopsy sampling field procedures for cetaceans used during the Natural Resource Damage Assessment of the MSC252 Deepwater Horizon oil spill. NOAA Technical Memorandum NMFS-SEFSC-nnn (36 pp.).

Smultea, M. A., K. Lomac-MacNair, G. G. Campbell, S. S. Courbis, and T. A. Jefferson. 2017. Aerial Surveys of Marine Mammals Conducted in the Inland Puget Sound Waters of Washington, Summer 2013–Winter 2016. Final Report. Prepared for Commander, U.S. Pacific Fleet and Naval Sea Systems Command. Submitted to Naval Facilities Engineering Command Pacific, Pearl Harbor, Hawaii under Contract No. N62470-15-D-8006, Task Order KB05 issued to HDR, San Diego, California. June 2017.

Southall, B. L., D. P. Nowacek, P. J. O. Miller, and P. L. Tyack. 2016. Experimental field studies to measure behavioral responses of cetaceans to sonar. Endangered Species Research **31**:293-315.

Stevick, P., A. Aguayo-Lobo, J. Allen, I. C. Ávila, J. Capella, C. Castro, K. Chater, L. D. Rosa, M. H. Engel, and F. Félix. 2004. Migrations of individually identified humpback whales between the Antarctic Peninsula and South America.

Stevick, P. T., P. J. Palsbøll, T. D. Smith, M. V. Bravington, and P. S. Hammond. 2001. Errors in identification using natural markings: rates, sources, and effects on capture recapture estimates of abundance. Canadian Journal of Fisheries and Aquatic Sciences **58**:1861-1870.

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.

Tershy, B. R., D. Breese, and S. Alvarez-Borrego. 1991. Increase in cetacean and seabird numbers in the Canal de Ballenas during an El Niño-Southern Oscillation event. Marine Ecology Progress Series:299-302.

Thompson, L. A., T. R. Spoon, C. E. Goertz, R. C. Hobbs, and T. A. Romano. 2014. Blow collection as a non-invasive method for measuring cortisol in the beluga (Delphinapterus leucas). PLoS One **9**:e114062.

Thompson, P. M., and P. S. Hammond. 1992. The use of photography to monitor dermal disease in wild bottlenose dolphins (Tursiops truncatus). Ambio:135-137.

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

Tollit, D., J. Harwood, C. Booth, L. Thomas, L. F. New, and J. Wood. 2016. Cook Inlet Beluga Whale PCoD Expert Elicitation Workshop Report. Prepared by SMRU Consulting North America for NOAA Fisheries.

Trego, M. L., N. M. Kellar, and K. Danil. 2013. Validation of blubber progesterone concentrations for pregnancy determination in three dolphin species and a porpoise. PLoS One **8**:e69709.

Trickey, J. S., S. Baumann-Pickering, A. Širović, J. Hildebrand, A. Brewer, A. J. Debich, A. Rice, B. Thayre, and B. Wiggins. 2015. Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex July 2013 - April 2014. Marine Physical Laboratory Scripps Institution of Oceanography University of California San Diego. MPL TECHNICAL MEMORANDUM # 557.

Trites, A. W., and R. Joy. 2005. Dietary analysis from fecal samples: how many scats are enough? Journal of mammalogy **86**:704-712.

Trumble, S., and S. Usenko. 2017. Determining baseline stress-related hormone values in large cetaceans. 2017 Marine Mammal & Biology Program Review Abstract Book, 20-24 March 2017.

Trumble, S. J., E. M. Robinson, M. Berman-Kowalewski, C. W. Potter, and S. Usenko. 2013. Blue whale earplug reveals lifetime contaminant exposure and hormone profiles. Proceedings of the National Academy of Sciences **110**:16922-16926.

van Beest, F. M., J. Nabe-Nielsen, J. Carstensen, J. Teilmann, and J. Tougaard. 2015. Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS): Status report on model development.

Van Bressem, M.-F., K. Van Waerebeek, F. J. Aznar, J. A. Raga, P. D. Jepson, P. Duignan, R. Deaville, L. Flach, F. Viddi, and J. R. Baker. 2009. Epidemiological pattern of tattoo skin disease: a potential general health indicator for cetaceans. Diseases of aquatic organisms **85**:225-237.

Vu, E. T., C. Clark, K. Catelani, N. M. Kellar, and J. Calambokidis. 2015. Seasonal blubber testosterone concentrations of male humpback whales (Megaptera novaeangliae). Marine Mammal Science **31**:1258-1264.

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**.

Waite, J. N., W. J. Schrader, J.-A. E. Mellish, and M. Horning. 2007. Three-dimensional photogrammetry as a tool for estimating morphometrics and body mass of Steller sea lions (Eumetopias jubatus). Canadian Journal of Fisheries and Aquatic Sciences **64**:296-303.

Webster, T., S. Dawson, and E. Slooten. 2010. A simple laser photogrammetry technique for measuring Hector's dolphins (Cephalorhynchus hectori) in the field. Marine Mammal Science **26**:296-308.

Weijs, L., K. Das, U. Siebert, N. van Elk, T. Jauniaux, H. Neels, R. Blust, and A. Covaci. 2009. Concentrations of chlorinated and brominated contaminants and their metabolites in serum of harbour seals and harbour porpoises. Environment international **35**:842-850.

Wells, R. S. 2014. Social structure and life history of bottlenose dolphins near Sarasota Bay, Florida: insights from four decades and five generations. Pages 149-172 Primates and Cetaceans. Springer.

Wells, R. S., H. L. Rhinehart, L. J. Hansen, J. C. Sweeney, F. I. Townsend, R. Stone, D. R. Casper, M. D. Scott, A. A. Hohn, and T. K. Rowles. 2004. Bottlenose dolphins as marine ecosystem sentinels: developing a health monitoring system. EcoHealth **1**:246-254.

Wells, R. S., and M. D. Scott. 1990. Estimating bottlenose dolphin population parameters from individual identification and capture-release techniques. Report of the International Whaling Commission.

Wells, R. S., C. R. Smith, J. C. Sweeney, F. I. Townsend, D. A. Fauquier, R. Stone, J. Langan, L. H. Schwacke, and T. K. Rowles. 2014. Fetal survival of common bottlenose dolphins (Tursiops truncatus) in Sarasota Bay, Florida. Aquatic Mammals **40**:252.

Wiig, Ø., M. Heide-Jørgensen, C. Lindqvist, K. Laidre, L. Postma, L. Dueck, P. Palsbøll, and L. Bachmann. 2011. Recaptures of genotyped bowhead whales Balaena mysticetus in eastern Canada and West Greenland. Endangered Species Research **14**:235-242.

Williams, R., E. Ashe, and L. New. 2016 project. IPOD: Iterative PCoD for oceanic dolphins. Current ONR funded project.

Williams, T. 2015. High Risk Behaviors in Marine Mammals: Linking Behavioral Responses to Anthropogenic Disturbance to Biological Consequences. ONR MMB Award Number: N00014-13-1-0808.

Wilson, S. G., J. G. Taylor, and A. F. Pearce. 2001. The seasonal aggregation of whale sharks at Ningaloo Reef, Western Australia: currents, migrations and the El Nino/Southern Oscillation. Environmental Biology of Fishes **61**:1-11.

Yakovlev, Y. M., and O. Y. Tyurneva. 2005. A note on photo-identification of the western gray whale (Eschrictius robustus) on the northeastern Sakhalin shelf, Russia, 2002-2004. International Whaling Commission Scientific Committee, Ulsan, Korea.

Zhelezniakov, A., T. Eerola, M. Koivuniemi, M. Auttila, R. Levänen, M. Niemi, M. Kunnasranta, and H. Kälviäinen. 2015. Segmentation of Saimaa Ringed Seals for Identification Purposes. Pages 227-236 *in* ISVC (2).