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2014

Reducing Impacts of Noise from Human Activities on Cetaceans

Knowledge Gap Analysis and Recommendations

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Published in February 2014 by WWF Global Arctic Programme, Ottawa, Canada.

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Cover image: © John Calambokidis, Cascadia Research

Suggested citation
Wright, A.J. 2014. Reducing Impacts of Human Ocean Noise on Cetaceans: Knowledge Gap Analysis and Recommendations. WWF Global Arctic Programme, Ottawa, Canada

Prepared under contract for
WWF Global Arctic Programme, 275 Slater Avenue, Ottawa K1P 5H9, Canada

Authors Acknowledgements
Thanks to WWF Global Arctic Programme for funding this report. Additionally, many thanks to Jakob Tougaard and Courtney Smith for extensive helpful discussions on a number of the topics and details contained within these pages. I am also grateful to Mikhail Babenko, Louise Blight and Aimée Leslie of WWF, as well as Thea Bechshøft, Chris Parsons and Leslie Walsh for their helpful comments on earlier versions of the report. Finally, thanks to Mark Simmonds and Naomi Rose for their help and advice with the overview and direction of this report, and to Richard Greene and Michael Jasny for their assistance with tracking down various documents and publications.

Additional Acknowledgements
Thanks to Becky Rynor for copy-editing, Sue Novotny for layout and design, and Mary Wilton for photo research.

About WWF
Since 1992, WWF's Global Arctic Programme has been working with our partners across the Arctic to combat threats to the Arctic and to preserve its rich biodiversity in a sustainable way.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

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"The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased; and not impaired in value."

President Theodore Roosevelt

"Silence is one of the hardest arguments to refute."

Henry Wheeler Shaw (under the name Josh Billings)

"A noise annoys an oyster,
But a noisy noise annoys an oyster more."

R.P. Weston and Bert Lee, from the song
"A Noise Annoys an Oyster"

FOREWORD

We are living in a period of major and rapid change – technological change, climate change, attitude change, consumption pattern change.

These changes have driven human activities into areas previously pristine and silent, affecting ecosystems and wildlife, which in turn affect us. The ocean is one of the frontiers experiencing increasing human activity in forms including shipping, oil and gas development, and deep-water mining.

Many human activities in the ocean create significant noise. The impacts of noise on different marine species are increasingly being documented and understood (although much has yet to be confirmed regarding the significance of these effects). Previously silent ocean areas such as the Arctic are now exposed to noise pollution. When this exposure is added to stress from climate change, acidification, and other pressures, the consequences add up for life in the Arctic Ocean, and other oceans too.

WWF's objective in commissioning this report was to collate available knowledge about noise and cetaceans, examples of good regulations, and analyze the different mitigation measures currently available to address this complex issue. We believe that current knowledge needs to be translated into new policy and practical actions now, with a focus on the reduction of noise at the source through industry guidelines, technology improvements and regulation at a national and international level. Companies that want to be seen as responsible can adopt best practices immediately. Governments that want to be seen as responsible can immediately begin work on regulating sources of ocean noise. Many stressors that affect natural systems and the people who rely on them are complex and difficult to resolve. Reducing ocean noise is relatively simple and eminently achievable.

Aimée Leslie
Global Cetacean and Marine Turtle Manager
WWF International

Killer whale Off the coast of Kamchatka Peninsula, Russian Federation

FROM THE AUTHOR

Human activity in and on the oceans introduces noise into the marine environment that affects the lives of marine mammals and other marine species.

The topic of marine mammals and underwater noise is a subject that has been addressed in a number of previous reports, books and assorted literature. Almost invariably, these documents have included some level of introduction to a number of the basic concepts involved in acoustics or the study of sound. Although worthy in their intent, the pages that followed these primers have typically included increasing amounts of jargon and references to specific levels of sound. The latter is of particular note as this can lead many uninitiated readers into difficulties. There are many reasons for this, not least of which is the fact that there are a large number of different ways to measure sound. Although sound is typically associated with the unit decibel (dB), this is a relative measure (like a percentage) rather than absolute one. Furthermore, scientists may report levels of sound in terms of pressure, energy, or intensity and may measure and report those values in different ways over different times. As a result, many scientists may occasionally miss a clarification or even mix things up themselves, making their results difficult to interpret or apply.

This report is intended for policy makers, who are not expected to have a background in acoustics. It is not intended to be an extensive review of the impacts of noise on marine mammals. Instead, it is intended to provide information about the various options available to managers for reducing the human contribution to underwater noise. As a result, I have attempted to exclude unnecessary jargon and leave out specific values in favour of plain language and relative statements, such as louder or quieter. Specific values are not necessary to instil in a reader the understanding that one action introduces a certain amount of noise into the marine environment. Nor are they needed to convey the idea that a second action might be able to reduce the noise levels that move, or propagate, away from the original source and into the marine environment.

Therefore, some of the many subtleties presented in other reviews or original scientific reports may have been glossed over in favour of a more widely accessible presentation of the most relevant information. To address this minor limitation, references to other reports as well as the primary literature are presented to readers so that any who are interested in learning more will be quickly able to look further into the subject. It is my intention that this report should provide a means of access into these materials for both policy makers and the general public.

Finally this report contains a number of various recommendations for actions that may help reduce underwater noise. Some of these are quite forward looking, while others are more immediately applicable. Although some have been mentioned elsewhere, I have also attempted to consider the wider picture and offer some more original suggestions. I hope these recommendations will help guide policy decisions that benefit marine life in general by reducing human-introduced ocean noise, while not constraining commercial activities to any great extent. As always, the content of these pages represents just another step forward in the developing process of managing human impact on the environment. I look forward to any discourse these recommendations may generate.

Andrew J. Wright, Ph.D.
1st October, 2013

EXECUTIVE SUMMARY

Due to the physics of the underwater environment and factors such as turbidity, sound travels much further than light in the oceans.

Consequently, many marine animals have evolved to use sound as their primary means for communication, foraging, navigating, and generally perceiving features in the environment around them. Sound from human activities represents unwanted noise to these species. This noise can disrupt their natural activities, induce stress responses, degrade their environment and, in the more extreme cases, lead to permanent hearing damage, or even death.

The extent to which noise from human activities impacts populations of marine mammals has been highly debated. However, there is increasing evidence that the myriad of sound introduced into the oceans by humans is collectively damaging the health and reproductive capabilities of these animals in various ways. Furthermore, there are now a number of solid indications that what is currently known about the severity of the impact of human noise exposure on populations of marine mammals, as well as on individuals, is likely to be only the "tip of the iceberg" (one of two possible options presented by the U.S. National Research Council, NRC, 2005). This is due to the multi-faceted, and often subtle, range of effects that noise can have on the lives of marine animals.

Despite this, some argue that the impacts of noise are negligible in contrast to the expected consequences of climate change and other threats such as bycatch of marine mammals in fishing gear. However, the aggregated impacts of noise on marine mammals also combine with the effects of climate change and other human pressures. For example, marine mammals are exposed to chemical pollutants through their diet and store many of these in their blubber due to the interaction of these chemicals with the fats. This limits circulating levels of the chemicals (often called contaminants) as well as their total impact on the individual. However, in times of high energy use (e.g., pregnancy) or low energy availability (perhaps due to overfishing or avoidance of a feeding area due to high noise levels) these fat stores are metabolized, thus releasing the chemicals into the blood stream, leading to increased circulating levels at times of vulnerability.

As a consequence of these interactions between multiple threats (known as cumulative impacts), it is becoming increasingly clear that human impacts on the environment as a whole cannot be managed in isolation. In contrast, it may (in some cases) be possible to reduce the impact of one human activity through the implementation of measures to address another. More generally, the total chronic impacts of combined human activity on marine species can be decreased through reductions in the contributions of each component. As a consequence of this, the resilience of a species to the effects of climate change may increase if its exposure to other pressures, such as underwater noise, can be reduced (see 7th October 2009 Letter to President Obama in Wright, 2009).

Humans introduce a range of sounds into the marine environment. Some of the greatest attention has been paid to the very loud sounds produced by naval activity (including both the more narrowband sonars and the broadband explosions), the oil and gas industry (broadband seismic survey pulses for detecting deposits under the sea floor), construction (broadband pile driving pulses). Another source of note is commercial shipping. However, there are numerous other sounds that humans introduce into the marine environment. Industrial activities, such as drilling, dredging, and pipe- or cable-laying, all contribute noise to the environment. Pleasure craft and fishing activities can also be important sources of noise in coastal and remote areas respectively.

Regarding the impacts of noise exposure on marine mammals, attention has typically focused on hearing damage and behavioural effects. However, the value of using behavioural responses to infer more systemic impacts has become increasingly questioned, as observable reactions are highly context-dependent. Additionally, there are other consequences of noise exposure that must be considered, but which can occur without any outwards indication from the animal affected, such as physiological stress responses and masking.

Several specific noise-related resolutions and statements of concern have been issued by various international bodies and agreements. However, many nations are attempting to adapt their various national legislations, and the associated implementing regulations, designed to protect endangered species (e.g., the Canadian Species at Risk Act, *SARA*, 2002; the U.S. Endangered Species Act, *ESA*, 1973). Many of these laws were not particularly suited to the task.

Such environmental legislation typically includes exemptions, exclusions, permitting processes or other authorizations to explicitly consider societal interests. While some of these options are not bound by any findings regarding environmental consequences, others are conditional on demonstrating that some certain maximum impact level, which is to be determined based upon the best available science, has not been exceeded. For example, it may be that society has stated, though environmental laws, that a population should not be prevented from growth through human impacts, or that on ly a certain proportion of a given population can be exposed to such impacts in any given period (e.g., the *ESA*).

Achieving any such legal mandate requires an evaluation of the full consequences of all sub-injurious impacts to individuals and populations to completely assess the sum of all impacts of noise on marine mammals. This fact has been noted by an expert panel in the U.S., who stated that injury and behavioural harassment criteria “do not determine the overall level of impact [as] physiological stress and other factors also need to be considered” (Fitch *et al.*, 2011). However, with some specific notable exceptions, current mitigation measures are generally ineffective at reducing the aggregate impact of noise on marine mammals. This is largely because they typically focus on limiting damage to hearing and ignore the more insidious consequences of noise exposure that can arise at lower levels of sound.

Thus, while numerous options are available for mitigating the impacts of noise on marine mammals, many have limited effectiveness. Operational measures such as safety zones or slow speed requirements can suffer from compliance issues. Unfortunately, these are currently and for the most part the best options available for mitigating the impacts of noise on marine mammals. The implications of this are two-fold. Firstly, we must exploit any opportunities for the use of improved planning and protection measures that will help reduce the overlap between marine mammal and human activities. Secondly, and more importantly, we need to pursue any technological developments that will reduce or preferably eliminate the various sources themselves. This can be achieved either through refining or replacing the equipment in question, or by eliminating the demand for the activity entirely.

To that end there are two overarching recommendations that have arisen from this report:

1. **Governments and other responsible authorities around the world should phase in increasingly strict noise level standards for all noise-producing activities.** This will drive the necessary innovation to reduce noise at the source and take management truly into the realm of addressing the overall impacts of noise, rather than simply focussing concern on the potential for injury. The regulatory pressure on noise levels placed upon companies installing wind farms in Germany led to the necessary innovation to meet these standards. The result was a reduction in the dangerously high sound levels that are typically mitigated, and the levels of noise at greater distances. This reduction will also reduce the occurrence and extent of all the various non-injurious impacts of noise.
2. **Governments, industry and environmental organizations , including WWF, should seek ways to address and reduce the underlying demand for noise producing activities so that their occurrence can be reduced to the greatest extent possible.** Even on the rare occasions when it may not be possible to eliminate a particular source of sound due to its function, suppression of the demand for the result will curtail the activity itself. Consequently, it is recommended that governments take steps to reduce the need for oil, shipping and (where possible) military sonar through improved energy efficiency, support for local over foreign economies, and international agreements (see specific recommendations in WWF *et al.*, 2011). Use of the concept of the Genuine Progress Indicator (GPI) may be of particular importance to these goals and is thus also recommended.

Implementing these recommendations will result in a quieter ocean. However, this will take time. In the meantime, the currently available mitigation measures must continue to be used, although in a more precautionary manner. A visual summary of much of the information contained within this report is presented in Table 1. Specifically, the table includes details of the mitigation options deemed most worthy of use and/or development at this time for several specific sound sources. This is an admittedly subjective interpretation of the scientific assessment contained in this report of the effectiveness and likely extensiveness of application of the various presented management and mitigation tools. For example, it is not currently possible to implement safety zones at night with any degree of confidence, so suspension of activities during this period deserves strong consideration. Accordingly, these techniques score a medium to high viability of application, conditional upon the restrictions being put in place to limit the activities in question to hours of daylight.

Similarly, the effectiveness of ramp-up (see Section 5.4) is almost completely unknown, but application to stationary sources can be planned in such a way to allow at least some animals to move away, without risking possible entrapment in unfamiliar coastal features, ice edge environments, or other such areas. Such uncertainties are highlighted in Table 1, which may provide general indications of where more information is needed on the application and effectiveness of these particular management tools for those seeking to fund noise mitigation research. It is very important that any new information on the merits of the various management and mitigations measures be re-incorporated into the management process though truly adaptive approaches rather than being excluded from subsequent environmental impact assessments or management decisions. The same is true for details about the potential benefits of new technologies and techniques, or the various impacts of noise sources on marine mammals. It is only through such a mechanism that the quality of management decisions can improve over time.

It is extremely important to note that the content of Table 1 cannot reflect any special considerations required of specific locations or likely impacted species, such as those described in Chapters 8 and 9. For instance, source levels of near-coast operations need to be very carefully controlled to avoid unreasonably high exposures when animals are unable to move away, even in situations where entrapment is unlikely. Similarly, small populations with limited ranges may simply not be able to avoid noise sources introduced into their habitats.

Furthermore, the assessments of mitigation effectiveness in Table 1 are based primarily on the best possible implementation of the tools. Accordingly, a lack of compliance or (where appropriate) the use of untrained personnel has not been factored into any category, with the explicit exception of "Operational measures". The lack of compliance considered here is not regarded as malicious, but as a consequence of unclear regulations or uninformed participants.

In addition to the over-arching recommendations above, and the very general guidance in Table 1, Chapter 8 contains a number of more detailed recommendations for regulators, managers, industry, environmental organizations, and other interested parties. These provide some specific guidance on which measures for reducing impacts of noise on cetaceans (and other species) should be pursued further, as well as how they can best be implemented. While this guidance is, by necessity, often policy-based, the reasoning behind it is supported by current scientific knowledge applied in accordance with the general context of existing societal tenets, as enshrined in laws around the world. Most important of these is the belief that species should not be allowed to decline to extinction. To that end, a functional framework for actually managing the cumulative impacts of all human activity on marine mammals is critically needed, not only to prevent populations from declining, but also to make management decisions, and their consequences, more transparent to public scrutiny.

Source Type	Metric	Demand reduction	Alternative technology	Modify existing gear	MPAs and similar	Early planning options	Safety zones & shut-downs	Ramp-up	Mitigation sources	Isolation techniques	Operational measures
Seismic survey airguns	Viability	H	H	H	M-H	M-H	M-H	H	H	L	H
	Effectiveness	VH	M-H	L-M	M	M	(L-M)?	?	L?	L	L-M
	Availability	S-F	I-S	I	I	I	I	I	I	S	I
Navy sonar	Viability	L-M	?	M-H	M	M-H	M-H	H	M-H*	N	M
	Effectiveness	VH	?	H?	H?	H?	(L-M)?	?	?	N/A	M
	Availability	S?	F?	S?	I	I	I	I	I	N/A	I
Piledriving	Viability	?	M	H	M-H	M-H	M-H	H	L	H	N
	Effectiveness	VH	H	M-H	M	M	(L-M)?	M?	?	H	N/A
	Availability	?	I-S	I	I	I	I	I	I	I	N/A
Shipping	Viability	M	N	M-H	M	M	N	N	N	H	H
	Effectiveness	M-H	N/A	H	M	M	N/A	N/A	N/A	?	L-M
	Availability	I-S	N/A	I-S	I	I	N/A	N/A	N/A	S	I
Explosions	Viability	L?	?	N	H	H	H	H*	H*	V	N
	Effectiveness	VH	?	N/A	H	H	M-H	M?	M?	?	N/A
	Availability	I	?	N/A	I	I	I	I	I	I-S	N/A
Pleasure craft propellers	Viability	H?	M-H	N	H	N	N	N	N	N	M
	Effectiveness	L	H	N/A	H	N/A	N/A	N/A	N/A	N/A	(L-M)?
	Availability	I	S	N/A	I	N/A	N/A	N/A	N/A	N/A	I
Echo-sounders	Viability	H	N	N	H	N	N	N	N	N	L
	Effectiveness	VH	N/A	N/A	H	N/A	N/A	N/A	N/A	N/A	L
	Availability	I	N/A	N/A	I	N/A	N/A	N/A	N/A	N/A	I
Multi-beam sonar	Viability	?	?	?	H	H	M-H	H	H	N	L
	Effectiveness	VH	?	?	H	H	(L-M)?	?	L?	N/A	L
	Availability	?	?	?	I	I	I	I	I	N/A	I

TABLE 1

An indication of the relative merits of the different management and mitigation options. The metrics are defined based on the discussions throughout the report as follows: Viability is the likely applicability of the management option to the source; Effectiveness is the likely extent to which the management option can be expected to reduce noise; and Availability is an indication of the likely time before the tool becomes available to managers for use. N=None; L=Low; M=Medium; H=High; VH=Very High; I=Immediate; S=Soon; F=Further into the Future; N/A=Not Applicable; ?=Unknown or uncertain; and *=Indicates situations where Mitigation sources are linked to Ramp-ups, or vice versa. Colouring indicates overall preference based mainly on Effectiveness and Viability in the descending order: Green; Yellow; Orange; and Red. These assignments are determined as follows: Green required a high or very high Effectiveness and a high Viability score; Red required a low Effectiveness value; Yellow and Orange were separated based on the remaining balance of scores in both Effectiveness or Viability and the general uncertainty across all categories. Mitigation tool categories are generally synonymous with various headings in Chapters 5 and 6, except for: “Demand reduction” which covers a reduction in the use of the source through regulatory or financial incentives upon the activity causing the source (including consumer spending power); and “Modify existing gear” which was discussed as a subset of Alternative Technologies and reflects improvements to existing designs, such as use of pile caps or airgun modifications, rather than outright replacement. Specific case-by-case complexities, such as (but not limited to) the presence of particularly sensitive species or specific topography thought to increase likelihood of impact are not considered here.

BACKGROUND

1. INTRODUCTION

The physics of the underwater environment and factors such as turbidity makes sound travel much further than light in the oceans. Consequently, many marine animals have evolved to use sound as their primary means for communication, foraging, navigating, and generally perceiving features in the environment around them.

Sound from human activities creates unwanted noise for these species. This noise can disrupt their natural activities, induce stress responses, degrade their environment and, in the more extreme cases, lead to permanent damage to hearing, or even death.


© United States Coast Guard/Transocean

Sound from human activities creates unwanted noise for many marine species.

The fact that underwater noise is an issue of concern for marine life has now reached widespread recognition in scientific, managerial and political circles. Although much research has been focused on the study of impacts of navy sonar exercises on beaked whales in particular, attention has widened to include consideration of the impacts of sounds from oil and gas activities, construction, and the more generally increasing background noise levels in the ocean, primarily caused by commercial shipping. Similarly, while research has been undertaken on the effects of noise on a range of marine species, the focus has mainly been on marine mammals: cetaceans (whales, dolphins and porpoises) in particular. This attention is partly due to series of beaked whale strandings following sonar exposures and partly due to the inherent appeal of these 'charismatic megafauna' to the general public.

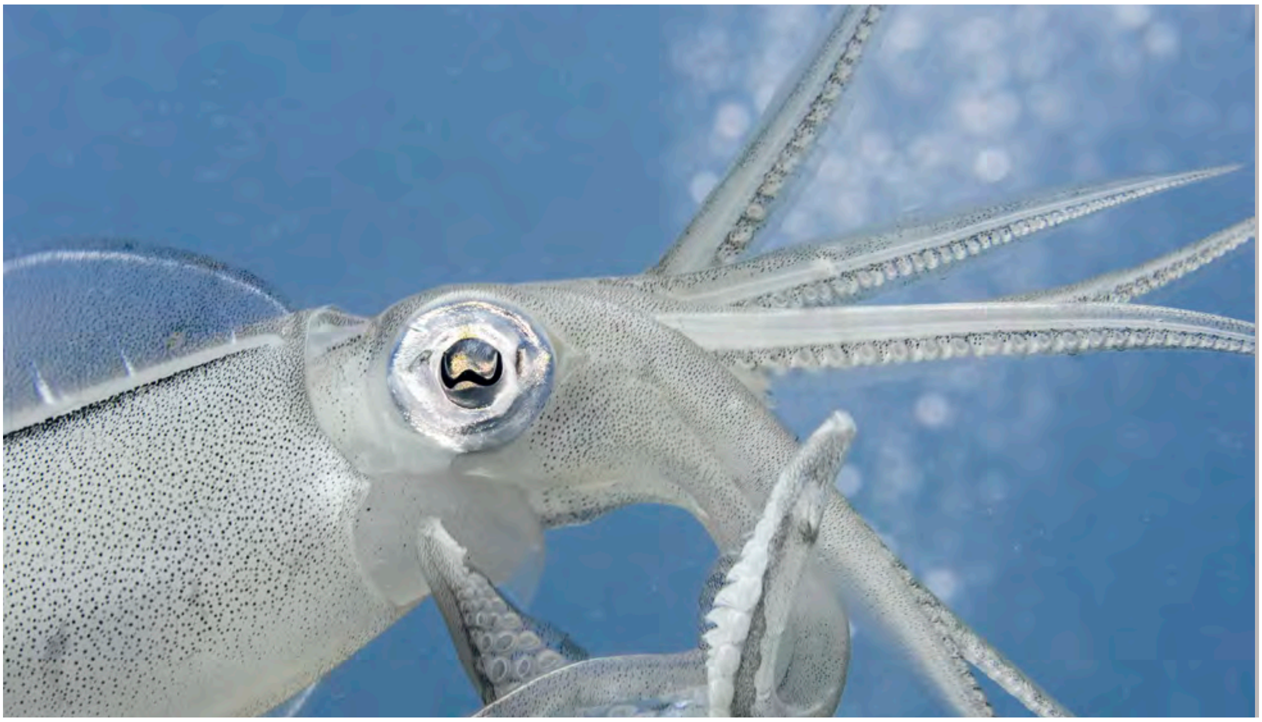
The extent to which noise from human activities impacts populations of marine mammals has been highly debated. However, there is increasing evidence that the myriad of sound introduced into the oceans by humans is collectively damaging the health and reproductive capabilities of these animals in various ways. Furthermore, there are now a number of solid indications about the severity of the impact of human noise on populations of marine mammals, as well as on individuals, making it likely that we have only seen then "tip of the iceberg" (one of two possible options presented by the U.S. National Research Council, NRC, 2005). This is due to the multi-faceted, and often subtle, range of effects of noise on the lives of marine animals.

Despite this, some argue that the impacts of noise are negligible in contrast to the expected consequences of climate change and other threats, such as bycatch of marine mammals in fishing gear. However, the aggregated impacts of noise on marine mammals also combine with the effects of climate change and other human pressures. Some of these combinations are relatively additive, while others can lead to total impacts that are greater or less than the sum of their parts. Others still may be emergent, with consequences absent in the presence of a single threat, but which appear when both are present. For example, marine mammals are exposed to chemical pollutants through their diet and store many of these in their blubber due to the interaction of these chemicals with the fats. This limits circulating levels of the chemicals (often called contaminants) and thus also their total impact on the individual. However, in times of high energy use (e.g., pregnancy) or low energy availability (perhaps due to overfishing or avoidance of a feeding area due to high noise levels) these fat stores are metabolized, thus releasing the chemicals into the blood stream, leading to increased circulating levels at times of vulnerability. Thus, in addition to the original pressure on the animal, the circulating contaminants are also able to act upon them, with possible consequences including immune system suppression and the associated increase in the risk of disease, as well as infertility and reproductive failure (e.g., Béland *et al.*, 1993; Jepson *et al.*, 2005a, Reddy *et al.*, 2001). Mothers may also transfer the mobilized chemicals to their young through their milk, which is thought to be responsible for an alarmingly low rate of survival in the first offspring in many marine mammal species (e.g., Wells *et al.*, 2005).

As a consequence of these interactions between multiple threats (known as cumulative impacts), it is becoming increasingly clear that human influences on the environment as a whole cannot be managed in isolation. In contrast, in some cases it may be possible to reduce the impact of one human activity through the implementation of measures to address another. More generally, the total chronic impacts of combined human activity on marine species can be decreased through reductions in the contributions of each component. Consequently, the resilience of a species to the effects of climate change may increase if its exposure to other pressures, such as underwater noise, can be reduced (see 7th October 2009 Letter to President Obama in Wright, 2009).

Over the last two decades, a number of treaties have been written on the subject of the impacts of underwater noise for marine mammals (e.g., NRC, 1994, 2000, 2003, 2005; Richardson *et al.*, 1995; Simmonds *et al.*, 2004; Hildebrand, 2005; Jasny *et al.*, 2005; U.S. Marine Mammal Commission, MMC, 2007; Nowacek *et al.*, 2007; Southall *et al.*, 2007; Weilgart, 2007). Many have been very scientific, while others have been more focused on conveying the information to a wider audience, including managers and the public. New information on the subject is consistently becoming available. However, the intent of this report is not to provide an update to previous reports but to focus more on the scientific merit behind available management strategies and mitigation options. Many of these actions have remained largely unchanged since they were first implemented as they have become highly institutionalized. Others have been altered or revised depending upon the legislative regime and risk tolerance in different nations. Therefore it is unsurprising that there has been a reasonable amount of scientific criticism of the inconsistent way that impacts of noise on marine mammals is managed within and between jurisdictions. Given the current general acceptance that noise (collectively) has the potential to be a threat to marine species, it is appropriate to consider the current state of science with regard to the possible mechanisms available to managers for reducing impacts of noise.

As mentioned above, the majority of research on the impacts of noise and, for better or for worse, public concern is with cetaceans. Accordingly this report will also focus on these animals. However, much of what follows can be applied, with due caution, to other species of marine mammals and even other marine life. Addressing the impacts of noise on these other species, such as fish, is beyond the scope of this report. However, there is increasing evidence that noise can affect other animals as severely as it can cetaceans (see Guerra *et al.*, 2004; MacKenzie, 2004;



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There is increasing evidence that noise can affect other animals as severely as it can cetaceans.

Popper & Hawkins, 2012). Accordingly, any action that reduces the amount of noise introduced into the marine environment will benefit all affected species.

It is important to consider the current availability and/or time to practical implementation of the various management strategies and mitigation tools for each noise source. A range of more immediate options will be provided and assessed along with long-term options that may have more extensive benefits. Although comprehensive cost-benefit analyses are beyond the scope of this report, some indications of how costs may be offset are also presented.

Thresholds for the onset of impact will also be discussed. Such thresholds are frequently debated levels of sound at which certain impacts, such as 'injury' , begin to occur. These particular numbers have immense importance to all concerned. Larger values offer more freedom to industry and the navy, while lower numbers offer more protection to the species concerned. While precise values will not be discussed, the process by which these thresholds are generated will be addressed.

Finally, the opening Arctic presents a special case in many circumstances. This ecosystem is especially vulnerable, particularly in the context of a changing environment, and presents a number of additional challenges for industry and management. The need for adapting certain measures for use in the Arctic will also be briefly discussed.

2. A BRIEF REVIEW OF SOUND, NOISE AND CETACEANS

As mentioned in Chapter 1, the principles of underwater sound, the uses of sound by cetaceans and the impacts of noise on marine mammals have been reviewed on many occasions at introductory and advanced levels. Accordingly, only a brief synopsis of these areas is included here. Sound is effectively a pressure wave generated by a vibrating source and transmitted (or 'propagated') through a medium, such as air or water, by the distortion (i.e., compression and extension) of that medium. Mammals detect sound through the increases in pressure associated with the compression waves.

Sound travels further in water than in air. Therefore, many marine animals have evolved to use sound rather than light (i.e., vision) to interact with their environment, communicate with each other for purposes such as reproduction, to find food, or to navigate. Sound can be used passively or actively. For example, animals may listen passively for the sounds produced by predators or prey. They may listen for specific environmental features such as the sounds of surf which would indicate coastlines. Many animals also produce sound for communication or to obtain additional information about their environment through the use of biosonar, such as echolocation in cetaceans.

Sounds can be produced at a range of frequencies, perceived by our ears as pitch. Lower frequencies travel further for any given source level. Sound can reflect off the sea floor and sea surface in much the same way light reflects off a mirror, meaning that it can arrive at any given point via a number of routes. The result is an elongation in the length of sounds that are dominated by increasing low frequencies as they travel further away from the source.

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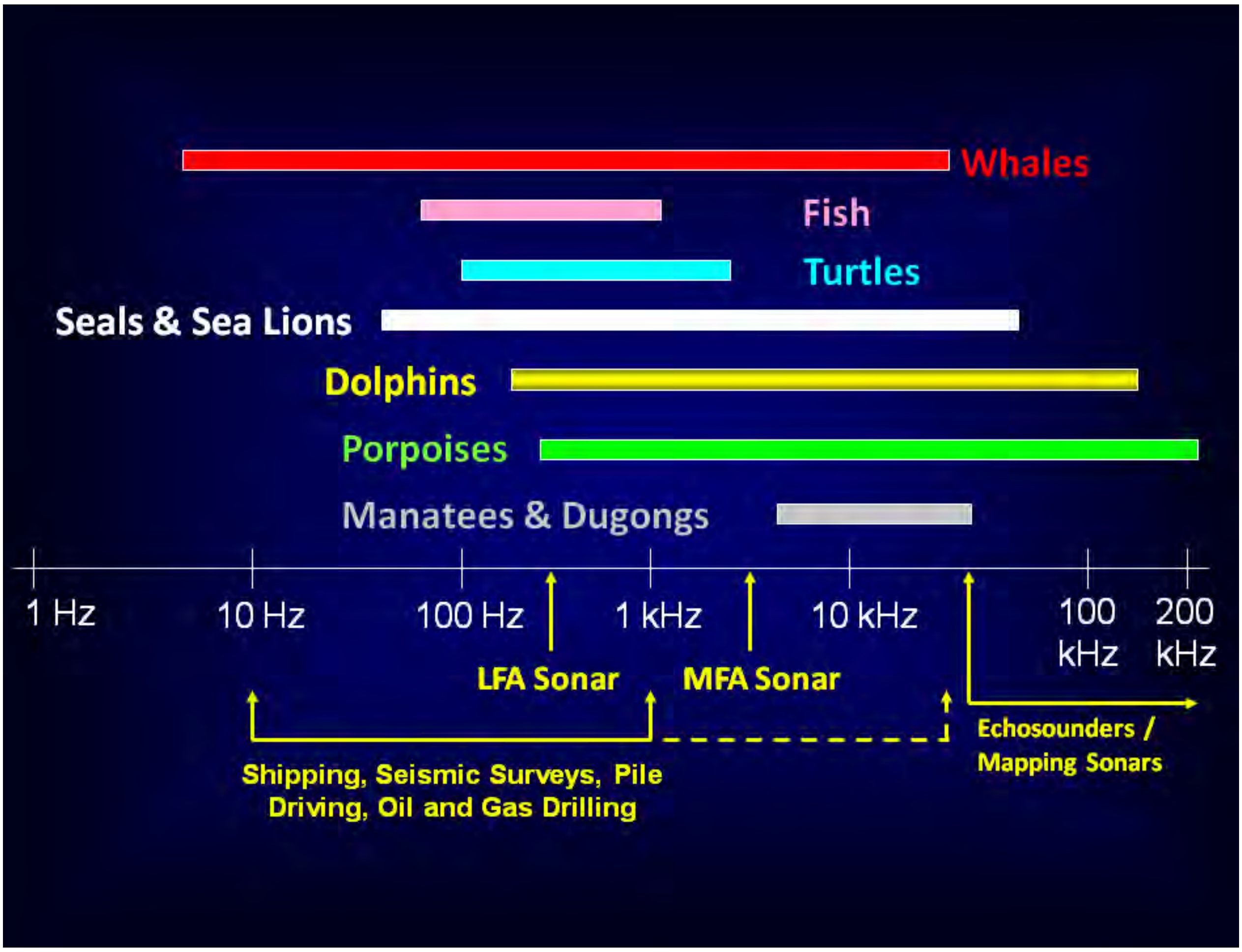
When struck, the bars of a xylophone vibrate, creating pressure waves in the air, which we perceive as sounds in the form of notes. The larger the bar, the lower the frequency of the resulting sound.

The hearing of any given animal is more sensitive at some frequencies than others. For example, human hearing is most sensitive between 2 and 5 kHz, becoming slowly less sensitive down to around 20 Hz and rapidly less sensitive up to around 20 kHz. For comparison of the frequencies involved, blue whales (*Balaenoptera musculus*) produce sounds typically around or below 20 Hz (see McDonald *et al.*, 2006) often below the range of human hearing. Harbour porpoises (*Phocoena phocoena*) produce clicks mostly at frequencies around 140 kHz (Goodson & Sturtivant, 1996; Au *et al.*, 1999; Kastelein *et al.*, 2002; Hansen *et al.*, 2008), well above human hearing. Hearing sensitivity, especially at higher frequencies, is typically reduced with age. Sounds may be narrowband, containing only a few frequencies, or broadband, containing a wide range of frequencies. With some notable exceptions, very short pulsed sounds are typically broadband, where longer sounds can be monotonic, incorporating only a single frequency.

Marine mammals use a range of sounds for communication and biosonar for foraging and navigation. Toothed whales and dolphins, known as odontocetes, produce clicks for echolocation of prey and their environment (see Richardson *et al.*, 1995). Some species, such as sperm whales (*Physeter macrocephalus*) and harbour por-



Courtesy of Brandon Southall, SEA, Inc.

Marine mammal hearing ranges.

poises, also rely on clicks for communication (Watkins & Schevill, 1977; Clausen *et al.*, 2010). However, many cetaceans use more tonal sounds for communication (in addition to, or instead of clicks), which are known by various names depending upon how they sound, such as whistles, grunts, moans and song (e.g., Payne & McVay, 1971; and see Richardson *et al.*, 1995).

Humans introduce a range of sounds into the marine environment. Some of the greatest attention has been paid to the very loud sounds produced by naval activity (including the more narrowband sonars and broadband explosions), the oil and gas industry (broadband seismic survey pulses for detecting deposits under the sea floor), and construction (broadband pile driving pulses). Another source of note is commercial shipping. Such ships can individually represent sizable local broadband sources, but collectively they have contributed greatly to the 10- to 100-fold rise in low frequency background noise levels seen in many of the world's oceans since pre-industrial times (with smaller increases seen in the Arctic and large areas of ocean in the Southern Hemisphere: see Wright, 2008a, and references therein). However, there are numerous other sounds that humans introduce into the marine environment. Industrial activities, such as drilling, dredging, and pipe- or cable-laying, all contribute noise to the environment, as does fishing. Pleasure craft can be a substantial source of noise in coastal areas. Less obvious sources include noise introduced through bridge pylons from traffic or trains, aircraft and rockets (under certain conditions), and noise transmitted into the water through activities on ice. It should also be noted that aerial activities are more important

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Two male Pacific walruses. Walrus Islands, Alaska, USA.

for amphibious animals, such as pinnipeds (seals, sea lions and the walrus, *Odobenus rosmarus*), polar bears (*Ursus maritimus*) and sea otters (*Enhydra lutris*).

Regarding the impacts of noise exposure on marine mammals, attention has typically been focused on hearing damage and behavioural effects. Originally, it was reasonably assumed that the ear and associated structures would be the most susceptible to damage from sound, given their necessary sensitivity. Similarly, it was acknowledged that behavioural responses occurred at lower levels of sound, but that these changes in behaviour might have important consequences. Unfortunately, these definitions have become more intertwined, as it now appears that the strandings of dead or dying beaked whales resulted from behavioural reactions to sonar exposures at relatively low noise levels (e.g., Hildebrand, 2005; Cox *et al.*, 2006; Rommel *et al.*, 2006; Tyack *et al.*, 2006). Similarly, the value of using behavioural responses to infer more systemic impacts has become increasingly questioned, as observable reactions are highly context-dependent. For example, the specific response may depend on the activity of the animal at the time of exposure, or any prior experience that the animal may have (e.g., Andersen *et al.*, 2012; Robertson *et al.*, 2013). They may also be variable depending upon the exact type (Melcón *et al.*, 2012) or extent of the disturbance (e.g., La Manna *et al.*, 2013).

This makes it incredibly difficult to quantify the actual impact on an individual or population. For instance, does it matter if one or more humpback whales (*Megaptera novaeangliae*) stop singing on breeding grounds for just a couple of hours in response to noise: does it affect their reproduction for the season? Similarly, how likely is it that harbour porpoises can find the same amount of food elsewhere if they abandon one particular feeding area due to noise; and what are the consequences if they cannot or must spend extra energy to obtain it? Furthermore, other consequences of noise exposure have emerged as important considerations in their own right, such as physiological stress responses and masking. Both of these are particularly difficult to quantify as they can occur without any outwards indication from the animal affected.

Masking – which is essentially when sounds of interest are obscured, or partially obscured, by a source of noise – may be a huge issue for the great whales that used low-frequency signals to communicate over vast distances of hundreds and possibly thousands of kilometres in a pre-industrial ocean (e.g., Møhl, 1980, 1981; Clark *et al.*, 2009). However, the extent of the effects of masking are dependent upon many variables, including the frequencies of the sound and the noise, as well as the locations of the sources of both, as well as the position of the receiver.

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The great tit's reproductive strategy has been shown to adapt to noise exposure.

Assessing the potential role of noise in inducing chronic stress presents a different set of challenges, as an individual will mount only a single stress response to all the factors affecting it at a given time. This makes it extremely difficult to determine the specific contributions of any given noise. Furthermore, natural fluctuations and existing stress responses may hide any short-term reactions to a particular noise and complicate any attempts to conduct studies.

Animals may use various compensatory mechanisms to reducing masking, including producing louder sounds or changing the frequencies of the sounds being produced so that they don't clash with the noise (e.g., Holt *et al.*, 2011). However, these particular mechanisms cannot be applied to sounds from other sources, may be of variable use depending upon call type, and likely carry costs to the animal (e.g., Holt *et al.*, 2011). These costs could be in terms of energy expenditure, but they may also extend to reproductive strategy trade-offs, as has been shown to be the case for at least one singing bird species, the great tit (*Parus major*: Halfwerk *et al.*, 2011). For example, male whales might have to balance an increase in the frequency of their sounds to avoid persistent low-frequency ship noise against reduced attractiveness by the females, or even risk not being recognized as the same species.

3. LEGAL STATUS OF NOISE

Nations have the rights, and obligations, to implement regulations on the vast majority of noise-producing activities within their waters, with the notable exception of shipping (see below). The implementing regulations of New Zealand's Marine Mammals Protection Act (NZMMPA, 1978) state, in Clause 20, that "...no person shall make any loud or disturbing noise near dolphins or seals" (Marine Mammals Protection Regulations, MMPR, 1992). However, more typically the various national legislations and regulations were more generally designed to protect endangered species (e.g., the Canadian Species at Risk Act, *SARA*, 2002; the U.S. Endangered Species Act, *ESA*, 1973) and have not included specific mention of noise (see Koper & Plön, 2012). Their implementing regulations needed to be adapted to deal with the issue of noise, despite the fact that many of these laws were not particularly suited to the task. To complicate matters further, the increasing awareness of noise-related impacts is placing huge demands upon these regulatory patches. For example, requests for authorization to harm marine mammals (known legally as a 'take') through incidental noise exposures under the U.S. Marine Mammal Protection Act (USMMPA, 1972) have become commonplace (Roman *et al.*, 2013).

Despite these efforts, unilateral action on underwater noise, although necessary, may not be the most optimal course of action. Industries often refer to the complications of navigating numerous and sometimes highly variable standards and processes as they conduct activities around the world. In addition, underwater noise is a trans-boundary issue and may instead be best regulated through international policy (see McCarthy, 2004). Such international cooperation is likely to be the only way to avoid a tragedy of the commons in the high seas, arising from the traditional customary law of the sea enshrining the right of innocent passage (formalised in the United Nations Convention on the Law of the Sea – UNCLOS – the most recent version of which was signed in 1982).

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Bottle-nose dolphin, Black Sea, Crimea, Ukraine

To that end, noise-related resolutions and statements of concern have been issued by various international bodies and agreements including, but not limited to: the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS); Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS); the European Parliament and Commission; the International Whaling Commission (IWC); Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR"); and the International Council for the Exploration of the Sea (ICES). (For details see McCarthy, 2004; Environmental Caucus, 2006; Covi *et al.*, 2008; Parsons *et al.*, 2008; Koper & Plön, 2012; Parsons *et al.*, 2012.) While these draw attention to the issue and provide a mix of binding and non-binding obligations to their member states, widespread application of clauses in many international agreements and national laws requires that noise be defined as pollution. To that end, it is appropriate to consult UNCLOS, the most extensive international treaty governing the marine environment. UNCLOS states that "pollution" must be controlled and reduced, defining the term as "substances or energy [introduced either directly or indirectly] by humans into the marine environment..., which results or is likely to result in such deleterious effects as harm to living resources" (Article 1, UNCLOS, 1982). Sound unquestionably represents a form of energy, providing strong support for its control by countries that have ratified the treaty. One notable exception to this list is the U.S.

In 2004, the International Union for Conservation of Nature (IUCN) Resolution 3.068 also defined noise as pollution implicitly through use of the term "noise pollution" (IUCN, 2004). This non-binding resolution included a call to member states to limit the use of military sonar, drawing a dissenting statement from the U.S. (IUCN, 2004). In the same year, the European Parliament also stated that

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Whale diving near ship.

noise was a form of pollution and explicitly stated that this meant it was covered by the UNCLOS definition, with all the associated due considerations and implications (European Parliament, 2004). The European Union (EU) followed this in 2008 with explicit consideration of underwater noise in determinations of good environmental status (GES) under the Marine Strategy Framework Directive (MSFD: 2008/56/EC). Accordingly, member States are required to monitor and ultimately limit the amount of anthropogenic noise in European waters. Unfortunately, the monitoring requirements for continuous noise are focused on low frequencies, apparently for assessment of shipping (see Van der Graaf *et al.*, 2012). However, there are many parts of Europe where these low frequencies do not propagate well due to the shallowness of the waters (e.g., the North Sea and Kattegat), meaning that these requirements may not be very applicable in those areas. In such situations, ship noise may reach biologically important coastal areas at slightly higher frequencies that are not covered by the MSFD monitoring requirements. Nevertheless, the MSFD represents a substantial step forward in coordinating international efforts to address the issue. As such, it is highly recommended that other international institutions take similar steps to monitor and ultimately reduce both acute and chronic underwater noise levels.

Legal obligations to monitor, limit or reduce noise levels form the basis of a need for management of the various human activities that produce noise. Although some guidelines for how to achieve this exist (e.g., ACCOBAMS, 2010), they are rarely presented with the associated reasoning. Accordingly, the following chapters discuss current management and mitigation practices, as well as outline steps towards additional reductions in noise introduced into the marine environment by human action.

Grey whale, San Ignacio Lagoon Baja. © naturepl.com / Todd Pusser / WWF-Canon

CURRENT MANAGEMENT AND MITIGATION

4. MANAGEMENT TOOLS

Initially closely linked, the concepts of management and mitigation are becoming increasingly separated regarding marine noise and other aspects of human impacts on the marine environment.

The management of human impacts was once almost purely focused on the elements of impact that could be reduced through specific acts of mitigation. However, there is growing appreciation of the need to consider the wider effects of a given project or activity beyond those capable of being addressed through mitigation, as well as the wider-still consequences of interactions between impacts from different human activities, known as cumulative impacts.

Perhaps the best explicit expression of this by regulators has arisen out of the Open Water Meeting series undertaken by the U.S. National Marine Fisheries Service (NMFS). These public meetings are an opportunity for industry planning activities in Arctic waters to present monitoring plans and share the results of monitoring programs from the previous year. The peer review process for these plans has been extremely supportive of efforts to consider and manage far-reaching risks, while mitigating certain direct impacts to the greatest extent possible (e.g., Brower *et al.*, 2011).

4.1. The Management Process

The management of the impact of human activity on marine mammals and other marine life describes the holistic process of:

- monitoring and maintaining the status of the species and ecosystems concerned;
- establishing general protections where necessary;
- planning for activities (including any decommissioning);
- assessing the environmental risks associated with different options for achieving the desired goal (including cumulatively with other existing and future human action);
- selecting the most appropriate solution provided that legal thresholds for environmental safety (including to animal populations) are not exceeded;
- employing mitigation measures to reduce the impacts of the activity (including noise) to the greatest extent possible;
- monitoring the consequences of the activity; and
- incorporating the results back into the management process for improving future decisions (known as ‘adaptive management’).

Ideal management requires an investment in time and a certain amount of information. Areas of environmental sensitivity or importance to species of interest are best identified well in advance of the need to make management decisions pertaining to industrial development. Likewise, a working knowledge of the noise generated by particular activities, the reasons behind this, the impacts that it has on marine mammals, and the mechanisms involved facilitates long-term planning for human use of the marine environment. This would allow the use of prescriptive management options, such as marine spatial planning, marine protected areas and alternative technologies.

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North East Tenerife, Canary Islands, Spain.

4.2. Marine Spatial Planning and Marine Protected Areas

There is growing consensus that making certain areas of the marine environment unavailable to industry, at least during sensitive periods, represents one of the most effective methods for reducing impacts of noise on marine mammals (e.g., Agardy *et al.*, 2007; Dolman *et al.*, 2009; Götz *et al.*, 2009; Lubchenco, 2010). A number of conservation efforts have focused on the establishment of reserves, sanctuaries, marine parks and other area-based management zones, collectively known as marine protected areas (MPAs). While these terms all imply some level of limitation on human activities in these areas, the actual amount of restriction (or enforcement) is extremely variable (see Hoyt, 2011). However, the size of these areas is a major concern for noise due to the distances over which sound propagates in the marine environment, especially at lower frequencies (Wright *et al.*, 2011). Recent interest has also grown in wider planning approaches incorporating more consideration of the resulting locations of human activities, known as marine spatial planning and ocean zoning. The effective establishment of MPAs or the implementation of wider planning frameworks requires that managers have access to a certain level of information, the needs for, and the availability of, which will vary on a case-by-case basis. For example, establishing an MPA to protect a critically endangered species will mostly rely upon information regarding their biology and their preferred habitats. In contrast, wider management of noise-producing activities along the U.S. Atlantic Seaboard as offshore renewable energy development proceeds may involve not only information on all the species of concern, but also details on the preferred locations of the various activities and an assessment of the various environmental trade-offs likely to be associated with their relative and/or cumulative presence (Petruny *et al.*, In Press).

Perhaps the most notable area closure with respect to marine mammals and noise can be found in the Canary Islands. Following a series of beaked whale strandings associated with navy sonar exposure in this area, the Spanish government imposed a moratorium on naval exercises in the waters of these islands in 2004 (Parsons *et al.*, 2008). There have been no mass strandings on the Canary Islands since the Spanish government imposed this moratorium (Fernández *et al.*, 2013).

Another example can be found in Stellwagen Bank National Marine Sanctuary (NMS). Here, data on the local seasonal distribution of endangered North Atlantic right whales (*Eubalaena glacialis*) were used to reroute the shipping channel into Boston Harbour to reduce collisions between ships and baleen whales (U.S. Office of National Marine Sanctuaries, 2010). Speed-reduction measures and passive acoustic monitoring are additional measures to help protect large whales and other marine mammals with likely incidental benefits in terms of noise reduction. In addition to various fairly standard seasonal or permanent management areas in and around the Sanctuary, a system of short-term dynamic management areas, with temporary, voluntary 10 knot speed restrictions were introduced (Stellwagen Bank NMS, 2012). Sounds from multiple right whales are detected in real-time by a system of listening devices stationed within the shipping lane. Even if only a single whale is detected (within the last 24 hours), ships receive a warning to be aware of increased risk of colliding with a whale and are able to take appropriate steps. Slower ships typically produce less noise, although it should be noted that some concerns may remain regarding the duration of time spent in the area by any given ship so there may be some trade-off in terms of total noise input. However, suggestions that this may also lead to increased ship strikes appear unfounded given that such measures have proven to reduce ship strikes in the U.S. (NMFS 2013). Furthermore, the Alert system in the Sanctuary provides an example of the sort of creative management strategies that are possible with enough information, technology and creative thinking.

Northern right whale mother and calf off the Atlantic coast of Florida.

4.3. Alternative Technologies

Alternative technologies are increasingly discussed in many industries introducing noise in the oceans. These represent new methodologies, technological modifications to gear, or replacement equipment that is less damaging to the environment, while still accomplishing the same goal. It is often argued that the engineering process has already produced the best equipment possible. However, gear that has been optimised for human needs is not necessarily the best option when considering environmental impacts. As with operational measures, alternatives are easiest to introduce when sound is an unintentional by-product of activity, as in shipping or pile driving. However, this does not mean that it is not possible to find alternatives in cases where sound is functional for some task (e.g., seismic surveys). It is often the case that more sound is introduced than is needed to achieve the task. Alternatives are obviously industry-specific as they must be tailored to the task at hand. Thus they are covered in more detail in the Chapter 6.

4.4. Planning and Environmental Impact Assessments

On the more typical occasion that areas of interest to industry have not been protected, environmental considerations surrounding the entire lifecycle of a project (i.e., survey, construction, operation and decommissioning, as relevant) should be included as early in the process of planning the proposed activity as possible. This facilitates informed decision-making about the best location to site activities to avoid hotspots of marine mammal abundance, or timing the most impactful activities around periods when animals are known to be particularly sensitive. Achieving this may require the collection of a certain amount of 'baseline' data about the presence of species in the area prior to the activity. Basic statistical theory states that a record of three or more consecutive years is needed to establish any existing population trends, making such a period preferable for the collection of baseline data. (It should, however, be noted that this may still not be enough given inter-annual variability and any possible sampling errors, both of which would reduce confidence in the results.) Similarly, it should be possible to plan for a period of gradual phase-in of an activity in situations when the impacts are unknown, which would inform management prior to escalation at each step.

If it is ultimately not possible to avoid marine mammals, then times of particular importance to resident species, such as breeding periods, should be avoided. During the activity, mitigation measures should be employed to minimise any remaining risks and efforts undertaken to monitor residual impacts. A report regarding any observed impacts, or lack thereof, will then feed back into the management system to improve future management decisions.

While legislative structures around the world have been put into place to ensure that such procedures are carried out accordingly, the practical application is less than ideal. Obviously, commercial interests may be unwilling to wait for (or fund) the collection of sufficient baseline data. Likewise, companies rarely enter the regulatory process until decisions regarding the exact location of their activities have already been made. Then, much of the process gauging risk takes place through environmental impact assessments (EIAs). However, the related activities and documents are not always given the consideration and attention that they deserve. Instead, they are often rushed through under pressure (or even contract) from those seeking to conduct the activity in question, without appropriate consideration of the consequences.

Expertise and funding for these assessments is often limited and consideration of cumulative impacts is frequently dismissive (if present at all), taking the position that impacts do not need to be incorporated into such an analysis if they are individually negligible. This approach simply runs contrary to the basic concepts underlying cumulative impacts. The resulting assessments typically downplay the risks and possible extent of impacts, obfuscating regulatory thresholds in what amounts to an administrative exercise in paperwork. One way to address this is through the use of strategic environmental assessments. These act as repositories of environmental baseline information for a given region upon which specific EIAs can rely. Another option are programmatic environmental impact assessments, which assess the likely impacts associated with a planned or potential amount of collective human activity at a specific site over a given period in addition to the baseline environment. The latter in particular facilitates more appropriate cumulative impact assessments (CIAs) and both can reduce the burden on those producing EIAs. However, these more generalised assessments often increase the workload or costs for regulators and must also be revisited and updated periodically to avoid becoming outdated.

Upon commencement of an activity, those conducting it are often in charge of ensuring required mitigation measures are used, for monitoring residual impacts and for subsequently reporting back to managers. (The merits of specific guidance documents on best operational practice are discussed in more detail in Chapters 5 and 6.) Potential exists for considerable non-compliance through inexperience, neglect or deliberate intent , especially in cases where the use of certain mitigation measures is voluntary rather than regulatory.

Finally, given the limited change in management procedures evident in many countries, the incorporation of any reported information into future planning appears to be essentially lacking. Clearly there is much potential for improvement across the entire management process.

4.5. Science and Society in the Management Process

At this point it needs to be acknowledged that the management process incorporates not only science, but also political interests and social well-being, both of which include economic elements. This means that not all decisions are based upon the best available science, but also on other factors, such as economic imperatives. In fact, environmental legislation typically includes exemptions, exclusions, permitting processes or other authorizations to explicitly allow for societal interests to be considered. While some of these options are not bound by consideration of environmental consequences, others are conditional on demonstrating that some certain maximum impact level, based upon the best available science, has not been exceeded. For example, it may be that society has stated though environmental laws that a population should not be prevented from growth through human impacts, or that only a certain proportion of a given population can be exposed to such impacts in any given period (e.g., the *ESA*). However, even in cases where this has been demonstrated to be the case, there may still be legal mechanisms to override any decision based on the perceived human benefits (e.g., the Endangered Species Committee, more commonly referred to as the "God Squad," in the 1978 amendments to the *ESA*).

US Capitol Building.

Through these mechanisms societal interests are, in theory, expressly considered outside of the scientific appraisals in any environmental assessment process. However, the duration of the various exemption and authorization processes tend to be longer the greater the impact of a project, with the likelihood of approval increasingly uncertain. This has created a situation where there is huge benefit to the proponents of a given activity for a finding of impacts that are consistent with current legal standards. Additional pressure for consistent findings comes from the central role that these scientific assessments often play in the event of any legal challenge. The consequence of this, despite the external consideration of societal values, is that many EIAs have become an exercise in 'demonstrating' that these thresholds have not been exceeded, rather than an honest review of potential consequences. Any such supposedly scientific determinations of whether the impacts of any given project exceed societally-driven management thresholds set into law simply fail the environment and those closely dependent upon it, while also undermining the purpose and value of the entire management system.

One final consideration on the interaction between science and society in the management of noise relates to where the burden of proof lies. Many environmental laws state that those proposing the activities must demonstrate (through the use of scientific analyses in EIAs) that their plans would not lead to unacceptable environmental consequences. However, lack of available scientific information to achieve this does not often (if ever) prevent industrial activities from moving forward. Essentially, the burden of scientific proof falls to others to demonstrate that a given threshold has been exceeded and an impact is likely, against the legally outlined wishes of society.

4.6. Noise Exposure Thresholds

Some of the most debated thresholds under which scientifically-based decisions relating to noise are supposed to be made are exposure thresholds. The U.S. took the lead in setting thresholds for levels of sound beyond which marine mammals should not be exposed in 1995. This has come to represent the level at which 'injury,' as defined by the USMMPA, occurs as a consequence of noise exposure. Additional, lower criteria were also introduced to define the onset of 'behavioural harassment,' also in accordance with the USMMPA. These levels have been changed only once in nearly two decades, when levels for the threshold for 'injury' for all cetaceans were reduced to the lower sound levels at which 'injury' was already defined for baleen whales and sperm whales. This is largely due to the support for the existing criteria that was provided a few years after their introduction in the findings of an 'expert' panel, which involved numerous representatives from the oil and gas industry (High Energy Seismic Study, HESS, 1999). These criteria (and the 'injury' threshold in particular) have since been re-used in many other countries around the world, despite advancing scientific understanding.

Recognising the need to revise these criteria, the U.S. again took the lead and convened another panel of scientific experts to review new information and offer scientific guidance on appropriate thresholds (Southall *et al.*, 2007). Although firmly linked to the U.S. legal thresholds (i.e., injury and harassment under the USMMPA), this group moved forward by taking into consideration the complexities of sound and introducing dual criteria for 'injury' based upon the instantaneous greatest sound levels and the equivalent level of continuous noise. They effectively abandoned setting levels for the behavioural criteria due to the numerous factors that influence responses, not least of all the context of exposure. Here, 'context' refers to: any prior experience of the animal exposed; its health and activity at the time of exposure (e.g., feeding, breeding, resting, migrating, etc.); its age, sex and reproductive status; and many other considerations.

Through this process Southall *et al.* (2007) offered noise exposure criteria that were measured in a different way to previous ones. They were also effectively higher than the earlier regulatory thresholds, although these values have yet to be officially integrated into U.S. regulations.[1] However, this was soon followed by the decision of the German government to implement considerably lower dual noise criteria, based upon predominantly the same scientific information (Werner, 2012; Comments and discussions at the Quieting Technologies for Reducing Noise During Seismic Surveys and Pile Driving Workshop held by the U.S. Bureau of Ocean Energy Management, BOEM, 2013; Liebschner and Merck pers comm., cited in Simmonds *et al.*, In Review).

1 At the time of writing, an effort was underway to revise the thresholds in U.S. regulation. Internal discussions of Southall et al. (2007) and all other available literature will result in a proposed regulatory framework that is expected for release soon. It will then go through a period of public scoping and revision prior to being finalized.

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Humpback Whales feeding.

These differences essentially stem from contrasting opinions on two issues: what impact from noise should be avoided (i.e., what constitutes 'injury'); and which species are considered to be representative for others where data is missing. With regard to the first issue, Southall *et al.* (2007) focused their concern on avoiding immediate and permanent reduction in hearing sensitivity (i.e., partial hearing loss), known as permanent hearing threshold shift (PTS), as a consequence of exposure. In contrast, German regulators determined that they should seek to avoid inducing a temporary reduction in hearing sensitivity, known as a temporary hearing threshold shift (TTS). The argument for the higher values is that TTS occurs quite often in nature making regulation to this level overly protective. On the other hand, there is evidence (at least in humans) that experiencing multiple TTS can lead to PTS. Also, there are indications that permanent hearing-related nerve damage can occur at levels associated with reversible TTS in mice (Kujawa & Liberman, 2009). Natural variation complicates the issue further, as any given individual may be more or less sensitive to noise exposure. This lends some support to use of a more cautious lower value to ensure that no animal is 'injured' as a consequence of human noise exposures (see Gedamke *et al.*, 2011).

As indicated in Section 4.5, the level at which a society determines noise exposure to be unacceptable is largely a non-scientific issue. If policy makers announce that TTS is unacceptable, as occurred in Germany, then scientists can only advise on the appropriate associated noise levels. However, science has provided some guidance on appropriate ways to handle natural variability in responses to threats and disturbance. For example, if regulatory threshold for injury (defined as TTS) was set to the average noise level required to induce TTS in a given species, then around half of all animals of that species exposed at that level of noise would still suffer TTS, due to the nature of an average. In contrast, setting a value at the level that would protect 95 % of all animals, given the range of natural variation, would instil a level of confidence in the ability of the regulation to achieve its goal. Again, the level of certainty (e.g., 75, 90 or 100 %) is a matter for the policy makers, albeit informed by science and somewhat constrained by any other legal requirements for preventing the decline of the wider population or species (e.g., the *ESA*, 1973).

In consideration of which species should be considered representative of others in terms of their responses to noise, science may have more to say. Southall *et al.* (2007) based a lot of their assumptions on the bottlenose dolphin (Tursiops truncatus), as we have the most information about this coastal species. In contrast, German regulators were primarily concerned about their most common cetacean, the harbour porpoise. Therefore they decided to focus on information specifically on this animal (e.g., the work eventually published by Lucke *et al.*, 2009), which has been found to be much more sensitive than the bottlenose dolphin.

More recent work has demonstrated that a growing number of species are, like the harbour porpoise, also more sensitive to noise (e.g., Moretti *et al.*, 2010; McCarthy *et al.* 2011; Miller 2011; Popov *et al.*, 2011a; Tyack *et al*,. 2011; Miller *et al.*, 2012; Pirotta *et al.*, 2012). This supports lower regulatory noise exposure criteria than would be suggested from work on bottlenose dolphins alone. This is further reinforced by the discovery that longer noise exposures lead to longer periods of recovery back to normal hearing following a TTS (e.g., Popov *et al.*, 2011b).

Harbour porpoise, Sognefjord, Norway

The German government did not propose behavioural criteria, partly because many management procedures and mitigation measures are actively designed to reduce 'injury' in favour of behavioural impacts. As mentioned above, Southall *et al.* (2007) also provided the U.S. government with little advice over their legislative need for behavioural criteria due to the various complexities involved. Regardless of the existence, or lack thereof, of behavioural criteria, an evaluation of the full consequences of all (other) sub-injurious impacts to individuals and populations is required to completely assess the sum of all impacts of noise on marine mammals (a legal mandate in many countries). This fact has been noted by another expert panel in the U.S., which stated that injury and behavioural harassment criteria "do not determine the overall level of impact [as] physiological stress and other factors also need to be considered" (Fitch *et al.*, 2011). Unfortunately, we are only beginning to understand how important these impacts must be to marine mammals. Accordingly, these impacts are discussed in more detail in Chapter 7.

4.7. Monitoring and Reintegration of Information

To improve our understanding of the impacts of noise, it is important that efforts be made to obtain additional information on the impacts of a given noise source on marine mammals. Comprehensive management plans should outline a formalised process for obtaining information gained through visual observers on-site for mitigation purposes (see Section 5.1), as well as through a more extensive research program (see Brower *et al.*, 2011 for more details). Although a large amount of research has been undertaken to date regarding behavioural responses to noise, it will be necessary to conduct more thorough, longer-term studies to identify and assess the ultimate individual and population-level consequences of the numerous emerging noise-related issues (see Chapter 7). This may be of particular importance in areas designated for protection through MPAs, etc.

Although many management frameworks are often touted as employing 'adaptive management' of the type discussed here, actual working feedback of information into future management decisions is typically lacking. This is often evident through the lack of consideration of such data in subsequent EIAs. Consequently, a formalised and public report submission process in addition to data integration efforts within the regulatory agencies would be useful inclusions into management systems. Much of this is actually covered by the United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters ("The Aarhus Convention", 1998), although many signatories do not meet the requirements. While data re-integration into the on-going management process isn't strictly part of this Convention, it does require that pertinent environmental information be made available to the public, making it more difficult for governments to avoid using any new data in the future.

4.8. Compliance and Enforcement

All of the best management and mitigation measures in the world are meaningless without compliance and active enforcement of infringements (Bearzi, 2007).

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The Canadian Coast Guard Ship Louis S. St-Laurent makes an approach to the Coast Guard Cutter Healy in the Arctic Ocean.

Unfortunately, the vast majority of assessments of compliance with regard to noise-producing activities involve self-reporting by the industries concerned. Fisheries managers addressed the need for accurate compliance data in several countries through the deployment of fisheries observers. While this data is available for use in enforcement proceedings in some countries, such as Canada, observer data cannot (for better or for worse) be used for this purpose in others, such as the majority of fisheries in the U.S. (Porter, 2010). Regardless, the question as to how to encourage compliance with regard to noise-related mitigation measures remains open.

It is always possible to deploy vessels with the relevant authorities, or to mandate that operations be subject to unannounced inspections as part of any regulatory permit process. However, both of these measures carry a certain expense and impracticality when off-shore activities are being considered. The Universal Ship-borne Automatic Identification System (AIS) currently deployed on larger ships transmits their locations, among other information, and can be used to track compliance with no-go areas, regulated shipping lanes, or even speed restrictions. However, this is generally limited to near-shore areas due to the range of on-board AIS transponders, with coverage typically more limited beyond 40 nautical miles. To resolve this, it has been suggested that independent on-board data recording systems be put in place to keep a detailed record of firing airguns during seismic surveys (Weir & Dolman, 2007). Similar systems could also be developed and deployed in various ways to track pertinent information regarding other noise-producing activities, including drill ships, dredging and commercial shipping in general.

In addition to the threat of enforcement, compliance can also be encouraged in more proactive ways. For example, public relations might be improved if a company can display the fact that they have achieved a certain standard of noise reduction through green certification programs. A less formal alternative is simply for a government agency or even a watchful non-governmental environmental organization to send companies letters either thanking them for their compliance or asking them to improve efforts.[2] In either case, it might be a requirement for any associated research program to supply data to inform such efforts.

2 As the Canadian Whale Institute, in collaboration with other partners, did so in the case of vessel compliance with the International Maritime Organization designated "Area to be Avoided" in Roseway Basin off Nova Scotia, Canada.

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Dr. Pablo Cermeno, aboard the WWF's 'Columbus' boat.

5. MITIGATION OPTIONS

If approved through management processes, noise-producing activities are often required to be mitigated to the greatest extent practicable (e.g., under the USMMPA) to reduce exposure of, and thus impacts on, marine mammals and other marine species. There are numerous tools available to achieve this. Although many are industry-specific, a number are more generally applied in various ways to multiple sources. However, the effectiveness of these tools is generally limited by the fact that the majority do not reduce the level of noise introduced into the environment. In fact, several mitigation tools actually rely on the introduction of additional sound into the ocean to be effective. Furthermore, the ability of these tools to reduce underwater noise overall is also limited if they are applied on a case-by-case basis in the face of an increase in the overall amount of industrial activity.

5.1. Visual Observers, Safety/Exclusion Zones and Shutdowns

Undoubtedly the most common measure to mitigate the exposure of marine mammals to noise is that of the safety or exclusion zone. Designed to reduce injury at high levels of exposure, this is an area around the source, typically circular and defined by its radius, which is visually scanned by marine mammal observers (MMOs). When the visual observers spot a marine mammal, the industrial operations are generally required to cease (or are not permitted to begin in pre-activity surveys) until the safety zone is once again clear. This is known as a shutdown. While in principle this measure should prevent marine mammals from being exposed to a given level of noise, there are a number of issues with the use of this mitigation option. These issues have been acknowledged and detailed in many other places (e.g., Weir & Dolman, 2007; Parsons *et al.*, 2009), but are briefly summarised here.

Firstly, most safety zones are based on arbitrarily defined, easy to handle radii, rather than being based on distances at which levels of noise inducing a particular unwanted impact are likely to occur. Additionally, observer estimates of distance to a sighting may be inconsistent. Further issues arise when the required distances are beyond the visual range of the observers, when weather, darkness or sea conditions compromise their ability to spot marine mammals (e.g., Teilmann, 2003; Barlow & Gisner, 2006; Harwood & Joynt, 2009; Parente & de Araújo, 2011), or when observers have been on duty for too long, reducing their effectiveness (e.g., Harwood & Joynt, 2009; Gill *et al.*, 2012).

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Humpback whales.

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Cuvier's beaked whale surfacing.

Furthermore, the level of experience for observers is an extremely important factor in their ability to detect a marine mammal. Even with experienced, fresh observers at the beginning of their shifts and in perfect conditions, scientists have long recognized that their own visual surveys are imperfect. Marine mammals spend the majority of their time underwater and it is entirely possible to miss an animal that is exactly on the survey line (e.g., Thomsen *et al.*, 2005). Many animals, especially deep divers such as sperm whales and beaked whales, may even approach the sound source from beneath, crossing the visually unmonitored (and undefined, but implied) vertical boundary of the safety zone at depth. The result is that some marine mammal species (especially those with low-profile surfacings and small blows) are seldom spotted as they cross the invisible line into the safety zone. Instead, when animals are first spotted within a safety zone, they might already be some distance inside of it and may have already been exposed to levels of sound higher than that at the boundary. Thus setting the radius of a safety zone at the exact distance where the level of sound is expected to begin to generate the unwanted impact will be intrinsically unsuccessful at achieving this goal.

Finally, larger safety zones may also be problematic to actually implement, even if they are appropriate for mitigating an activity that produces particularly high levels of noise. When observers are fresh, visibility is clear enough to extend to the required distances, and sea conditions are optimal, sightings rates are still known to decrease with distance. As a result, any large, well-intentioned safety zone becomes unworkable in the field, without deploying additional satellite vessels or providing some other means to scan out to the edge of the safety zone. One option is to include airborne observers in aerial surveys. However this (like the use of additional vessels) has a range of drawbacks including the need for more observers and the use of additional craft, which in turn produces a number of other concerns, ranging from additional noise input and a larger environmental footprint in terms of carbon and other pollutants, to the more practical safety concerns for the crews involved. Other alternatives include technologically augmented searching using

Radar, Lidar (Light Detection and Ranging) and thermal or infra-red detectors, although these have typically been shown to have limited benefits (e.g., see discussion of night-vision equipment in Section 6.2). One possible exception to this is the thermal system developed by Zitterbart *et al.* (2013) for automatically detecting the heat signatures of whale blows. However, even this promising technology is less reliable during the daytime and will be limited to use in cooler waters, as well as to detecting animals of at least a certain size (or that have a certain size blow).

Partly as a consequence of all the ways that sighting rates of marine mammals can be reduced, some management agencies have added restrictions on when noise-producing activities can begin. The most common is the requirement for industry to only begin producing noise during hours of daylight, so that a pre-activity visual survey can be completed with the greatest level of confidence. The idea here is that animals will not approach the source once it is running and can thus continue at night (see more critique of this thinking in Section 5.4). The same logic (i.e., if marine mammals are actually bothered by the sound, they won't approach the source) underpins the typical resistance of industry to shutdowns. Shutdowns, especially at night in cases where restrictions require that a restart must wait until dawn, can be extremely expensive for some noise producing activities as costs of crews, ship time and other factors remain even if work is not being undertaken. Although unquestionably beneficial to the particular animals concerned, there may also be other environmental considerations related to continual and potentially increased noise and chemical pollution from other sources (e.g., the ship towing an array of seismic survey airguns).

In summary, safety zones can reduce the number of marine mammals exposed to high levels of noise, especially when combined with shutdowns. However, the efficiency of this mitigation measure is limited in a number of very important ways, with particular dependence upon the consistent availability of fresh, experienced observers and visibility. It is clear that safety zones cannot at this time protect all marine mammals from dangerous exposures, even in situations where they are not arbitrarily delimited. Accordingly, supplementary or alternative impact reduction efforts may be required.

5.2. Passive Acoustic Monitoring

Recently, visual detection methods for maintaining safety zones have been supplemented or, in some cases, replaced entirely by systems that assess continually incoming sound recordings for marine mammal sounds in real time. These are typically referred to as passive acoustic monitoring (PAM) systems. Mostly the incoming sounds are assessed by human operators, but the technology is advancing so that automated detections are increasingly viable, albeit with different degrees of accuracy, for certain species. Several software products have also been developed to assist operators detect incoming sounds.

While PAM solves the issue of detecting underwater marine mammals, it suffers from a number of drawbacks (see Bingham, 2011; Gill *et al.*, 2012). Obviously, the system can only work with vocalising marine mammals and even then only for known vocalization types. Similarly, there are a number of ways that incoming information can be displayed to the PAM operator. As a result, one specific set-up for displaying the sounds can aid the operator in identifying one (or more) species, but at the cost of reducing the chance of detecting other animals that produce sounds at different frequencies. As with visual observers, operator experience and exhaustion also come into play, with detection rates greatly improved if an operator knows what to listen for (e.g., Barlow & Gisiner, 2006). Furthermore, subtle variations in the sounds produced by marine mammals between one population and another, as well as changes in the received sounds as a consequence of the spreading effect related to distance, can reduce the accuracy of any automated detection process. Finally, orientation of the sound-producing animal in relation to the PAM system will influence the levels received and thus also the estimation of distance to the animal. The same problem arises as marine mammals are also known to produce sounds at variable levels. While the issue of orientation can to some extent be resolved through the use of multiple hydrophones in the system, allowing the direction of animal movement to be tracked, this does not address the problems of variable source levels. Finally, marine mammal sounds may also be masked by other noise, including that of the source the PAM system is being used to mitigate for.

As a consequence of these issues, PAM suffers from many of the same issues as visual surveys (e.g., undetected animals, errors in distance estimations, reliance upon experienced, fresh operators), as well as some additional specific problems of its own (Bingham, 2011; Gill *et al.*, 2012). However, the technology is still relatively young and rapidly developing in terms of efficiency as a mitigation tool.

Sonar operator

5.3. Active Acoustic Monitoring

To deal with the issue of PAM being ineffective at tracking marine mammals when they are quiet, it is possible to use active acoustic monitoring (AAM, or whale-tracking sonar) to locate animals. While this is certainly true, there are some issues with efficiency and range determination (Bingham, 2011). AAM also requires additional equipment and does introduce additional noise into the marine environment that might itself impact marine mammals or other species. This is not necessarily a concern if AAM is being used to mitigate a very loud source, such as an explosion, where it could also function as an alarm and prevent animals from experiencing extremely hazardous sound levels (see discussion under Mitigation sources). However, the potential exists, especially with regard to the quieter sounds, for the AAM to contribute relatively large amounts of additional noise to an entire operation, increasing the occurrence of masking and stress responses. One further concern in interpreting monitoring data after a project has been completed is that it is not necessarily possible to separate the response of any animal to the main source from that of the AAM. Accordingly, the use of AAM is not highly recommended, except perhaps in the case of mitigating single loud sounds, where they can also be ramped-up and used simultaneously as an alarming source (see Ramp-Ups / Soft Starts and Mitigation Sources for further consideration to the viability of use of AAM in these contexts).

5.4. Ramp-Ups / Soft Starts

This mitigation measure is employed at the beginning of loud sound-producing activities in the marine environment. It involves slowly building noise levels to operational levels over a period of time. The thought behind this is that animals exposed to the rising levels will move away from the source and avoid being exposed

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Manatees have been observed responding to boat noise exposure by moving into the nearest deep waters.

to dangerously high levels. Once up and running, the source will act as if it were continually ramping-up as animals approach the source, or vice versa. It is a long-standing cornerstone of operational guidelines for seismic surveys (e.g., the U.K.'s Joint Nature Conservation Committee – JNCC – guidelines: JNCC, 2010a) and is becoming increasingly common practice in sonar exercises and pile driving. However, we are only just beginning to look into the effectiveness of this technique.

Crucially, there are a number of fundamental assumptions that remain untested. For example, the procedure relies on the idea that animals will move away from the source in a logical manner. Anyone who has chased a shorebird along the strandline will recognize this is not a given. Instead of moving around the oncoming disturbance (i.e., the walker) for the minimal avoidance effort, these birds will typically fly further up the beach, remaining in the path of the walker and soon be in need of repeating the manoeuvre. Similar 'illogical' responses have been reported in both North Atlantic right whales and manatees (*Trichechus manatus*). One study found that right whales responded to some novel sounds by moving near, but not actually to, the surface, placing them at greatest risk of being struck by ships. (Nowacek *et al.*, 2004). Likewise, manatees have been observed responding to boat noise exposure by moving into the nearest deep waters, which were typically boat channels and thus increased their risks of both higher exposures and being struck (Miksis-Olds *et al.*, 2007). The 'logical reaction' assumption also relies on the further supposition that animals both can move far enough away from the disturbance and are willing to do so. Again, neither may be true. For example, coastal and ice-edge areas may 'trap' animals too close to a source, or force them into geographical features that they may be unable to subsequently escape from, with potentially fatal consequences (e.g., Heide-Jørgensen *et al.*, 2013; Southall *et al.*, 2013). Similarly, it is possible that animals may remain in an area of high interest to them, such as a rich food source, until exposure levels become 'dangerous'. Alternatively, animals that do leave may be excluded from rich foraging, also to their detriment.

There are other problems with this technique, especially with regard to moving sources, including: the introduction of additional noise into the environment; the complications raised by 'shadow zones' where levels of noise may be greatly reduced at certain points closer to a source than would be expected (either as a consequence of the source, or the topography of the area, especially around coastlines and islands); and the need to carefully consider the relative speeds of moving sources and marine mammals likely to be exposed. However, all of the above have been discussed in greater detail elsewhere (e.g., Weir & Dolman, 2007; Parsons *et al.*, 2009). Despite this, only the concern over additional noise seems to have worked its way into guidelines, as some regulatory agencies are now setting upper limits on the maximum duration of ramp-ups (e.g., JNCC, 2010a).

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North Atlantic Right Whale.

Actual research and field studies into the effectiveness of ramp-ups are only now being conducted with seismic surveys and humpback whales in Australia (e.g., Cato *et al.*, 2012; Noad *et al.*, 2013). Unfortunately, the available results are still too preliminary to draw any firm conclusions. Some assessments have also been made using computer simulations (e.g., Hannay *et al.*, 2010; von Benda-Beckmann *et al.*, In Press). However these are, by their very nature, simplifications that are based on a number of assumptions. These include not only a number of suppositions regarding the environment in which the noise will propagate, but, more importantly, also about the reactions of the animals (for a discussion of the importance of this, see Wensveen, 2012). Accordingly, a model result in which, "no instances were found in which the threshold levels for hearing injury for cetaceans were reached during the initial stages of the soft-start sequence" (International Association of Oil & Gas producers, OGP, 2011) simply means that the low levels of noise at the beginning of a ramp-up will not 'injure' marine mammals, defined in this assessment as a permanent reduction in hearing sensitivity.

Despite this, OGP (2011) went on to conclude that, "this suggests that the animals are not at significantly greater risk of harm when a soft start is initiated in low visibility conditions." Unfortunately, this cannot be determined from the model result. In fact, those responsible for the modelling contained within the OGP (2011) report noted that animals would have time to move away from the source only if those early exposures were "sensed as disagreeable" (Hannay *et al.*, 2010). However, the extent to which (and point when) animals indeed find the slowly increasing sounds 'disagreeable' has not been investigated. Other considerations include suppositions regarding: the smooth reduction of noise levels with distance from the source; the lack of shadowing of the sound source in any way; the degree of natural variation in responses of the exposed animals; their direction and consistency of movement; their willingness to leave an area even if the exposures are disagreeable; and their ability to move far enough away, which in turn is conditional on coastlines and other barrier features. Finally, it has been noted that the time between the production of two consecutive sounds can also have a bearing on the efficiency of the ramp-up in activities with a duty cycle. If there is enough time between the sounds, as might be common for navy sonar, it is possible that a marine mammal might get close enough to an approaching source to be adversely effected by the next signal (von Benda-Beckmann *et al.*, In Press). Accordingly, mitigation sources between regular sound production may be a useful avenue of investigation (see Section 5.5).

The merits of ramp-ups are still unknown, although it seems likely that it reduces the number of high-level marine mammal exposures to some degree. However, it seems clear that if ramp-ups worked with great efficiency, there would never be cause to implement a shutdown (see Section 5.1). In any case it is important to realise that the ramp-up is designed to reduce injury from high acoustic exposures by inducing avoidance responses at lower sound levels. Accordingly, this technique is not able to reduce the vast majority of the suite of impacts that occur as a consequence of noise exposure.

5.5. Mitigation Sources

Mitigation sources are based on logic similar to that of a ramp-up approach with many of the same limitations. These are low-level sources of noise, at least relative to the main source, that may serve one of two purposes. Firstly, they may continue between short breaks in the operation of the noise-producing activity in order to keep marine mammals away from the source and prevent 'injury' upon restarting. While typically employed at times where operational breaks are decided by the industry (e.g., JNCC, 2010a), these may also be implemented instead of a full shutdown when a marine mammal enters a safety zone, as is the case for seismic surveys in Greenland (Kyhn *et al.*, 2011). Mitigation sources are functionally a way for industry to avoid a full ramp-up in situations where their operations are interrupted for brief periods. Thus, there are usually some constraints upon the length of time for which they can be used (e.g., JNCC, 2010a). However, such constrains would be inappropriate in situations where the 'breaks' in operation might be inherent within the duty cycle of the source being used (see Section 5.4). To prevent marine mammals from coming too close to a source during these pauses, it may be possible to use a mitigation source to effectively fill the gap, maintaining the effect of a ramp-up arising from a moving source (von Benda-Beckmann *et al.*, In Press).

The second type of mitigation source can be employed prior to the production of noise during operations. They are typically employed around static sources and in situations where ramp-ups are not possible due to mechanism of sound production or the fact that the sound is produced in a single event (e.g., explosive detonations). The intention is that a circle of alarms, known as acoustic deterrent devices or (if loud enough) acoustic harassment devices, can be used to prevent the marine mammal from coming too close to the main source. It may also be possible (in some cases) to ramp-up the source levels of these alarms to limit their impact.

Mitigation sources, like ramp-ups, rely on untested assumptions, particularly about the avoidance behaviour of marine mammals in the face of increasing levels of noise exposure. It is likely that these additional sources will also not be completely effective at eliminating the exposure of marine mammals to high-level noise and may, in any case, have additional impacts of their own (e.g., Culik *et al.*, 2001; Franse, 2005; Gönener & Bilgin, 2009; Haelters & Camphuysen, 2009). Although it is not possible to weight the benefits against the detriments of this tool, it must be acknowledged that mitigation sources do introduce additional noise into the marine environment. Similarly, there is a risk of entrapping an animal within any ring of alarms and thus close to a main source, which also requires additional consideration.

5.6. Bubbles, Cofferdams and Isolation Casings

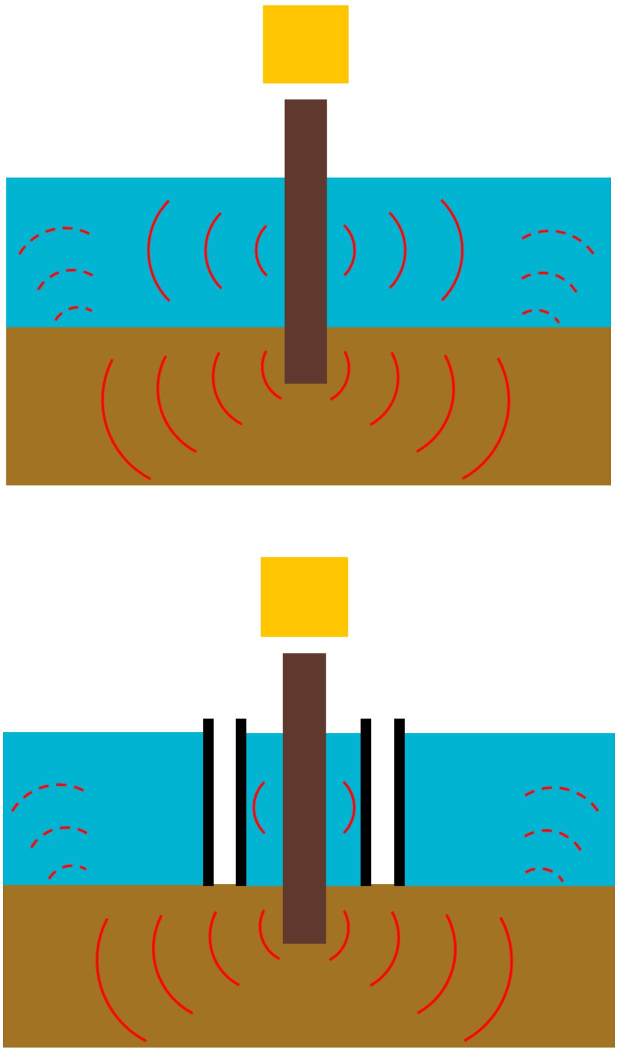
These mitigation measures generally exploit the fact that sound does not pass easily from air into water or vice versa. They do this by surrounding the source with air (or some other dampening material), either partially or completely, and sometimes in combination with other materials. The earliest development in this area was the bubble curtain. Although the production of bubbles itself generates some noise, these are typically much lower than the source that is being muffled. However, these free bubbles were uncontrollable with regard to bubble size and behaviour, which are linked to their effectiveness at dampening transmission of sound at different frequencies. The curtains were also easily disrupted by moving currents. A number of more stable systems have been developed that either encase individual bubbles (consider bubble wrap), or air-spaces in more general terms, including enclosed within larger housings similar to floats or between two barrier walls. The ultimate application of these techniques is that of the cofferdam, where a dry island is essentially created using barriers made of steel or similar material, within which one or more sound source can be completely isolated from the water. On a smaller scale, isolation casings can be deployed around, for example, single piles (e.g., the Temporary Noise Attenuation Pile: Reinhall & Dahl, 2011). These can be more quickly deployed and re-deployed than cofferdams, but provide less air isolation around the source.

A bubble curtain being installed.

These mitigation measures have all been demonstrated to be effective (to varying extents) at reducing levels of sound beyond them relative to levels propagating from unmitigated sources, although their capabilities are not consistent across different frequencies (see Saleem, 2011; Continental Shelf Associates Ocean Sciences, CSA 2013). The main problem with these techniques is that they are only viable in relatively shallow waters. Furthermore, while cofferdams and, to a lesser extent, isolation casings are particularly effective at reducing levels of underwater noise emanating from a source, even these do not completely eliminate it. This is a consequence of the fact that sound, especially at lower frequencies, can also travel through the sea floor substrate. This means that the noise from striking a pile with a pile driver is transmitted through the pile, into the substrate, under any air barrier and into the water beyond, often at considerable distances. This obviously represents a noteworthy limitation to this otherwise highly effective strategy.

The two other key limitations to efforts to isolate a source is that it is much harder, although not impossible, to isolate a moving source; and that it is of less use when sound is intentionally introduced (e.g., naval sonar). Despite this, some exploratory efforts have been made to reduce the propagation of sound from seismic survey airguns in unwanted directions (e.g., horizontal directions or upwards), albeit mostly with a view to reducing the amount of self-noise for better interpretation of the echo responses (e.g., Ross *et al.*, 2005). These efforts have not been particularly successful, especially given the often large amounts of additional equipment that are required. Consequently, they have not been pursued with any great vigour.

One area where there appears to be some promise of isolating moving source from the marine environment is in commercial shipping. By releasing large numbers



How sound is transmitted from a pile (brown) being driven by a hammer (yellow) into the sea floor. Noise (red) transmitted directly from the pile into the water can be blocked using barrier techniques, but the noise that enters the water after passing through the substrate will still persist.

of small bubbles against the hull of a ship, transmission of internal machine noise into the water can be reduced, although it is not the main source of noise from commercial vessels (see Section 6.3). Employed primarily to reduce drag from the ocean on the hull of ships (e.g., Mistubishi's Air Lubrication System: see Kantharia, 2013), this mitigation measure may have complimentary benefits to fuel efficiency and usage.

5.7. Operational Measures

Operational measures are changes in the use of equipment or the conduct of an activity that reduces the introduction of noise into the marine environment. These include running ships at optimal (usually slower) speeds to reduce the formation of vacuum 'bubbles' around the propeller, known as cavitation, that accounts for the majority of noise produced by most commercial vessels with fixed pitch propellers (e.g., Leaper & Renilson, 2012). However, it should be noted that there may still be an optimum amount of cavitation for fuel efficiency and the relationship may not hold for ships with variable pitch propellers and other propulsion systems.

Certain limitations may be placed upon the operational flexibility of a particular activity to maintain a level of safety, or if the sound introduced is done so intentionally for the purpose of completing some specific task. However, it is often the case that at least some small changes in procedure to reduce the impact of the sound produced on marine life are possible. Some of the most common operational procedures are the ramp-up and the shutdown, both of which are discussed earlier in this Chapter. However, other more industry-specific options also exist. These are discussed in Chapter 6, in connection with the industries in question.

6. CURRENT MANAGEMENT AND MITIGATIONS BY ACTIVITY

As mentioned earlier, there is a huge range of human activities that introduce sound into the marine environment. The four biggest noise-producing industrial activities are: oil and gas development; military exercises; commercial shipping; and pile driving.

A range of guidance documents have previously been offered to the different industries, especially oil and gas surveys, regarding which mitigation measures are best suited for their activities. However, many of these 'best practice guidelines' have changed little since their introduction and remain based on the state of knowledge at their conception, rather than reflecting the level of information available today.

6.1. Oil and Gas Activities

For various historic reasons, one of the most regulated sources of noise has been the seismic surveys conducted by the oil and gas industry and, to a much lesser extent, by geological surveys. These surveys currently employ a number of airguns to produce sound for mapping structures beneath the sea floor. The airguns do this by explosively releasing air that was kept under pressure in a sound-producing event that cannot be precisely controlled. The result is a sharp, intense loud sound (characteristics known to increase risks to hearing; see Southall *et al.*, 2007) across a wide range of frequencies (e.g., Goold & Coates, 2006; Goold & Fish, 1998), although the majority of the noise energy is at the very low frequencies that are also used by baleen whales in their sounds. It should be noted that while these lower frequencies are actually functional for the surveys, the noise at other frequencies is unnecessary to the task at hand.

There are currently (as of 2013) 142 seismic survey vessels in existence around the world (Kliewer, 2013). Although this is down from 150 in 2012, newer high-capacity vessels are coming online (Kliewer, 2013). A large proportion of these will be simultaneously active at any given time and the surveys may persist for months and extend over huge areas (e.g. 35,000-70,000 sq. km; Clark & Gagnon, 2006). These facts in combination with the good propagation of the low frequency noise from these typically coastal surveys mean that surveys can be detected above natural background noise levels on 80-95 % of days at some locations on the Mid-Atlantic Ridge (Nieukirk *et al.*, 2012). Simply put, the cumulative exposure of these surveys for marine life collectively is enormous.

Behavioural reactions to noise from seismic surveys such as avoidance, startle responses, vocalization changes, and the alteration of dive and respiration patterns, have been documented in a range of cetacean species (e.g., Gordon *et al.*, 2004). However, given the damaging nature of the sharpness and loudness of the sounds produced, the majority of management and mitigation efforts have focused on avoiding 'injury' to marine mammals. With this focus on avoiding 'injury' the JNCC became the first regulatory body to issue guidelines for minimising impacts of noise from seismic surveys on marine mammals (JNCC, 1998). This focus ran contrary to the fact that the guidelines were actually called "Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Surveys" (emphasis added). Nevertheless, these guidelines filled a policy vacuum and have thus been adopted, in whole or in part, by several other management agencies around the world (Compton *et al.*, 2008).

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A ship towing seismic equipment.

In short, these guidelines state that those planning seismic surveys should, at the planning stages: discuss the merits of the design of any monitoring programs; plan the timing of their surveys to reduce the likelihood of encounters with marine mammals; seek to reduce the unnecessary high frequency noise; and, in areas of importance to marine mammals (as was to be determined "in consultation with the JNCC") seek to provide the most appropriately qualified and experienced personnel to act as MMOs on board the seismic survey vessel (preferably experienced cetacean biologists, but at a minimum it was "recommended that observers should have attended an appropriate training course;" JNCC, 1998). The JNCC also reserved the right to request additional precautions in 'sensitive areas'. By the 2010 version of these guidelines (JNCC, 2010a), a requirement to use the lowest practicable power levels necessary to achieve the survey objectives was also added to the planning stages. Even here, there is no specific mention that planning should consider complete avoidance of particularly important areas, although it could be argued that this might be covered by the additional precautions that JNCC can impose on a case-by-case basis. (It should also be noted, however, that a certain amount of advice regarding wider risk assessments are present in the wider joint JNCC, Natural England and Countryside Council for Wales guidelines for the Protection of Marine European Protected Species from Injury and Disturbance: JNCC *et al.*, 2010: although these seemingly remain in draft form.)

Mitigation measures required by the 1998 JNCC guidelines were very limited. Essentially, they consisted of a 30 minute, pre-survey visually-determined 500 m safety zone, followed by a 20 minute ramp-up period before formal operations. The ramp-up (and thus also operations) was to be delayed by "at least 20 minutes" if a marine mammal was sighted within this 500 m during the pre-survey scan.

The use of PAM to supplement visual surveys was encouraged, especially during periods of low visibility, and operational sound levels were to be kept as low as possible throughout the surveys. The guidelines also called for a report of certain relevant details, including information pertaining to the seismic survey itself, as well as the observer watches and sightings (JNCC, 1998).

By 2010, the basics of these requirements remained unchanged, although there had been several refinements (JNCC, 2010a). For example, the duration of the pre-survey visual scan was extended to 60 minutes in waters deeper than 200 m to account for long, deep diving species. Likewise, the training required of visual observers had become formalised into a JNCC-approved course. More in-depth discussions of PAM and ramp-ups were also included. However, the most notable addition was the recognition that visual observers need to be fresh to be effective. Accordingly, JNCC advised that "two marine mammal observers should be used when daylight hours exceed approximately 12 hours per day... or the survey is in an area considered particularly important for marine mammals." Given that JNCC only requires monitoring prior to seismic operations, this is probably sufficient. The discussion of whether the lack of within-survey visual scanning is appropriate is another matter. Similarly, the 2010 guidelines expressly state that there is no shutdown requirement, which is another debatable decision (JNCC, 2010a).

The limitations of the JNCC procedures, as well as the particular drawbacks (discussed above) of the mitigation measures included within the guidelines, have been widely recognized (e.g., U.K. Department of Trade and Industry, DTI, 2002; Barlow & Gisiner 2006; Weir & Dolman 2007; Parsons *et al.*, 2009; Lubchenco, 2010; Parente & de Araújo, 2011). Partly for this reason, the majority of other regulatory agencies mandate continual visual monitoring and a shutdown if marine mammals are sighted in the safety zone during operations (see Weir & Dolman, 2007). The size of the exclusion zone is, however, highly variable from one region to the next (e.g. 200 – 3,000 m), often with little regard for the actual source levels of the particular airgun array being used (Weir & Dolman, 2007). Only California and Russia (around Sakhalin Island) is known to select an operations-based, site-specific safety zone (Weir & Dolman, 2007; Compton *et al.*, 2008).

Despite initially following the JNCC guidelines, requirements around the world have become increasingly more comprehensive than those in the U.K. (Compton *et al.*, 2008). One good example can be found in Greenland. The guidelines set out by the Danish Centre for Environment and Energy (DCE: Kyhn *et al.*, 2011) include descriptions of not only mitigation measures that should be used, but also requirements for what should be included in EIAs of planned seismic surveys. This explicit involvement in the planning stages has been extended in the most recent guidelines (Kyhn *et al.*, 2011), as they now require that noise propagation modelling be included and that these models must take account of all surveys to be carried out in the area. The results of the model must then be confirmed through measurements in the field. Other forward-thinking aspects of these guidelines include a requirement for the use of PAM in situations that are not suitable for visual safety zone scans, and the obligation to use whatever means available to reduce unnecessary transmission of noise in a horizontal direction. There are also designated marine mammal protection zones where seismic surveys would be even more restricted, although not banned outright. In fact, only a few countries have actually designated areas as seismic-free (see Weir & Dolman, 2007), although a recent legal settlement in the U.S. has, at least temporarily, established some new seismic-free areas in the Gulf of Mexico (Natural Resources Defense Council, NRDC, *et al.*, 2013).

As mentioned above, airguns generate sound through the explosive release of air under pressure into the water. Much unnecessary noise is produced at higher frequencies. However, unnecessary sound is also produced at the frequencies of interest to the oil and gas industry due to the uncontrolled oscillations of the bubbles formed. Accordingly, there is much room for improving upon the current seismic survey. For example, by reducing extraneous noise relative to the useful sound produced by the airguns at the receiver (e.g., Ross *et al.*, 2005), it may be possible to employ lower levels of sound. Furthermore, it should be possible to make design modifications to the airguns themselves, by changing the designs or adding silencers to further reduce unnecessary noise and/or the introduction of sound into the water in the horizontal direction (see Spence *et al.*, 2007; Weilgart, 2010).

Numerous alternatives to airguns are also being considered (see Spence *et al.*, 2007; Weilgart, 2010). The most advanced of these is the marine Vibroseis, with a commercially available system expected perhaps as early as 2014 (as per discussions at the Quieting Technologies for Reducing Noise During Seismic Surveys and Pile Driving Workshop held by BOEM, 2013). These are controlled sources that produce the same amount of sound over longer periods than the brief airgun ulses, but at much lower levels of sound.[3] The results are sounds that are not as damaging (i.e., sharp or loud) as those from airguns, with less unnecessary noise outside operational frequencies (see LGL & Marine Acoustics Inc., MAI, 2011). These devices have other advantages of being safer for operators, as well as more reliable and much more efficient than airguns. Furthermore, they can be operated over a wider range of depths and also deeper in the water column than the pressure-sensitive airguns. Sinking the seismic source closer to the sea floor means that it does not have to travel as far and can thus be reduced in level, as well as avoiding exposing animals near the surface to the full sound levels (LGL & MAI 2011). Deep-water sources would also avoid the issue of horizontal propagation from the source into near-surface waters.

© Deepwater Horizon Response

Noise from oil and gas activities is not limited solely to seismic surveys.

Perhaps the largest problem with marine Vibroseis (except for the fact that no commercial systems are yet available) is that longer sounds may lead to greater masking for marine mammals using sound at the same low frequencies. Although absolute levels will be lower than those from airgun arrays and fewer animals will be exposed, those that are exposed will find background noise levels are increased for longer periods. However, it should also be noted that airgun pulses typically elongate with increasing distance from the array, due to the way sound travels through the ocean. This may also be a concern regarding masking to some extent. Another concern with spreading the same amount of noise over a longer period is that less total energy appears needed to generate TTS than would be needed if the sound exposure occurred in a much shorter amount of time (Mooney *et al.*, 2009). The implications of this for the total number of animals experiencing TTS are uncertain, given that it must be balanced against the lower number of exposed animals. One other more indirect problem may also arise if industry pushes for surveys closer to protected areas due to the lower sound levels involved. This is because the surveys can, obviously, lead to oil extraction, which will increase risks of other environmental harm to those protected areas as a result.

3 Consider a lump of butter on a long, thin cracker. You can eat your way along the cracker and get all the butter in one single mouthful, or you can spread the butter along the cracker and get a little with each bite.

Noise from oil and gas activities is not limited solely to seismic surveys (see Spence *et al.*, 2007). Drilling rigs and drill ships, tankers and offshore terminals all contribute noise to the environment. However, none of these have received much focus in terms of noise management or mitigation to date, as they are often individually considered to be negligible sources of noise. This is despite the requirement for comprehensive CIA present in many countries around the world.

6.2. Military Exercises

Military manoeuvres and equipment testing can produce a wide range of noise including weaponry, explosions and sonar signals, as well as noise from aircraft and rockets. However, noise from ships is not a major concern here as many navy vessels are designed to be as quiet as possible to reduce detection by enemies.

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HMAS Collins prepares to berth at Fleet Base West.

Sonar has proved to be the most contentious issue for the navies of the world. Following a number of little-publicised 'atypical mass stranding' events that had been tentatively linked to naval activities (e.g., Van Bree & Kristensen, 1974; Simmonds & Lopez-Jurado, 1991; Frantzis, 1998, 2004; Frantzis & Cebrian, 1999), the event that occurred in the Bahamas in March 2000 really established the issue. Over a short period of time, at least 16 beaked whales of three species stranded over several kilometres of coastline and islands in the Bahamas. Scientists working with the local beaked whale populations suggested that the event resulted from the use of loud military sonars (Balcomb and Claridge, 2001). Additionally, the unprecedented levels of data on the marine mammals in the area of this event (in comparison to at the locations of previous events) led a subsequent U.S. government investigation to conclude that the use of sonar was the most likely cause of these strandings and of the injuries sustained by the animals (Evans & England, 2001).

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Cuvier's Beaked Whale.

Over a period of two decades running up to 2004, a series of mass strandings of beaked whales coincident with military exercises occurred in the Canary Islands (e.g., Taylor *et al.*, 2004; Fernández *et al.*, 2005; ICES, 2005). These are notable for two particular reasons. Firstly, it was in these strandings that decompression-sickness-like bubble lesions were discovered in the stranded animals (Jepson *et al.*, 2003), which have since been reported in a number of other animals that stranded coincident with naval activity (e.g., Fernández *et al.*, 2004, 2005; Wang & Yang, 2006). Although discussions over the merits of connecting these lesions to sonar (or other high-level noise) exposures continue, similar bubbles have now also been reported in other cetacean species (see Jepson *et al.*, 2005b) and also a single California sea lion (*Zalophus californianus*: see Van Bonn *et al.*, 2011). In the last particular case, Van Bonn *et al.* (2011) suggested that death and disease associated with cases of pressure-related injury (whether from sound exposure or otherwise) in marine mammals may depend upon several factors. Accordingly, they note that the true rate of occurrence of the condition, and thus also its importance in causing or diagnosing sound-related strandings, is unknown (Van Bonn *et al.*, 2011).

The second reason the Canary Islands strandings were notable is because of the management decision that ultimately resulted. In response to the strandings and the increasing concern in European fora over military sonar (e.g., ACCOBAMS, ASCOBANS, etc.; see Parsons *et al.*, 2008), in 2004 the Spanish government passed a moratorium on the use of naval sonar within 50 nautical miles of shore in the Canary Islands. A decade has now passed and there have been no further mass strandings in these Islands (Fernández *et al.*, 2013).

While this is highly suggestive that a ban on sonar use protects the whales, there are two viable explanations. Firstly, if the sonar activities were displaced further offshore and away from the coast, it is possible that the same number of animals may still be dying following exposures, but are simply not being found on beaches. The alternative possibility is that deaths have indeed been prevented entirely, due to the need for a convergence of several factors to have deaths occur (such as unusual propagation conditions, unusual underwater bathymetry, the extended duration of intense military exercises, and the presence of sensitive animals in a constricted channel), as was suggested by the U.S. Navy (Evans & England, 2001). Additional research is needed to differentiate between these two possibilities.

What has become clear over the years of research since 2000 is that the beaked whale strandings worldwide appear to be the result of an interruption in their natural diving patterns, possibly through initiation of a flight response (see Cox *et al.*, 2006; Rommel *et al.*, 2006; Tyack *et al.*, 2006). This has been concluded in part due to the comparatively low levels of noise to which they were most likely exposed in the Bahamas (Hildebrand, 2005). This runs contrary to much of the initial speculation that direct damage to the ears (or other organs) was responsible for the strandings as a consequence of high exposure levels. Directed studies of the responses of animals to experimental sonar exposures further supports this idea (Tyack *et al.*, 2011; Southall *et al.*, 2012; Goldbogen *et al.*, 2013).

Harbour Porpoise

The role of navy sonar exposure has also been implicated, or could not be ruled out, in an increasing number of strandings and other unusual events involving other cetacean species (e.g., Parsons *et al.*, 2008). Most recently, naval activity was unable to be dismissed as a factor in a stranding of more than 50 short-beaked common dolphins (*Delphinus delphis*) in Falmouth Bay, Cornwall, U.K., in 2008 (Jepson *et al.*, 2013). Navy exercises could also not be ruled out as a contributing factor in another study of at least 85 harbour porpoises that stranded on the Northwest coast of Denmark in 2005 (Wright *et al.*, 2013a). The particular event is notable as the proposed mechanism ultimately resulting in death and stranding is one of distraction. It was suggested that unusual sounds may simply have diverted the attention of the porpoises from other potential hazards, such as fishing nets, leading to increased rates of bycatch, rather than noise exposure being directly responsible for the strandings (Wright *et al.*, 2013a).

While evidence continues to mount about various consequences of naval activities on marine mammals, the U.S. Navy continues to operate under its own mitigation program, rather than accept any restrictions on its geographic operation. Accordingly, they have developed a 29-point mitigation plan (England, 2007), which was touted as highly protective of marine mammals (e.g., Noel, 2007). Essentially their mitigation plan boils down to 5 steps: (1) planning exercises to avoid bringing together all the factors that were determined by Evans & England (2001) to all be required for strandings to occur (see above); (2) training and using U.S. Navy personnel to act as MMOs (employing night lookout techniques between sunset and sunrise); (3) using standard sonar equipment to listen for marine mammals; (4) employing a safety zone with a 1,000/500/200 yard (/m) stepwise source reduction; and (5) coordinating with, and producing reports for, NMFS as necessary. Additional precautions are also used during exercises in narrow straits or passage (known as chokepoint exercises), if these areas are not avoided.

Without specific details of naval operations, it is hard to assess the merits of the mitigation plan. With the exception of the planning, the other elements have all been shown to have variable, questionable or unknown effectiveness, mostly as discussed in Chapter 5 and Section 6.1. However, there are some additional concerns worth noting. Firstly, the use of night-vision devices by observers is known to result in surveys that are much less effective than those conducted during the daytime (e.g. Barlow & Gisiner, 2006). Furthermore, questions arise about the use of lookouts undergoing “on-the-job-training” or the value of the Navy’s Personal Qualification Standard certification program. Although details of this program were not provided, this training is known to include “a marine species awareness video that provides lookouts information to identify the presence of marine mammals and their behaviors.” (Alexander, 2009). The lookouts are then equipped with “a marine mammal chart that displays pictures of many mammals they may encounter while standing watch” (Chief Boatswain’s Mate (SW/AW) Christopher White quoted in Alexander, 2009). [4]

Accordingly, concerns arise over the capabilities of the lookouts, as observer experience is crucial to their detection rates, as discussed in Chapter 5. Furthermore, the U.S. Navy are themselves apparently conducting Lookout Effectiveness (LOE) studies, to compare the relative merits of trained, experienced MMOs against Navy personnel that have gone through the Navy training program. Actual data analysis does not appear to have yet taken place, as data from each vessel are to be “combined with future monitoring efforts in order to determine the effectiveness of Navy lookouts as a whole” (Watwood *et al.*, 2012a,b). However, the raw data presented in those reports, which apparently represent two of the seven ships upon which LOE studies have been conducted as of August 2012 (Watwood *et al.*, 2012b), seem to suggest that the Navy personnel are not as effective as more experienced MMOs. Based on the results of four more studies from the Atlantic Fleet, the U.S. Navy echoes this conclusion: “Results are preliminary, but indicate that the U.S. Navy LOs are not completely effective, and that additional data are needed for more in-depth evaluation” (U.S. Department of the Navy, DoN, 2013).

The debate over these various issues of impact and mitigation was taken to court by various entities, with one case ultimately arriving at the U.S. Supreme Court in November 2008 (see Parsons *et al.*, 2008). Chief Justice John G. Roberts Jr. wrote the majority opinion following the 5-4 vote against NRDC (Roberts, 2008) that resulted without the Court actually addressing the merits of the lawsuit (i.e., determining if the U.S. Navy had violated the U.S. National Environmental Policy Act – NEPA, 1969 – or other federal laws). Instead the Chief Justice stated that

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4 A video of the use of the U.S. navy’s Whale Wheel, to which this seems to be a reference, can be found at: http://www.youtube.com/watch?v=D9vsxI7CzWk.

“the lower courts failed properly to defer to senior Navy officers’ specific, predictive judgments.” Expanding upon this, he drew heavily on the ‘debate’ over the extent of harm to marine mammals and said that, “the most serious possible injury would be harm to an unknown number of marine mammals that they (sic) study and observe,” while, “forcing the Navy to deploy an inadequately trained antisubmarine force jeopardizes the safety of the fleet.” Dissenting opinion written by Justice Ruth Bader Ginsburg criticised this conclusion partly on the basis that the U.S. Navy’s own assessment predicted “substantial and irreparable harm to marine mammals” (Ginsburg, 2008).

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United States Supreme Court

While the decision definitely favoured the Navy, it did not overturn the need for the production of appropriate EIA documentation established by the lower courts. Likewise, the decision itself relied partially upon the fact that the extent of harm to the whales was unknown. This situation may, however, be changing given the growing body of science discussed in Chapter 2, and the increasing acceptance of numerous more subtle impacts of noise (see Chapter 7). While the lack of unusual mass strandings in the Canary Islands for a decade is perhaps the clearest demonstration of this, a more important development may be the discovery that beaked whale populations in the California Current ecosystem are in decline (Moore & Barlow, 2013). Naval sonar and ecosystem change were suggested as possible reasons for this, while other factors, such as bycatch in fisheries, were ruled out (Moore & Barlow, 2013). This is a key point as the lack of mass stranding events in California over the last 40 years of naval exercises was used by Chief Justice Roberts in the decision to support the existence of the ‘debate’ over the potential for sonar to harm marine mammals. Although still more information will be needed before the Supreme Court would reassess their decision, the legal battles over the use of sonar by the U.S. Navy continue in the lower courts. Most recently, NMFS was ruled by United States District Court Northern District of California to have failed to meet the “best scientific data available” standard under the *ESA*. The District Court also ruled that NMFS illegally constrained the environmental analysis to a 5-year window related to the permit, rather than considering the long-term nature of Navy exercises. As a result, the District Court concluded that the environmental analyses conducted were insufficient and that the authorizations to the U.S. Navy for the taking of marine mammals that were based on those analyses were not legal at this time (Vadas, 2008).

As mentioned above, sonar is not the only form of underwater noise produced by military activities. Use of aircraft is more widespread than merely for military use and is addressed within Section 6.5. Noise from explosions is regulated and guidelines for its mitigation do exist in some countries (e.g., JNCC, 2010b). However, the vast majority of the tools used are the same as those employed for seismic surveys and pile driving, and therefore will not be discussed further here. It is important to note, however, that even small explosions are capable of producing extremely high levels of sound. Unlike seismic surveys, which rely on multiple sources to generate the effective levels that are required, the high levels of these point sources are actually realised near the explosion. This fact must be accounted for when establishing any safety zone sizes.

Finally, the extensive and unparalleled financial contributions of the U.S. Navy to research on the subject of the impacts of noise on marine mammals must be noted, as a contribution to future management. Although some of the funding is in response to litigation and the impartiality of much of the resulting science has been called into question (e.g., Wade *et al.*, 2010), the fact remains that large amounts of research would not have been undertaken at all without Navy support.

6.3. Commercial Shipping

When it comes to noise, commercial shipping is the prime example of how otherwise negligible individual sources can combine cumulatively to produce widespread impacts on marine mammals. In this case, the global merchant fleet is collectively the greatest contributor to the unprecedented doubling in background noise levels underwater in every decade over the last half-century (see Wright, 2008a). As mentioned above, the bulk of this noise comes from inefficiencies in the propeller, although other through-hull sources (such as the ship engines and generators) also contribute, as does the noise generated by the hull as water passes over it. A large number of these sources and related inefficiencies can be reduced either through operational and design solutions.

A wide range of possible design solutions are indeed available (see Wright, 2008a). Many of these are already being used to produce quiet military vessels and are becoming increasingly common in research ships. The benefits of quiet platforms for these uses can outweigh the costs of the current solutions. However, not all the designs are viable for incorporation into commercial ships, which are often considerably much larger and are also operated for profit.

© Michael Elleray

Ship in dry dock.

In fact, many of the currently available technological solutions are simply too expensive to be applied to existing ships through the necessary retrofits. However, a number can be incorporated into new-builds with relatively little additional cost to the overall price of the vessel, and some may also confer an associated reduction in running costs once operational (Leaper & Renilson, 2012). For example, propeller inefficiency can be reduced considerably through appropriate pairing with the hull, due to the importance of the flow of water into the propeller. Computer simulations of the hull and propeller followed by physical testing at a ship model basin are needed to achieve this, all of which slows the design process in addition to raising costs. This combination of consequences means that few ships undergo such steps, resulting in a sub-optimal flow of water into the propeller. Additional hull and propeller attachments, such as fins, etc. can also be used to improve the water flow and reduce the troublesome vacuum bubble formation. These attachments can also be made at relatively low cost during a retrofit, meaning that they also have the benefit of being viable for use with current ships.

Another notable design solution involves at least a partial return to wind-powered vessels. It is now possible to equip commercial vessels with a huge computer-controlled towing kite that can help pull it through the water with not only reduced fuel usage, but also a lower operational load on the propeller.[5] This new technol-

5 SkySails, GMBH: http://www.skysails.info/english/

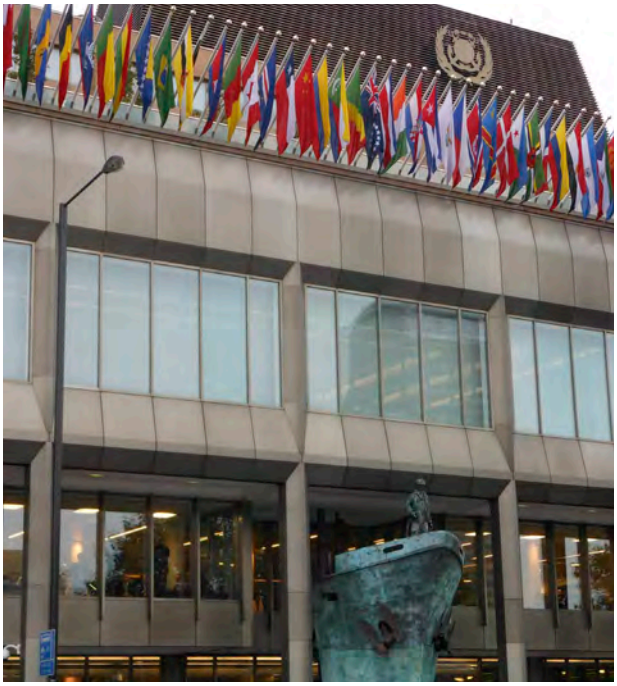
© David Watkins

Commercial shipping, Plymouth, UK.

ogy has already been fitted to a handful of ships to date, but has yet to capture widespread market attention. A little further behind this is the lubrication of hulls using air bubbles. While this technique is designed to improve propulsion efficiency, it may also confer some additional benefits to underwater noise by at least partially trapping internal machinery noise within the hull.

Operational measures to reduce the inefficiency of the propeller are mostly limited to the reduction of speed (although not for all propulsion types, as noted above). Once a completely taboo subject in an industry that relies upon maximising the number of trips completed, the global increase in oil prices has led many operators to consider, if not implement, slow shipping to save on fuel costs among other environmental benefits (Leaper & Renilson, 2012). There are also some instances where slow steaming has been mandated to address other environmental concerns (e.g., to reduce ship strikes of cetaceans: Stellwagen Bank NMS, 2012) and these will also typically have associated noise-related benefits. One other operational measure is the implementation of a regular schedule of propeller maintenance. This is because repair or replacement of damaged blades will also limit cavitation, reducing noise and increasing efficiency of ship operation.

Unfortunately, many of the technologies available today for quietening the second largest source of noise in most ships, that of the engine and associated machinery, cannot be up-scaled to the sizes needed for commercial shipping. The majority of these techniques require isolation mounts that essentially disconnect the engine from the hull so that vibrations and noise are kept inside the engine room and not transmitted directly to the hull and then further into the water. However, the size of the engines needed to provide thrust for many commercial vessels make this option either economically crippling at best, or impossible at worst. Despite this,



Linda Nowlan

Headquarters, International Maritime Organization.

smaller commercial vessels (e.g., ferries and some cruise ships) may still be able to incorporate some of these techniques. Research into adapting these technologies for larger vessels should be funded as soon as possible to resolve this issue. Once such solutions are beginning to develop, the appropriate authorities should revisit the issue of quieting technologies .

The most appropriate authority for guiding the implementation of ship-quietening technologies is the International Maritime Organization (IMO). Following a call for a specific reduction in the contributions of shipping to low frequency background noise (Wright, 2008a), the IMO were requested to work to develop voluntary guidelines for technical measures for quieter commercial vessels. Accordingly, the Design and Equipment Subcommittee of the IMO has produced some technical advice and voluntary guidelines for the amount of noise introduced by shipping (IMO, 2013). Essentially recommending consideration of noise in the design of propellers and hulls, as well as the selection of on-board machinery, these provisional guidelines also encourage model testing during the design phase and maintenance during operation to keep propellers and hulls clean and smooth. These guidelines will be considered for adoption at the IMO's Marine Environment Protection Committee in March 2014. Although voluntary, the adoption of these guidelines would represent acknowledgment of the severity of the issue and represent a substantial step forward in reducing ship noise.

6.4. Pile Driving

Noise impacts on marine mammals from pile driving associated with the installation of foundations for offshore wind turbines have been an issue for some time in Europe (see Madsen *et al.*, 2006). Given the otherwise 'green' image that these offshore installations have (especially in the U.K., where onshore sites have received an unexpected level of resistance that has not been seen elsewhere), the wind farm industry has been, for the most part, willing to discuss and address any environmental concerns. The resulting, mostly collegial, collaboration between regulators, scientists, environmental organizations and industry has led to rapid progress in our understanding of the impacts of these operations on marine mammals, particularly the harbour porpoise that is the most common cetacean in many European waters (e.g., Madsen *et al.*, 2006). Germany set new low exposure criteria for pile driving (see Section 4.6) in response to one study assessing TTS in a porpoise in response to a single exposure to an airgun, which demonstrated that porpoises may be more sensitive to noise than bottlenose dolphins (Lucke *et al.*, 2009). Originally criticised by the industry as unworkable, this standard inspired an equally rapid development in better methods and systems for reducing the noise propagated away from foundation installation.

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Pile driving operations in the Port of Tampa, Florida, United States.

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Jacket foundations.

This has been achieved partly through the extensive use of bubble curtains, cofferdams and isolation cases, many of which have undergone a process of design selection from numerous proposed designs as a consequence of the German standard. The German standard has also driven a more rapid development in the previously existing alternatives to the increasing large (and thus also loud) monopiles foundation. These include tripod, jacket, gravity and suction caisson foundations (e.g., E.ON Climate & Renewables, 2011; Malhotra, 2011; CSA, 2013). Tripod and jacket foundations are structures that distribute the forces required to keep the wind turbine upright in currents and waves over multiple 'legs'. Each leg of the structure still needs to be attached to a pile. However each one can be much smaller than the equivalent monopile. Hammering smaller piles produces lower noise levels and takes considerably less time, although multiple piling sessions are needed for each turbine foundation, potentially increasing total piling time. A recent study demonstrated that the total amount of noise energy produced driving in a monopile and the multiple piles for a jacket were comparable, however the noise was spread over longer periods of time for the jacket, meaning that absolute levels at any time were much lower for this foundation (Norro *et al.*, 2013).

The selection between jacket (or tripod) and monopile foundations thus incorporates many of the same trade-off considerations as the decision between marine Vibroseis and airguns (see Section 6.1). However, in this case there is still much debate over whether there are actually any net benefits for marine life. Nevertheless, like Vibroseis, jacket foundations may have some other advantages. For example, jacket foundations allow the construction of wind farms in deeper waters (e.g., up to 45 m at the Beatrice demonstration project in comparison to the maximum of around 20 meters for monopile foundations, as seen in Barrow, U.K., and gravity-based foundations). This opens up considerably more ocean area for use by the offshore wind industry, and provides managers with increased flexibility when selecting the most environmentally optimal locations.

Gravity-based platforms are effectively huge weights at the base of a column that can be 'simply' dropped into place. In this case, 'simply' involves construction of these huge weights and transport to the deployment location, with all the associated environmental costs (including carbon emissions) of this process. They also eliminate comparatively large amounts of sea floor. While this loss may only represent a tiny fraction of the total ocean floor and the foundations themselves soon offer another substrate, the greater loss of any relatively rare habitat needs to be considered. As no pile driving is involved, they are typically presumed to be low-noise foundations and have not been assessed in noise-related studies of other foundation types (e.g., Norro *et al.*, 2013). However, boring or jet cutting of the sea floor might be necessary to prepare the sea floor for their deployment (e.g., Nedwell & Howell, 2004). An additional consideration is that their use is limited to relatively shallow waters (e.g., Malhotra, 2011).

Suction foundations may also require modification of the seafloor before the hollow base of the foundation is lowered into position and all the water is pumped out. The resulting (near-)vacuum holds the foundation purely through suction. Although not yet used to support wind turbines, these foundation types have been used for offshore oil rigs. A further modification to this would be the use of one or more suction foundations connected by tethers to a buoyant wind turbine at the surface (e.g., Malhotra, 2011). This would allow wind turbines to move into even deeper waters.

Untrakdrover / Wikimedia Commons

A prototype floating wind turbine, approximately 5km offshore of Póvoa de Varzim, Portugal

Tethered floating foundations can, however, be moored using any type of pile. It is worth noting that the floating turbine platforms can be constructed almost exclusively onshore, with the wind turbine attached, and then transported out to the construction site by barge. Although this does have noise-related implications, there may be an additional net benefit over transporting the turbine out separately and building it onto the foundation on site.

Two other pile types are currently being developed that both attempt to reduce the vibration of part of the pile in contact with the water by reducing the radial expansion (i.e., increase in diameter) of the pile that results from each hammer blow (as per discussions at the Quieting Technologies for Reducing Noise During Seismic Surveys and Pile Driving Workshop held by BOEM, 2013). The first of these is an adaption of mandrel-driven piles, known as a mandrel pile (for details see Reinhall *et al.*, 2013). Mandrel-driven piles are basically hollow piles driven by specialised equipment into the ground and later filled with concrete. Mandrel piles are essentially two concentric piles, with one thin pile inside a wider cylindrical pile. These two piles are separated by air (or another dampening substance) along the length and only connected at the tip of the pile that is being driven into the substrate. The inner part receives the hammer strikes of a normal pile-driver and vibrates accordingly, while the external part serves as an attached isolation case and ultimately carries the load. The inner pile can then be removed, leaving the external pile in place as the load-bearing structure which may be filled with concrete. Initial tests have produced some promising noise reductions.

The other type of pile in development, the slit pile (or reduced radial expansion pile), is as yet untested. However, they seek to reduce external vibration through the inclusion of vertical slits in the surface of the pile. These should, in theory, allows some of the energy from each hammer blow that normally gets converted into brief radial expansion to be instead transferred into expansion of the pile material into the slits instead. Accordingly, this would decrease the distance that the pile vibrates into the water column, or substrate, and thus also the level of sound generated as a result of that vibration (as per discussions at the Quieting Technologies for Reducing Noise During Seismic Surveys and Pile Driving Workshop held by BOEM, 2013).

One final foundation type likely to be adapted for use with offshore wind turbines in the future is the screw or helical pile (van den Akker & van der Veen, 2012/2013). A relatively old technology also referred to as 'ground screws,' these are quite literally screwed into the ground through the application of torque. Although most are quite small at present, they have already been used to support onshore wind turbines (van den Akker & van der Veen, 2012/2013). Their use will likely remain limited to certain substrates, but they do offer a way to eliminate the need for pile driving altogether, without the need for the preparation, or extensive loss, of the sea floor.

Instead, or in addition, to changing the pile types, it is also possible to use pile caps or cushions of another material on top of the piles. This may be done in some cases to protect the pile itself from the hammer. However, these cushions then act, to some extent, as a silencer, providing a variable amount of noise reduction, depending on the material. ICF Jones & Stokes, & Illingworth and Rodkin Inc. (2009) reported wood caps to be the most effective, with micarta (a resin-based composite material) and then nylon as less effective materials.

Finally, there are a few alternatives to the use of the traditional pile driver, which is essentially a large weight that is repeatedly raised inside a sleeve through use of air, hydraulics, or diesel and dropped onto the top of the pile through gravity (sometimes aided with hydraulics). The first alternative is the vibration hammer. This is a heavy block that is vibrated using internal unevenly distributed rotating weights that can be clamped onto the end of a pile to generate a large number of smaller 'taps' in the same period as the traditional impact hammer can deliver one large one. (Consider a washing machine with an unevenly distributed load on a spin cycle.) Vibration hammers are quicker and quieter than traditional impact hammers (van den Akker & van der Veen, 2012/2013), and they can even be used to help remove piles, or drive them into the sea floor at a modest angle (known as a raked pile) without modification. However, it is not possible to assess the strength and stability of a pile deployed in this way, which is why a traditional impact hammer is often used to complete the installation (van den Akker & van der Veen, 2012/2013).

One alternative to hammering a pile directly into the seabed is to pre-drill a borehole that will subsequently house the pile, (e.g., Dazey *et al.*, 2012). Although this process produces lower sound levels, it may need to be balanced against a longer-duration sound production, as is the case for Vibroseis and vibration hammers. The practical application of drilling is also arguable, given the much longer time spent in the field during pile installation in addition to the physical difficulties of pouring concrete into a temporary casing in a marine environment (Dazey *et al.*, 2012).

The final alternative to pile driving is the use of a hydraulic press or ram (White *et al.*, 2002). Press-in, or push, pile driving is an inherently quiet technology that uses static force to install one pile through resistance against a previously installed pile. The ram simply grips onto the previously installed pile and slowly forces the next pile into the substrate. There are, however, a few problems with this technology. The first problem is that you need to drive the initial pile. While this may sound trivial for a large wind farm, the second issue is that the ram has nothing to grip to if the piles are widely spaced. Accordingly, it may not be possible to use a hydraulic press to deploy the vast majority of offshore piles at this time.

6.5. Other Human Activities

Probably the most highly debated other source of human-introduced marine noise are the studies that use temperature-dependent sound speed to assess ocean warming over ocean scales. These are known as the Heard Island Feasibility Test and the subsequent Acoustic Thermometry of Ocean Climate (ATOC) and North Pacific Acoustic Laboratory (NPAL) experiments. As the sound was required to travel across ocean basins, only a few mitigation measures were possible while still allowing the project to function. These were the inclusion of a ramp-up and the limitation of the source to as low a level as possible at a duty cycle as low as could be achieved without preventing the research (especially in humpback whale breeding season: ONR, 2001; Hildebrand, 2005). It was thus effectively impossible to truly mitigate the impacts of the source and a legal settlement over ATOC led to an extensive, multi-year Marine Mammal Research Programme to assess the impacts of this low frequency source. However, a subsequent review of this programme determined that the results were inconclusive, mostly due to the collection of insufficient data (NRC, 2000).

In contrast, the most common source of noise in the oceans is without doubt the pleasure craft. From jet skis to luxury yachts, these represent more single point sources than any other activity. To make matters worse, many boats do not just produce noise from their engines and propellers, but also as a consequence of their depth finders or fish finders, collectively known as echo-sounders. The frequencies incorporated in these sounds are generally higher than those produced by commercial ships, meaning that they travel much lower distances and thus have only local effect. However, they can be a considerable source of noise in some coastal areas that may disrupt the activities of local species (e.g., Wharam *et al.*, 2006, cited in Whale and Dolphin Conservation Society, WDCS, Undated). Unfortunately, pleasure craft are essentially completely unregulated in many countries (such as the U.K.). Others countries require only minimal information to register or licence boats with engines over a certain size (e.g., Canada).

Higher power echo-sounders may also be used for research, as well as industry. These include side-scan sonar and multi-beam sonar. Side-scan sonars transmit sound to the sides of the vessel to obtain high-resolution details of objects on the seafloor. Multi-beam sonars are essentially multiple echo-sounders used together to generate a high-resolution image of the topography of the sea floor under the vessel. Multi-beam sonars have recently raised public concern following the recent release of an independent scientific investigation of the 2008 mass stranding of melon-headed whales (*Peponocephala electra*) in Antsohihy, Madagascar (Southall *et al.*, 2013). Several sources of noise were considered in this investigation, including a high-power multi-beam sonar that transmitted at 12 kHz (i.e., at a frequency higher than military sonar), which was employed in the area to accurately map the seafloor prior to a seismic survey. While the role of the seismic survey was ruled out based on the time of stranding, the scientific panel deemed the multi-beam sonar use "to be the most plausible and likely behavioral trigger for the animals initially entering the lagoon system," starting a chain of events that ultimately led to the death of 75 animals (Southall *et al.*, 2013). Lower power eco-

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Small boat harbour, Seward, Alaska.

sounders are typically employed by fishing vessels, which (like most other vessels) also introduce noise from their engines and various machinery as well. While undoubtedly contributing to the noise levels in the oceans, especially in remote areas where fishing is the primary, if not only, industry, the amount of noise introduced by fishing and its effects are unknown.

Limiting these sonars to minimal levels required for the task at hand is an obvious mitigation option, but others may prove more fruitful. For example, a combination of factors was likely required to produce the strandings, such as the use of the sonar in the typical habitat for these whales and the nearby lagoon entrance offering these offshore animals with acoustic shelter in unfamiliarly shallow waters (Southall *et al.*, 2013). Thus, careful planning, in terms of both location and timing, is likely to again be a critical management strategy with these sources. It is worth noting, however, that applying ramp-up to the sonar use may not have avoided the stranding, since it is thought that it was the avoidance of the source by the animals that led to them being trapped in the lagoon.

Another loud and, in some parts of the world, fairly common noise source is that of devices to discourage the interaction between marine mammals and fishing gear. These come in two basic types: the acoustic deterrent device (ADD) or pinger; and the acoustic harassment device (AHD) or seal scarer. The object of the former is to prevent cetaceans from getting entangled in fishing gear and being killed as by-catch. The latter intends to dissuade pinnipeds from approaching nets or aquaculture pens and 'stealing' fish and damaging gear. The main difference between the two is that the sound levels produced by the seal scarers are substantially higher than those produced by the pingers.

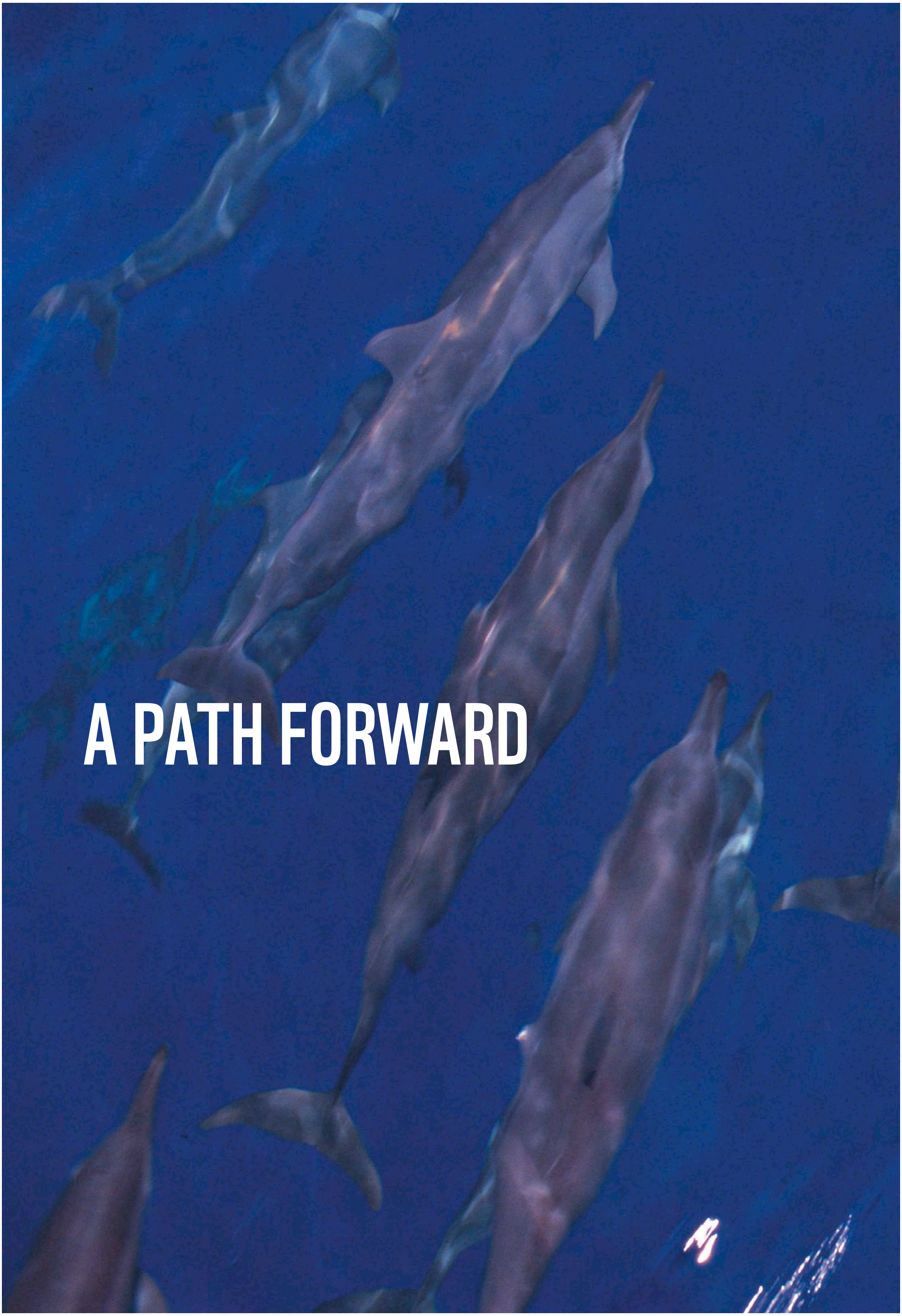
Pingers are known to exclude some species from large parts of their habitat (e.g., Culik *et al.*, 2001) and they may also have some additional physiological consequences (including chronic stress) in high-density areas. While some efforts have been made to limit sound production of pingers to occasions when sounds from cetaceans are detected, this mitigation option may potentially also undermine the function of devices (see Wright *et al.*, 2013a). Similar concerns surround a reduction in source levels. Accordingly, the only realistic mitigation measure for pinger noise is to reduce the amount of fishing undertaken using gillnets (the most frequent gear type associated with cetacean bycatch). This can be achieved through development and implementation of alternative low- or no-bycatch gear, or through reduction in fisheries. Gillnet restrictions in particularly important habitats for sensitive species are one potential mechanism.

Similar solutions are available for reducing the impacts of noise from seal scarers. Area-based restrictions or wider controls on aquaculture could reduce their usage, at least in regions of particular importance to sensitive marine mammals. The main alternative here is the development of seal-resistant equipment, although this is likely to be a challenging proposition.

Other noise sources, such as dredging, cable-laying, aircraft activity, and on-ice activity are typically handled on a case-by-case basis. As aircraft noise can enter water only under certain conditions, it may appear suddenly to marine mammals. Accordingly, when aircraft noise is considered in management and mitigation plans, minimum altitude requirements are typically put into place (e.g., Office of National Marine Sanctuaries, 2012), although there may be no specific consideration of the source levels involved. In contrast, reducing noise from dredging to date has largely focused on limiting in-air exposure to humans (e.g., Epsilon Associates, Inc., 2006), although there seems to have been some increase in acknowledgement of underwater noise recently (e.g., Central Dredging Association, 2011; Hoffmann, 2012; Thomsen, 2013). This is all fairly similar to the way the issue of underwater noise took hold in the commercial shipping industry (e.g., Wright, 2008b), so further engagement is expected in the future. Finally, construction of bridges typically involves pile driving and thus follows that model closely. However, little is known about 'operational' noise from bridges.

Beverly Bray

Golden Gate Bridge, San Francisco, USA.



A PATH FORWARD

7. ADDRESSING SCIENTIFIC KNOWLEDGE GAPS

The vast majority of research to date on the impacts of noise on marine mammals has focused on hearing and other physical effects (initially thought to be related to the atypical strandings), as well as easily observable behavioural reactions. However, this has been changing as we have expanded our knowledge about potential consequences of noise exposure. Driving this in many ways has been the realization by scientists that chronic noise impacts may be at least as serious to populations, if not more so, that the more acute effects (including strandings). For example, the obscuring by noise of sounds of interest to an animal (i.e., masking) may have some serious implications for the populations of which the animals are a part, even though masking effects are often left out of management decisions. Such implications may include the consequences of increased difficulty in communication, which may in turn extend to a breakdown of group cohesion or an interruption of reproductive behaviours (see discussion of masking in Chapter 2).

Masking not only interrupts communication signals, it may also compromise foraging efforts. The extent to which masking can do this is not fully known. We are just beginning to investigate the ability of odontocetes to hear and discriminate between outgoing and incoming clicks (Li *et al.*, 2011; Linnenschmidt & Beedholm, 2012), which has some implications for how sound might interfere with these signals in previously unexpected ways (Linnenschmidt & Beedholm, 2012). Noise likely also limits the ability of marine mammals to sense their environment through sound, known as acoustic scene analysis. For example, it may be very important for whales to be able to hear surf from coastlines as they navigate through visually featureless waters. Accordingly, when a whale's "communication space" is reduced through masking (Clark *et al.*, 2009; Hatch *et al.*, 2012) there may be serious repercussions for breeding, foraging and navigation. The potentially extensive consequences of masking by human noise are not limited to marine mammals. So great is the likely impact for acoustically-sensitive animals that Francis *et al.* (2011) went so far as to suggest that acoustic masking by noise may be a strong selective force shaping the ecology of birds worldwide.

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Acoustic masking by noise may be a strong selective force shaping the ecology of birds worldwide.

For these reasons and others, it is has been supposed by many that noise exposure in marine mammals will lead to increased stress responses, as it does in humans and other terrestrial animals (e.g., Wright & Highfill, 2007). Chronic stress has been associated with a number of serious issues in these other species, including a suppression of both the immune system and reproduction, disruption of learning and other cognitive functions, and increased mortality rates (Clark & Stansfeld, 2007). The validity of extrapolating this interpretation to marine mammals has been supported through data collected on North Atlantic right whales in the Bay of Fundy, Canada. Rolland *et al.* (2012) found a reduction in levels of the main mammalian stress hormone, cortisol, in faeces of right whales in association with a substantially curtailed level of maritime traffic immediately following the 9/11 attacks in 2001. An added complication here is that, despite the focus on cortisol for studies of stress responses, there are several other stress-related hormones that need to be investigated at greater depth (e.g., Spoon & Romano, 2012) before we can begin to have a complete picture of how cetaceans respond physiologically to noise and other disturbances.

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Fear conditioning has been observed following noise-induced startle reflexes in grey seals.

Also connecting masking and chronic stress is the idea that the psychological state of an animal can influence its interpretation of novel, imprecise or incomplete information. For example, an animal that is in a state of chronic stress, or compromised in another way, may treat imperfect information (perhaps only partially received as a consequence of masking) in a risk-averse or pessimistic way. In contrast, an animal in a positive situation is more likely to be optimistic in the face of the same uncertainty. While this may sound far-fetched or even human-centric, the existence of such 'cognitive bias' has been demonstrated though a number of studies in birds (Bateson, 2007). We are also learning that the psychological state of marine mammals can be influenced by noise in various ways, such as the fear conditioning that has been observed following noise-induced startle reflexes in grey seals (*Halichoerus grypus*: Götz & Janik, 2011).

Another related issue is that of attention and distraction. Following theoretical work by Dukas (2004), data have demonstrated that the focus of animals can be diverted from the presence of prey or predators through noise or disturbance. Such changes of focus have been observed in Caribbean hermit crabs (*Coenobita clypeatus*: Chan *et al.*, 2010a,b), three-spined sticklebacks (*Gasterosteus aculeatus*: Purser & Radford, 2011), the shore crab (*Carcinus maenas*: Wale *et al.*, 2013), and possibly also greater mouse-eared bats (*Myotis myotis*: Siemers & Schaub, 2011). Lack of attention was first proposed to be a problem for cetaceans when Dudok van Heel (1966) suggested that it might be a cause of strandings. More recently it has also been suggested that distraction might increase the risk of bycatch of harbour porpoises in fishing nets (e.g., Nielsen *et al.*, 2012; Wright *et al.*, 2013a).

A further complication arises when the ultimate consequences of behavioural responses are taken into consideration. Although the seriousness of this issue has been acknowledged with regard to beaked whales and navy sonar exposures (e.g., Cox *et al.*, 2006; Tyack *et al.*, 2006), other species may also be at risk. For example, over 1,000 narwhals died in Canada and Northwest Greenland as a result of ice entrapments that may have been the result of seismic survey noise disrupting their normal migration (Heide-Jørgensen *et al.*, 2013).

In addition to all the above-mentioned impacts of noise, we are also discovering our knowledge of how hearing works is incomplete. Sometimes the deficiencies are clear. For example, we do not even have measurements of frequency-dependent hearing capabilities, known as audiograms, for most species. However, we are also beginning to understand that the hearing capabilities in marine mammals are actually not stable, but dependent upon a variety of factors. For example, relative hearing sensitivity across different frequencies has been reported to change depending upon how loud the sound is (e.g., Finneran & Schlundt, 2011). Furthermore, if the sound moves across a range of frequencies or includes harmonics, this may increase the detectability of a sound in comparison to pure tones (e.g., Kastelein *et al.*, 2011; but also see Finneran *et al.*, 2011). One final example is the observation that the presentation of other relatively loud sounds preceding a very loud test sound may decrease the sensitivity of an animal to that test sound (Nachtigall & Supin, 2013). In this case, the observed reduction in hearing sensitivity is unlikely to be the consequence of even short-term TTS (Nachtigall & Supin, 2013). Instead, the particular multi-pulsed nature of the loud preceding sounds may have induced synaptic fatigue or depression in a similar way to that described by Simons-Weidenmaier *et al.* (2006), although this would need to be investigated further.

Research from other species also suggests that we may have much more to discover along these lines. For example, lactation and odours were shown to increase hearing sensitivity in mice (Cohen *et al.*, 2011). Furthermore, it has been shown that sounds at frequencies too low to be ‘heard’ by humans can still be detected on some level, and still produce impacts (Chen & Narins, 2012). Many of these revelations raise doubt over the marine mammal hearing functions proposed by Southall *et al.* (2007), and further complicate issues such as masking, TTS and PTS, and stress responses.

Additionally, there are some more fundamental questions regarding hearing that also need to be addressed. For example, while we have a growing appreciation of some important differences between cetacean hearing and that of terrestrial mammals (e.g., Lemonds *et al.*, 2011), we still have not fully identified exactly how the middle ear functions in odontocetes (see Hemilä *et al.*, 2010).

Thus, it is increasingly evident that we really are only looking at “the tip of the iceberg” with regard to impacts of noise on the conservation of marine mammal populations, rather than “a second-order effect” (NRC, 2005). All the above-mentioned subtle and cryptic impacts thus seriously undermine the position often taken by industry that the presence of animals in an area of exposure (particularly in an area of frequent exposure) implies that they do not suffer any impact as a consequence of this exposure. Much more research is needed on the emerging topics of masking, stress responses, cognitive bias, fear conditioning, and attention and distraction, as well as the consequences of all these factors for the survival and reproduction of marine mammal populations. Even information on hearing capabilities and mechanisms is lacking and needs to be addressed, specifically in certain groups of species such as baleen whales. Furthermore, the growing list of suggested interactions between noise and other factors resulting in increased mortality through ice entrapments, higher bycatch, etc., highlights the need for

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Harbour porpoise (Phocoena phocoena) killed in fishing nets. Vado, Norway.

both a better scientific understanding of how noise exposure can contribute to cumulative impacts. It also points to the need for a more thorough CIA process in management. Increased awareness of basic biological and ecological data, as well as region-specific considerations, will be an important component of this.

The realization that much remains unknown means a cautious management approach is both appropriate and essential for the long-term survival of many of these species. The risks extend well beyond merely losing marine mammal populations. Estes *et al.* (2011) eloquently demonstrated that substantial declines in top predators, such as odontocetes, can lead to extensive changes in their associated ecosystems and a decline in overall biodiversity. Based on their conclusions, they argued “that the burden of proof be shifted to show, for any ecosystem, that consumers do (or did) not exert strong cascading effects.”

8. MAIN RECOMMENDATIONS

8.1. Cross-Purpose Long-Term Solutions

With some specific notable exceptions, current mitigation measures are generally ineffective in reducing the aggregate impact of noise on marine mammals. This is largely because they typically focus on limiting damage to hearing and ignore the more insidious consequences of noise exposure that can arise at lower levels of sound. To properly address the introduction of noise into the marine environment, we must first acknowledge and tackle the reasons for its introduction. Accordingly, the most appropriate way to reduce a substantial proportion of underwater noise is through a reduction in our use of oil.

The benefit of reduced oil consumption with regard to noise from seismic surveys is clear. However, noise from shipping will also decrease, especially if coupled with advanced hull-propeller designs. Electric motors (and fuel cell stacks) are inherently much quieter than the diesel engines used by most modern ships. Not only are diesel engines loud, they also generate a lot of vibration, which typically leads to the production of more noise through associated equipment.

The link between oil and both national security and defence spending is also frequently discussed, although it is much less straight-forward (e.g., Cotet & Tsui, 2010). Accordingly, reduced oil consumption may not be of great help in reducing noise from naval activities. Likewise, pile driving related to construction of bridges and wind farms is unlikely to be heavily affected by reductions in oil consumption. (Pile driving, at least, can instead be reasonably adequately addressed through alternative technologies, as discussed in Sections 6.4 and 8.5.) Despite this, eliminating combustion engines will likely also reduce noise (to some extent) from personal water craft and other powered activities in the marine environment.

How can this be achieved? Obviously a move away from combustion engines is the long-term solution. However, a reduction in the use of oil (and natural gas) in plastics would complement this, albeit on a much smaller scale.[1] Measures as simple as eliminating free plastic bags in supermarkets, through to wider bans on plastic disposable food ware in favour of compostable bamboo and corn-based alternatives, are already underway (at least to some extent). Any increased corn usage could also be offset by reductions in the use of corn-based sugars in food products and the financial impacts on producers of food eased through adjusting tax subsidies, potentially by diverting some subsidies and tax credits away from the oil production.

A shift in subsidies and tax credits can also speed this process along, as well as help to reduce consumption in the interim. Mostly hidden away in tax code, the oil and gas industry receives a staggering amount of government money on a global scale. Although the figure is difficult to pinpoint due to the burial in tax breaks, it has been estimated that the global subsidy of fossil fuels is around US$523billion in 2011, which was six times the US$88billion directed at companies developing and deploying renewable energy technologies (International Energy Agency, IEA, 2012). The proportion of fossil fuel subsidies hidden in U.S. tax code was estimated to be 80 % by the Environmental Law Institute (ELI), compared with only 50

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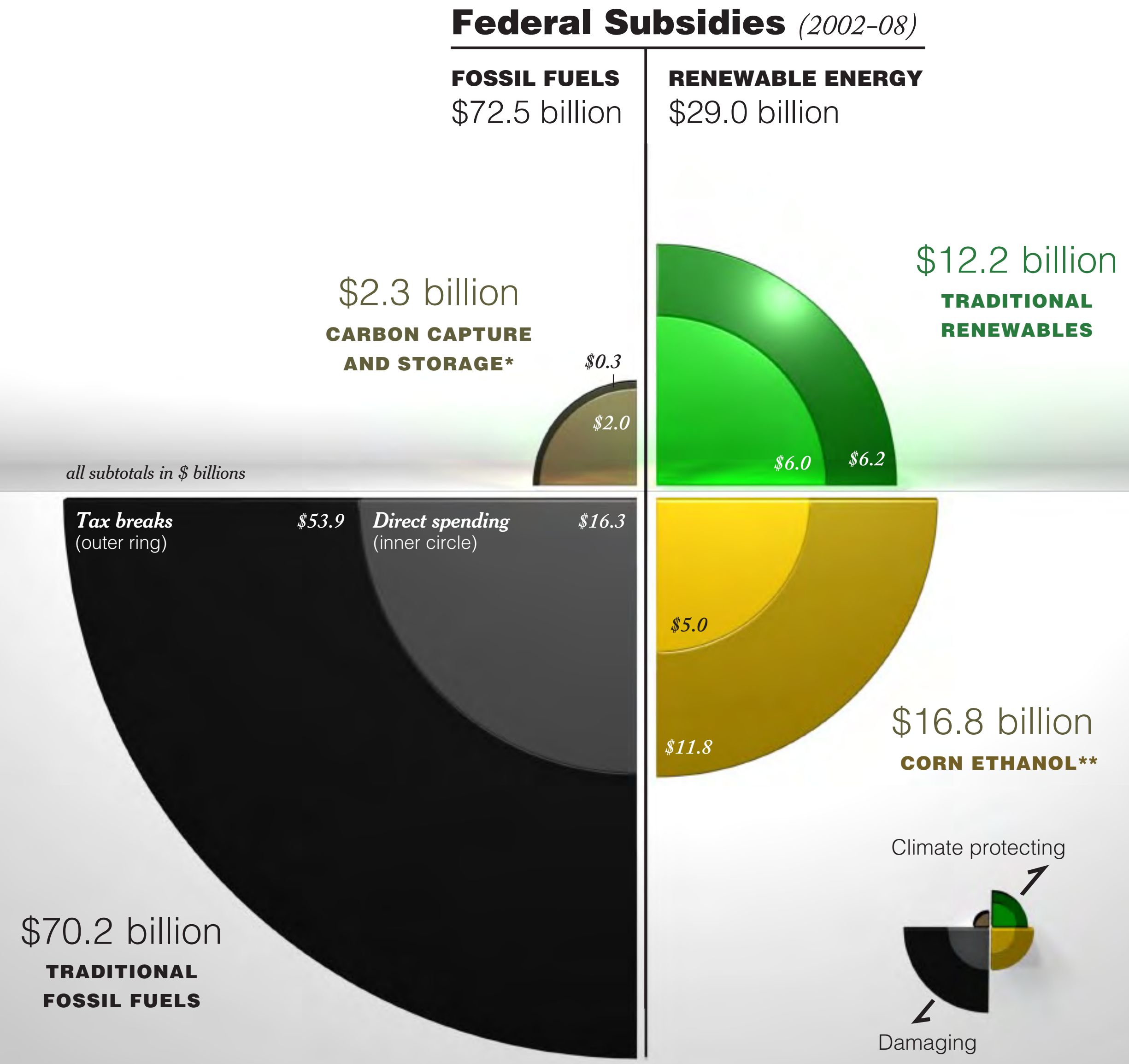
1 According to the U.S. Energy Information Administration (USEIA), plastic production accounted for 2.7 % of total U.S. petroleum consumption and 1.7% of total U.S. natural gas consumption in 2010 (USEIA, 2013). However, this proportion will, of course, increase considerably if the use of oil for fuel is substantially reduced.

Energy Subsidies Black, Not Green

A soon-to-be released study of federal energy subsidies by the Environmental Law Institute, a nonpartisan research and policy organization, shows that the federal government has provided substantially larger subsidies to fossil fuels than to renewables. Subsidies to fossil fuels totaled approximately $72 billion over the seven-year study period, while subsidies for renewable fuels totaled $29 billion over the same period. The vast majority of subsidies support energy sources that emit high levels of greenhouse gases when used as fuel. Moreover, just a handful of tax breaks make up the largest portion of subsidies for fossil fuels, with the most significant of these, the Foreign Tax Credit, supporting the overseas production of oil. More than half of the subsidies for renewables are attributable to corn-based ethanol, the use of which, while decreasing American reliance on foreign oil, has generated concern about climate effects.These figures raise the question of whether scarce government funds might be better allocated to move the United States towards a low-carbon economy.



Notes: *Carbon capture and storage is a developing technology that would allow coal-burning utilities to capture and store their carbon dioxide emissions. Although this technology does not make coal a renewable fuel, if successful it would reduce greenhouse gas emissions compared to coal plants that do not use this technology. **Recognizing that the production and use of corn-based ethanol may generate significant greenhouse gas emissions, the data depict renewable subsidies both with and without ethanol subsidies.

Sources: Internal Revenue Service, U.S. Department of Energy (Energy Information Administration), Congressional Joint Committee on Taxation, Office of Management and Budget, & U.S. Department of Agriculture, via Environmental Law Institute.

% for renewables, while the ratio of total U.S. subsidies is comparable to the global figure (e.g., US$70billion vs. US$12billion: ELI, 2009). Reducing the subsidies for fossil fuels will lead to reduced demand, partly through lower consumer wastage (IEA, 2009). More stringent efficiency standards will also help here. These should not just be applied to vehicles, but also lawn mowers, leaf blowers and other products that are fuelled by oil- (or gas-) based substances.

While this may all sound like an ambitious and expensive proposition, many efficiency-related measures will lead to long-term cost-saving (see McKinsey & Company, 2010). The required innovation and modifications to buildings and vehicles will actually create more jobs (American Council for an Energy-Efficient Economy. 2011) and represent an investment in human and social capital that is sorely needed in the current economic climate (see more below). There will also be associated benefits to carbon dioxide (CO_2) outputs. For example, the IEA estimate that over half of the CO_2 savings needed to cut global production by 50 % can be achieved through end-use fuel switching and end-use fuel and electricity efficiency alone (IEA, 2010), although this figure also includes reductions in energy obtained from other fossil fuel sources. For more information on the realistic potential for transitioning to renewable energy sources, as well as the mechanisms for achieving this, can be found in the extensive report by WWF *et al.*, (2011).

Obviously, oil and gas companies are resistant to these ideas as it would cut consumption of their product and ultimately limit their profits. However, it is unreasonable to think that they will not be able to redirect their considerable resources, including the creativity of their engineers, to the task at hand. Furthermore, it is the norm for one industry to eventually give way to another, as occurred when whale-oil fuelled lamps gave way to fossil fuels. Regardless, new energy technologies represent an important investment in economic capital. Unfortunately, the true sustained economic benefits of this would be hidden in the current single-aspect indicator of marketed economic activity, Gross Domestic Product (GDP). To reflect the benefits more accurately, we need to move to a more inclusive indicator of economic welfare that also reflects the value of community and environmental capital (among other things), like the Genuine Progress Indicator (GPI: see Kubiszewski *et al.*, 2013). It should be noted that, while global GDP/capita has been constantly increasing, global GPI/capita peaked in 1978, meaning that current economic progress is unsustainable due to declining capital in terms of reduced value of human and environmental resources (Kubiszewski *et al.*, 2013). Accordingly, some reinvestment in that capital, through investment in new energy technologies and infrastructure as well as education, measures to improve the general wellbeing of the middle class, and a more sustainable use of environmental resources in general is needed to circumvent long-term economic turmoil.

In short, in consideration of ocean noise, as well as other environmental and economic factors (see Swift-Hook, 2013), **widespread reductions in the use of oil (and other fossil fuels) is recommended.** To this end, governments should provide considerable support into research and development of energy-efficient technologies, as well as oil-free engines. Finally, governments should also seek to end subsidies and tax credits for oil and gas companies to allow not only a fair market for energy, but also to fund some of the initiatives that will be required at the onset of this undertaking.

8.2. Cross-Purpose Medium- and Short-Term Solutions

Area-based solutions are widely accepted as being the most effective way to reduce the impacts of noise on marine mammals (e.g., Agardy *et al.*, 2007; Dolman *et al.*, 2009; Götz *et al.*, 2009; Lubchenco, 2010). This assumption is further supported

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The flukes of a Humpback whale (Megaptera novaeangliae) breaching near Gill Island in the Great Bear Rainforest, British Columbia, Canada.

by the apparent success of the Canary Island sonar moratorium (Fernández *et al.*, 2013). Accordingly, and based on the limited or unknown effectiveness of other management and mitigation measures, it is appropriate to **strongly recommend that, where supported by data, management agencies implement proactive area-based management efforts** (e.g., establishment of MPAs or time-area closures that are restrictive of noise-producing activities). Management agencies should include consideration of habitat use when making decisions on protected areas, as this may form an important part of the context of the response of exposed animals (Ashe *et al.*, 2010). Similarly, **industry is strongly recommended to include environmental considerations in the very early stages of project planning to avoid activity in marine mammal hotspots, breeding areas or other habitats of importance, where possible.** Finally, **governments are recommended to prioritise the collection of the necessary biological data (e.g., baseline information on species distributions, abundance and habitat use) to make such area-based determinations in regions where this is not yet possible, potentially funded through public-private partnerships with industry user groups.** In the meantime, industrial uses of these lesser-known areas should be undertaken only very cautiously as the same lack of baseline data will ensure that full extent of impacts will remain unknown. With regard to area-based management efforts, it must be acknowledged that noise propagates well beyond the location of the noise-producing human activity in many cases (see discussion in Wright *et al.*, 2011). Thus **management agencies are recommended to implement buffer zones around established protected areas to ensure that levels of noise within are not raised beyond acceptable levels.** Buffer zones are areas around core protection zones where industry that may still impact the environment within the core area remains restricted (at least to some extent), while other forms of human activity are allowed to continue.

Management agencies and regulators are also recommended to begin addressing the spectre of cumulative impacts (from noise exposures and other pressures) through appropriate cumulative impact assessment and management (see Wright & Kyhn, 2012). One way to deal with the assessment side of cumulative impacts is through strategic assessment of any wider development program (as is mandated under UNECE, 2003), although this is not always possible in a commercial environment. In any case, it also needs to be acknowledged that standards of environmental assessment on even comparatively basic, project-based scales are often woefully low (Wright *et al.*, 2013b). Perhaps most importantly, the common practice of ignoring individually negligible impacts in many current CIAs, which runs contrary to their purpose and often also ignores the laws behind them, needs to be curtailed. Thorough CIAs are time consuming, but it is possible for management agencies to pass some of the workload and responsibility off to the proponents of a given activity, provided an internal expert review of the resulting documents can be maintained. For example, companies wishing to conduct seismic surveys in Greenland must, by a given time in the year, submit at least one joint noise exposure model for consideration by authorities as part of their assessment requirements (see Kyhn *et al.*, 2011). **Management agencies and regulators are thus recommended to adopt similar protocols for encouraging cooperation within industry in the preparation of cumulative impact assessments to facilitate a more holistic approach to the management of noise exposures.**

In addition to developing assessment tools, **management agencies are recommended to seek ways to limit the combined impacts of human activity on marine mammal populations, so that those populations may remain sustainable.** It is simply unreasonable to increase the level of impact on declining populations and expect that long-term consequences can be avoided. Likewise, the large amount of unknowns surrounding the extent of noise impacts mean that legal thresholds for initiating (or limiting) action must include a margin of error if marine mammal populations are to be prevented from declining. This is especially important in areas where large increases in marine industry are expected. British Columbia, for example, faces massive projected increases in shipping in association with new infrastructure for liquefied natural gas (LNG) and oil (e.g., Dembicki, 2013), among other planned development. Accordingly, **governments and regulators are strongly recommended to incorporate the uncertainty in the best available scientific information when establishing any such legal thresholds.** Specifically, any average values presented in that information should be used with caution, as these inherently do not address the existence of natural variation.

8.3. Medium- and Short-Term Solutions for Oil and Gas

It is going to be some time before we can move completely away from oil. However, a number of the efforts to improve efficiency mentioned in Section 8.1 can be implemented immediately, or in the near future, thus contributing to a reduced need for seismic surveys in the medium-term. A complimentary effort for medium-term improvements would be the widespread replacement of airguns by marine Vibroseis. Modifications to airguns to reduce extraneous noise are also currently possible, and their use should be encouraged. However, it does not make sense to mandate the use of any single type of equipment as that might constrain the development and use of superior designs and limit innovation. Likewise, any mandate to use the best available technology leaves no incentive for improvement in that technology. Instead, inspiration can be found in the way the German government handled the noise from pile driving. The German Federal Environment Agency (UBA) simply set a lower threshold than used elsewhere as it believed their standard was biologically appropriate. Industry initially protested, claiming that the standard was unobtainable without compromising the economic viability of their activities. However, engineers quickly advanced the technology of bubble curtains and other measures to allow piling to continue despite these more stringent requirements.

To that end, governments should not be wary of setting stringent standards for noise levels from seismic surveys that are considered by society or science to be relevant to the health of an animal or the persistence of a species. Such standards will not prevent the oil and gas industry from proceeding with exploration and extraction, or even turning a huge profit. They will, however, drive the innovation and creativity needed to address the environmental consequences of the current technology by reducing the noise introduced by their arrays. Accordingly, **governments and regulators are strongly recommended to implement technology-forcing, scientifically based noise limits for oil and gas activities, including, but not limited to, exploration, extraction and decommissioning, that can be phased in over a period of not more than 10 years.**

It is clear that the most appropriate way to address underwater noise in the short term is through the establishment of scientifically-based management objectives and the subsequent development of mitigation measures that can meet these objectives (as discussed above). However, it must be acknowledged that this process would not provide guidance to already-planned or other very near future seismic surveys. With regard to such surveys, there are few effective options for mitigating the impacts of their noise, with the exception of keeping levels from the seismic array as low as possible. Despite this, it probably remains better to use pre-operation surveys and safety zones with shutdowns than to proceed without. However, several factors can maximise the effectiveness of these mitigation tools including, but probably not limited to, those listed below. Thus, to improve mitigation of noise impacts from imminent seismic surveys, while acknowledging additional measures may be needed due to special considerations on a case-by-case basis, **management agencies are recommended to include in their mitigation guidelines requirements that:**

- Safety zones should be manageable, yet biologically relevant, with a size is required to be dependent upon the sound level of the seismic source and the sound propagation characteristics of the area;
- Safety zones should be maintained throughout a seismic survey, with shutdowns implemented if a marine mammal is detected within the area;
- Pre-shoot watches should be of appropriate length for species likely to be encountered, being longer when deep divers are likely present or recently observed;
- A team of visual observers are deployed, so that two may be scanning at any given time, with at least one of those being highly experienced;
- Visual observers should not scan for more than 2 hours at a time, to avoid a drop in their efficiency;

- PAM should be used to supplement visual scans, but should only replace the visual scans entirely in rare cases where the species in question are known to produce sound for the vast majority of the time, such as sperm whales and porpoises;
- PAM operators should be additional, dedicated, well-trained personnel and not simply off-shift visual observers, and be limited to shifts of not more than 2 hours to avoid efficiency reductions;
- PAM systems should be set up to detect the sounds produced by species that are expected to be in the area. This may require several displays and more than one operator; and
- Surveys at night or in adverse weather conditions should not be conducted unless the conditions for using PAM without visual observers are met.

In addition to safety zones, consideration should be given to the use of ramp-ups. However, information is simply not available to offer educated advice on their length or the best procedure for how noise levels should be increased. Noting this, as well as their well-known drawbacks, research is needed immediately to determine their effectiveness under real world conditions at reducing high-level exposure to marine mammals. Additional studies will also be required to assess the optimal duration of a ramp-up, if ramp-up is indeed effective. It should also be noted that ramp-up effectiveness is, in particular, likely to vary from species to species and its use will not always (if ever) be appropriate.

Beyond the immediate mitigation options, there is a pressing need for assessments of the long-term consequences of exposure to seismic activity on marine mammals. This is due to the plethora of non-injurious impacts that will all, to some extent, be occurring beyond the boundaries of the safety zone. This will likely require carefully designed, long-term studies that governments should fund with due haste. It is not unreasonable to assign the cost of this work to the oil and gas industry. However distance should be maintained between the industry and the researchers conducting the work itself to retain public confidence in the results.

In addition to the above information needs, assessments of the noise-related and cumulative impacts of drilling rigs, drill ships, offshore terminals, and other aspects of oil and gas activity are needed. Research into reducing the noise produced by these activities should also be conducted.

8.4. Medium- and Short-Term Solutions for Shipping

Most medium-term solutions can be found in alternative technologies. In shipping, the implementation of low noise propulsion systems will unquestionably be required to curb shipping's contributions. Further improvement can be made through other quietening technologies as research makes them practically feasible and commercially viable. Although the IMO voluntary guidelines (IMO, 2013) may lead to some increase in quiet-ship technologies, it is likely that more local regulations will also play a part. For example, although countries cannot unilaterally mandate that ships in innocent passage meet environmental standards, port authorities can place limitations on access to their facilities if vessels do not meet certain requirements. This does provide a mechanism for regionally-based vessel noise management in a similar vein to the air pollution controls under the Northwest Ports Clean Air Strategy (Port of Seattle *et al.*, 2007). The benefits of this have the potential to extend beyond these areas if any such requirements are met through technological modifications rather than operational solutions. Co-ordinated efforts between neighbouring ports will be needed so that traffic does not simply

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Port of Vancouver, Canada.

move to the neighbouring harbour. **Port authorities are strongly encouraged to develop such regional port partnerships and adopt noise-related green certification standards.** To that end, **certification programs, such as Green Marine Environmental Program[2], are recommended to include noise-related criteria in their standards.**

The primary goal of any port authority requirements and green certification standards should be to incentivise inclusion of low-noise propulsion technologies. However, it is entirely possible that they could include, or be immediately achievable through, operational mitigation measures, such as slow steaming and regular propeller maintenance. In fact, providing a dual standard (i.e., if a ship does not have some specific quietening technology, operational measures would be required) would allow current ships to continue to operate under some operational limitations (especially close to shore), while new-builds might have greater freedom due to the lower levels of sound that they already produce. To provide guidance to port authorities and green certification organizations, as well as incentivise the construction and use of quieter ships, **governments are recommended to actively support the efforts of the International Maritime Organization to address noise.** Governments can also provide more direct encouragement of the use of new technologies by offering incentives for ship builders that invest in low-noise designs, many of which also have associated efficiency benefits to subsequent operators.

Governments are also recommended to make it mandatory for all new publicly funded vessels to be built as quiet ships by incorporating

2 http://www.green-marine.org/environmental-program/summary

all necessary ship-quieting technologies. This should not be a substantial change as most military vessels are already built to be quiet, as are an increasing number of research vessels. However, the express statement of this intention and the additional use of the technologies will increase familiarity of the technologies involved among ship-builders and potentially reduce production and installation prices.

One further option for reducing noise from ships is to use them less. While consumers can push for this through the simple act of buying (or not buying), they may be unaware of the noise-related consequences of their purchasing decisions. Likewise, general consumption needs to be reduced. However, this may be an unlikely proposition when repair costs on many products are now larger than the cost of replacement. To that end, **environmental organizations, including WWF, are recommended to take steps to raise public awareness about this issue and the power they have as consumers.** To compliment this, **governments are recommended to implement laws designed to stop companies shifting manufacture overseas, or perhaps increase commercial import fees, as well as seek more creative regulatory measures that would promote local labour (e.g., for repair, refit and reuse) over foreign labour (e.g., production).**

8.5. Medium- and Short-Term Solutions for Pile Driving

Efforts to find alternative foundations for wind turbines resulting largely from the noise restrictions implemented by the German government (see Sections 4.6 and 6.4) provide a relatively hopeful future for reducing the total amount of noise from pile driving in the marine environment. However, research and development of these and other alternatives should continue to be fostered in Germany and elsewhere through the implementation of increasingly restrictive noise standards. As with seismic surveys, this would continue to drive the required innovation through necessity.

With regard to specific techniques, it must be noted that even the noise produced during installation of gravity-based and suction foundations remain unknown. The environmental consequences of noise exposure (and other impacts) from installation of both of these foundations, as well as other piles driven into the sea floor through use of vibratory hammers, should also be assessed as soon as possible. Finally, the screw pile shows promise as a very low noise foundation option. Efforts that adapt it for use with offshore turbines should be encouraged through whatever means are possible.

With regard to immediate options for reducing impacts of noise from pile driving, it is clear that the technology exists for the industry to meet the current German standard mostly through the use of isolation mitigation methods such as bubble curtains, isolation casings, (with the particular options dependent upon depth, currents and other factors), vibratory hammers and alternative foundations. Accordingly, there is no reason that these standards cannot be applied more widely throughout the world. Because the majority of these mitigation measures either reduce noise production or isolate the source from the marine environment, they are expected to reduce the range and extent of both hearing damage and the various non-injurious consequences of noise exposure. Despite this, population impacts may persist, primarily as noise can re-enter the water after travelling beyond any such barrier through the seabed.

Therefore, it is recommended that **governments acknowledge this and slow-**

ly make their standards more restrictive over time, rather than trying to mandate the use of specific mitigation measures or foundation types on a long-term basis, as these options may be limited by depth or substrate. However, it is also recommended that **regulators include a shutdown safety zone complimentary to the distance of any noise requirement (e.g., the 750 m distance included in the German pile driving noise requirements), which would need to be monitored by visual observers and potentially also with PAM.** Although not entirely effective, a properly executed safety zone can help prevent at least some animals from high level exposures, as noted in Section 8.4. While the efficacy of ramp-ups remains dubious, a short period of increasing sound levels may still aid in displacing animals from the stationary sound source. It should be noted that the length of duration should also be shorter than that used for moving sources, as animals will not be subjected to both approach and rising source levels at the same time. However, research should be directed at establishing the effectiveness of this mitigation tool in real world conditions, as well as the optimum duration of the ramp-up.

8.6. Solutions for Naval Activity

There has been some apparent success of measures that avoid exposing cetacean to sonar exercises in areas with sharply changing depths, such as the coastal moratorium in the Canary Islands and the planning components of the U.S. Navy's 29-point mitigation plan (see Section 6.2. Military exercises). However, it is not clear if these resolve the issue, or merely displaced it beyond human observation. Thus, **it is cautiously recommended that governments, regulators and managers seek, at very least, to avoid sonar exercises in locations with topographical characteristics thought to be important in leading to strandings. Governments are strongly recommended to compliment this with funding for research to assess if indeed such efforts actually reduce fatalities, rather than just move them to areas further from coastlines.** If possible, early planning should actually attempt to separate sonar exercises from areas of high cetacean numbers entirely, although it is acknowledged that in many cases avoiding areas with sharply changing depths and coastlines may incidentally achieve the same goal.

During the exercises, world navies are recommended to use of the lowest possible source levels, pre-survey scans, safety zones and ramp-ups, under the same conditions noted in Section 8.4 for seismic surveys. In addition to these conditions, the **navies are also recommended to include lower-level mitigation pings between sonar pulses if modelling demonstrates that there is time for marine mammals to approach too close to the ship; use of experienced marine mammal observers instead of lookouts; and restricting sonar exercises to hours of daylight (where possible).** The latter recommendation is merited because even enhanced night time monitoring is known to be ineffective, and because the use of sonar equipment for passively detecting marine mammals is also likely to be inefficient given the need for the use of species-specific settings in dedicated PAM operations.

With regard to explosives, navies are recommended to engage in early and effective planning, with their use eliminated in exercises where possible. In remaining cases, **navies planning explosions are recommended to use isolation technologies (such as bubble curtains), source-appropriate safety zones and carefully designed ramp-up procedures of mitigation sources**. It is also necessary to fully assess the merits of ramp-ups

Blainville's beaked whale.

for reducing both explosive and sonar exposures in marine mammals, as discussed in Sections 8.4 and 8.5.

Additionally, as mentioned in Section 8.1, the use of the majority of mitigation measures does not reduce the various non-injurious impacts to individuals and populations that we are discovering to be a consequence of noise exposures. It is possible that sonar exposures have produced a combination of these various impacts, which in turn may have contributed to the decline of beaked whales in California (Moore & Barlow, 2013). For example, in one animal DeRuiter *et al.* (2013) noted an extended break in foraging activity associated with strong swimming away from a source of simulated sonar. If repeated often enough, the combination of reduced energy intake and increased energy expenditure associated with this reaction might be detrimental to the long-term health of the animal (see Williams *et al.*, 2006).

Thus, **it is strongly recommended that governments and navies seek to address these issues over the long-term through efforts to refine military sonars to produce signals that are less damaging to marine mammals and, if at all possible, to reduce or eliminate the use of sound entirely.** Meanwhile, **governments are recommended to develop or adapt international agreements to restrict the use of military sonar.**

8.7. Solutions for Other Human Activities

Methods for reducing noise from other sources will be as varied as the sources themselves. However, we are at the stage currently where research and development is the most common requirement for all. Accordingly, efforts should be made to quantify each of the noise from each source, identify the causes, and find ways to minimise their sound levels.

Of particular importance is reducing noise from the millions of pleasure craft around the world. This will not only require research, but probably also regulatory action regarding the equipment that can be used. For example, many echo-sounders produce sound at both high frequencies (HFs) from around 24 to 50 kHz that within the range of odontocete (and other marine mammal) hearing, and at very high frequencies (VHFs) typically around or above 200 kHz, which are likely to be outside that range (at least for the majority of species). Some sport fishermen or yachtsmen may venture offshore to depths where the VHFs are unable to penetrate the water to the bottom for finding fish or navigating by depth contours, necessitating the use of HFs instead. However, the vast majority of echo-sounders do not need to be operated at the HFs that are within marine mammal hearing ranges.

Some of the best ways to limit unnecessary HF echo-sounder use would be through the use of regulations. This could be done through requiring that echo-sounders in shallow waters be operated at only VHFs, although this could be problematic as it would require enforcement. One easier option would be to regulate their installation of units on ships that can produce only the VHFs, unless a special licence is obtained. Accordingly, a more stringent registration process than is currently present around most of the world is needed so that echo-sounder use can be regulated.

For noise from pleasure craft propellers, there may be some benefits to be gained from some already (slowly) emerging alternative propulsion systems. For example, surface-piercing propellers reduce the generation of loud vacuum bubbles by essentially replacing them with air bubbles dragged down from the surface. Although much quieter, technical and operational limitations (such as inefficient reversing) need to be addressed before they can enjoy widespread use (see Kamen, 1995; Peterson, 2005). Similarly, a new propeller-jet hybrid propulsion system has recently been developed, which has also been purported to produce lower noise levels than conventional systems (Anon, 2012). Reducing noise from pleasure craft could produce notable improvements in noise levels in coastal areas. Accordingly, funds should be directed to assessing the value of these and other systems potentially capable of reducing the introduction of noise and reducing their functional limitations. This should be followed by installation requirements. Until these measures are implemented, the only viable management options are area-based restrictions. This could involve limited (or no) access areas, no-wake restrictions, or designated use areas, such as might be most appropriate for jet skis given the unique propulsion systems in this wider group. However, these measures could be complemented through responsible boater outreach efforts that could improve compliance, introduce recreational boaters to noise-reduction options (such as proper propeller maintenance), and potentially also instigate more awareness of underwater noise in general. This could be achieved most readily through modifications to existing outreach programmes (e.g., http://www.bewhalewise.org/).

Options for reducing the impacts of multi-beam sonars on marine mammals are very similar to those available for navy sonars, in that careful planning of timing and location is likely to achieve some of the best results. The simple separation of these sonars and marine mammals will be in many cases easier than for navy sonars given that relatively higher frequencies are involved which do not travel as far. However, caution must still remain about simply siting the sonar surveys away from certain topographical features and coastlines pending confirmation that this measure actually does reduce, rather than relocate, fatalities. Given the very recent appearance of multi-beam sonars as a serious concern, noise-reducing technologies are yet to be considered.

With regard to dredging, methods for reducing in-air noise on dredging vessels (e.g., Epsilon Associates, Inc., 2006) may also reduce underwater noise. However, this will need to be assessed. Furthermore, there may be a potential for the use of isolation technologies such as bubble curtains, given the shallow waters where this activity occurs. Until that time, and given the necessary association of dredging with coastal and often port-related shipping, only seasonal operation restrictions are likely to produce benefits in terms of reducing noise exposure to marine mammals.

An SH-60B Sea Hawk helicopter conducts flight operations over the Pacific Ocean.

Options for other activities are similarly limited. Aircraft should continue to be required to fly at minimum altitudes, although with more consideration of their source levels. On-ice operations will need to be considered case-by-case depending upon the specific activity (e.g., ice roads, oil and gas infrastructure, research operations, landing strip operation, etc.). While it may be possible in some cases to reduce through-ice transmission through isolation mounts similar to those used on ship engines, it may only be possible to apply time-area management to the majority of activities. The construction of bridges and other offshore structures can typically be mitigated in the same way as pile driving, which is often a major component of such activities. Accordingly, the same recommendations apply here. However, the contribution of traffic over bridges to underwater noise levels is largely unknown, as is the potential for them to act (at least in some situations) as barriers to marine mammals. It may be that bridge noise could be limited through installation of vibration dampeners similar to those incorporated into the Golden Gate Bridge and other bridges in earthquake zones. The need for, and benefits of, this potential mitigation measure should be assessed.

In summary, **it is strongly recommended that governments and other responsible authorities, through the use of regulation and other incentives, support efforts to: (a) assess the extent and characteristics of the many sources of human-introduced noise in the marine environment; and (b) lessen their impacts on cetaceans and other marine life by reducing the demand for their use, implementing technological solutions for eliminating or isolating the source, or refining the properties of their sounds.**

8.8. Special Considerations

Reductions in source levels will, in every eventuality, lead to fewer marine mammal noise exposures and ultimately less impact to populations. In contrast, any of the other mitigation measures discussed throughout Chapter 8, while generally applicable, may be inappropriate or insufficient to address noise impacts on a given species or in a particular region. For example, beaked whales are known to strand and die as a consequence of exposure to naval sonar at levels well below those normally associated with direct injury (e.g., Hildebrand, 2005). Accordingly, any guidelines for reducing the impacts of noise on marine mammals should not be used as firm instructions for operation for any given activity, but as a foundation upon which to

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Coastal lagoon landscapes around the island of Hiddensee near Stralsund, Germany.

build additional safeguards and other modifications as required to ensure adequate protection in any particular circumstance. The most obvious of these relate to the fact that large safety zones or minimum flight restrictions should be applied to louder sources of sound. However, there are many other considerations that should be taken into account on a case-by-case basis.

One interesting example is the increase in marine activity associated with coastal developments, as well as near-coast mining and other industry. Sound behaves differently in coastal areas in comparison to noise in more open ocean environments, due to the various interactions with the seafloor and shorelines. While lower frequencies may not propagate as far in shallower areas, reflections off the water surface, the sea floor, and any other topographical features (such as headlands) mean that levels at any given location may be enhanced or reduced erratically. Advanced propagation models that are location-specific will be needed to assess the likely noise levels in such areas.

The complexity of coastal soundscapes has implications for the response of exposed marine mammals, as well as their capacity to move away from high noise levels, if suddenly exposed by a source coming out of a sound shadow area. The potential for several of these factors to contribute to unusually large impacts has even been noted by the U.S. Navy (Evans & England, 2001). Similarly, animals in such coastal environments may not be able to avoid increasing noise levels due to land barriers, especially if they are effectively chased into fjords, inlets and small bays will no outlets (e.g., Southall *et al.*, 2013).

Another example is the movement of industrial activities into increasingly remote locations. This typically leaves managers with less information regarding the marine mammal species that may be affected. However, it can also reduce the value of any generic information about the levels of noise from particular sources in addition to any previously reported marine mammals. The first reason for this is that many (although not all) remote areas have low levels of background noise. This means that any new source can travel further before it can no longer be perceived and that the levels reported to induce responses may be different than in more industrialised waters as the sound may appear louder to marine mammals. The second reason for this is simply that animals in more remote areas have less experience of noise from human activities. This may means that they may have a totally different context against which to base a response than more 'urban' species and that the responses of those animals may not be representative.

Perhaps the most important special consideration is that required by small (and often endangered) populations with limited ranges, such as the vaquita (*Phocoena sinus*) and the eastern Taiwan Strait Indo-Pacific humpbacked dolphin (*Sousa chinensis*). Many of these populations are already in decline and may require protection in areas beyond their current range in order for them to recover (e.g., Ross *et al.*, 2011). The ability of such species to avoid (additional) human-introduced noise is expected to be extremely low. Furthermore, the margin for error in any risk assessment is extremely small if the continued existence of such populations is desired (e.g., Ross *et al.*, 2011). In these situations, it is advisable for managers to be extremely cautious when considering noise-inducing activities in the ranges of these animals.

To further demonstrate the need for additional protections in particular cases, the following Chapter considers the modifications necessary to protect marine mammals from noise one example region: the Arctic.

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Ships off the coast of Greenland.

9. AN EXAMPLE OF REGIONAL CONSIDERATIONS: APPLICABILITY TO THE ARCTIC

The Arctic ice sheet is shrinking in response to global climate change. This is opening up the Arctic Ocean to new industrial uses and bringing a whole suite of noises into the region. The potential also exists for at least one completely new industrial activity that would be unique to the Arctic. Following a recent successful test extraction by Japan (Tabuchi, 2013), the stage now seems set for eventual exploitation of methane hydrates, a high-energy crystalline form of natural gas, found in large quantities beneath the floor of the Arctic Ocean. However, commercial enterprise in the Arctic faces a range of unique challenges associated with the cold, often hostile environment. Similarly, efforts to maintain the environmental quality in the region must also take into account the particular vulnerabilities and circumstances present.

With regard to noise, the most important consideration is the presence of a set of oceanographic conditions associated with the cold that can 'trap' sound near the surface, allowing sounds to be transmitted over very long distances. Low frequencies travel particularly well in this 'surface duct' as it reduces the normally disruptive interactions of the sound with the sea floor. It should also be noted that the natural background noise levels will also be different in the presence of ice, being somewhat louder around the ice edge due to wave-ice interactions. This will be supplemented by the occasional ice collisions and iceberg cleavage events that will send sound both away from and under the ice. Further under the ice, the separation of wind from water reduces noise from this source (e.g., wind and waves).

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Black carbon, or soot, from the exhausts of ships typically settles near to the source. If it settles on ice it can accelerate the uptake of heat, even at concentrations that are invisible to the naked eye.

However ice-related sounds (e.g., cracking, etc.) will be present instead. The result is a different set of background noise against which human-introduced noise must be compared.

This has a number of implications for management of human noise. The first is that human noise may travel over much greater distances here than at lower latitudes, and near-surface levels are likely to be higher. Therefore safety zones or other distance-based measures based on information from more temperate areas are likely to be insufficient. Secondly, comparisons of levels of noise against thresholds for different impacts, especially responses dependent upon perception of loudness (e.g., masking, stress responses and behavioural reactions), may need to include consideration of the different background noise conditions in the region.

Certain mitigation measures may also require adjustments to deal with specific Arctic conditions. For example, the long summer days mean that a much larger team of visual observers is needed for spotting marine mammals to prevent inefficient scanning as a result of extended shifts and associated fatigue. Similarly, systems for monitoring marine mammal sounds also need to consider that detection ranges may be increased.

Other mitigation measures for noise may simply have reduced overall merit in the Arctic. For example, pre-exposure surveys, ramp-ups and source suspension will all extend the amount of time industry spends in the Arctic, which in turn increases the amount of emissions produced in the area. Of particular note here are small particles of soot and other solid matter, known as black carbon. Black carbon that settles on ice and snow reduces the reflectivity to the sun and increases the absorption of heat. This all means that near-ice industrial activity has an enhanced impact on climate change. Accordingly, the benefits of any noise mitigation measures that increase industrial near-ice time must be weighed against this additional concern. Some additional measures would help alleviate these concerns. For example, there are several ways to reduce black carbon emissions from industry such as using better fuels and the use of emission filters. Furthermore, engines can be designed to be most efficient in terms of producing the least amounts of pollution at the speeds most likely to be used in Arctic waters. However, it should be noted that the only way to eliminate this concern entirely over the long-term is through the development of commercially viable alternative power sources. Meanwhile, immediate results could be obtained through a ban (or at least heavy restrictions) on Arctic activities. However, this too has problems when it comes to commercial shipping. Use of the Arctic routes may shorten trips and reduce overall climate impact, provided that this does actually reduce total time spent in transit, rather than simply allowing ships to make more trips. With this in mind, a more commercially friendly alternative would be the implementation of a strong IMO Polar Code for safe and environmentally responsible Arctic (and Antarctic) shipping. Currently under development at the IMO, this could be supported by designation at the IMO of the Arctic as a particularly sensitive sea area (PSSA), which would facilitate the use of additional environmental measures.

Internationally accepted guidelines or regulation may be the best way to address a number of noise sources in the Arctic in the face of often disputed Arctic sovereignty and access rights. Much of this could be resolved as countries may claim exclusive resource rights (and associated environmental obligations) over extended contiguous continental shelf areas beyond their exclusive economic zones (as well as dispute the claims of others) under the UNCLOS. However, the U.S. has not yet ratified the treaty and seems unlikely to do so in the near future. Further complications arise due to the long-standing dispute between Canada and the U.S. over jurisdiction of the Northwest Passage, with Canada claiming that they are territorial waters, while the U.S. asserts that they are, like the high seas, an international waterway.

The other major consideration in the management of Arctic impacts from noise is the lack of information about the animals living there due to the remoteness of the locations. This prevents managers from making informed, environmentally appropriate decisions, such as determining optimal locations for particular activities around habitats of importance to marine mammals. Similarly, many of the animals in these locations have not been regularly exposed to noise from human activities, so it is not possible to determine with any certainty how they will react.

The end result of all these elements is that assessing, managing and mitigating the impact of noise in the Arctic is more difficult than it already is elsewhere. Basic biological and ecological knowledge is missing and the additional complications presented by the Arctic environment mean that the information needs for effective management here are greater than in most other areas. Additional complications arise when cumulative impacts of Arctic industry are considered, as noise impacts cannot be considered in isolation. These issues should be given due consideration before the industrial development of the Arctic proceeds further at the current rate.

10. CONCLUSIONS

While numerous options are available for mitigating the impacts of noise on marine mammals, the effectiveness of many is limited. Operational measures, such as safety zones or slow speed requirements, can also suffer from compliance issues. Unfortunately these are, for the most part, the best options for mitigating the impacts of noise on marine mammals available at the present time. The implications of this are two-fold. Firstly, we must exploit any opportunities for the use of improved planning and protection measures that will help reduce the overlap between marine mammal and human activities. Secondly, and more importantly, we need to pursue any technological developments that will reduce or preferably eliminate the various sources themselves. This can be achieved through refining or replacing the equipment in question, or by eliminating the demand for the activity entirely.

To that end there are two overarching recommendations that have arisen from this report:

1. **It is recommended that governments and other responsible authorities around the world phase in increasingly strict noise level standards for all noise-producing activities.** This will drive the necessary innovation to reduce noise at the source and take management truly into the realm of addressing the overall impacts of noise, rather than simply focusing concern on the potential for injury. The regulatory pressure on noise levels placed upon companies installing wind farms in Germany led to the necessary innovation to meet these standards. The result was a reduction in not only the dangerously high sound levels that are typically mitigated, but also the levels of noise at greater distances. This reduction will also reduce the occurrence and extent of all the various non-injurious impacts of noise.

2. **It is recommended that governments, industry and environmental organizations, including WWF, seek ways to address and reduce the underlying demand for noise producing activities so that their occurrence can be reduced to the greatest extent possible.** Even on rare occasions when it may not be possible to eliminate a particular source of sound due to its function, suppression of the demand for the result will curtail the activity itself. Consequently, it is recommended that governments take steps to reduce the need for oil, shipping and (where possible) military sonar through improved energy efficiency, support for local over foreign economies, and international agreements (see specific recommendations in WWF *et al.*, 2011). Use of the concept of the Genuine Progress Indicator (GPI) may be of particular importance to these goals and is also recommended.

Implementing these recommendations will result in a quieter ocean. However, this will take time. Meanwhile, the currently available mitigation measures must continue to be used, although in a more precautionary manner. A visual summary of much of the information contained within this report is presented in Table 1. Specifically, the table includes details of the mitigation options deemed most worthy of use and/or development at this time for several specific sound sources. This is an admittedly subjective interpretation of the scientific assessment contained in this report of the effectiveness and likely extensiveness of application of the various presented management and mitigation tools. For example, it is not currently possible to implement safety zones at night with any degree of confidence, so suspension of activities during this period deserves strong consideration. Accordingly, these techniques score a medium to high viability of application, conditional upon the restrictions being put in place to limit the activities in question to hours of daylight.

Similarly, the effectiveness of ramp-up (see Section 5.4) is almost completely unknown. However, application to stationary sources can be planned to allow at least some animals to move away, without risking possible entrapment in unfamiliar coastal features, ice edge environments, or other such areas. Such uncertainties are highlighted in Table 1, which may thus provide general indications of where more information is needed on the application and effectiveness of these particular management tools for those seeking to fund research in the area of noise mitigation. It is very important that any new information on the merits of the various management and mitigation measures be re-incorporated into the management process though truly adaptive approaches rather than being excluded from subsequent environmental impact assessments or management decisions. The same is true for new details about the potential benefits of new technologies and techniques, or the various impacts of noise sources on marine mammals. It is only through such a mechanism that the quality of management decisions can improve over time.

It is extremely important to note that the content of Table 1 cannot reflect any special considerations required of specific locations or likely impacted species, such as those described in Chapters 8 and 9. For instance, source levels of near-coast operations need to be very carefully controlled to avoid unreasonably high exposures when animals are unable to move away, even in situations where entrapment is unlikely. Similarly, small populations with limited ranges simply may not be able to avoid noise sources introduced into their habitats.

Furthermore, the assessments of mitigation effectiveness in Table 1 are based primarily on the best possible implementation of the tools. Accordingly, a lack of compliance or (where appropriate) the use of untrained personnel has not been factored into any category, with the explicit exception of "Operational measures". The lack of compliance considered here is not regarded as malicious, but instead as a consequence of unclear regulations or uninformed participants.

In addition to the over-arching recommendations above, and the very general guidance in Table 1, Chapter 8 contains a number of more detailed recommendations for regulators, managers, industry, environmental organizations, and other interested parties. These provide some specific guidance on which measures for reducing impacts of noise on cetaceans (and other species) should be pursued further, as well as how they can best be implemented. This guidance is, by necessity, often policy-based. However, the reasoning behind it is supported by current scientific knowledge applied in accordance with the general context of existing societal tenets, as enshrined in laws around the world. Most important of these is the belief that species should not be allowed to decline to extinction. To that end, a functional framework for actually managing the cumulative impacts of all human activity on marine mammals is critically needed, not only to prevent populations from declining, but also to make management decisions, and their consequences, more transparent to public scrutiny.

Source Type	Metric	Demand reduction	Alternative technology	Modify existing gear	MPAs and similar	Early planning options	Safety zones & shut-downs	Ramp-up	Mitigation sources	Isolation techniques	Operational measures
Seismic survey airguns	Viability	H	H	H	M-H	M-H	M-H	H	H	L	H
	Effectiveness	VH	M-H	L-M	M	M	(L-M)?	?	L?	L	L-M
	Availability	S-F	I-S	I	I	I	I	I	I	S	I
Navy sonar	Viability	L-M	?	M-H	M	M-H	M-H	H	M-H*	N	M
	Effectiveness	VH	?	H?	H?	H?	(L-M)?	?	?	N/A	M
	Availability	S?	F?	S?	I	I	I	I	I	N/A	I
Piledriving	Viability	?	M	H	M-H	M-H	M-H	H	L	H	N
	Effectiveness	VH	H	M-H	M	M	(L-M)?	M?	?	H	N/A
	Availability	?	I-S	I	I	I	I	I	I	I	N/A
Shipping	Viability	M	N	M-H	M	M	N	N	N	H	H
	Effectiveness	M-H	N/A	H	M	M	N/A	N/A	N/A	?	L-M
	Availability	I-S	N/A	I-S	I	I	N/A	N/A	N/A	S	I
Explosions	Viability	L?	?	N	H	H	H	H*	H*	V	N
	Effectiveness	VH	?	N/A	H	H	M-H	M?	M?	?	N/A
	Availability	I	?	N/A	I	I	I	I	I	I-S	N/A
Pleasure craft propellers	Viability	H?	M-H	N	H	N	N	N	N	N	M
	Effectiveness	L	H	N/A	H	N/A	N/A	N/A	N/A	N/A	(L-M)?
	Availability	I	S	N/A	I	N/A	N/A	N/A	N/A	N/A	I
Echo-sounders	Viability	H	N	N	H	N	N	N	N	N	L
	Effectiveness	VH	N/A	N/A	H	N/A	N/A	N/A	N/A	N/A	L
	Availability	I	N/A	N/A	I	N/A	N/A	N/A	N/A	N/A	I
Multi-beam sonar	Viability	?	?	?	H	H	M-H	H	H	N	L
	Effectiveness	VH	?	?	H	H	(L-M)?	?	L?	N/A	L
	Availability	?	?	?	I	I	I	I	I	N/A	I

TABLE 1

An indication of the relative merits of the different management and mitigation options. The metrics are defined based on the discussions throughout the report as follows: Viability is the likely applicability of the management option to the source; Effectiveness is the likely extent to which the management option can be expected to reduce noise; and Availability is an indication of the likely time before the tool becomes available to managers for use. N=None; L=Low; M=Medium; H=High; VH=Very High; I=Immediate; S=Soon; F=Further into the Future; N/A=Not Applicable; ?=Unknown or uncertain; and *=Indicates situations where Mitigation sources are linked to Ramp-ups, or vice versa. Colouring indicates overall preference based mainly on Effectiveness and Viability in the descending order: Green; Yellow; Orange; and Red. These assignments are determined as follows: Green required a high or very high Effectiveness and a high Viability score; Red required a low Effectiveness value; Yellow and Orange were separated based on the remaining balance of scores in both Effectiveness or Viability and the general uncertainty across all categories. Mitigation tool categories are generally synonymous with various headings in Chapters 5 and 6, except for: "Demand reduction" which covers a reduction in the use of the source through regulatory or financial incentives upon the activity causing the source (including consumer spending power); and "Modify existing gear" which was discussed as a subset of Alternative Technologies and reflects improvements to existing designs, such as use of pile caps or airgun modifications, rather than outright replacement. Specific case-by-case complexities, such as (but not limited to) the presence of particularly sensitive species or specific topography thought to increase likelihood of impact are not considered here.

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APPENDIX 1: GLOSSARY OF ABBREVIATIONS

AAM: Active acoustic monitoring. Also known as whale-tracking sonar. Use of sonar equipment for detecting marine mammals.

ACCOBAMS: Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area.

ADD: Acoustic deterrent device. Also known as a pinger. Designed to produce sounds that warn marine mammals (particularly small cetaceans, like harbour porpoises) of the presence of fishing gear in an effort to prevent them becoming bycatch.

AHD: Acoustic harassment device. Sometimes called a seal scarer. Designed to produce sounds at levels that are unpleasant to marine mammals (often seals and sea lions) to keep them away from deployed gear. Typically used around aquaculture pens.

AIS: Automatic identification system. A ship-borne transponder system, currently deployed on all larger ships, which transmits the locations of that ship, among other things. The information is received by shore-based receivers that are within range.

ASCOBANS: Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas.

ATOC: Acoustic Thermometry of Ocean Climate. A study that uses sound to assess ocean warming over ocean scales due to the effects of temperature on the speed of sound.

BOEM: U.S. Bureau of Ocean Energy Management.

CIA: Cumulative impact assessment. Although definitions vary, this is typically a report of the likely and/or potential impacts of a given project or action in combination and interacting with the impacts of existing (and sometimes also foreseeable future) human activities. This may be part of an environmental impact assessment (see EIA). Note, this term is used to refer to such assessments generically, regardless of the official term in any given country or legislation.

CSA: CSA Ocean Sciences Inc. An ocean-focused branch of the environmental consulting company Continental Shelf Associates.

dB: decibel. A unit of relative measurement typically used to assess the level of sound.

DCE: Danish Centre for Environment and Energy.

DoN: U.S. Department of the Navy.

DTI: U.K. Department of Trade and Industry.

EIA: Environmental impact assessment. A report of the likely and/or potential impacts of a given project or action. Note, this term is used to refer to such assessments generically, regardless of the official term in any given country or legislation.

ELI: International Energy Agency.

ESA: U.S. Endangered Species Act

EU: European Union.

GDP: Gross Domestic Product.

GES: Good environmental status. Measures of environmental standard under the Marine Strategy Framework Directive.

GPI: Genuine Progress Indicator. An economic indicator that, unlike GDP, also reflects the value of community and environmental capital (among other things).

HF: High frequencies. This term is often used in a relative one and covers no particular set of sound frequencies.

Hz: Hertz. A measure of the frequency of sound, which in turn is perceived as pitch by human ears.

ICES: International Council for the Exploration of the Sea.

IMO: International Maritime Organization. The United Nations agency responsible for improving maritime safety and preventing shipping pollution.

IUCN: International Union for Conservation of Nature.

IWC: International Whaling Commission.

JNCC: U.K.'s Joint Nature Conservation Committee.

kHz: Kilohertz. See Hz.

LGL: An environmental consulting company, named from the initials of its three founding partners.

LNG: Liquefied natural gas.

LOE studies: Lookout Effectiveness studies. U.S. Navy studies into the effectiveness of their marine mammal lookouts in comparison to experienced MMOs.

MAI: Marine Acoustics Inc.

MMC: U.S. Marine Mammal Commission

MMO: Marine mammal observer. Typically required as part of a mitigation effort to watch for the presence of marine mammals in a specified area around a source of noise.

MMPR: New Zealand's Marine Mammals Protection Regulations. Implementing regulations for the New Zealand's Marine Mammals Protection Act.

MPA: Marine protected area.

MSFD: Marine Strategy Framework Directive.

NEPA: U.S. National Environmental Policy Act.

NEPA: U.S. National Environmental Policy Act.

NMFS: U.S. National Marine Fisheries Service.

NMS: National Marine Sanctuary. A type of marine protected area used in the U.S.

NPAL: North Pacific Acoustic Laboratory. A study that uses sound to assess ocean warming over ocean scales due to the effects of temperature on the speed of sound.

NRC: U.S. National Research Council.

NRDC: Natural Resources Defense Council.

NZMMPA: New Zealand's Marine Mammals Protection Act.

OGP: International Association of Oil & Gas producers.

"OSPAR": Convention for the Protection of the Marine Environment of the North-East Atlantic.

PAM: Passive acoustic monitoring. Use of equipment to listening passively for marine mammals.

PSSA: Particularly sensitive sea area. Designation that can be given to areas that require additional levels of protection by the IMO. The levels are variable, but can extend to declaration as an area to be avoided.

PTS: Permanent threshold shift. A permanent loss of hearing sensitivity (as a consequence of noise exposure), at least over a particular range of frequencies. This does not mean loss of hearing, but that sounds must be louder to be heard.

SARA: Canadian Species at Risk Act

TTS: Temporary threshold shift. A temporary loss of hearing sensitivity (as a consequence of noise exposure), at least over a particular range of frequencies. This does not mean loss of hearing, but that sounds must be louder to be heard.

UBA: German Federal Environment Agency.

UNCLOS: United Nations Convention on the Law of the Sea.

UNECE: United Nations Economic Commission for Europe.

USEIA: U.S. Energy Information Administration.

USMMPA: U.S. Marine Mammal Protection Act.

VHF: Very high frequencies. This term is often used in a relative one and covers no particular set of sound frequencies.

WDCS: Whale and Dolphin Conservation Society. An environmental organisation now known as Whale and Dolphin Conservation, WDC.

WWF: World Wide Fund for Nature

+100

WWF is in over 100 countries, on 5 continents

+5 M

WWF has over 5 million supporters globally

1961

WWF was founded in 1961

+5,000

WWF has over 5,000 staff worldwide

Why we are here

To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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