Cetacean stock assessment in relation to exploration and production industry sound: current knowledge and data needs

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Executive Summary

1 The offshore oil and gas industry (E&P industry) currently operates ~ 6,200 offshore oil and gas installations worldwide. It generates underwater sound at every stage of its process (exploration, construction, extraction, decommissioning) and each activity has the potential to affect the behaviour and physiology of individual cetaceans, with most concerns expressed towards seismic survey explorations. However, the relationship between offshore E&P industry activities and trends in local cetacean stocks has not been investigated to date. Therefore, the effects of E&P sound on cetacean stocks are completely unknown. This review is aimed at a first step in assessing the relationship between cetacean stocks and E&P industry sound.

2 We first characterise the physical properties of E&P related sound with regards to the hearing abilities of cetacean species in order to identify key issues for further assessment. We then provide a global overview of the E&P industry activity in relation to cetacean stocks, with the aim of identifying case studies for a more detailed analysis. In the case studies, we describe the E&P activity in the region in terms of the scale of production and exploration activities so as to get a more detailed picture of sound exposure. Then we look at the target cetacean stock in the region, document its status and try to discern population trends. We also investigate other factors controlling or influencing the case study population, with the aim of putting the potential impacts of E&P industry sound in perspective. For this purpose, we have developed and applied an impact analysis matrix. Further, we discuss the major outcomes of the study and try to outline any limitations inherent in our approach. Finally, we provide suggestions for further research.

3 The available data on E&P sound related profiles vs. cetacean hearing abilities suggests that baleen whales might be more affected than other groups. Potential impacts on other cetaceans can't be ruled out. Our assessment of cetacean stocks in relation to E&P sound therefore focuses on mysticetes (baleen whales), but also include other species with similar hearing abilities compared to mysticetes, such as species of the families Ziphiidae and Phocoenidae.

4 Approximately 6,200 oil and gas installations are presently operating in the marine environment, 65% of these are located off the coast of North America with the Gulf of Mexico area comprising almost all of them. This is followed by the Asian Pacific region, the coasts of North-West Europe, the west coast of Africa and South America. Data on the occurrence, effort, and type of surveys undertaken in seismic explorations is difficult to obtain in most cases, but the level of activities mostly follows the above-mentioned trend. Apart from some areas in North America and Europe, for many regions with a high proportion of oil and gas platforms there are huge knowledge gaps regarding cetacean stocks in the area. In the case studies, we focussed therefore on a representative sample of well studied species, including four low-frequency cetaceans (humpback, blue and fin whales off the coast of California, minke whales off the East Coast of the UK), two mid-frequency cetaceans (sperm whales in the Gulf of Mexico, Northern bottlenose whales off Nova Scotia), and one high-frequency cetacean (harbour porpoises off the East Coast of the UK).

5 The volume of E&P industry activity in the **Gulf of Mexico** is large and, coupled with vast amounts of shipping, these waters are heavily utilised. Despite this, the Gulf of Mexico remains rich in cetacean diversity, with at least 19 different species. The

sperm whale population of the Gulf of Mexico lent itself to further investigation with respect to the oil & gas industry, being one of the few species with a habitat overlapping that of the industry and the deeper, less coastal waters; having a number of studies conducted on it over several of years, and of course, its apparent relatively discrete stock nature and endangered status. Despite much effort, no definitive population trends can be drawn, however, it appears that the population is not showing a decline and no long-term displacements have been identified as yet. Furthermore, a relatively stable number of animals have been found yearly in a couple of 'hotspot' regions, around the Mississippi canyon. There are several other factors that could potentially affect this population, including pollution, contaminants, harmful algal blooms/red tides, ship strikes, and environmental factors with climate change appearing to be the most potentially harmful, possibly through changes in prey availability. Although the severity of some of these effects could be high, in most cases the uncertainty is also high and the likelihood of occurrence appears to be rather low. The population is only likely to come under threat by cumulative factors and/ or as a result of intense or prolonged environmental changes.

6 The E&P industry activity has been high off the **Californian coast** in terms of seismic exploration and medium in terms of construction and production activities, with platforms located off the southern Californian coast. There are a wide variety of cetacean species off California, of which **humpback**, **blue** and **fin whales** are most suitable for closer study with regards to stock assessments and impact analysis. All three species belong to subpopulations that are parts of larger stocks, although population identity is rather uncertain. Humpback whales have been increasing in numbers since the cessation of whaling with a recovery rate of 8% per annum. Blue whales have inhabited the Californian waters only since the 1970s, and have undergone shifts in distribution, probably due to prey abundance more than anything else. Fin whales are abundant off California and results from line transect surveys indicate that numbers in that particular area have remained at similar levels since the 1990s. There are several factors besides E&P industry sound that can potentially affect stocks with predation by killer whales; entanglement in fishing gear, ship strikes, interspecific competition for food and pollution the potentially most severe, although the uncertainty of the levels of the effects is very high in almost all cases. The impact analysis indicates that no single factor will contribute to a negative effect on each of the three species, but that cumulative effects might lead to longer-term effects that might influence population trends.

7 E&P activity has been comparably high off **Nova Scotia**, especially during the late 1990s with a high level of seismic exploration, followed by construction and production activities since the beginning of this century. It is likely that sound levels from the E&P industry were audible over considerable ranges to most cetacean species inhabiting the Scotian Shelf, especially those sensitive to low frequencies. As case studies in this and other regions have shown, behavioural reactions are likely at ranges up to several kilometres. The Scotian Shelf is home to a variety of cetacean species with **Northern bottlenose whales** being resident in a particular confined area, known as the Gully. Field studies undertaken between 1988-2003 indicate that the population in the Gully has remained relatively unchanged during this period. Due to the relatively short history of these field studies, further results will clarify the demographic features and their development in the Northern bottlenose whales in the Gully and adjacent waters. The impact analysis indicates that E&P industry sound and other human impacts such as shipping sound, interactions with fisheries, and contamination could only affect the population cumulatively.

8 The **North Sea** houses a large amount of oil & gas industry with the southern North Sea experiencing the greatest increases recently with also a high level of seismic surveys being conducted. Despite this and many other pressures, results from large-scale surveys have indicated no significant changes in the abundance of **harbour porpoises** between 1994 and 2005. The numbers of porpoises in the southern North Sea have doubled between 1994 and 2005, most likely due a shift in distribution of animals from the north, which in turn might have been caused by shifts in prey distribution. By-catch numbers have decreased recently, possibly as a result of declines in commercial fisheries, improvements in nets and other mitigation measures. The impact matrix indicates that the main threats to this species are fisheries interactions, pollution and climate change. Sound from construction and seismic surveys will potentially lead to short-term displacements of porpoises, yet effects on the populations are not apparent. The movement of harbour porpoises farther into areas more densely populated with oil & gas industry activities and structures is difficult to interpret, as it may be that animals are forced to move into these areas due to other environmental pressures. As it appears that, despite the many man-made pressures, harbour porpoise abundance in the mid- southern North Sea has been relatively stable over the past decade, ongoing surveys will provide a more detailed picture on the development of the population. The outlook for **minke whales** appears to be relatively positive in the offshore waters of the UK. No large increases in strandings have occurred recently, and survey results seem to indicate an increase in numbers overall, with localised fluctuations mostly likely a result of changes in prey distribution. Minke whales remain the most abundant balaenopterid in the North Atlantic, and may be approaching pre-exploitation (whaling) levels. Their healthy numbers in this region and movements into and around busy areas of the North Sea indicate that this species is not significantly threatened by the number of factors affecting them, including the oil and gas industry.

9 This study identified very large gaps in our understanding of the distribution and abundance of cetaceans in areas of high E&P activity. The data on long term trends is only adequate for areas off the Northwest European coast and off North America; but, even here, only a very few stocks lend themselves to more detailed study with regard to exposure to E&P industry sound. One important future research task should be a more comprehensive mapping of cetacean stocks worldwide and a fostering of case studies, particularly off the West coast of Africa but also off Asia. Another confounding factor in this analysis was the lack of open-access data on oil and gas platforms and even more so on the number of seismic surveys conducted in almost all parts of the world.

The case studies revealed that two of the stocks have been increasing in numbers or surveys indicate population growth (Californian humpback whales, and UK minke whales, respectively). Three of the investigated stocks seem to at least hold their own in terms of population size (northern bottlenose whales off Nova Scotia, harbour porpoises off the UK east coast, fin whales off California). One stock seems to remain unchanged, although trends are difficult to assess due to the magnitude of error in abundance estimates (Gulf of Mexico sperm whales). Finally, individuals of one stock (blue whales off California) show a clear decrease in numbers of sighted animals, which is probably due to a shift in whale distribution that is in turn related to shifts in prey rather than man-made effects.

There are at least three possible explanations for the lack of negative population trends despite the many man made factors documented here. First, it is likely that measures are too crude to detect differences as variability in cetacean abundance estimates is, in general, too high to document population trends in many cases. In this regard, uncertainties persist for the sperm whales off the Gulf of Mexico, the minke whales off the UK, and fin whales off California. Yet, for harbour porpoises off the UK, humpbacks and blue whales off California and possibly also the northern bottlenose whales in the Gully, data were relatively robust, and the documented trends appear therefore to be reliable. One alternative explanation for a lack of negative response on the population level might be that the factors we discussed are either not severe enough, or that individuals are able to adapt to changes in their environment to compensate for any negative effects. Finally, it is possible that individuals might not react to unwanted signals just because the benefits that come with staying in an area outweigh the costs of human disturbance.

It is very likely that none of the factors we identified in the case studies are harmful enough to cause a decline in cetacean stocks, but together they may create conditions leading to reduced productivity and survival. It is evident that potential impacts of sound have to be placed in a wider context, addressing the consequences of acoustic disturbance on cetacean populations in conjunction with other factors.

There are several areas where research on the effects of E&P industry sound on cetacean stocks will specifically focus in the future, including the fostering of studies intended to provide better data on cetacean stocks and focussing on particular areas. It will also be necessary to develop better methods to quantify sound exposure. Finally, focus will be put on the development of methods that adequately measure changes in cetacean populations, in order to overcome limitations in our interpretations of the effects of anthropogenic activities on cetaceans.

Glossary

Ambient Noise. Background noise in the environment without distinguishable sources.
Audiogram. Graph showing the absolute auditory threshold versus frequency.
Auditory brainstem response. A method of measuring hearing by placing electrodes on the head to record the electrical activity in the brain when sound occurs.
Auditory threshold (Hearing threshold). Minimum sound level that can be perceived by an animal in the absence of background noise.
Bandwidth. Range of frequencies of a given sound.
Decibel (dB). The logarithmic measure of sound intensity / pressure. The decibel value for sound pressure is 20 log10 (P / P0) with P = actual pressure and P0 = reference pressure.
Duty cycle. Percent of a time a given event occurs. A 1 s long tone with silent intervals of 1 s has a duty cycle of 50%.
Hertz. The unit for frequency where 1 Hz = 1 cycle per second. One Kilohertz (kHz) are 1,000 cycles per second.
Masking. Obscuring of sounds of interest by interfering sounds at similar frequencies.
Micro Pascal (μPa). Reference pressure for underwater sound. 1 μPa = 10-5 μbar.
Pascal. Unit of pressure equal to one Newton per square metre.
Permanent threshold shift. A permanent elevation of the hearing threshold due to physical damage to the sensory hair cells of the ear.
Propagation loss (Transmission loss). Loss of sound power with increasing distance.
Pulse. A transient sound having a finite duration.
Rise time. Time needed to go from zero to maximum sound pressure.
Source level. Acoustic pressure at a standard reference distance of 1 m. Unit in dB re 1 μPa at 1 m (sometimes given as: @ 1m).
Sound pressure level. Expression of the sound pressure in decibel (dB)
Spherical spreading. Sound spreading for spherical waves. Given by 20 log (r), with r being range.
Temporary threshold shift (TTS). Temporal and reversible elevation of the auditory threshold.
Waveform. Graph showing the oscillations of a sound wave (in Pa or mV/V over time).
Ultrasonic. Sound with frequencies too high to be audible to humans (~ > 20 kHz).

Acronyms

dB	Decibel
deg	Degrees
Hz	Hertz
KHz	Kilohertz
km	Kilometre
m	Metre
ms	Milliseconds
m/s	Metre per second
PTS	Permanent threshold shift
rms	Root-mean-square
s	Seconds
SEL	Sound exposure level
TTS	Temporary threshold shift
μPa	Micropascal

1 Introduction

Concerns about the potential adverse effects of anthropogenic sound[1] on cetaceans have been raised from within the scientific community since the 1970s, and research on the topic expanded in the 1980's (e.g. Payne & Webb 1971; Richardson *et al.* 1995). During the last decade the topic has been investigated extensively by a number of scientific institutions, governmental agencies and intergovernmental bodies, with major reviews dealing with behavioural and physiological responses of cetaceans to various anthropogenic sound sources. The results indicate that some of the sounds introduced in the marine environment, such as seismic pulses and sound from pile driving, can potentially be detected by cetaceans over considerable distances. The emitted sound field of more continuous sounds, such as those emitted by ships, has the potential to mask communication signals and echolocation clicks. Loud sounds have the potential to induce behavioural reactions, and in some cases and at very short distances, high intensity pressure waves might even result in tissue damage or other injuries in individual cetaceans (reviews by Richardson *et al.* 1995; Würsig & Richardson 2002; Würsig & Richardson 2002; ICES-AGISC 2005; NRC 2003, 2005; Thomsen *et al.* 2006b; Madsen *et al.* 2006a; Southall *et al.* 2007; MMC 2007, Nowacek *et al.* 2007).

Despite this progress in our understanding, there are still basic uncertainties and data gaps in our knowledge of the effects of anthropogenic sounds on cetaceans. One major gap concerns whether and how anthropogenic sound may affect populations of marine mammals. This is a quite important issue, since the basic goal of cetacean conservation is to prevent human activities from harming populations (NRC 2005). In order to analyse population level effects, one has to establish links between sound exposure and changes in cetacean abundance or life history parameters, for example recovery rates, mortality and birth rates. Recently, NRC (2005) developed a 'population consequence of acoustic disturbance model' (PCAD model). The model involves different steps that are required to relate acoustic disturbance to effects on marine mammal populations, including variables such as 1) sound source characteristics, 2) behavioural changes, 3) life functions impacted, 4) effects on vital rates, and 5) population consequences. Most of the variables within the PCAD model cannot currently be estimated. Challenges to filling gaps come in many ways, due to uncertainties in population estimates for several species and in various regions, and the difficulties in weighting noise against other stressors such as, for example, by-catch in fisheries, contamination, predation and decrease of prey numbers (see NRC 2005 for a detailed discussion). Despite these uncertainties, models like the one developed by NRC 2005) will become vital in future impact assessments of man-made sound, as it will be paramount to assess the impacts of sound in relation or in addition to other stressors, either to assess cumulative impacts and / or to focus protection efforts.

The offshore oil & gas industry (hereafter: exploration and production industry or in short E&P industry) has seen considerable expansion and growth since the 1960s.

[1] The terms 'sound' and 'noise' are not clearly separated in the literature and are used often synonymously. The Advisory Committee on Acoustic Impacts on Marine Mammals defines sound as an all-encompassing term referring to any acoustic energy. Noise is defined as a subset of sound, referring to sound that is 'unwanted' to a particular receiver. However, since it is almost impossible to define or outline what is meant by 'unwanted', we use the neutral term 'sound' throughout the document, except where referring to scientifically accepted terms such as 'ambient noise' or 'masking noise'. Noise is also used if a term is explicitly used to describe stressors, effects etc.

About 30% of the total world oil production and 50% of the world's production of natural gas is conducted offshore (NRC 2003). There are currently 6,500 offshore oil & gas installations worldwide, about 4,000 of which are situated in the U.S. Gulf of Mexico, 950 in Asia, 700 in the Middle East and 400 in Europe (UNEP). The E&P industry generates underwater sound at every stage of its process, during 1) exploration (seismic surveys and side scan sonar), 2) construction (pile-driving and vessel activity), 3) extraction (drilling, maintenance vessels), and 4) during decommissioning. Each activity has the potential to affect the behaviour and physiology of individual cetaceans, with most concerns expressed towards seismic survey explorations (reviews by Richardson *et al.* 1995; McCauley *et al.* 2000; Gordon *et al.* 2004; Nowacek *et al.* 2007). Despite documented responses of individuals, or groups of cetaceans, the relationship between offshore E&P industry activities and trends in local cetacean stocks has not been investigated to date. Therefore, the effects of E&P sound on cetacean stocks are completely unknown. Hence, environmental risk assessments with regards to the E&P industry are challenging and more specific mitigation measures that are protective of cetaceans, relatively cost-effective and credible to outside stakeholders are very difficult to establish.

This review is intended as a first step in assessing the relationship between cetacean stocks and E&P industry sound. By doing so, we are particularly interested in investigating the status and trends of cetacean stocks that are exposed from sound by the E&P industry in order to answer this key question.

2 Methods

2.1 General approach to the problem

This study aims to provide a desk-based assessment of cetacean stocks in relation to Exploration & Production industry generated sound. In doing so, the key question – **whether E&P industry sound affects cetacean stocks** - has to be investigated in three phases that are outlined in Figure 1.

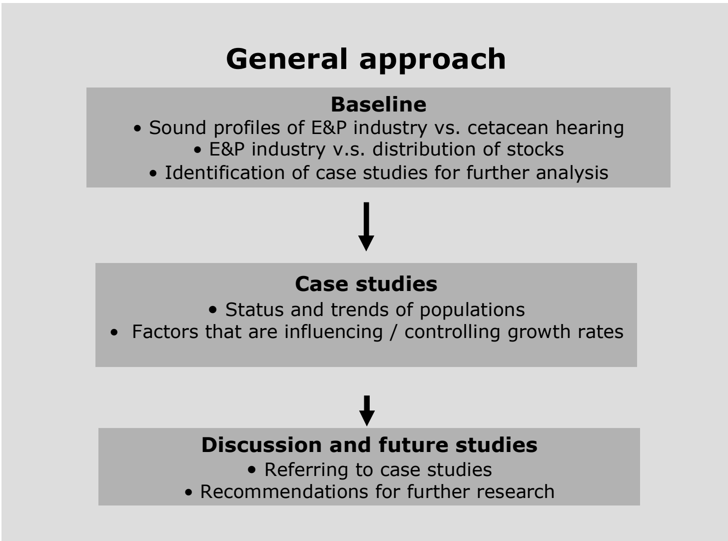

Figure 1 Outline of the technical approach to the study.

In answering this key question it is important to establish a **baseline** for the further investigations by characterising all E&P related sound in terms of sound pressure levels (dB re 1μPa) and bandwidth (kHz). These will then be related to the documented or potential hearing abilities of cetacean species in order to identify key issues for further assessment. This will be achieved through a review of the existing literature and also partly by using our own data, for example detailed sound profiles collected during pile driving operations in the German Bight (Thomsen *et al.* 2006b). Following this initial step, we will provide a global **overview of E&P industry activity in relation to cetacean stocks** with the aim of identifying case studies for more detailed analysis. In this stage, data will be gathered from various sources including in-house and external sources (e.g. UK Department of Business, Enterprise and Regulatory Reform, Clarkson Research Services Limited). We will then investigate available cetacean stock data using the scientific literature and published reports / papers by institutions that are regularly involved in cetacean stock assessments (e.g. IWC, NAMMCO, NOAA).

In the **case studies** we will look at the relationships between E&P sound, other factors and cetacean stocks in more detail. We will describe the E&P activity in the region in terms of the number of platforms and seismic surveys conducted so as to get a more detailed picture of sound exposure. Then we will look at the target cetacean stock in the region and will document its status (e.g. population size, birth and death rates) and try to discern trends (growth rate, current level of mortalities). For this analysis we will use published material (reports and papers) on population / stock parameters over time. Next, we will investigate factors controlling or influencing the case study population, with the aim of putting the potential impacts of E&P industry sound in perspective. One important task in this section will be a comparative description of the different factors, in order to provide a comprehensive overview of all possible factors influencing stocks. For this we have developed an impact analysis matrix (see below).

Finally, we will **discuss** the results and also try to outline any limitations inherent in our approach. Based on this (an essential part of the project) we will provide detailed **suggestions for further research** into the topic.

2.2 Impact analysis

In order to weight the different factors and to provide a comprehensive assessment, we will use a system that has been developed for environmental impact assessments of offshore wind farms in the North Sea (see Morkel 2006). As it bears some resemblance to our previous work, we have also used the threat analysis table outlined in the recovery plan for fin whales (NMFS 2006).

The impact analysis aims at assessing the severity of an effect, for example of behavioural responses due to exposure to sound from seismic exploration. This is done in two steps that are outlined in Table 1 and Table 2.

First, it is necessary to assess the effect based on three factors, *range* (the spatial dimension), *duration* (temporal dimension), and *intensity* (the biological dimension). Table 1 gives a definition for the various terms.

Table 1 Impact analysis - step 1: Assessing the effect.

Factor	Dimension	Definition
Range	Close	Effects to be expected only in the close-vicinity of the factor; less than 100 m range.
	Medium	Effects to be expected in medium range within the factor (>100 m - 5,000 m)
	Long	Effects to be expected in long range from the factor; more than 5,000 m range.
Duration	Short term	The system falls back to the original state after a short-term impact. The effect duration is not longer than the duration of the factor itself.
	Long term	The factor is of continuous nature, or the system doesn't fall back into the original state after being affected. The effect is of longer duration than the factor.
Intensity	Low	Within the zone of influence, the receiver is only impacted to a small degree, or only a few receivers are impacted within the zone of influence.
	Medium	Within the zone of influence, the receiver is affected to some degree. Either the effect does not impact all individuals; or if all individuals are affected, the effect is not significant.
	High	Within the zone of influence the receiver is affected significantly, and the effect impacts all individuals within the zone of influence.

It is important to note that the assessment is concerned with *effects* rather than *factors.* For example, if we to assess the effect of pile driving sound on the behaviour of harbour porpoises, we would first define the range in which disturbance is possible and - according to modelling exercises and empirical studies (see Thomsen *et al.* 2006b for review) - we would define it as being *long* as, in some cases behavioural disturbance can happen at ranges of ~ 20 km from the source. The duration of the effect would be *short-term*, as porpoises exhibit their usual behaviours shortly after pile driving has ceased (Thomsen *et al.* 2006b). The *intensity* is the most difficult variable and, looking at startle responses and subtle changes in swimming speed, etc., we would define it as being low or, if we want to be precautionary, medium.

In the second step, we then apply the assessment undertaken in step 1 to derive the *severity* of the effect on a scale from zero (no measurable effect) to very high (population level effects, see Table 2 and Table 3). In our case, we would come up with the combination LONG (range)-SHORT-TERM (duration)-LOW/MEDIUM (Intensity) and the severity would be either *medium* or *high*. At worst, behavioural responses due to pile driving can lead to negative influences on part of the population.

A statement on the uncertainty of the information that is available on the effects complements the assessment. This done on a scale from zero (information is sufficient) to very high (on information available; see also NMFS 2006). Finally, to assess the frequency of occurrence of an effect, we also judge the *likelihood* that the effect will occur in relation to the area that the animals use and their population size.

Table 2 Impact analysis - step 2: Estimating the severity of the effect.

Range	Duration	Intensity	Severity
Close	Short-term	Low	Zero
		Medium	Low
		High	Medium
	Long-term	Low	Low
		Medium	Medium
		High	High
Medium	Short-term	Low	Low
		Medium	Medium (High)
		High	High
	Long-term	Low	Medium
		Medium	Medium
		High	High
Long	Short-term	Low	Medium
		Medium	High
		High	High
	Long-term	Low	Medium
		Medium	High
		High	Very high

Table 3 Severity scale for describing the effects of a factor.

Severity scale	Explanation
Zero	The effects are not measurable
Low	The effects are measurable to some degree but within normal fluctuations
Medium	The effects are measurable above normal fluctuations
High	The effects can lead to negative influences on parts of the population.
Very high	The effects can lead to population-level changes

3 SOUND PROFILES FROM EXPLORATION & PRODUCTION INDUSTRY AND CETACEAN HEARING SYSTEMS

A detailed review of E&P related sound profiles vs. cetacean hearing systems is beyond the scope of this paper. Instead, the task here is to outline sound profiles on the one hand, and to summarise what is known about cetacean hearing on the other to identify key issues for further assessment. An overview of oil & gas related sound profiles are given in Table 4. The most information is available regarding sound emissions from seismic surveys. There are no published accounts of pile driving sound during the construction for oil & gas platforms and the data presented here were gathered during various investigations looking at pile driving during construction of aviation fuel facilities, bridges, and offshore wind turbines. Drilling sound has been only very sparsely documented. Despite these uncertainties, it can be seen that sound profiles vary greatly, with most energy emitted during seismic surveys and through the use of explosives during decommissioning. In general, the frequencies emitted during E&P industry operations are in the lower frequency ranges below 1 kHz, although recently some studies suggest that higher frequencies up to 150 kHz can be emitted as a by-product of the air-gun sound source. The energy at these higher frequencies is low compared to the overall output of the air-gun, yet, it is considerably higher than ambient noise levels in some cases, and it is likely that at least frequencies up to 15 kHz can potentially be perceived by some odontocetes over several km distance (Goold & Fish 1998; Tolstoy *et al.* 2004; Goold & Coates 2006; Madsen *et al.* 2006a).

Table 4 Overview of E&P industry related sound profiles (Sources 1) Richardson *et al.* 1995; 2) Goold & Fish 1998; 3) Gausland 2000; 4) Madsen *et al.* 2006a; 5) Madsen *et al.* 2006b; 6) Thomsen *et al.* 2006b; 7) Würsig *et al.* 2000; 8) McKenzie-Maxon 2000; 9) Caltrans 2001; 10) Nedwell *et al.* in press; 11) McCauley 1998).

Sound source	Source level	Bandwidth	Main energy	Duration	Directionality	Source
Seismic air gun arrays	220 - 255 dB re 1μPa zero to peak	5 Hz - 15 kHz	10 - 120 Hz	10 ms - 100 ms	Downwards	1), 2), 3), 4)
Pile driving	220 - 257 dB re 1μPa peak to peak	10 Hz - > 20 kHz	100 - 200 Hz	5- 100 ms	Omnidirectional	5), 6), 7), 8), 9), 10)
Maintenance ships	150 - 180 dB 1 μPa rms	20 Hz - 20 kHz	< 1 kHz	Continuous	Omnidirectional	1)
Drilling	115-117 dB re 1 μPa at 405 and 125 m	10 Hz -~ 1 kHz	< 30 - 60 Hz	Continuous	Omnidirectional	1), 11)
Decommissioning: explosives	272 - 287 dB re 1 μPa zero to peak	2 Hz - ~ 1 kHz>	6 - 21 Hz	~ 1 ms	Omnidirectional	1)

Looking at the receiver, data on cetacean hearing is relatively sparse, with published audiograms for only 10 of the ~ 77 species of cetaceans, with nine being members of the family Delphinidae and one (white whale, *Delphinapteras leucas*) belonging to the family Monodontidae (for example audiograms see Figure 2). There are considerable data gaps as, for example, no audiograms exist for baleen whales (overviews in Nedwell *et al.* 2004; Southall *et al.* 2007). Nonetheless, based on an analysis of comparative anatomy, modelling, and the sounds emitted, Southall *et al.* 2007), assigned species and subspecies of cetaceans to one of three functional hearing groups:

- Low-frequency cetaceans (13 species/ subspecies) with functional hearing between 7 Hz and 22 kHz comprising all mysticetes (baleen whales),
- mid-frequency cetaceans (57; hearing 150 Hz - 160 kHz) including 32 species of dolphins, six species of larger toothed whales, and 19 species of beaked whales, and
- high-frequency cetaceans (21; hearing 200 Hz - 180 kHz) comprising eight species and subspecies of porpoises, six species and subspecies of river dolphins plus the franciscana, the genus Kogia, and four species of Cephalorynchidae (for details, see Southall *et al.* 2007).

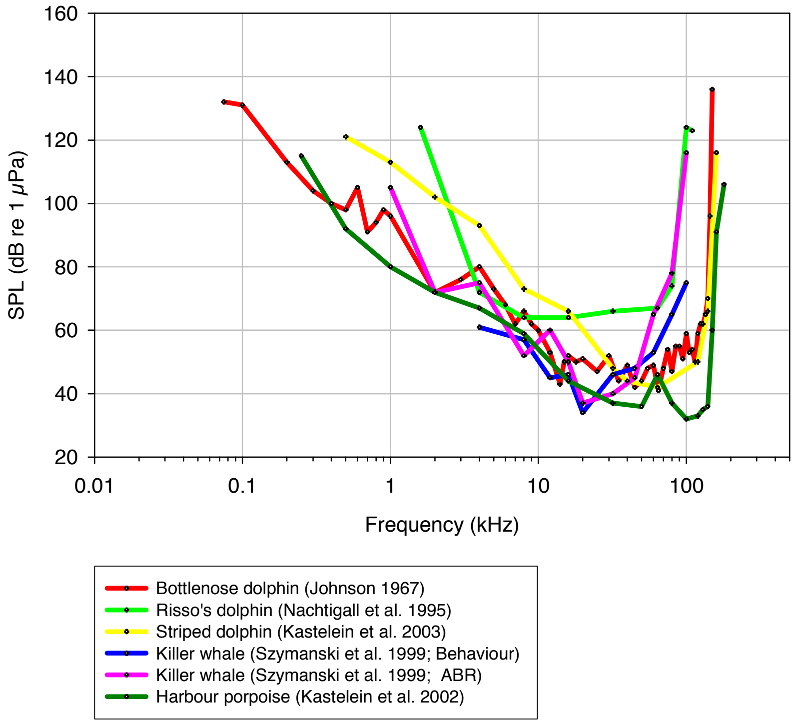

Figure 2 Representative audiograms of some odontocete cetaceans.

At first sight we might conclude that an assessment of cetacean stocks with regards to potential impacts from E&P industry sound should focus on low-frequency and, perhaps to a much lesser extent, on mid-frequency cetaceans, as most acoustic energy from the E&P industry is below 1 kHz. Yet, looking at the issue in more detail, the story gets more complicated, for various reasons:

- There is sound in frequencies at least up to 15 kHz, and in the case of pile-driving, at even higher frequencies, which could potentially affect all three hearing groups (see Thomsen *et al.* 2006b; Madsen *et al.* 2006a),
- the auditory bandwidth estimated by Southall *et al.* 2007) is, in general, quite large, with a considerable overlap in areas of best hearing across groups. For example, audiograms obtained from harbour porpoises - a high-frequency cetacean according to Southall *et al.* 2007) - indicate that their hearing threshold between 300 Hz and 1 kHz is as least as good, if not better, than those found in mid-frequency bottlenose dolphins, killer whales and Risso's dolphins at the same frequencies (Johnson 1967; Andersen 1970; Nachtigall *et al.* 1995; Szymanski *et al.* 1999; Kastelein *et al.* 2002; Lucke *et al.* 2004, Lucke *et al.* 2006). It is therefore important to consider the groups on the basis of the overall auditory bandwidth, rather than on the range of best hearing,
- it is possible that some odontocetes are able to detect low-frequency sounds using mechanisms other than conventional hearing, for example, by detecting particle velocity or a combination of pressure and velocity in the near-field (Turl 1993). In line with this, some observations in the field indicate that behavioural reactions to seismic surveys are not restricted to the low-frequency mysticetes, but can also occur in other groups, including, for example, bottlenose dolphins, common dolphins and harbour porpoises. Injury is a concern for all functional hearing groups of cetaceans at close ranges to seismic airguns and pile driving

(Richardson *et al.* 1995; Gordon *et al.* 2004; Stone & Tasker 2006; Nowacek *et al.* 2007; Lucke *et al.* 2007; Lucke *et al.* 2008).

To summarise: while the available data on E&P sound related profiles vs. cetacean hearing systems suggests that baleen whales might be more affected than other groups, potential impacts on other cetaceans cannot be ruled out. Our assessment of cetacean stocks in relation to E&P sound should therefore focus on mysticetes, but also include other species with a potential higher frequency range of best hearing compared to mysticetes, such as species of the family Ziphiidae and Phocoenidae.

3.1 Assessing the impacts of E&P sound on individual cetaceans

As stated earlier, in this particular assessment, we are concerned with population level rather than individual level impacts of E&P sound on cetaceans. Yet, since our assessment is based on an impact matrix that also considers effects on an individual level, we will provide a quick overview on how to assess impacts of sound in general and draw some conclusions on potential impacts of E&P sound in particular.

When evaluating the effects of underwater sound sources, peak pressure, received energy (received sound pressure level), signal duration, spectral type, frequency (range), duty cycle, directionality, and signal rise times are important. Possible effects can vary depending on a variety of internal and external factors, and can be broadly divided into behavioural disturbance, masking, temporary threshold shift (TTS), and injury, either as permanent threshold shift (PTS) or other injuries such as tissue damage. In extreme cases, very intense sounds might also lead to the death of the receiver at very close ranges to the source (Richardson *et al.* 1995; Southall *et al.* 2007).

Masking occurs when the sound is strong enough to interfere with detection of other sounds, such as communication signals or echolocation clicks. It starts when the sound level of the masking sound, for example sound from a nearby ship, equals the ambient noise at the frequency of the signal. Masking can shorten the range over which conspecifics are able to communicate, for example mother and calf pairs of odontocetes. **Behavioural disturbances** are changes in activity in response to a sound. These effects can be very difficult to measure and depend on a wide variety of factors such as the physical characteristics of the signal, the behavioural state of the receiver, its age, sex and social status and many other factors. Therefore, the extent of behavioural disturbance for any given signal can vary, both within a population as well as within the same individual. Behavioural reactions can range from very subtle changes in behaviour to strong avoidance reactions. In some cetaceans, they can also be exhibited as changes in vocal activity (review by Richardson *et al.* 1995; Würsig & Richardson 2002; Southall *et al.* 2007).

Both **TTS** (=temporary threshold shift) and **PTS** (=permanent threshold shift) represent changes in the ability of an animal to hear, usually at a particular frequency, with the difference that TTS is recoverable after hours or days and PTS is not (Southall *et al.* 2007).

Based on the different effects that sound can have, Richardson *et al.* (1995) defined several theoretical zones of noise influence, depending on the distance between source and receiver. The zone of **audibility** is the largest, and the one leading to the death of the receiver, the smallest. This model, shown in Figure 3, has been used very often in impact assessments where the zones of noise influences are determined based on sound propagation modelling or sound pressure level measurements on the one hand, and information on the hearing capabilities of the species in question on the other (see for recent examples Madsen *et al.* 2006a; Thomsen *et al.* 2006b). As sound spreads, in principle, omnidirectionally from the source, the zones of noise influences, given as distance from the source, indicate a radius rather than a straight line. For example, a radius (r) of 10 km results in a zone of audibility of $A = \pi * r^2$; = 314.16 km^2.[2]

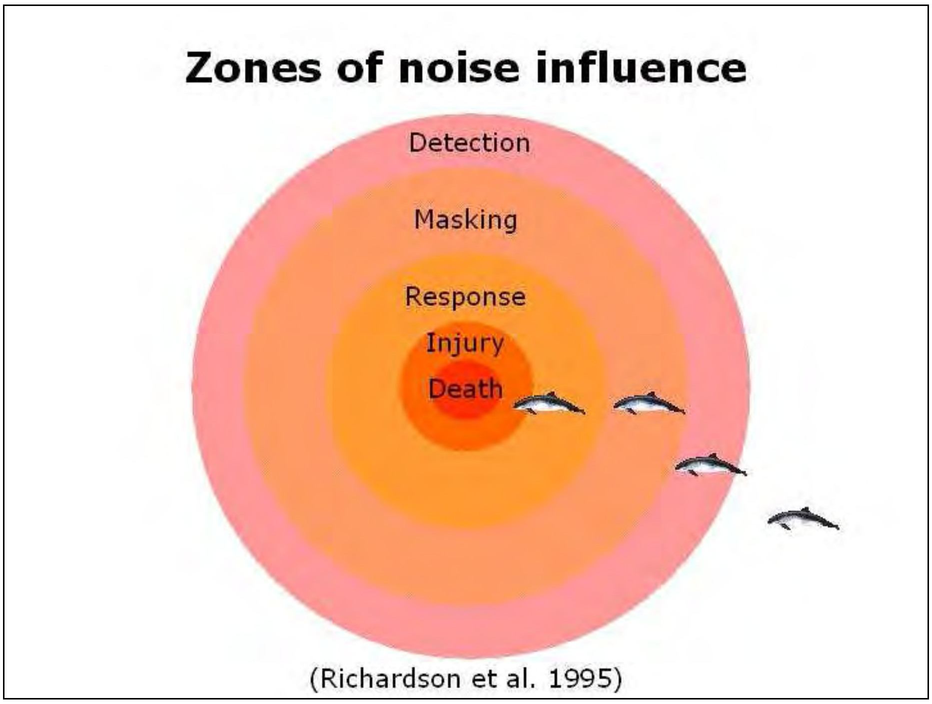

Figure 3 Outline of the zones of noise influence (after Richardson *et al.* 1995).

Following standard calculations and recent studies we shall draw some first rough estimates on potential impact zones for E&P related sound sources. If we take the maximum reported source sound pressure level for pile driving and airgun pulses from Table 4, (257 dB), and calculate transmission loss for different scenarios, we can see that at 100 km distance there is still considerable sound energy, with received levels of at least 157 dB re 1 μPa Peak[3].

[2] It should be noted here that this model gives only a very rough estimate of the zones of influence as sound in the seas is always three-dimensional. The interference, reflection and refraction patterns within sound propagation will inevitably lead to much more complex sound fields than those based on the model by Richardson *et al.* 1995). This complexity may lead to paradoxes such as increases of sound energy with distance.

[3] Please note that source levels are usually back-calculated from rather far-field measurements, and as the 1 m range is within the near field of seismic pulses, the sound level at 1 m may be different from the calculated source level.

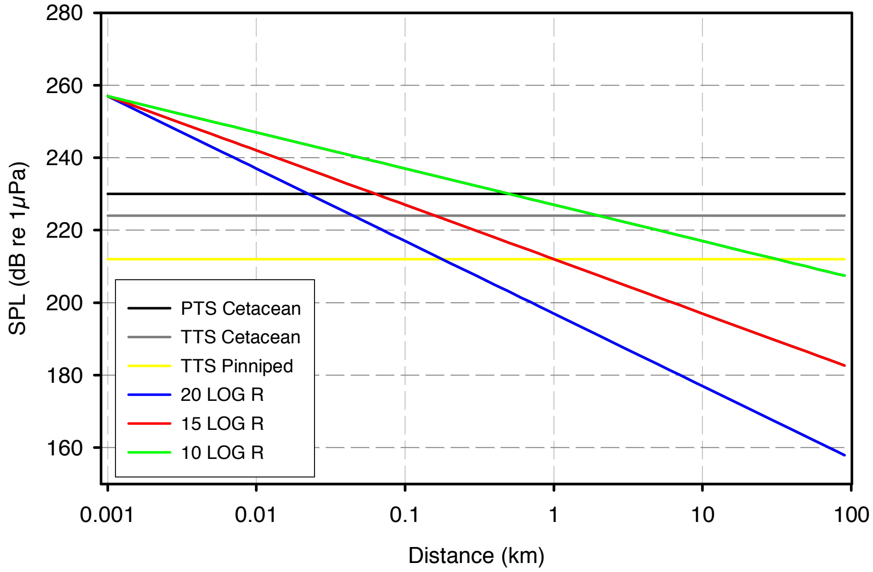

Figure 4 Transmission loss of single pulse of 257 dB re 1 μPa Peak calculated with different transmission loss scenarios and sound exposure criteria after Southall *et al.* (2007).

Recently, Southall *et al.* (2007) developed noise exposure criteria for TTS and PTS for cetaceans and pinnipeds that are also shown in Figure 4. These criteria can be viewed as thresholds that, if exceeded, will lead to TTS and PTS respectively. If we estimate the distance from the source at which the criteria are reached, we can define the different zones that are shown in Table 5. The values for pinnipeds are shown for comparison.

Table 5 Zones of noise influences for a single pulse (seismic airgun, pile driving) of source sound pressure level of 257 dB re 1 μPa Peak after Southall *et al.* (2007) calculated for different transmission loss scenarios.

Threshold	20 log (r)	15 log (r)	10 log (r)
PTS Cetacean (230 dB re 1 μPa Peak)	23 m	64 m	480 m
TTS Cetacean (224 dB re 1 μPa Peak)	44 m	151 m	1,900 m
TTS Pinniped (212 dB dB re 1 μPa Peak)	175 m	972 m	31,000 m

It can be seen that TTS is reached between 44 m and 1.9 km, depending on transmission loss, and that irreversible hearing loss (at certain frequencies) happens between 23 m and 480 m. As most pile driving and seismic activities are restricted to shallower waters, a TL between 15 and 20 log (r), and maybe more (see Madsen *et al.* 2006a) is realistic, leading to rather short ranges for both seismic airgun pulses and pile driving. The source levels from drilling activities are not high enough to lead to either PTS or TTS (see Table 4)[4].

[4] It should be noted that these are very rough estimates for all hearing groups (see above) Southall *et al.* (2007) developed not only criteria for peak but also for sound exposure levels that theoretically might lead to different zones of impacts than those described here. First calculations with pile driving source levels from the German Bight, however, didn't show much differences from the above values (Thomsen unpubl.).

The zone of behavioural response is much more difficult to assess, as it depends on a number of variables that are very difficult to account for or to estimate (see above). We will try to elaborate on these further as we deal with the case studies in chapters 5 - 8.

4 E&P industry and cetacean stocks - an overview

Table 31 (see appendix) provides an overview of the E&P industry worldwide, and a rough assessment of cetacean stocks in the respective regions. The table lists the number of platforms in different regions and provides a first overview of seismic activity. For descriptive purposes, the numbers of platforms in different regions are shown in Figure 5.

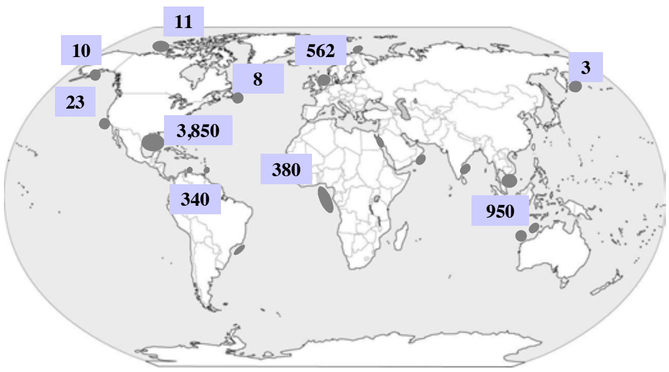

Figure 5 Schematic overview of the number of oil & gas platforms in different parts of the world (data GESAMP 2007; MMS 2008 and www.og.dti.gov.uk; grey: areas of high production).

Approximately 6,200 oil & gas installations are presently operating in the marine environment, with between 25 and 30% of global production of oil & gas estimated to come from offshore reservoirs (GESAMP 2007). As can be seen in Figure 5 and as depicted in Table 31, there are clear differences in the distribution of offshore oil & gas platforms in the world's coastal waters: 65% of them are located off the coast of North America with the Gulf of Mexico comprising almost all of them (95% of North American installations, 62% of total). The area with the second highest concentration of oil & gas platforms is the Asian Pacific region (15% of all platforms) with most facilities located off the coasts of Indonesia and Malaysia and with some activity off the west and north coasts of Australia. The third most active region in terms of platforms is located off the coasts of North-West Europe, notably off the East Coast of the UK and the southwest coast of Norway (8% of overall). This is closely followed by the west coast of Africa and South America (6%, 5.5% respectively, Figure 5). Seismic survey data is difficult to obtain in most cases but, as can be seen in Table 31, the level of activities mostly follows the above-mentioned trend.

Looking at the distribution of platforms, one might conclude that case studies - investigating cetacean stock assessments with regards to E&P industry sound - should concentrate on areas with the highest number of platforms and greatest seismic activity. The obvious candidate for a closer look is the **Gulf of Mexico** with its vast number of platforms, and more than 1 million km of seismic surveys undertaken since the beginning of oil & gas exploration in that region (Table 31). There is also a variety of cetacean species present in the Gulf of Mexico, and data for sperm whales - a mid-frequency cetacean (Southall *et al.* 2007) - has been collected in various studies and summarised in various NOAA Stock Assessment Reports (SAR; 1995-2007). As the data available seem to be adequate, the sperm whales in the Gulf of Mexico will be our first case study.

If we look at Figure 5 and also analyse the information given in Table 31, we conclude that for many other regions with a high proportion of oil & gas platforms, there appear to be huge gaps in our knowledge on cetacean stocks. We should bear in mind that, in order to assess stocks, information on abundance and distribution of cetacean populations over several years as well as some basic demographic data on mortality and productivity is an absolute prerequisite. Ideally, further data on age and sex classes and genetic composition with which to postulate the presence of a stock should also be available. This information, however, is absent for the **Asian Pacific** region, with the exception of western and northern Australia, where field studies on humpback whales have been undertaken since at least the beginning of the 1990s (e.g. Jenner *et al.* 2001). This area is under investigation by a team working in parallel to us, and is therefore not included in our assessment.

Information on **West African** cetaceans is only available in form of presence / absence data or lists of species encountered during more or less opportunistic surveys (sources, see Table 31). The situation in **South America** is very similar, and we were unable to include any cetacean from both regions in our assessment. In fact, one of the first major results of this study appears to be that - with the notable exception of the Gulf of Mexico - the largest data gaps exist in those regions where there is a comparatively high level of E&P industry activity.

The picture looks much more promising for **North America,** with several established field studies off both the west and the east coast (NOAA 1995 - 2007 and therein). For example, for the coast of California, stocks of humpback, fin and blue whales - all low-frequency cetaceans (Southall *et al.* 2007) - have been monitored for at least a decade and shall therefore be studied in more detail in a second case study (NOAA 1995 - 2007 and therein). The relationship between E&P activity and the behaviour of bowhead whales (*Balaena mysticetus*) in the Beaufort Sea (Alaska) has been studied since the beginning of the 1980s (Richardson *et al.* 1985, Richardson *et al.* 1986, Richardson *et al.* 1990, Richardson *et al.* 1995) and results are under review in parallel to the present study by a different team. In order not to duplicate the effort, the area is omitted from the case studies in this report. Since 1988, the mid-frequency northern bottlenose whales (*Hyperoodon ampullatus*) have been studied off **Nova Scotia** in an area close to E&P activity, and data on distribution and abundance is available for a period of almost two decades (Gowans *et al.* 2000; Hooker 1999; Hooker & Baird 1999; Hooker *et al.* 2002; Hooker *et al.* 2008The northern bottlenose whales off Nova Scotia therefore seem to be a promising third candidate for closer study.

For **North West Europe**, data are available from large-scale surveys such as SCANS I and II and opportunistic sighting schemes such as the one maintained by the Sea Watch Foundation in the UK, and much information is also provided by smaller-scale studies with the best data available for the harbour porpoise (*Phocoena phocoena*; Reid *et al.* 2003; Hammond *et al.* 2002, Hammond 2006a; Thomsen *et al.* 2006a, Thomsen *et al.* 2007). It is true that porpoises echolocate well into the ultrasonic range (130-150 kHz; Verboom & Kastelein 1995; Au *et al.* 1999; Teilmann *et al.* 2002). Consequently, Southall *et al.* 2007) list them as a high-frequency cetacean with a hearing range between 200 Hz to 180 kHz. One might argue that, since most E&P sound is restricted to the lower frequency band, the issue of disturbance of porpoises by E&P industry sound is negligible. Yet, as mentioned above, some of the emitted sound extends to at least 20 kHz (Table 4). Furthermore, the species has reportedly a greater absolute sensitivity at nearly all frequencies compared to the species for which audiograms are currently present (overview in Nedwell *et al.* 2004; Thomsen *et al.* 2006b). Harbour porpoises in the central and southern North Sea - where most oil & gas platforms are located and most seismic surveys have been undertaken - shall therefore form one focus for the present assessment. To complement the picture, minke whales (*Balaenoptera acutorostrata*) off the central and southern North Sea - like all baleen whales a low-frequency cetacean (Southall *et al.* 2007) - will also be investigated.

To summarise: In our case studies we will look at 1) sperm whales in the Gulf of Mexico, 2) humpback, blue and fin whales off the coast of California, 3) Northern bottlenose whales off Nova Scotia, and 4) harbour porpoises and minke whales off the East Coast of the UK (central and southern North Sea). Our selection comprises therefore a representative sample of seven species, with four being low-frequency cetaceans, two mid-frequency cetaceans, and one high-frequency cetacean.

5 Case study 1: Gulf of Mexico - Sperm whales

5.1 Introduction to the region

The Gulf of Mexico is the ninth largest body of water in the world, and is engulfed by the United States of America to the north, Mexico to the west and Cuba to the southeast (Figure 6). As a consequence of its large coastal area, its shores are home to a very high number of people; approximately 44.2 million people (in 1995, and this figure is predicted to rise to 61.4 million by 2025 (www.gulfbase.org)), in the five US Gulf states alone. As such, the Gulf of Mexico is heavily utilised for pleasure and tourism as well as for its valuable natural resources.

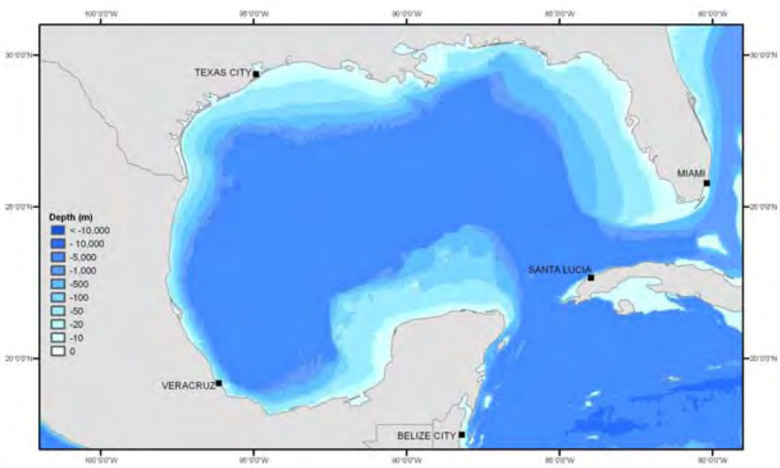

Figure 6 Overview over the Gulf of Mexico.

5.2 E&P industry activity

Production The Gulf of Mexico supports a very large oil & gas industry. Offshore operations in the Gulf alone produce a quarter of the U.S. domestic natural gas and one-eighth of its oil, according to the US Minerals Management Service. Figures from the same source reveal that the Gulf of Mexico is currently home to 3,855 active platforms and 7,169 active leases (Table 6).

The Gulf of Mexico is split into three planning areas: the Western, Eastern and Central Planning Areas. The planning areas are then subdivided into blocks each approximately 16.7 km^2 in size.
Most of the oil & gas exploration and production have been focused in the Central Planning Area and, to a lesser extent, the Western Planning Area. The Eastern Planning Area has seen far less activity to date (Figure 7).

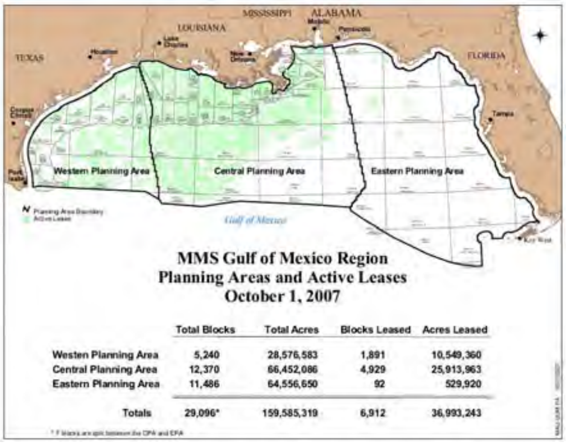

Figure 7 Planning Areas within the Gulf of Mexico as defined by the US Mineral Management Service. The areas shaded in green are the locations of active leases. (Source Mineral Management Service, US Government).

Drilling activity has been closely recorded since 1959 (see http://investor.shareholder.com/bhi/rig). The data show the average number of rigs drilling per week (Figure 8). Drilling activity has been high across the Gulf of Mexico, with a minimum of only 45 rigs actively drilling in 1992. Three distinct peaks in drilling activity can be seen in 1966 (with an average of 107 rigs actively drilling per week), 2001 (with an average of 148 rigs actively drilling per week), with the period of highest activity during the late 1970s to the early 1980s, peaking in 1981 with 231 rigs actively drilling per week.

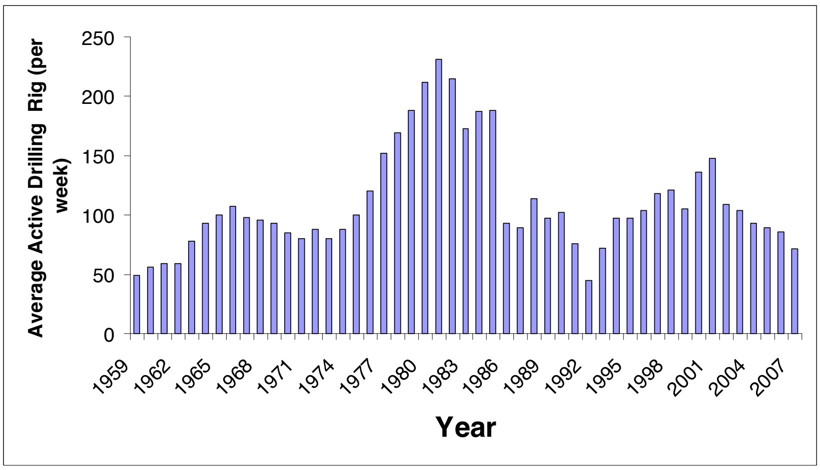

Figure 8 Average Active Drilling Rigs (per week) between 1959 and 2007 within the Gulf of Mexico (http://investor.shareholder.com/bhi/rig).

The vast numbers of platforms and their wide distribution means that they will overlap with the distributions and movements of the resident and visiting sperm whales. Maps from sightings, tagging data and acoustic recordings during the Sperm Whale Seismic Study in the Gulf of Mexico (SWSS) surveys provide a good indication that such overlaps do occur. Aggregations of female and mixed juvenile/calf groups were commonly sighted around the Mississippi canyon (Mullin *et al.* 1991; Davis *et al.* 2000; Mullin & Fulling 2004; Jochens *et al.* 2006) while bachelor groups were commonly seen around the DeSoto Canyon and Florida slope (Jochens *et al.* 2006).

Table 6 The number of platforms in the Gulf, and the depths they occupy as of 11 February 2008 (Source: Minerals Management Service – Gulf of Mexico Region (https://www.gomr.mms.gov/homepg/fastfacts/WaterDepth/WaterDepth.html)).

Water depth in meters	Active leases	Approved applications to drill	Active platforms
0 to 200	3,268	43,577	3,798
201 to 400	195	1,328	21
401 to 800	389	946	9
801 to 1000	364	496	7
1000 and above	2,953	1,387	20

The number of rigs occupying regions correlating to sperm whale movement's changes with area, but the northern Gulf is certainly a hotspot for both sperm whales and the oil & gas industry. Using maps of movement and residency, sightings and tagging data (NOAA and SWSS studies, see below), we correlated these to oil & gas leases and maps of rig locations. The areas in which sperm whales moved were related to the oil & gas field name, and Table 7 shows the fields (from east to west) and the associated numbers of rigs found there.

Table 7 O&G fields from the east to west distribution of sperm whales in the northern Gulf. (Source: Minerals Management Service – Gulf of Mexico Region (https://www.gomr.mms.gov/homepg/fastfacts/platform/master.asp)).

Region	Number of structures	Shallowest (metres)	Deepest (metres)	First installation	Most recent installation
DeSoto Canyon	0				
Main Pass	236	7.3152	128.016	01-Jan-54	15-Aug-07
South Pass	122	4.2672	152.4	01-Jan-58	23-Aug-04
Mississippi Canyon	23	104.5464	2438.4	01-Jan-78	11-Jun-07
South Timbalier	347	7.9248	147.5232	01-Jan-56	23Dec-07
Ship Shoal	436	2.4384	141.4272	01-Jan-50	12-Jun-07
Green canyon	19	184.0992	2148.84	01-Jan-86	16-Oct-07
Garden Banks	12	164.8968	1615.44	01-Jan-80	05-Aug-04
East Breaks	6	201.168	1120.14	01-Jan-81	28-Apr-02
Corpus christi	0				

The DeSoto canyon is the favoured region for bachelor males to be found in. Although currently no platform structures are located in this region, 19 applications for permits to drill (APD) were approved from 2001 - 2007. Also, approximately 63 blocks (2007) have had bids received for lease sales. With these drilling permits being approved, and technology advancements, it would appear that the offshore deep DeSoto canyon could soon face oil & gas exploration and development.

Moving westwards, the Main and South Pass fields also have some sightings around them, despite being located in shallower water. These regions are thick with structures (236 and 122 respectively). As already mentioned, the Mississippi Canyon is the region with the highest sperm whale numbers. Currently there are 23 rigs in the Mississippi Canyon region, and their depths range from 105 - 2,438 m. The first three were installed 1/1/1978, and the latest and deepest on 6/11/2007. It appears that deep rigs (i.e. farther into the sperm whales deep diving habitat) are becoming more commonplace as technology develops allowing them to be so placed.

The remaining regions, farther west, are also in line with sperm whale movements, although the fields with highest rig densities (South Timbalier and Ship Shoal), are generally in shallower water and so will not be used by the animals with the frequency with which they are seen in and around the canyons.

New proposals have been put forward to start drilling for deep gas in the Gulf of Mexico (https://www.gomr.mms.gov/homepg/offshore/deepgas.html). Despite being targeted towards shallow water rigs, the deeper drilling may have implications for the sperm whales in the area, possibly through increased sound emissions, increased vibrations, etc.

Another potential addition to the already busy waters of the Gulf of Mexico is the construction of LNG (Liquefied Natural Gas) terminals. As of 14 January 2008, one has been constructed already in the Gulf (Gulf Gateway Energy Bridge), two have been approved: offshore Louisiana and Port Pelican, and two more have been proposed: GOM and offshore Florida.

Exploration Seismic surveys within the Gulf of Mexico are licensed in the form of permits issued by the US Department of the Interior through the Minerals Management Service. Under the conditions of the survey permits, industry is required to provide seismic data obtained to the Minerals Management Service. Because of the volume of data, concerns over data quality, and a lack of resource within the Minerals Management Service to process all the data, and constraints over when pre-lease data can be released to the public, only estimates of the amount of seismic activity undertaken can be made using the data readily available from public sources.

As is typical across the oil & gas industry, the first surveys were conducted using 2D techniques. 2D survey data has been recorded since 1968 (Figure 9) averaging approximately 33,210 km of survey lines per year until 1975. Following a drop in 2D survey activity in 1977 (down to an estimated 8,306 km), 2D surveys increased at a relatively stable rate until 1990 at a peak, by this point, of an estimated 142,034 km.

2D survey methods continued to be used and, indeed, peaked in 1998 at an estimated 167,991 km. By 1993, technological advances allowed 3D Surveys to become commonplace, with a steady increase in their use from an estimated 26,000 km^2 to an estimated 119,526 km^2 by the end of 2002.

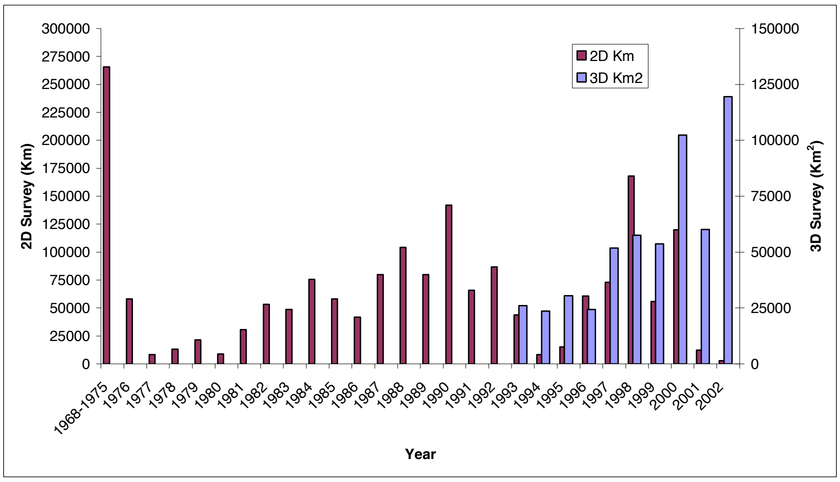

Figure 9 Total km of 2D surveys and total km^2 of 3D surveys carried out in the Gulf of Mexico between 1968 and 2002 (adapted from Dellagiarino 2004).

There does not appear to be any readily available breakdown of the seismic data to a block level or even within regions of the Gulf of Mexico, however, the report by Dellagiarino (2004) does provide some breakdown of 2D data by planning areas (Table 8)

Table 8 Estimations of the 2D Survey with the Gulf of Mexico Planning Areas between 1968 and 2002 (Dellagiarino 2004).

Planning Area	2D Survey in km
Eastern Gulf of Mexico	294,468
Central Gulf of Mexico	848,216
Western Gulf of Mexico	657,460
Total	**180,0144**

While no information can be gained on the yearly distribution of 2D seismic activity, the data does reinforce the concentration of activity within the Central and Western Planning Areas compared to the Eastern Planning Area (It is worth noting that these planning areas refer to the planning areas as defined pre-July 2007 (Peterson *et al.* 2007) which are slightly different in distribution to the current planning areas).

5.3 Overview of cetaceans of the Gulf

The Gulf of Mexico is a semi-enclosed subtropical marginal sea in the western North Atlantic Ocean covering an area over 1,500,000 km^2 with an average depth of 1,700 m (Gore 1992), and is a particularly rich area for cetacean diversity. This is a likely consequence of the diverse range of habitats provided by this sea. The continental shelf (< 180 m) makes up 22% of the area, the continental slope (180-3000 m) 20%, the abyssal area (> 3000 m) 20% and shallow and intertidal areas (< 20 m) make up the remaining 38% (Gore 1992).

Mullin & Fulling (2004) reported at least 19 different species from their 1996 - 1997 and 1999 - 2001 surveys of the northern Gulf of Mexico. The species sighted most commonly included the pantropical spotted dolphin (*Stenella attenuata*), sperm whale (*Physeter macrocephalus*), dwarf/pygmy sperm whale (*Kogia sima/breviceps*), Risso's dolphin (*Grampus griseus*) and bottlenose dolphin (*Tursiops truncatus*). Other species sighted or known to inhabit the Gulf of Mexico include: Bryde's whale (*Balaenoptera edeni*), killer whale (*Orcinus orca*), false killer whale (*Pseudorca crassidens*), pygmy killer whale (*Feresa attenuata*), melon-headed whale (*Peponocephala electra*) and short-finned pilot whales (*Globicephala macrorhynchus*); Cuvier's beaked whale (*Ziphius cavirostris*), Blainville's beaked whale (*Mesoplodon densirostris*) and Gervais' beaked whale (*Mesoplodon europaeus*); and striped (*Stenella coeruleoalba*), spinner (*Stenella longirostris*), rough-toothed (*Steno bredanensis*), clymene (*Stenella clymene*) and Fraser's (*Lagenodelphis hosei*) dolphins.

This rich species diversity has a distinct distribution; only 2 of the 20 species found here, the bottlenose dolphin (*Tursiops truncatus*) and Atlantic spotted dolphin (*Stenella frontalis*), occur regularly over the continental shelf (Fritts *et al.* 1983; Mullin *et al.* 1994). The deeper waters of the continental slope and abyssal regions attract and support the remaining wide diversity of species by potentially supplying a large number of ecological niches (Baumgartner *et al.* 2001).

The distribution of the resident and visiting cetacean species varies both spatially and temporally. For example, the bottlenose dolphins of the Gulf are separated into 6 different stocks (NOAA) for management purposes, from coastal residents (such as the well-studied Sarasota Bay dolphin population) to the Northern Gulf of Mexico oceanic stock. Not all species can be found in these waters year-round, for example, the Northern Gulf of Mexico killer whale stock, which is provisionally being considered as a separate stock, despite no information being available to differentiate it from the Atlantic stock (Waring *et al.* 2006), has only been sighted in the Gulf of Mexico between May and November (O'Sullivan & Mullin. 1997; Mullin & Fulling 2004).

5.4 Sperm whale stock assessment

In this case study we will focus on the sperm whales of the Gulf of Mexico. This species was chosen because:

- It is one of the most commonly sighted species in the Gulf (Mullin & Fulling 2004),
- it can be found in Gulf waters all year round (Mullin *et al.* 1994),
- its distribution overlaps with the waters being utilised by the oil & gas industry,
- the information for this species in this area is more comprehensive than for most other species in the region, and
- the sperm whale is listed as an endangered species (U.S. Endangered Species Act), is CITES appendix I listed, and is listed as IUCN (1996) vulnerable, making studies on this species of particular value and importance.[5]

Sperm whales have been sighted throughout most of the deeper waters of the Gulf of Mexico (Figure 10; see Waring *et al.* 2006 for SEFSC survey results and Mullin *et al.* 1991); however, particularly high aggregations are often found near the Mississippi River delta (Mullin *et al.* 1991; Davis *et al.* 2000; Mullin & Fulling 2004; Jochens *et al.* 2006). This is probably a consequence of the very high primary production associated with the Mississippi River plume that is enhanced by nutrient upwelling (Mullin & Fulling 2004). This is likely to be the foundation of large food sources for the whales, in the form of squid. Mullin *et al.* (1991) suggests that shortfin squid (*Illex illecebrosus*) and

[5] Despite numbers being abundant locally and possibly on a worldwide scale (although not near their pre-whaling numbers), not enough information on the stocks are available to be able to downgrade/list them.

the orange back squid (*Ommastrephes pteropus*), which are known to occur in the deep Gulf waters (Voss 1956) and are a recognised part of the sperm whales' diet (Rice 1989), are likely to be the species making up the bulk of sperm whales' food in this region.

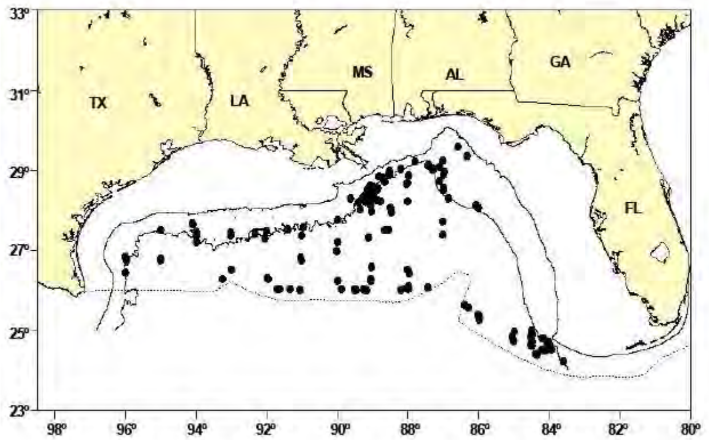

Figure 10 Distribution of sperm whale sightings from SEFSC spring vessel surveys during 1996 - 2001 (taken from Waring *et al.* 2006).

5.4.1 Population structure and size

Obtaining estimates for the population size of this stock is not straightforward, for a number of reasons:

- There is some uncertainty that these animals are actually from one discrete stock, although recent SWSS studies (Jochens *et al.* 2006) support NOAA's methodology treating them as such, through positive results from genetic analyses, coda vocalisations and population structure,
- their deep diving behaviour means that they stay submerged for long periods of time, and are not as gregarious at the surface as some other species, such as bottlenose dolphins,
- this species is normally sexually segregated; individuals only come together for mating, and so, depending upon the time of the year, males may or may not be present, which could skew the population numbers.

However, the National Marine Fisheries Service of NOAA has undertaken three stock assessments on the Northern Gulf of Mexico sperm whale stock since 1995. Table 9 gives the estimates of abundances available[6].

[6] The values differ since the area covered differered slightly: 1991-1994 covered the 'area from approximately the 200m isobath along the U.S. coast to the seaward extent of the U.S. Exclusive Economic Zone. 1996-2001, covered 'northern Gulf of Mexico oceanic waters', hence a larger total area.

Table 9 Overview of abundance estimates of the Gulf of Mexico sperm whales.

Estimate of abundance	Coefficient of variation	Year	Source data	NOAA SAR Year
143	0.58	1991	Hansen *et al.* 1995	1995
931	0.48	1992	Hansen *et al.* 1995	1995
229	0.52	1993	Hansen *et al.* 1995	1995
771	0.42	1994	Hansen *et al.* 1995	1995
530	0.31	1995 (1991-1994 average)	Hansen *et al.* 1995	1995
805	0.27	1991-1994 (re-analysis of above)	Hansen *et al.* 1995	2003
1,349	0.23	1996-2001	Mullin & Fulling 2004	2003
1,349	0.23	1996-2001	Mullin & Fulling 2004	2005

Minimum population estimates were also calculated during NOAA's SAR's and were 411 (1995) and 1114 (2003 and 2005).

5.4.2 Demographic variables

Information on age classes within the population is also lacking. Visual observations indicate that groups consisting of adult female and juvenile/calves of both sexes are the most common aggregation in the area. Bachelor groups and lone males also occur within the Gulf of Mexico, however, the SWSS surveys found them closer to the DoSoto canyon and spatially separated from the female and juvenile/calf groups (Jochens *et al.* 2006). It is still unclear whether adult breeding bulls inhabit the area. However, lone males (i.e. breeding bulls) were never/rarely sighted in this area, indicating that older males do not commonly make up part of this stock. It is likely that they move in and out of the area for breeding purposes and, as literature suggests, they spend the rest of their time in colder-water feeding grounds at higher latitudes (Whitehead 2002). The SWSS summary report (2002 - 2004) by Jochens *et al.* (2006), found that the proportion of calves to overall group size was 11.5%. This study also found that mean group sizes around Mississippi canyon, where female and juvenile/calf mixed groups were most commonly sighted, were 9 – 11 animals.

These findings indicate that the population appears to consist of all age classes, if only at certain times of the year (as is likely for large breeding bulls), although estimates of population dynamics are not available. Sperm whale young are born (almost always) singularly and with an equal sex ratio (Best *et al.* 1984; Whitehead 2002). The sex ratio does not appear to remain equal into adulthood, however. Modern whaling has been held responsible for the higher proportion of females to males. Modern whaling concentrated primarily on males, partially because they are larger and more valuable, but also because of the view that, given the supposed "harem" system of the sperm whale, only one breeding male was needed per group of females (Whitehead 2002). In some areas, e.g. Peru, this has left the number of large males devastatingly low, and has affected pregnancy rates in populations from Galapagos Islands and off mainland Ecuador (see Whitehead 2002 for an overview).

The sex ratio of the northern Gulf of Mexico stock was found to be 2.61:1 females to males during the SWSS surveys (2000 - 2003) (Jochens *et al.* 2006). Given the low latitude of the area, and the prominence of female mixed groups, the authors did not find this result unexpected. During the surveys, none of the males appeared to be physically and sexually mature, indicating that, in this area, and at this snapshot in time (May - August), only female mixed groups and bachelor herds were present.[7] The GulfCet II study documented no large adult males in the area; it is unclear whether females leave the area to mate or whether lone adult bulls enter the Gulf periodically for breeding (Davis *et al.* 2000); yet it seems more likely that lone males would enter the area, given the year round presence of female mixed groups.

Female sperm whales can live into their eighties, and probably sometimes reach a century in age, but we know little about reproduction at these older ages (Whitehead 2002). Sperm whale carcasses are not often washed ashore and, in a region like the Gulf of Mexico, where they live around deep water, it is likely their bodies would sink into the abyss. They are believed to have low mortality rates.

The IWC (1982) estimated the following mortality rates:

- Mortality of males over the age of 1 year was 6.6% per year,
- mortality of females over the age of 1 year was 5.5% per year,
- mortality between birth and age 1 was 9.3% per year, and
- birth rate of mature females was 20% per year[8].

5.4.3 Migrations / seasonality

Few animals are as widely distributed as the sperm whale, though the sexes have very different distributions (Whitehead 2002). Females almost always inhabit latitudes less than 40^{o}, and they are accompanied by juveniles and calves of both sexes until the young males leave the group between 4 - 21 years old, gradually moving to higher latitudes: the larger and older the male, the higher the average latitude (Whitehead 2002).

Distinct migration patterns for sperm whales have not been described; it appears that even individual stocks do not make clear movements between areas periodically; this may be a result of suitable temperatures, and rich food sources being present in the regions they are found in abundance and, as such, removing the need for migrations for breeding, food or warm temperatures to rear young. In some mid-latitudes there appears to be a general seasonal north-south migration, with whales moving poleward in summer, but, in equatorial and some temperate areas, there is no clear seasonal migration (Whitehead 2002).

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[7] Best 1979 calculated the proportion of sexually mature females to sexually mature males to be 2.6:1. Although coincidentally the same as discovered in the Gulf of Mexico during the SWSS survey, this value was not obtained from observed data, but from calculations of age at sexual maturity against cumulative percent frequency. The ratio is so biased, as a result of only sexually mature males being included; with Best 1979 setting the age of male sexual maturity to be 26 - obviously this comprises only a small percentage of a population. The ratio obtained from the SWSS survey is indiscriminate of age and maturity, and gives a more realistic ratio of the whales in the Gulf during May-August.

[8] However, Whitehead (2002) believes the figures used by the IWC (1982) for mortality rates were probably underestimated, and concludes that it is more realistic to use the well-established mortality schedule of killer whales (Orcinus orca) by Olesiuk *et al.* 1990 who estimated wild calf (neonate) mortality to be 43%. Bain 1990 estimated neonate mortality of resident killer whales off northern Vancouver Island to be 42%. Olesiuk *et al.* 1990 estimated a per capita death rate of 2.2%. Yet, it is questionable whether data from one species can be transferred to another.

Field studies suggest that there is no long-distance movement of sperm whales out of the Gulf, given that no matches of identified individuals (185) have ever been made to individuals in the Atlantic catalogue (~2500) (Jochens *et al.* 2006). However, evidence also suggests that lone bulls are not resident in the Gulf, and it seems likely that they move in and out of the area solely for breeding. DNA matrilineal evidence found that all sperm whales sampled in the northern Gulf contained one of five haplotypes; this combined with different code repertoires also supports the hypothesis that they are a discrete stock with female mixed and possibly bachelor groups exhibiting residency, with no evidence for migrations into and out of the Gulf, given sightings year-round.[9]

5.4.4 Population trends

No population trends from NOAA stock assessment reports have been established as yet. Blaylock *et al.* (1995) suggests that apparent changes in abundance may represent inter-annual variation in distribution rather than a real change. The average abundance estimates from the 1995 and 2003/2005 reports were not found to be significantly different, due to the lack of precision obtainable in the estimates. However, it can be inferred from the data that has been gathered so far, that this population is, at least, not declining to a substantial degree. The sighting rates in most cases are relatively stable, and no areas previously rich in sperm whale sightings have reported declines or seasonal absences. It is likely that changes are identified relatively early: Jochens *et al.* (2006) reported that, during early summer 2003, sperm whales moved out of their 'hotspot' area of the Mississippi canyon for a short period of time. This bodes well for the early detection of long-term or permanent displacement, and changes in abundance of this population.

5.5 Other factors potentially affecting the stock

5.5.1 Whaling

The sperm whale population in the Gulf of Mexico was once subject to whaling, indicating not only their historical presence in the same grounds, but also that numbers were high enough to support this industry. Townsend (1931) first indicated the Gulf of Mexico Ground (28˚–29˚N, 89˚-90˚W) to be a summer whaling ground, and Townsend (1935) compiled logbook data from whalers from the mid-1700s to the early 1900s and documented that sperm whaling was practised there but only to a limited extent between February and May. 42 kill locations were reported in the Gulf; all kills were made between the Mississippi River delta and the western end of Cuba (Mullin *et al.* 1991). There is a lack of documentation beyond Townsend's records and, due to protection measures, whaling doesn't present a threat to the sperm whales in the Gulf of Mexico any more.

[9] Tagging studies (Mate & Ortega-Ortiz 2006) involving 39 sperm whales as part of the SWSS survey, found that during 'tag transmitting life', only 1 whale moved out of the gulf into the North Atlantic; this happened to be a large male, potentially sexually mature, but not large enough to be considered a successful breeding bull. During the 610-day transmission, the male moved out of the Gulf for a period of 2 months, providing evidence that movement such as this does occur, albeit possibly determined by variations in the individual/maturity. Despite more females being tagged than males, no movements were recorded out of the Gulf, and in general the movements made by females remained around the upper slope edge, with far less movements made over deep water, than exhibited by males (Jochens *et al.* 2006).

5.5.2 Fisheries

Activities Fishing in the Gulf is a very productive and valuable resource to the coastal states. According to the National Marine Fisheries Service, the commercial fish and shellfish harvest from the five U.S. Gulf states was estimated to be 1.3 billion pounds valued at $689 million in 2006 (http://www.epa.gov/gmpo). Figure 11 shows the importance of commercial fisheries to the Gulf States in terms of economic value and fisheries landings by volume to U.S. markets.

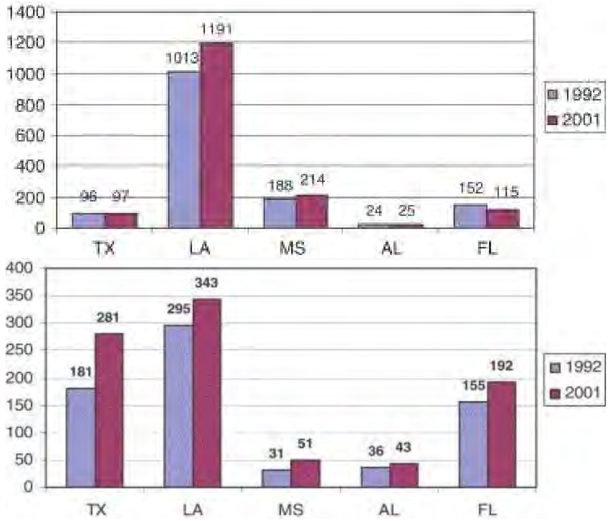

Figure 11 Fisheries activity in the Gulf of Mexico 1992 and 2001 (left: commercial fisheries landings for the Gulf States – 1992 and 2001 (million pound units); right: pane commercial fisheries dockside value for Gulf States – 1992 and 2001 (million $ units); taken from Adams *et al.* 2004; TX = Texas, LA = Louisana, MS = Mississippi, AL= Alabama, FL = Florida).

This large and economically important industry of the Gulf waters is associated with highly utilised waterways, and large amounts of vessel traffic. According to Adams *et al.* (2004) a total of 24,879 commercial fishing craft (Figure 12) are registered within the Gulf region (excluding Texas), representing approximately one-third of the nation's entire commercial fishing fleet.

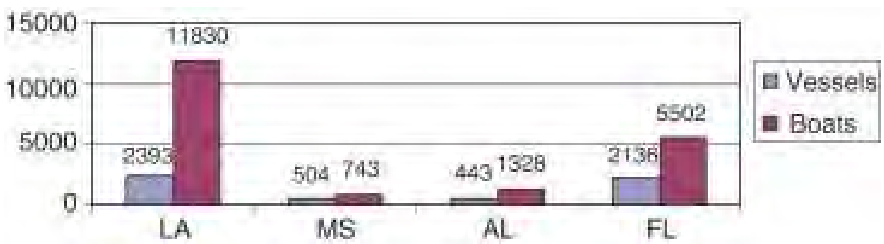

Figure 12 Commercial fishing vessels and boats in the Gulf States in 2001 (taken from Adams *et al.* (2004); Florida's figures include vessels from both coasts, and values for Texas are not available).

Recreational fishing is also lucrative, with a total weight of 78.8 million pounds of fish taken from the Gulf of Mexico in 2006 (http://www.epa.gov). During 2001, the Gulf region had 8.3 million participants, who took 35.4 million trips (Adams *et al.* 2004). Although the available data indicate huge additional amounts of boat traffic in the Gulf waters, it must be considered that a large proportion of these participants, trips and vessels will have been taken or operate in coastal locations and waters, and as such will not come into contact with the waters inhabited by sperm whales offshore in the Gulf of Mexico.

The volume of commercial and recreational fisheries poses several risks for the sperm whales in the Gulf, for example **disturbance due to sound** but also **entanglement in fishing nets and gear**. Although the NOAA SAR's do not have any deaths formally attributed directly to the fishing industry, they do suggest that the extent of fishery-related mortality and serious injury to sperm whales is probably underestimated because not all carcasses that wash ashore are discovered, reported or investigated and not all will show signs of entanglement or other fisheries interaction (Waring *et al.* 2006).

Food depletion Sperm whales are known to feed generally on squid living in deep water (e.g. Santos *et al.* 1999). As already indicated, the deep canyons around the Mississippi River delta, and DeSoto attract high numbers of whales (Mullin *et al.* 1991; Davis *et al.* 2000; Mullin & Fulling 2004; Jochens *et al.* 2006) indicating rich food sources. Some anecdotal information supports the assumption that the canyon provides rich food sources for the sperm whales and, if this food source becomes depleted, that the whales move out of the area[10]. Given the 'normal' circulation patterns in the Gulf of Mexico, the food supply should not become exhausted unless circulatory patterns change for long periods of time.

The movements of sperm whales within the Gulf of Mexico also support the evidence that the area is a rich food source. Compared to displacement patterns of sperm whales in other oceans, the small horizontal daily displacement (35 km), as well as the pattern of their small-scale movements made by Gulf whales (zig-zag pattern over a smaller area and longer periods during which the animal stays within a particular area), indicate that they may be feeding on small but dense patches of prey and suggest a high feeding success (Jochens *et al.* 2006).

The high feeding success suggested in Jochens *et al.* (2006) appears to be supported by squid landings data from the FAO FishStat database. An extraction of all squid landings from the Western Central Atlantic between 1950 - 2005 reveals no declines in landings, in fact, 2005 had by far the highest landings recorded (618 tonnes of Northern shortfin squid alone). Figure 13 shows the landings in this area from 1950 - 2005.

[10] For example, in early summer 2003, a Loop Current eddy that effectively "flushed" the canyon with low chlorophyll, low nutrient Caribbean water was located in close proximity to Mississippi Canyon. During this time sperm whales were rarely seen or heard in the region (Jochens *et al.* 2006). In contrast, approximately one month later that same summer, sperm whales were encountered in the Mississippi Canyon region, when the current eddy had rebounded farther seaward, and normal along margin and off-margin flow had been re-established (Jochens *et al.* 2006).

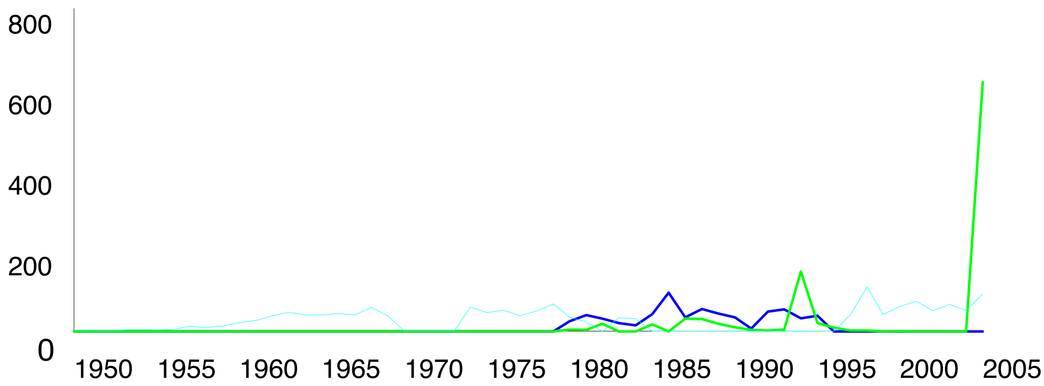

Figure 13 Landings in tonnes of all squid species in the Western Central Atlantic from 1950-2005. X-axis is year, Y-axis is landing in tonnes. Blue line is long fin squid, green line is Northern shortfin squid and turquoise line is various squid species[11].

The diet of sperm whales from the Gulf of Mexico was analysed by Barros (2003) from necropsy and faecal samples, and it was found that they preyed only on cephalopods, however, they were not fastidious in their species choice, with 13 species within 10 families of cephalopods being identified as components of their diet. The most important prey species found was *Histioteuthis*, a midwater squid important in the diet of sperm whales worldwide (Barros 2003). *Histioteuthis corona* and *H. arcturi* are known to occur in the Gulf of Mexico (Voss 1956; Barros 2003), with the former being the most common and abundant, particularly off the mouth of the Mississippi River (Barros 2003). Given that this region has been identified as a ‘hotspot’ for sperm whales, this indicates once again that the sperm whales congregate here due to the abundant food sources.

This diversity in diet might indicate that the sperm whales in the Gulf of Mexico are capable of adapting to changes in the abundance of various squid species, and the risk of food depletion in this area might, therefore, be relatively low. However, as Rodhouse (2001) points out, populations of squid are, in general, rather labile, and recruitment variability is driven, to a greater or lesser extent, by environmental parameters. Therefore, if conditions make the Gulf of Mexico unfavourable for several cephalopod species, there could be negative effects for sperm whales.

5.5.3 Shipping

Activities The easy access to the Gulf waters, and the heavy industry occurring on the shores of the coastal States, has resulted in many busy ports lying on the Gulf coasts. Two of the 10 busiest ports in the world by cargo volume lie on the Gulf coast, South Louisiana (New Orleans) and the Port of Houston; while seven of the top 10 ports in the Unites States are located on the Gulf of Mexico (http://www.epa.gov/gmpo). A large volume of shipping operates in the waters of the Gulf, with a variety of import and export activities and also the petroleum and oil industry in the area. According to the

[11] These figures should be viewed a a rough estimate and treated with some caution. A large number of squid species, including those that make up the diet of sperm whales in the Gulf, are not targeted by commercial fisheries (Barros 2003), and as such we have no real knowledge of their status from one year to the next.

US port rankings by cargo volume in 2006 (http://www.aapa-ports.org), the combined cargo volume being carried through Gulf waters is 1,167,353,090 short tons (Figure 14).

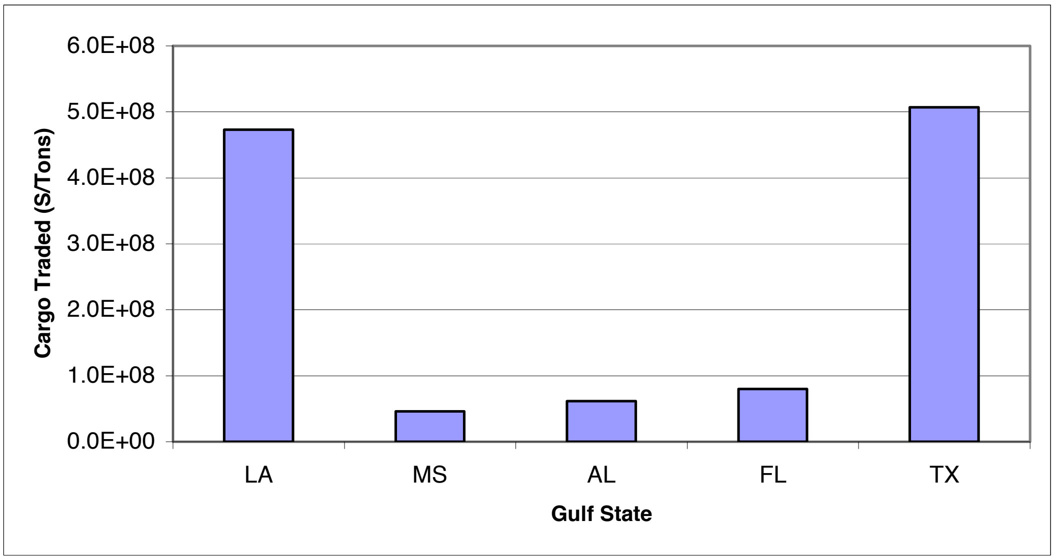

Figure 14 Volume of cargo traded by Gulf States in 2006 (units in short tons, LA = Louisana, MS = Mississippi, AL= Alabama, FL = Florida, TX = Texas).

Obviously, the large volume of ships traversing the Gulf waters will overlap the areas occupied by the sperm whales. In fact, Adams *et al.* (2004) cites that there is significant shipping activity occurring along the Mississippi River corridor into the Gulf and as stated earlier, the Mississippi Canyon region is a 'hotspot' for sperm whale occurrence. Seventy percent of all US waterborne commerce ton-miles of shipping and 60 percent of all petroleum and petroleum products shipped via waterborne means occur in the Gulf of Mexico (Adams *et al.* 2004), hence much of this traffic through the Gulf waters can be associated with the oil & gas industry.

Ship Strikes In busy shipping lanes, sperm whales are in danger of injury or death resulting from collisions with vessels (Whitehead & Weilgart 2000). Jensen & Silber (2003) detailed 17 reported sperm whale ship strikes around the world from the large whale ship strike database, one of which occurred off Grande Isle, Louisiana in 1998, killing the whale. Despite this isolated strike, the problem of ship strikes does not appear to present a large risk to sperm whales in the Gulf of Mexico, despite the heavy vessel traffic in the area. From 1987-1994, nine sperm whales stranded in the northern Gulf of Mexico. Only one of these could be attributed to a vessel strike; exhibiting deep propeller cuts (Blaylock *et al.* 1995). Between 1997 and 2002, 17 strandings were reported; again, only one could be directly related to a vessel strike (Waring *et al.* 2004). Finally, between 1999 and 2003, a further nine strandings were recorded, and none of these could be attributed to human interactions (Waring *et al.* 2006). This is surprising given the large volume of vessel traffic in the Gulf. However, this figure may not be a true representation of the full extent of ship strikes that occur in this region. Carcasses are often not recovered, and, in the case of recovery; their state of decomposition often makes it very difficult to assign the cause of death.

5.5.4 Tourism

As well as recreational fishing, tourism provides a huge income for the Gulf states, and much of this centres around water based activities. Swimming, water sports, and visiting the beach attract large number of visitors and residents alike, and the shores of the Gulf support a $20 billion tourist industry (www.gulfbase.org). With large numbers of people residing in the Gulf states comes large amounts of industry and, consequently, given the easy access to the world through the Gulf, a high volume of importing and exporting through shipping. Consequently, the Gulf of Mexico waters are some of the busiest and most heavily utilised in the world, by industry and tourism alike.

Whale watching Whale watching is not a large industry in the Gulf of Mexico waters, especially in areas inhabited by sperm whales. Their residency around the deep offshore continental shelf waters makes them inaccessible to potential day-trip whale-watching operations. Hoyt (2001) assessed the worldwide status of whale-watching, and grouped the east coast USA with the Gulf of Mexico; of these large areas, just 16 communities offered tours, but largely for dolphin watching. With such a diffuse industry, operating at a modest level in the midst of a large, overall tourism industry, the impact of whale watching is also modest (Hoyt 2001)[12]. Therefore, it appears that sperm whales in the Gulf of Mexico are not greatly exposed to disturbance from whale watching activities, which have been shown to cause disruption to natural movements in other sperm whale populations (e.g. Richter *et al.* 2006).

5.5.5 Pollution

Oil Spills/Leakage The huge volume of oil being transported around the Gulf waters in ships poses the potential risk of collisions, spills, and leaks that could lead to short-term or longer term pollution which may adversely affect sperm whales. Although no large-scale disasters have occurred in the Gulf, there have been a number of incidents involving oil spills. Between November 1979 and July 1984 alone, four incidents involving tankers resulted in the spilling of 16.3 million gallons of oil into the Gulf. A further 870,000 gallons of oil were spilled in Galveston Bay and its estuary alone between 1987 and 1991. Shipping incidents however, pale into insignificance when disastrous oil well blowouts occur. In 1979, a major oil well blowout at the IXTOC-1 platform released an estimated 0.8 - 1.7 million gallons of oil per day for nearly 10 months, leaving an estimated 140 million gallons of oil in the Gulf waters. A further blowout at the Ranger exploratory well in 1985 added a further 6.3 million gallons to the Gulf (for more details see Gore 1992).

Despite these incidents, no cetacean deaths have currently been attributed to oil spills in the Gulf of Mexico. There are possible risks to cetacean health should they come into contact with oil, however. Yet, if a spill was to occur, sperm whales deep diving behaviour makes the risk of contact with oil considerably less than for inshore species, although it remains a possibility, especially as oil exploration moves into deeper water, such as has occurred around the Mississippi Canyon. However, some sperm whale behaviours could put them at increased risk should a spill occur; the social cohesion of sperm whales female/mixed and bachelor groups means that the whole herd could be exposed to oil, while their deep diving foraging behaviour often means that calves are

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[12] The only specific interaction with the sperm whales of the Gulf comes from a Mississippi marine laboratory whose classes go out to meet cetaceans three days a year (Hoyt 2001).

left behind on the surface, and their natural curiosity might also draw them to surface slicks (see Würsig 1988 for a review).

Contamination No evidence showing sperm whales to be suffering from contaminant loads in their body has been shown for the Gulf of Mexico whales. Law *et al.* (1996) analysed blubber samples from seven sperm whales stranded around the North Sea, for organochlorine pesticides and metabolites, and a range of chlorobiphenyl (CB) congeners. The concentrations of these contaminants were lower or similar to those found in by caught harbour porpoises and another sperm whale analysed previously (see Law *et al.* 1996).

5.5.6 Competition

As sperm whales have rather little overlap in dietary preferences with other species and usually eclipse their potential predators in terms of biomass, it seems that interspecific competition is not usually a key regulator of sperm whale populations (Whitehead 2002). In contrast, *intraspecific* competition could be a potential risk in the future for sperm whales in the Gulf of Mexico, if they are at or nearing their carrying capacity. Yet, no interpretation of this can be made given the lack of population trend data, slightly uncertain population estimates and vague estimates of prey densities.

5.5.7 Environmental changes

Climate change could have an effect on this sperm whale population in a number of ways. As mentioned earlier, squid populations are labile and recruitment variability is driven, to a greater or lesser extent, by the environment (Rodhouse 2001). Such environmental changes occurred when a change in circulation patterns and the formation of a loop current eddy near the Mississippi canyon in early summer 2003 (Jochen *et al.* 2006), resulted in a loss of food temporarily, forcing the whales away from this preferred region (see above). Should long-term changes in the circulation pattern of the Gulf of Mexico occur, this could force the whales to move out of the area in order to find prey.

Water temperature increases are another possible environmental factor, which could have both direct and indirect implications for these whales. An increase in temperature is not likely to have much direct effect, given that sperm whales are found at lower latitudes and in warmer waters than those occurring in the Gulf of Mexico. Yet, indirectly, it could have large repercussions from the bottom of the food chain (plankton etc) all the way up to the sperm whales' prey, and ultimately the sperm whales themselves; dependent upon each trophic level's sensitivity to such temperature rises. Given the large dynamic expanse of the Gulf of Mexico, an exact estimate of changes in seawater temperatures is not possible to date.

Climate change can have drastic consequences: Saunders & Lea (2008) found that a 0.5℃ increase in tropical Atlantic sea surface tem peratures (August to September) was associated with a ~ 40% increase in hurricane frequency and activity (1996 - 2005). However, any effect that hurricanes may have on sperm whales is relatively unknown. It is likely that whales will detect an approaching hurricane and avoid exposure long in advance of its arrival, given their suspected sensitivities to underwater sound[13]. Given the whales' capability to perform very deep and prolonged dives, it is unlikely that sperm whales would face any difficulties during a hurricane.

Hurricanes could, however, pose more of a threat indirectly, due to materials being carried by the hurricane and deposited in the sperm whales' habitat. This could mean that not only solid materials, but also, and more importantly, liquids and chemicals, could be expelled into the water resulting in increased pollution.

Harmful Algal Blooms / Red Tide In the Gulf of Mexico, one recurring environmental phenomenon is harmful algal bloom (HAB) outbreaks. These can have detrimental effects throughout the food chain, even on the top predators. In one incident, 740 bottlenose dolphins stranded along the Atlantic coast between June 1987 - May 1988, wiping out approximately 50% of the coastal migratory stock between New Jersey and Florida; brevetoxin was suspected as the proximate cause of mortality (FWC). Red tides due to HAB outbreaks have also been responsible for the death of large whales. Saxitoxins were implicated in the death of 14 humpback whales over a 5-week period in Cape Cod Bay, Massachusetts, in 1985 (Vos *et al.* 2003). In this region there are at least two saxitoxin producing dinoflagelate (*Alexandrium tamarense*) blooms annually, and therefore saxitoxins were investigated as the causative agent, transmitted into the whales from the mackerel on which they were feeding (Vos *et al.* 2003). To date, no sperm whale deaths in the Gulf of Mexico have been attributed to red tide outbreaks, and the risk they pose to the sperm whales is largely unknown. Commonly, the blooms affect coastal regions, however, they have also been known to occur offshore, but not usually in waters as deep as those inhabited by the sperm whales. Sperm whales are only likely to be susceptible if their prey directly or indirectly feed upon these toxic dinoflagelates, which is dependent upon the feeding strategies of their prey, and whether they come to surface waters to feed. With HABs occurring every year in the Gulf of Mexico, one may assume that sperm whales are not threatened by this phenomenon given that no deaths have ever been linked to this, and the stock has not experienced any large-scale die-offs.

5.6 Sperm whale response to O&G activity in the Gulf of Mexico

As shown above, seismic surveys have been very frequent in the Gulf of Mexico. Additionally, there are 1,000 boat trips (mostly recreational fishing), and 2,000 helicopter flights per day as well as 100 exploratory and development wells which are drilled every year - many now in deeper waters (Norris 2001).

The OCS EIS/EA MMS 2004-054 (MMS 2004) report suggests that sperm whales may potentially be at some risk of auditory impact from seismic surveys. This is based on findings and suggestions by Norris *et al.* (2000); Richardson *et al.* (1995) and Goold & Jones (1995) who reveal different aspects of sperm whale click frequencies and hearing abilities, suggesting that these will overlap with the sound levels of seismic surveying. However MMS (2004) concludes that seismic operations are potentially adverse but not significantly so to the sperm whales of the Gulf of Mexico.

The behavioural reaction of sperm whales to airguns has been disputed in the literature. Mate *et al.* (1994) found that, within the area of a seismic operation, the sighting rate changed significantly from 0.092 whales/ km to 0.038 whales/ km during the first two days and then to 0.0 whales/ km for the following 5 days; indicating that

[13] During a study by Mate & Ortega-Ortiz 2006, a male sperm whale was tagged in the Gulf. Subsequently, the animal left the Gulf and moved into the North Atlantic, until it approached the path of Hurricane Isabel, at which point it turned around and went back into the Gulf of Mexico.

prolonged acoustic exposure forced them out of the area. Bowles *et al.* (1994) reported on the Heard Island Feasibility Test study (Indian Ocean) and documented that, although sperm whales were sighted during both the base line and transmission period, they stopped vocalising during some times when seismic pulses were received from an airgun array > 300 km away. Sperm whales were heard in 23% of 1,181 min of baseline acoustic surveys; but in none of 1,939 min during the transmission period; however they were heard again within 48 h after the end of the test (Bowles *et al.* (1994). Norris *et al.* (2000) found that during the GulfCet surveys, the percentage of time seismic exploration sounds were recorded increased from 21% of the total time in GulfCet I to 34.1% in GulfCet II, and during the final cruise, up to 49.8%; a likely indication of the increased presence of the industry in this area. Norris *et al.* (2000) measured the average signal to noise ratio as 8.4 dB re 1 μPa, with a maximum of 13.1 dB and a minimum of 4.3 dB; the sperm whale sighting rate did not differ significantly between the different sound levels. However, as Norris *et al.* (2000) point out that, despite the intense oil industry activity around the mouth of the Mississippi, the sperm whales still exhibit site fidelity after hundreds of years, indicating a low sensitivity to seismic sound, habituation and hence toleration, or a high motivation to remain in the area. Likewise Madsen *et al.* (2002) did not observe any avoidance or reduced vocalisations from adult, male sperm whales in polar waters during exposure to pulses from a remote (> 20 km) seismic survey vessel, and actually found that they stayed in the area for at least 13 days of exposure. The results of the SWSS Jochens *et al.* (2006) using three different approaches found no horizontal avoidance of sperm whales in the Gulf of Mexico to seismic survey activities. They also did not find any evidence that whale swam away from an airgun array during ramp up procedures or when approaching at full speed (however few exposures were above 160 dB re 1 μPa). With limited data and several caveats, however, their data on feeding appears to indicate a possible disruption in foraging during airgun exposures ranging from < 130-162 dB re 1 μPa (Jochens *et al.* 2006).

The number of sperm whales that may be exposed to high sound pressure levels from airguns might be relatively small. According to the MMS (2004). Recent density estimates of sperm whales in the northern Gulf of Mexico are 0.29, 0.44, 0.25 individuals/100 km^2 for the Eastern, Central, and Western Gulf of Mexico Planning Areas, respectively (K. Mullin, NMFS, written comm., 2003; cited in MMS (2004). When cumulative annual seismic survey operations are considered, a total of three sperm whales may potentially be exposed to levels of 180 dB or greater if they do not avoid exposure (i.e., one sperm whale per planning area) (MMS 2004). However, this does not address the issue that potentially large numbers of sperm whales (especially in hotspot regions, such as the Mississippi Canyon) may exhibit behavioural avoidance of these areas and could remain displaced until the sound source has ceased, and with certain areas also being 'hotspots' for seismic surveying, this may be for long periods of time.

5.7 Impact analysis

Table 10 indicates that environmental changes are the factors that foster effects that result in consequence for the sperm whales of the Gulf of Mexico at a population level. Climate change cannot be addressed on the local scale and it is also very difficult to mitigate against. Effects that could have negative influences on parts of the population are fisheries, shipping and pollution. Given that only one confirmed death has been attributed to a ship strike in the Gulf thus far, it is very unlikely that this will suddenly increase and pose any real threat to the population, despite uncertainties regarding the percentage of carcasses washed ashore (see above). Behavioural responses due to seismic exploration and construction activities are of medium severity, as are injuries due to entanglement. Both of the former have supposingly long ranges, yet, as shown above, the uncertainty about behavioural reactions due to sound is very high.

Table 10 Impact analysis for sperm whales in the Gulf of Mexico. (Range: Short: < 100m, medium > 100 m < 5,000 m, long: > 5,000 m; Duration: Short: short-term, Long: long-term; intensity: Low (L), medium (M), high (H); severity, uncertainty(U) and likelihood(LH): Zero, low (L), medium (M), high (H), very high; likelihood U: unknown; for explanations, see chapter 2.2; dark grey: potential impacts on parts of population; light grey: measurable effects above normal fluctuations)

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
E&P industry	Exploration	Masking	M	Short	L	L	H	M
		Response	Long	Short	L	M	Very H	M
		TTS	Close	Short-long	M	L-M	Very H	M
		PTS	Close	Long	H	H	Very H	L
	Construction	Masking	M	Short	L	L	H	M
		Response	Long	Short	L	M	Very H	M
		TTS	Close	Short-long	M	L-M	Very H	M
		PTS	Close	Long	H	H	Very H	L
	Production	Masking	Close	Long	L	L	H	H
		Response	Close -M	Long	L	L	M-H	H
Fisheries	Sound	Masking	M	Short	L	L	H	M
		Response	M	Short	L	L	H	M
	Entanglement in gear	Injury	Close	Long	M	M	M-H	U
		Death	Close	Long	H	H	M-H	U
Shipping	Sound	Masking	M	Short	L	L	H	M
		Response	M	Short	L	L	H	M
	Ship strikes	Injury	Short	Long	M	M	M	M
		Death	Short	Long	H	H	M	M
Tourism	Whale-watching	Masking	M	Short	L	L	H	Very L
		Response	M	Short	L	L	M-H	Very L
Pollution	Spils leakages	Contamination	Close	Long	M	M	H	L-M
	Contaminants	Decreased health	Long	Long	M	H	H	U
Competition	Interspecific competition	Emigration /avoidance	None					
		Starvation	None					
Environment	Hurricanes	Response	Long	Short	L	M	H	L
	Climate Change	Emigration	Long	Long	H	Very H	Very H	M

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
		Starvation	Long	Long	H	Very H	Very H	M

5.8 Conclusions

The volume of E&P industry activity in the Gulf of Mexico is large, with 3,855 active platforms at present, and 119,526 km^2 of 3D seismic surveying occurring in 2002. Coupled with vast amounts of shipping, these waters are heavily utilised. Despite this, the Gulf of Mexico remains rich in cetacean diversity, with at least 19 different species (Mullin & Fulling 2004). The sperm whale population of the Gulf lent itself to further investigation with respect to the oil & gas industry, being one of the few species with a habitat overlapping that of the industry and the deeper, less coastal waters; having a number of studies conducted on it over several of years, and of course, its apparent relatively discrete stock nature and endangered status. Despite much effort, no definitive population trends can be drawn, however, it appears that the population is not showing a decline and no long-term displacements have been identified. Furthermore, a relatively stable number of animals have been found yearly in a couple of 'hotspot' regions, namely around the Mississippi Canyon. There are several other factors that could potentially affect this population, including pollution, contaminants, harmful algal blooms/red tide, ship strikes, environmental factors with climate change appearing to be the most potentially harmful, possibly through changes in prey availability. Although the severity of some of these effects could be high, in most cases the uncertainty is also high and likelihood appears to be rather low. The population is only likely to come under threat from cumulative factors and/ or by intense or prolonged environmental changes.

6 Case study 2: California - humpback-, blue- and fin whales

6.1 Introduction to the area

The west coast of the US includes (from North to South) Washington State, Oregon and California, which we will focus on in this chapter (see Figure 15). California is the third largest state of the USA by land area and the most heavily populated with ~ 37 million people, enclosing very large urban areas in and around Los Angeles and San Francisco, resulting in a variety of pressures on the marine environment. On the other hand, biodiversity is high, especially with regards to cetaceans, and the area has been one of the centres since the beginning of whale research after the Second World War.

Figure 15 Overview of the coast of California, Oregon and Washington State.

6.2 E&P activity

Oil & gas activity on the U.S Pacific Outer Continental Shelf (OCS) is predominately concentrated off the coast of Southern California. Petroleum fields have been discovered along the majority of the U.S. Coast, however, only the fields discovered offshore of Southern California (Figure 16) are currently exploited.

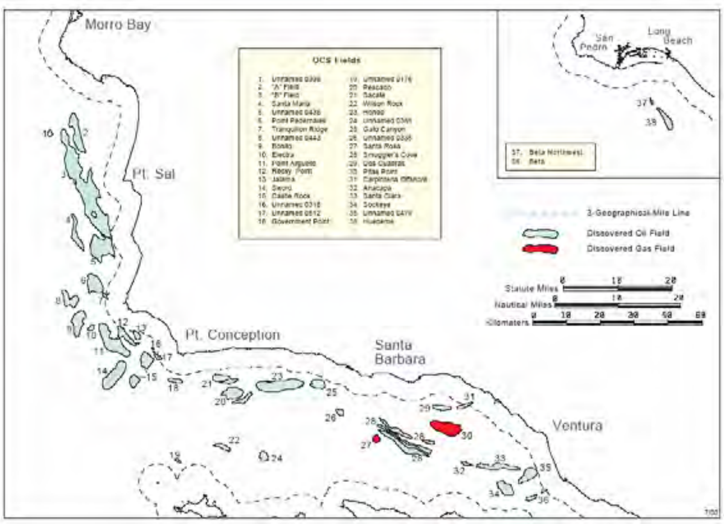

Figure 16 Map of discovered fields in the Pacific OCS Region (offshore southern California). (Source Dunkel 2001).

Production Drilling activity offshore of the state of California has been recorded since 1990 and information is freely available via Baker Hughes – Hughes Christianson rig counts. From their data, it is possible to see the average number of rigs per actively drilling per week (Figure 17). Drilling activity has been shown to be steady, with on average 2 - 4 rigs actively drilling per week every year. A peak in activity is seen in 1993 with, on average, 6 rigs actively drilling per week during that year. With dips in activity occurring during 1999 and 2007 when, on average, only 1.5 drilling rigs were active per week.

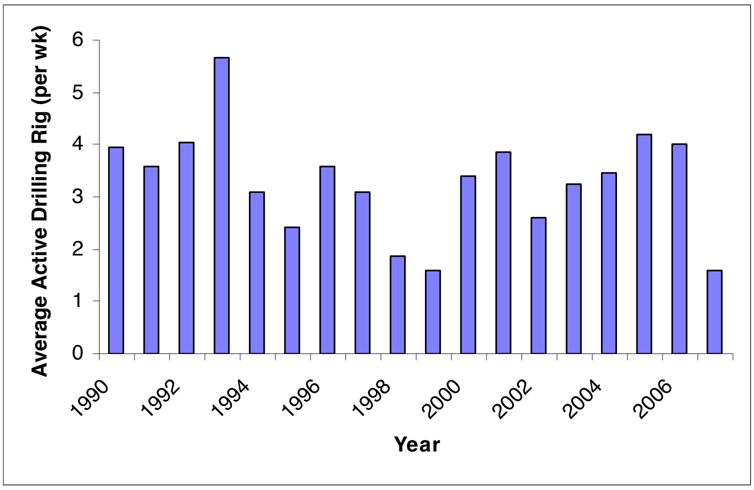

Figure 17 Average Drilling Rigs (per week) between 1990 and 2007 offshore California (Baker Hughes 2007).

There are currently 23 active platforms within the Pacific OCS (MMS 2008). The first platform was constructed during 1967 and, by 1970, five platforms were producing offshore. Platform construction peaked between 1978 and 1984, with 10 platforms constructed within six years. Construction of platforms steadily increased, including the construction of an offshore processing facility in 1980, to number 24 offshore structures by 1989 (Figure 18). Decommissioning began in 1994 with the removal of the Santa Ynez OS&T platform; further decommissioning activity is planned for the future and total platform numbers are expected to decrease (Minerals Management Service, US Government 2008).

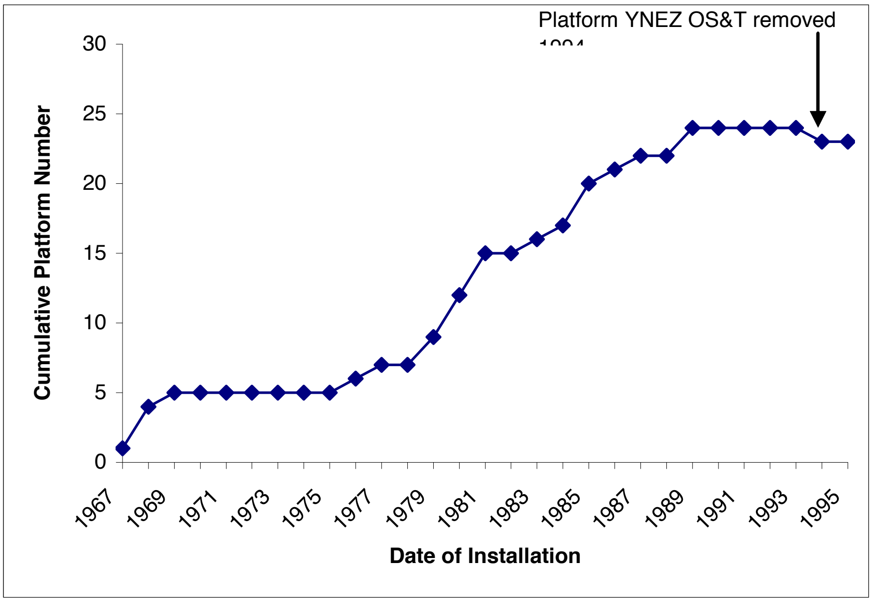

Figure 18 Cumulative Platform number over time offshore of California (Source Minerals Management Service, US Government).

For the platforms constructed off the coast of California, there has been a trend of moving into deeper offshore waters in recent years. Figure 19 shows platform water depth and distance from shore, with the date of installation. The two most recent platforms have been constructed in the deepest water depth, > 300 m, taking advantage of improved technology that allows viable exploration and production at depth. All platforms are found relatively close to shore, 7 - 19 km distance, with a slight trend of moving further offshore over time.

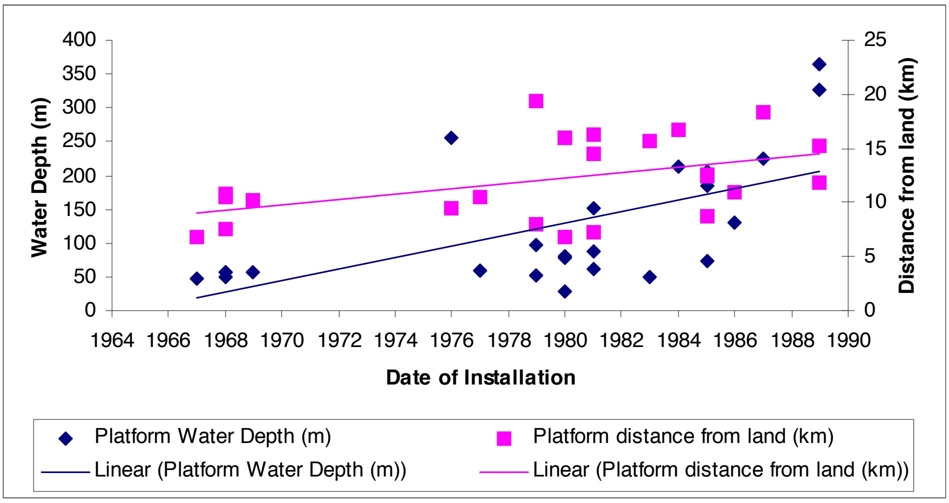

Figure 19 Platforms over time with water depth (ft) and distance from land (miles). (Source Minerals Management Service, US Government).

Exploration Seismic data have been obtained from the Minerals Management Service as part of the conditions of survey permits. However, these data can only provide a rough estimate of the actual activity carried out and cannot represent the true amount of data acquired by the industry. This is because of the volume of data, concerns over data quality, a lack of resource within the Minerals Management Service to process all the data and constraints over when pre-lease data can be released, therefore constraining the amount of data readily available in the public domain.

Of the data obtained it shows that activity has occurred since 1968, with early activity solely undertaken using 2D survey techniques (Figure 20). The seismic activity shows three peaks in 2D survey activity; pre-1977, 1982 - 1984 and 1988, and then an increase in 3D activity after a period of inactivity. The levels of 2D activity coincide with platform construction, with the majority of seismic and platform construction occurring before 1990. More recently 3D surveys have been carried out, these are restricted solely to the Southern California area (Figure 20) and, although the surveys do not coincide with any platform construction, they represent a renewed interest in Southern California by the oil & gas industry.

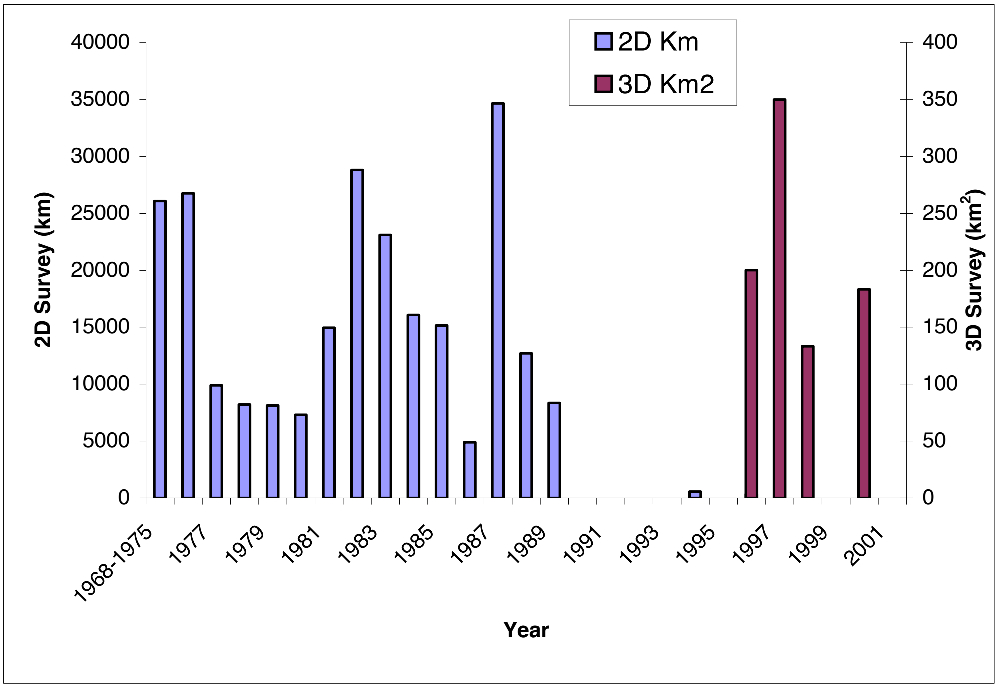

Figure 20 Total km of 2D Surveys and Total km^2 of 3D Surveys carried out within the Pacific OCS between 1968 and 2002 (adapted from Dellagiarino *et al.* 2002).

Figure 20 shows seismic activity over time for the whole Pacific OCS. However, it is difficult to obtain data to extrapolate seismic activity into specific geographical areas. Table 11 provides a breakdown for total 2D survey activity over the Pacific OCS giving an indication of where seismic activity is concentrated.

Table 11 2D Surveys within the Pacific Planning Areas between 1968 and 2002 (Dellagiarino *et al.* 2002).

Planning Area	2D Survey in km
Southern California	157,420
Central California	38,892
Northern California	35,188
Washington-Oregon	14,816
Total	246,022

While oil & gas activity is predominately focused within Southern California, seismic activity has occurred as far north as Washington - Oregon. Figure 21 shows the distribution of the seismic surveys contained within the Dellagiarino *et al.* (2002) report, showing that 3D surveys have only occurred within the Southern California planning area, highlighting the concentration of activity within this area.

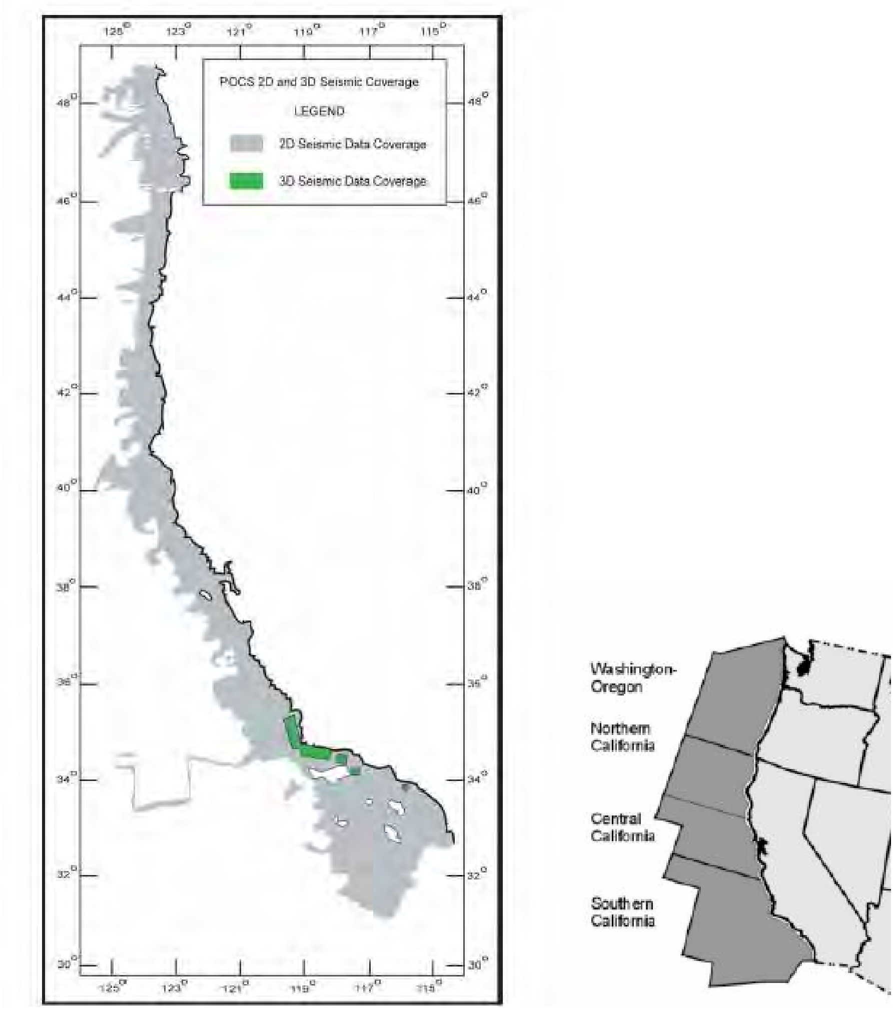

Figure 21 2D and 3D Seismic coverage, and Pacific OCS Planning areas (Adapted from Dellagiarino *et al.* 2002).

6.3 Overview of cetaceans off California

Carreta *et al.* (2007b) give the most recent overview of cetaceans occurring off the coasts of California, Oregon and Washington State. Table 12 summarises this information. It can be seen that cetacean diversity is quite great, ranging from the small harbour porpoise to the largest animal on the planet, the blue whale.

Table 12 Overview of cetacean species occurring off the coast of California, Washington and Oregon (from Carreta *et al.* 2007b; Carreta *et al.* 2007a).

Species	Range / Stock	Timing	Numbers
	Odontocetes		
Sperm whale (*Physeter macrocephalus*)	California/Oregon/Washington	Year round	2,265 (0.34)*
Pygmy sperm whale (*Kogia breviceps*)	California/Oregon/Washington	Unknown	247 (1.06)
Dwarf sperm whale (*Kogia sima*)	California/Oregon/Washington	Unknown	Unknown

Species	Range / Stock	Timing	Numbers
Killer whale (*Orcinus orca*)	Eastern North Pacific Offshore Stock – Southeast Alaska to California	Year round	422*
	Eastern North Pacific Southern Resident Stock - Queen Charlotte Islands in North to Monterey Bay in South	Year round	89
Short-finned pilot whale (*Globicephala macrorhynchus*)	California/Oregon/Washington	Variable	245 (0.97)*
Baird's beaked whale (*Berardius bairdii*)	California/Oregon/Washington	Mainly late spring to early fall	313 (0.55)*
Mesoplodont beaked whales (*Mesoplodon* spp.)	California/Oregon/Washington	Unknown	1,024 (0.77)*
Cuvier's beaked whale (*Ziphius cavirostris*)	California/Oregon/Washington	Year round suspected	2,171 (0.75)*
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	California/Oregon/Washington	Year round	25,233 (0.25)*
Risso's dolphin (*Grampus griseus*)	California/Oregon/Washington	Year round	12,093 (0.24)*
Short-beaked common dolphin (*Delphinus delphis*)	California/Oregon/Washington	Year round	48,7622 (0.26)*
Long-beaked common dolphin (*Delphinus capensis*)	California Stock	Year round	1,893 (0.65)*
Striped dolphin (*Stenella coeruleoalba*)	California/Oregon/Washington	Year round? (Only summer/fall survey)	23,883 (0.44)*
Bottlenose dolphin (*Tursiops truncatus*)	California Coastal Stock	Year round	323 (0.13)
	California/Oregon/Washington Offshore Stock	Year round	3,257 (0.43)*
Northern-right whale dolphins (*Lissodelphis borealis*)	California/Oregon/Washington	Year round	15,305 (0.32)*
Dall's porpoise (*Phocoenoides dalli*)	California/Oregon/Washington	Year round	57,549 (0.34)*
Harbour porpoise (*Phocoena phocoena*)	Morro Bay Stock	Year round	1,656 (0.39)
	Monterey Bay Stock	Year round	1,613 (0.42)
	San Francisco-Russian River Stock	Year round	8,521 (0.38)

Species	Range / Stock	Timing	Numbers
	Northern California/ Southern Oregon Stock	Year round	17,763 (0.39)
	Oregon / Washington Coast Stock	Year round	37,745 (0.38)
	Washington Inland Waters Stock	Year round	10,682 (0.38)
	Mysticetes		
Humpback whale (*Megaptera novaengliae*)	Washington to wintering grounds in Mexico and central America	Mainly summer	1,396 (0.15)*
Blue whale (*Balaenoptera musculus*)	Largely unknown – possible from Gulf of Alaska to central America	Mainly summer	1,186 (0.19)*
Bryde's whale (*Balaenoptera edeni*)	Eastern tropical Pacific stock	Unknown	Unknown
Fin whale (*Balaenoptera physalus*)	California/Oregon/Washington – likely to extend beyond these waters	Year round but lower in winter and spring	3454 (0.27)*
Sei whale (*Balaenoptera borealis*	Eastern north Pacific stock	Unknown	43 (0.61)*
Minke whale (*Balaenoptera acutorostrata*	California/Oregon/Washington	Year round	898 (0.65)*

*new draft 2007 estimates, remaining data from 2006 SAR's

Despite the great cetacean diversity, the actual number of species that suit themselves for a closer look with regards to E&P industry sound and other factors is rather limited, with many of the odontocete species distributed further offshore (for example sperm whales) or in areas with a rather low E&P industry activity. A number of species are also only sporadically present, such as pilot whales and pygmy and dwarf sperm whales. Looking at the mysticetes, data for Bryde's, sei and minke whales are rather sparse, with probably only minke whales appearing in any numbers. On the other hand, humpback, blue and fin whales have been thoroughly investigated for a substantial amount of time and they overlap in distribution with the E&P industry off the Santa Barbara region and in adjacent waters, although to different degrees (see below). All three species are also known to produce quite elaborate vocalisations that are well within the range of E&P related sound (for an overview see Richardson *et al.* 1995).

In this particular case study, we are going to focus on humpback, blue and fin whales for the following reasons:

- All three species belong to the low-frequency group of cetaceans that is of special concern when looking at potential impacts from E&P industry sound (see Southall *et al.* 2007),
- the species are well studied in these waters and stock assessment information is comprehensive over a number of years,
- their distribution overlaps with that of the oil & gas industry in the area, and

- all three species are listed as endangered under the US Endangered Species Act of 1973. They are all also listed as ‘depleted’ under the Marine Mammal Protection Act of 1972 and blue whales of the North Pacific stock are also IUCN Red Listed as “Lower risk/conservation dependent”.

Since all three species have some general features in common (overlap in dietary preferences, sound spectrum (to some degree), and other life history parameters, etc.), our approach in this case is a cumulative one, looking at all three species together.

6.4 Stock assessment of humpback, blue and fin whales

6.4.1 Population structures

All three species are represented off the Californian coast as sub-populations within larger populations / stocks. Humpback whales form several sub-populations within the North Pacific, with summer feeding grounds from southern California up to Alaska and with breeding grounds off Mexico and Hawaii. The blue whale population off California, Washington State and Oregon belongs to the North Pacific stock that is currently comprised of approximately 3,000 animals (Carreta *et al.* 2007a; for a detailed species description see www.nmfs.noaa.gov; for information on acoustic repertoires and morphometric features see Stafford *et al.* 2001; Gilpatrick *et al.* 1997). The waters off California represent an important feeding area for blue whales in summer and fall (autumn) (Carreta *et al.* 2007b). As can be seen in Figure 22, blue whales are widely distributed off California with a relatively high concentration south off San Francisco

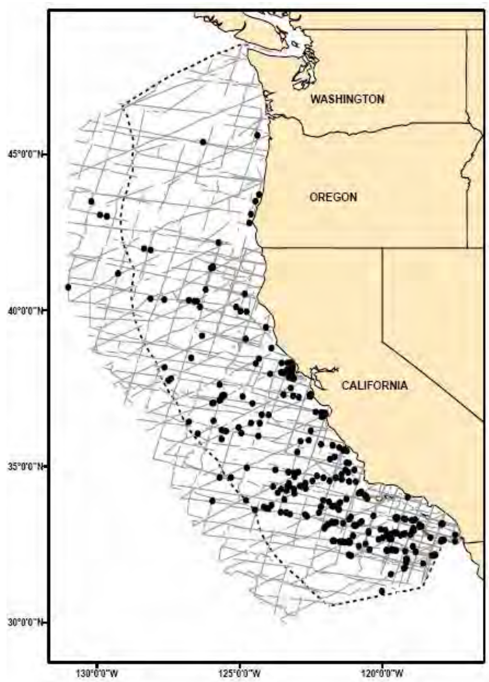

Figure 22 Blue whale sightings locations based on aerial and summer/autumn shipboard surveys off California, Oregon and Washington 1991-2005 (taken from Carreta *et al.* 2007b).

For fin whales, information on population structure is insufficient and, in principle, three stocks are recognised in the North Pacific, with the current number of animals unknown[14]. Seasonal patterns of abundance of fin whales are less well understood than those for both humpback and blue whales, yet some observations indicate a higher presence in summer and fall off California compared to spring and winter (NMFS 2006; Carreta *et al.* 2007b).

6.4.2 Population size and Potential Biological Removal (PBR)[15]

The most recent assessments give an abundance estimate of 1,396 (CV = 0.15) for humpback whales based on an unweighted geometric mean of 2002 / 2003 mark-recapture results, and 2001-2005 line transect estimates. For blue whales the estimate is 1,186 (CV = 0.19) and is also based on a combination of mark-recapture and line transect data. Fin whales appear in higher numbers than both humpbacks and blue whales, with 3,454 individuals present between 2001 - 2005, based on line transect estimates (CV = 0.27; all data from Carreta *et al.* 2007b). Potential biological removals - indicating number of animals that can be 'taken' without harming the population - are 2.5 in humpbacks, 1.0 in blue whales, and 16 in fin whales (Carreta *et al.* 2007b).

6.4.3 Demographic variables

Calambokidis & Barlow (2004) observed 17 humpback whale mothers with calves in 2003, accounting for 4.4% of the individuals identified in that year. They note that this relatively low observation rate is consistent with observations from previous years. However, survey effort was higher in late summer, when some of the calves might have been weaned and difficult to recognise as such. No data on sex ratio or age classes in any of the three species are provided, but there is no mention of sexual segregation in any publication that we are aware of, indicating that male and females occur in relatively equal proportions (for data from stranding, see Norman *et al.* 2004; acoustic studies in blue whales with reference to sexes see Oleson *et al.* 2007b,Oleson *et al.* 2007a). Natural mortality (plus serious injury) is low in all species (humpbacks: > 2.2 individuals per year; blue: 0.6; fin: 1.4; (Carreta *et al.* 2007a).

6.4.4 Migrations / seasonality

Humpback whales move between summer feeding grounds off California, Washington State and Oregon and winter breeding grounds of Mexico and Hawaii (Carreta *et al.* 2007b). Blue whales are seasonal in distribution too, with summer areas off California, especially concentrated in the Monterey Bay area, and winter breeding areas near Mexico and Costa Rica (Calambokidis *et al.* 1990; Mate *et al.* 1999; Stafford *et al.* 2001). Yet it is interesting to note that blue whales are thought to feed also on breeding grounds (Reilly & Thayer 1990; Palacios 1999), indicating that they are not totally relying on the resources offered on the summer grounds. This might explain their rather opportunistic shifts in distribution that have been linked to shifts in prey abundance (see above). Fin whales are less migratory than both humpbacks and blue whales, as they have been observed off California all year round, with the highest numbers in summer and fall (NMFS 2006). Passive acoustics have revealed a year round trend as

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[14] In 1973, Ohsumi and Wada estimated the North Pacific fin whale population to be comprised of 13,000-18,00 animals.

[15] Potential Biological Removal (PBR) Level: defined by the Marine Mammal Protection Act (US) as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population (details see www.nmfs.noaa.gov).

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well, though calling frequency is highest between September and March (Moore *et al.* 1998; Watkins *et al.* 2000).

6.4.5 Population trends

If we try to discern population trends in all three species off the Californian coast, we see a quite complex picture and a good example of uncertainties that can persist even when sampling effort is comparably high. According to Carreta *et al.* (2007b), systematic line transect surveys have been undertaken in 1996, 2001, 2005 and 2007 with additional photo-identification studies for humpback whales and blue whales since the 1980s. Yet population trends are far from certain. Table 13 lists the various estimates for the three species published in the NOAA stock assessments since 1995, including the most recent one from 2007.

Table 13 Overview of abundance estimates for three species of baleen whales off California, Oregon and Washington according to NOAA stock assessment reports 1995-2007 (after Barlow *et al.* 1995 , Barlow *et al.* 1997; Forney *et al.* 2000; Carreta *et al.* 2001, Carreta *et al.* 2003, Carreta *et al.* 2004; Carreta *et al.* 2007a; *: mark recapture estimate, **: line transect estimate; ***: combination of mark recapture and line transect estimates ": numbers unchanged ^: survey area for fin whales different from 1995-2000 surveys; Value in parentheses: CI).

Species/ Year	1995	1996	1999	2000	2001	2003	2004	2007
Humpback whale	597 (0.07)*	"	843 (0.06)*	905 (0.06)*	1,024 (0.10)*	1,314 (0.30)**	"	1,396 (0.15)***
Blue whale	2,134 (0.27)***	1,785 (0.24)***	"	1,940 (0.15)***	"	1,480 (0.32)***	1,744 (0.28)***	1,186 (0.19)***
Fin whale	935 (0.63)*	933 (0.27)*	"	1,236 (0.20)*	1,851 (0.19)*^	3,279 (0.31)*^	"	3,454 (0.27)*^

It seems that the most straightforward case when it comes to interpreting trends is that of the humpback whales. As can be seen in Table 13, there is a general upward trend in abundance of humpback whales off California, which is well in line with a general increase of the North Pacific population which recovered from 1,200 individuals in 1966 to more than 6,000. Some estimates are even as high as 8,000 whales, which is about 40 - 50% of the pre-whaling population estimate (Carreta *et al.* 2007b). Yet, Calambokidis (2004) noted a drop in numbers - although it was not statistically significant - in 1999/2000 and 2000/2001, and an increase thereafter (Figure 23). Interestingly enough, this increase might have been the result of an influx / recruitment of individuals from other areas, since there was a relatively high proportion of 'new' whales seen in 2003 (Calambokidis *et al.* 2004). Overall, numbers of humpback whales are increasing off California at a rate of 8% per year.

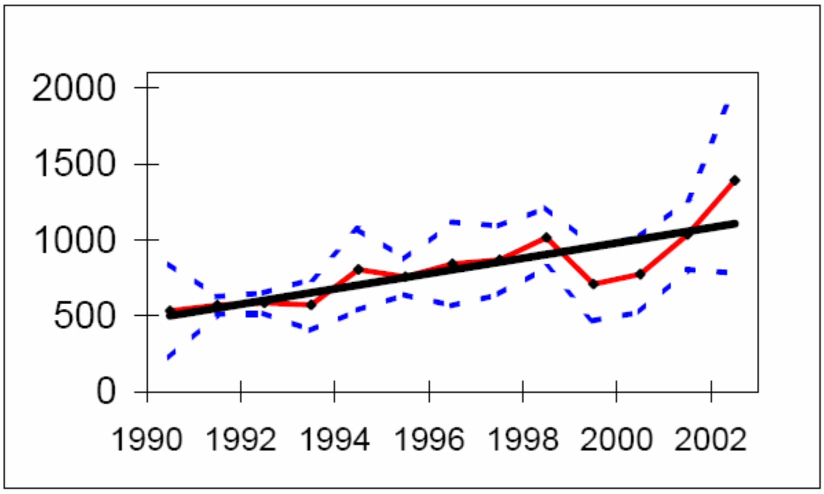


Figure 23 Mark recapture estimates of the abundance of humpback whales feeding off California, Oregon and Washington based on photo-identification studies (Calambokidis *et al.* 2004 , Dotted lines indicate +/- standard errors for each estimate. Straight, bold line indicates linear regression (take from Carreta *et al.* 2007a (x-axis = years y axis = number of animals)).

For fin whales, the numbers in the various reports indicate an increase from 1979/80 and 1996 although, as noted by NMFS (2006), this trend was not statistically significant. The recent estimates have been made over a larger area and are difficult to compare to the 1995/1996 data and, since abundance estimates are constantly being re-assessed, comparisons based on the NOAA reports are quite challenging. According to Carreta *et al.* (2007b), population estimates from line transect surveys in an area out to 300 nautical miles in 1996, 2001 and 2005 have been 2,951, 3,636 and 3,281 (CV = 0.31, 0.5 and 0.25), respectively, with no population trend discernable. The presence of blue whales off California is noteworthy in the light of their rarity in these regions prior to the late 1970s; Calambokidis (1995) concluded that such changes in distribution reflect a shift in feeding from the more offshore euphausiid, *Euphausia pacifica*, to the primarily neritic euphausiid, *Thysanoëssa spinifera*. Population estimates derived from line transect surveys then declined between 1991 and 2005 (Figure 24) and stayed level until 2002 for the mark-recapture data, indicating that there is considerable interannual variability in the fraction of the North Pacific population that utilizes California waters during the summer and spring. Using passive acoustic techniques, Oleson *et al.* (2007a) observed an increase in the length of the overall calling season in blue whales recorded off Cortez and Tanner Banks from 2000 to 2004, and conclude that this might be due to increased prey availability in the Southern California Bight relative to more southerly feeding areas. Calambokidis *et al.* (2004) suggest that the number of blue whales off the Californian coast hasn't been increasing, as is the case for humpback whales in that area.

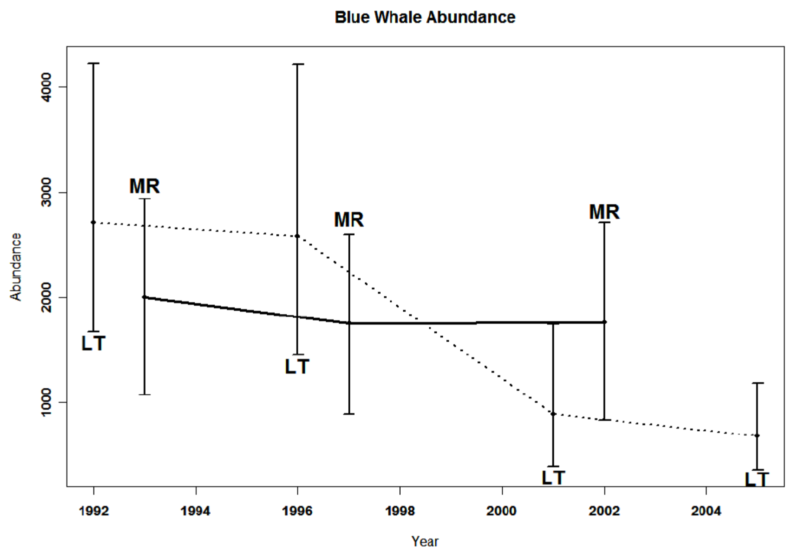


Figure 24 Estimates of abundance from vessel-based line transect and mark-recapture (MR) surveys conducted in California waters 1991-2005 (MR = Mark recapture, LT = Line transect).

6.5 Other factors affecting stocks

6.5.1 Whaling

Historically, whaling is the factor that affected all three stocks to the highest degree. The North pacific humpback whale stock originally comprised 15,000 animals and was reduced to 1,200 in 1966. About 3,600 whales were taken off California. A total of 9,500 blue whales were killed in the North Pacific between 1910 and 1965, of which 2,000 were taken off the west coast of North America, leaving a stock of approximately 2,000 individuals in the entire North Pacific in 1970 (Reeves *et al.* 1998). Finally, the original North Pacific stock of fin whales of 42,000 - 45,000 was down to 13,000 - 18,000 in the beginning of the 1970's (NMFS 2006; Carreta *et al.* 2007b).

6.5.2 Predation

Killer whales are know to hunt all three species (overview by Jefferson *et al.* 2001). A high proportion of the blue whales in the Gulf of California bear injuries or rake-like scars that are the result of encounters with killer whales, although the extent to which such attacks are fatal is unknown (Sears 1990). In a systematic investigation of identification photographs from 1990 - 1993, Steiger *et al.* (2008) found that 20% of humpback whales off California bore rake-marks caused by interactions with killer whales. The proportion of marked individuals for the wintering area off Mexico was even higher (26%). Steiger *et al.* (2008) therefore concluded that killer whales attack a relatively high proportion of humpback whales, and that predation by killer whales has the potential to be a major cause of mortality in humpbacks. Yet, based on the results of others' studies (Clapham 1996; Naessig & Lanyon 2004), the authors also hypothesise that attacks are made primarily on calves at the wintering grounds. This would contradict a recent and hotly debated hypothesis put forward by Springer *et al.* (2003) that the primary prey of 'transient' type killer whales in the North Pacific originally constituted large baleen whales and sperm whales (for a reply to this, see Wade *et al.* 2006). It has to be noted here that the data presented by Steiger *et al.* (2008) are not only relatively old, but also span a comparatively short period of time (4 years). It would be interested to compare the pre-1993 values to newer photographs to get a better idea of the more recent impression of scars on the whales. It should also be emphasised that all three species have developed anti-predator tactics allowing them to either fight back (humpback whale), or outrun the attackers (blue and fin whales, (Ford & Reeves 2007) making attacks on adult whales energetically costly for killer whales. Dietary preferences of mammal hunting killer whales in the Pacific Northwest suggest that predation of large whales by killer whales is relatively low (Ford & Ellis 1999).

6.5.3 Fisheries

Incidental catches and entanglement in fishing gear Recent data indicate that incidental catches and entanglement in fishing gear is of concern only for humpback whales.[16] Caretta *et al.* (2007) lists individual observations of whales entangled in fishing gear. Yet, the annual number of animals killed due to entanglement in fishing gear is 1.8 for humpback whales: and 1.8 and nil for blue and fin whales, respectively.

6.5.4 Shipping

Shipping sound The dominant source of sound from commercial vessels is often the ship's propeller, which at a certain speed causes the water around it to cavitate, producing loud, broadband sound. Large commercial ships can produce low-frequency underwater sound in the range of 190 dB re 1 μ Pa, or even louder (Richardson *et al.* 1995). Large ships mainly emit frequencies below 600 Hz (Richardson *et al.* 1995) and it is therefore logical that there is concern about the impact of sound from motorized shipping on baleen whales, due to their use of sound at low-frequencies that overlap with the main frequency band of shipping sound (overview by Richardson *et al.* 1995). This is especially true for blue and fin whales, as the sounds they emit are mainly in frequencies well below 100 Hz where ship sound can be loudest (Watkins *et al.* 1987; Richardson *et al.* 1995; Oleson *et al.* 2007b; Oleson *et al.* 2007a). As well as their songs that are mainly produced during the breeding season (Payne & Payne 1985), humpback whales also emit feeding sounds that are relatively low in frequency (Thompson *et al.* 1986). Looking at the emitted sound by ships on the one hand and the frequencies of the sounds used by the three species on the other, it is clear that there is considerable potential for masking that might interfere with feeding activities and / or reduces the range over which individuals can communicate (Richardson *et al.* 1995; Janik 2005). The west coast of North America comprises busy shipping lanes (Figure 25) with the potential to affect low-frequency cetaceans.

[16] It should be noted that despite the lack of observed fisheries interactions in the last decade, incidental take in fisheries might threaten the three species for two reasons. First, past records of entanglements suggest that interaction with fishing gear may affect the three species. Second, entanglement rates may be underestimated because whales may break through or carry away fishing gear, perhaps suffering unrecorded subsequent mortalities or serious injuries.

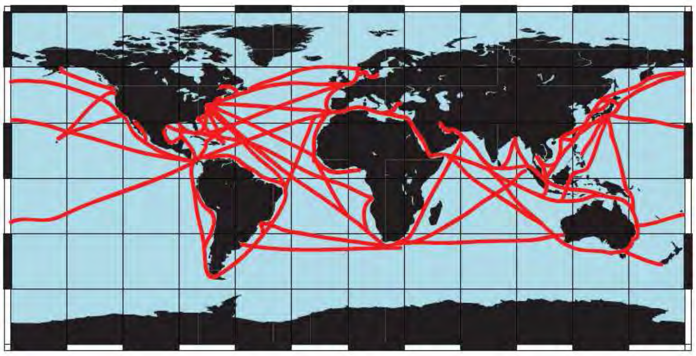


Figure 25 Major commercial shipping lanes in the worlds oceans (from MMC 2007).

Especially off the Californian coast, shipping density is high, for example, in the area used by blue whales in summer and fall: most California coastal vessel traffic passes through the Santa Barbara Channel en-route to major ports on the U.S. west coast. Exceptions to this are supertankers which, for safety reasons, generally avoid the channel by travelling to the south of the Channel Islands. Vessel transportation within the channel includes many types of vessels, including tankers, container ships, bulk carriers, military vessels, research vessels, cruise ships, tugs and tows, commercial fishing boats, and other commercial vessels. Between San Francisco Bay and the Port of Los Angeles (POLA) and the port of Long Beach POLB, large vessels make an estimated 4,000 coastal transits per year (approximately 11 per day). About 20 % of these transits are made by crude oil tankers. Most of the remainder is large commercial vessels greater than 300 gross tons, including container ships and bulk carriers (www.noaa.gov; for detailed information see also Southall 2005, MMC 2007, Figure 26).

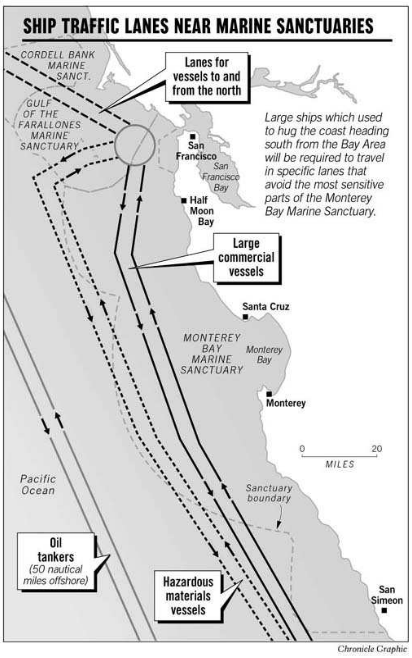


Figure 26 Placement of major shipping lanes off the Californian coast (source: San Francisco Chronicle, June 01, 2000).

One possible effect of shipping sound is the potential for masking of biologically relevant signals. However, the issue has not been well researched to date. Most investigations have been concerned with modelling exercises used to predict the potential masking zone, which can be quite large (e.g. Erbe & Farmer 2000; Erbe 2002;

Janik 2005; Thomsen *et al.* 2006b). This is partly due to the difficulties in selecting parameters for assessing 'disturbance' by masking. For example, behavioural reactions might be a poor indicator for masking, as animals might have to travel large distances in order to avoid it and reported behavioural reactions are equivocal at best: Gray whales (*Eschrichtius robustus*) ceased to use a particular breeding lagoon after an increase in industrial activities, including shipping and dredging (Bryant *et al.* 1984). However, no studies were made of the increase in sound or of the received sound pressure levels. Nowacek *et al.* (2004) found no change in diving behaviour of Northern right whales (*Eubalaena glacialis*) during playbacks of vessel sound (RL = 140 dB re 1μPa) indicating some habituation to shipping sound in the studied individuals. One way to compensate for masking is a change in acoustic behaviour, for example, by increasing the pitch or the duration of a call, that has only been investigated in response to low-frequency sonar (see below). To summarise: masking due to shipping sound is, in theory, an issue for all three species, empirical studies are non-existent and the effects of shipping sound on humpback, blue and fin whales are impossible to assess at present.

Ship strikes Mortality due to ship strikes might be of relatively high concern in all three species. Between 2000 and 2004, there were five injuries and three mortalities of unidentified large whales attributed to ship strikes off the Californian coast. Additional mortality might be not noted because the killed whales do not strand on the coastline (see footnote). On a larger scale, in the eastern North Pacific, ship strikes were implicated in the deaths of blues whales in 1980, 1986, 1987, 1993 and 2002. The average number of mortalities in California attributed to ship strikes is estimated to be 0.2 per year for humpback whales, 0.6 per year for blue whales, and 1.4 for fin whales (Carreta *et al.* 2007a).

6.5.5 Tourism

Whale watching Since the introduction of this ever-increasing industry in the 1970s, the potential effects of whale watching have been intensively debated within the scientific community. Effects can principally come in two ways, 1) sound of the vessels may affect the behaviour of the observed animals (see Erbe 2002 for an estimation of impact ranges), 2) movements of the observation vessel might result in startle or even flight responses. Both effects are difficult to separate, but reactions of odontocete cetaceans to vessels are well documented in the literature (e.g. Richardson *et al.* 1995; Janik & Thompson 1996; Nowacek *et al.* 2001; Williams *et al.* 2002; Hastie *et al.* 2003 ; Bejder *et al.* 2006a). Yet it is largely unknown how the rather temporary changes in behaviour translate into any significant biological effects at higher levels (e.g. population level effects). Williams *et al.* (2006) speculate on the energetic costs of behavioural disruptions in killer whales; yet, compensatory behaviour of the animals - for example foraging at other times - was not taken into account. Bejder *et al.* (2006b) showed that whale watching led to a decrease in size of one rather small population of bottlenose dolphins off Australia. Behavioural reactions to smaller observational vessels can occur in baleen whales as well, although there is limited information on this in the literature (Corkeron 1995).

Potential effects from whale watching should be monitored closely: whale watching is one of the major tourist attractions off the west coast of the US, with the highest concentrations of the industry off California. In 2001, there were at least 65 operators and more than 140 vessels operating off California, with a relatively high concentration off Monterey Bay, the Santa Barbara channel and southern California, in areas of blue whale concentration. Additionally, all three species are being watched in their wintering grounds, with the highest activity off the coast of Mexico (39 operators, 114 vessels, > 100,000 whale watchers; Hoyt 2001). To summarise, documented effects of whale watching on baleen whales are limited, yet the sheer size of the business might lead to more critical views on the issue in terms of effects.

6.5.6 Pollution

Contamination with organochlorines etc. There is only limited information on levels of contaminants in the three species. Humpback whales and blue whales off the Gulf of St. Lawrence carry concentrations of PCB and DDT in their blubber, yet, the levels are two orders of magnitude lower than those reported for beluga whales from the same region (Metcalfe *et al.* 2004). It is likely that all three species are less susceptible to accumulation of organochlorine or metal contaminants, compared to odontocetes, due to their more or less planktivorous diet and hence their relatively low trophic level feeding (for a systematic investigation in trophic levels in cetaceans see Pauly *et al.* 1998).

6.5.7 Competition

Food depletion by fishing industry The mainly planktivorous diet of all three species indicates that food depletion due to over fishing is only of minor concern. Californian humpback whales feed on krill (*Euphasia* spp.) and smaller fish (herring and others; NMFS 1991). Fin whales in the North Pacific prefer euphausiids (*Euphausia pacifica*, *Thysanoessa longipes*, *T. spinifera*, *T. inermis*), large copepods (*Calanus cristatus*), followed by schooling fish such as herring, walleye pollock, and capelin (NMFS 2006). The primary and preferred diet of blue whales is krill (euphausiids). In the North Atlantic, blue whales feed on two main euphausiid species: *Thysanoëssa inermis* and *Meganyctiphanes norvegica*. In addition, *T. raschiiand* and *M. norvegicahave* have been recorded as important food sources for blue whales in the Gulf of St. Lawrence. In the North Pacific, blue whales prey mainly on *Euphausia pacifica* and secondarily on *T. spinifera*. While other prey species, including fish and copepods, have been mentioned in the scientific literature, these are not likely to contribute significantly to the diet of blue whales off California (NMFS species description).

Interspecific competition Although theoretically possible due to similar dietary preferences, no information exists on competition between the three species (Reeves *et al.* 1998; NMFS 2006). Yet, we have to be reminded here that populations are probably well below carrying capacity due to whaling, so it is likely that competition is reduced.

6.5.8 Industrial activities

Marine dredging Dredging, for example to extract geological resources such as sand and gravel, to maintain shipping lanes, and to route seafloor pipelines is frequent along the US west coast (see mms.org for some information). Dredging emits continuous broadband sound during operations, mostly in the lower frequencies. In one investigation, estimated source levels ranged from 160 to 180 dB re 1 μPa at 1 m (maximum ~ 100 Hz). Bandwidth was between 20 Hz and 1 kHz (limited by the recording equipment; most energy was at frequencies below 500 Hz; Richardson *et al.* 1995). In a recent study, Defra (2003) measured sound spectrum levels emitted by an aggregate dredger at different distances, and found most energy to be emitted at frequencies below 500 Hz. Richardson *et al.* (1995) provided an overview of investigations into behavioural responses of cetaceans to dredging. Bowhead whales (*Balaena mysticetus*) did not apparently respond to a suction dredge in one study, but individuals avoided these dredges when exposed to 122 - 131 dB re 1 μPa (or 21-30 dB above ambient noise) in another investigation (see also Richardson *et al.* 1990).

Gray whales (*Eschrichtius robustus*) ceased to use a particular breeding lagoon after an increase in industrial activities, including shipping and dredging (Bryant *et al.* 1984). However, it is not clear if this was due to sound or the increased presence of ships; no studies were made of the increase in sound or of received sound pressure levels. There are, to our knowledge, no recent studies (post 1995) on the effects of dredging sound on marine mammals. As, in principle, dredging sound might affect our three target species, an assessment is indicated, however, no data to undertake a meaningful assessment are currently available.

6.5.9 Military activities - sonars

The US Navy uses the waters around California, Oregon and Washington State quite regularly in naval exercises etc. (see map in Jasny 2005). Most concerns have been expressed over the use of active military sonars and their potential effects on cetaceans during these exercises. Sonars can be categorised into low (<1 kHz), mid (1 to 10 kHz) and high-frequency (>10 kHz), with military sonars using all frequencies (ICES-AGISC 2005). Information on some parameters from sonar currently used by naval ships is given in Table 14.

Table 14 Military sonar systems relevant to beaked whale stranding events (taken from Zimmer 2004).

Sonar model	SURTASS LFA	SLC TVDS LF	SLC TVDS MF	AN/SQS-53C	AN / SQS-56
Stranding event	**none**	**Greece 1996**	**Greece 1996**	**Bahamas 2000**	**Bahamas 2000**
Frequency (kHz)	0.1-0.5	0.45 - 0.65, 0.7	2.8-3.3	2.6, 3.3	6.8, 7.5, 8.2
SPL (dB re 1μPa at 1 m)	240	214-228	223-226	235	223
Pulse duration (s)	6-100	2+2	2+2	0.5-2	-
Pulse interval (s)	360-900	60	60	26	26
Depth (m)	122	60-90	60-90	7.9	6.1

It can be seen that source levels are generally very high and, looking at the emitted frequencies, we might want to focus our assessment on the Surtass LFA, that also utilises a considerable ping duration. Research on LFA is relatively advanced and studies have revealed that:

- Foraging blue and in whales off California were unaffected by playbacks of LFA with received levels of 140 dB re 1 μPa RMS. Yet the sample size was small, and the animals were thought to be rather transitory as re-sightings were rare (Croll *et al.* 2001)
- Humpback whales exposed to RL of 120-150 dB re 1μPa increased the duration of their songs, indicating a compensatory effect. Five out of 18 whales ceased singing (Miller *et al.* 2000, see also Fristrup *et al.* 2003).

Much attention has been drawn recently to stranding events of cetaceans - mostly beaked whales - that occurred at the same time as military exercises (reviewed in ICES-AGISC 2005; Nowacek *et al.* 2007). Yet, considering the case study we are undertaking here, concerns might be not as high as in other areas, as the documented stranding events only involved baleen whales in very limited numbers (see Table 1.3 in

Jasny 2005). There is also mitigation in process. Just recently, a Federal court in Los Angeles ordered the Navy to refrain from using mid-frequency sonar within 12 miles of the coast of southern California. The court also ordered relatively strict mitigation measures.[17] For other mitigation measures employed in naval operations worldwide, see ICES-AGISC (2005).

To summarise: More concern shall be raised about low-frequency than mid-frequency sonar with regards to humpback, blue and fin whales off California. It is true that the results of playback studies are equivocal. Yet, we should bear in mind that controlled playback experiments have to follow animal welfare considerations, and the received sound pressure levels are low compared to the estimated source levels (~ 100 dB). If we consider a relatively high transmission loss of 20 log R (see Urick 1983), a 100 dB reduction in sound pressure level would take 10100/20 m = 100 km. Since many individuals would experience sounds at much closer ranges and therefore at considerably higher sound pressure levels, we have to be cautious in interpreting the results of controlled playback experiments.

6.5.10 Acoustic Thermometry of Ocean Climate (ATOC) 1995-1999

The ATOC project aimed to acoustically measure the oceans temperature. Two sound sources were installed for the first phase of the ATOC feasibility study, one on Pioneer Seamount off central California and one north of Kauai (Hawaii). The signal transmission started in 1995 and ended in 1998 (California) and 1999 (Hawaii) (http://atoc.ucsd.edu/). Transmission of sounds from the transmitting station off Hawaii resumed after 2002 under a different name (the NPAL project). Signal source levels are 195 dB re 1μPa RMS with a centre at 75 Hz (60-90 Hz bandwidth), very much in the range of acoustic signals of all three of the whale species that we are investigating here. In the NPAL project, that has identical characteristics to the earlier ATOC project, there are six-20 minute transmissions (one very four hours), every fourth day, with each transmission preceded by a 5-minute ramp up period (Office of Naval Research Environmental Impact Statement 2001). Nowacek *et al.* (2007) lists the results of the different studies that indicated behavioural response in humpback whales (longer dives, more distance covered during dives) at received levels of 130 dB re 1 μPa RMS in two investigations. The results of these studies indicate rather subtle behavioural reactions by the whales (Nowacek *et al.* 2007) but, again, we have to bear in mind that received sound pressure levels (RL) were rather low compared to the source (see above). Since signal transmission off California ceased ten years ago, any effect of the ATOC system on whales would be of historical nature as animals would have to be very close to the source to be injured (see Southall *et al.* 2007 for exposure levels).

6.6 Response to O&G activity

Peer reviewed studies investigating the effects of seismic surveys in our three species are limited. Richardson *et al.* (1995) summarises the sparse pre-1995 information for the three species and cite two studies with very little (humpback whales) or no documented responses during seismic explorations (blue and fin whales). McCauley *et al.* (2000) found no changes in distribution of humpback whales during 3D seismic surveys, compared to those observed before or after the survey. Yet, they noted

[17] For example, it is mandatory that the Navy spends an hour before it starts any training mission searching for marine mammals in the area and that it continue using shipboard observers and aircraft to monitor for whales and dolphins while the sonar is in use. If any marine mammals are spotted within 2,200 yards of a ship using sonar, the Navy will have to cease its use immediately (LA Times 04.01.2008;

localised avoidance by the whales up to 3 km at modelled RL of 157-164 dB re 1 μPa RMS (32 depth). The authors also noted that several individuals approached a firing airgun to 100 m distance and then swam away, in an apparent investigative attempt, probably because the sound was similar to that produced by breaching individuals (McCauley *et al.* 2000).

6.7 Impact analysis

As can be seen in Table 15, no single factor alone would lead to negative consequences at a population level. High severity - effects that can lead to negative influences on *parts* of the population - was reached for effects associated with predation, fisheries interactions, shipping interactions (ship strikes), pollution and competition, although much uncertainty exists in the latter two cases. Underwater sound can lead to effects of medium severity; yet, much uncertainty exists about the exact nature and range of reactions.

Table 15 Impact analysis for humpback whales, blue whales and fin whales off California (Range: Short: < 100m, medium > 100 m < 5,000 m, long: > 5,000 m; Duration: Short: short-term, Long: long-term; intensity: Low (L), medium (M), high (H); severity, uncertainty(U) and likelihood(LH): Zero, low (L), medium (M), high (H), very high; likelihood U: unknown; for explanations, see chapter 2.2; dark grey: potential impacts on parts of population; light grey: measurable effects above normal fluctuations).

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
E&P industry sound	Seismic exploration	Masking	Long	Short	L	M	H	M
		Response	Long	Short	L	M	H	M
		TTS	Close	Short	M	L	Very H	L
		PTS	Close	Long	H	H	Very H	L
	Construction	Masking	Long	Short	L	M	H	M
		Response	Long	Short	L	M	H	M
		TTS	Close	Short	M	L	Very H	L
		PTS	Close	Long	H	H	Very H	L
	Drilling	Masking	Close	Short	L	L	M	L
		Response	Close	Short	L	L	M	L
Predation	Predation by killer whales	Harassment	Close	Short	M	L	H	M
		Injury	Close	Short	M	L	L	M
		Death	Close	Long	H	H	M - H	M
Fisheries	Entanglement in gear, driftnet	Injury	Close	Long	M	M	H	U
		Death	Close	Long	H	H	H	U
Shipping	Ship strikes	Injury	Close	Long	M	M	M	L
		Death	Close	Long	H	H	M	L
	Shipping sound	Masking	Long	Short	L	M	H	M - H
		Response	M	Short	L	M	H	M
Tourism	Whale	Masking	Long	Short	L	M	H	M

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
	watching sound	Response	M	Short	L	M	M-H	M-H
		TTS	Close	Long	M	M	H	L
Pollution	Contamination	Reduced health	Long	Long	M	H	H	L-M
Competition		Emigration / avoidance	M	Long	H	H	Very H	U
Competition		Starvation	M	Long	H	H	Very H	U
Industrial activities	Aggregate dredging	Masking	Long	Short	L	M	H	U
		Response	M	Short	L	M	H	U
Military	Surtass LFA	Masking	None				L	U
		Response	M	M	M	M	M	U
		TTS	Close	Long	M	M	M	U
		PTS	Close	Long	M	M	M	U
	MF sonar	Masking	None				L	U
		Response	M	M	M	M	M	U
		Injury	Close	Long	M	M	M	U

6.8 Conclusions

E&P industry activity has been high off the Californian coast in terms of seismic exploration and medium in terms of construction and production activities, with platforms located off the southern Californian coast. There are a wide variety of cetacean species off California, of which humpback, blue and fin whales are most suitable for closer study with regards to stock assessments and impact analysis. All three species belong to subpopulations that are parts of larger stocks, although population identity is rather uncertain. Humpback whales have been increasing in numbers since the cessation of whaling with a recovery rate of 8% per annum. Blue whales have inhabited Californian waters only since the 1970s and have undergone shifts in distribution, probably due to prey abundance more than anything else. Fin whales are abundant off California and results from line transect surveys indicate that numbers in that particular area have remained the same since the 1990s. There are several factors besides E&P industry sound that can potentially affect stocks with predation by killer whales; entanglement in fishing gear, ship strikes, interspecific competition for food and pollution potentially the most severe, although the uncertainty of the levels of the effects is very high in almost all cases. This study shows that no single factor will contribute to a negative effect on each of the three species, but that cumulative effects might lead to longer-term effects that might influence population trends.

7 Case study 3: Scotian Shelf: Northern bottlenose whales

7.1 Introduction to the area

The Scotian Shelf surrounds the Canadian province of Nova Scotia, and extends more than 200 nm from the coast at some points. To the north the Laurentian Channel separates it from the Newfoundland Labrador Shelf. To the south it extends to the Fundian Channel (Northeast Channel). The Scotian Shelf has a complex topography consisting of numerous offshore shallow banks and deep mid-shelf basins (see, http://www.dfo-mpo.gc.ca; Figure 27).

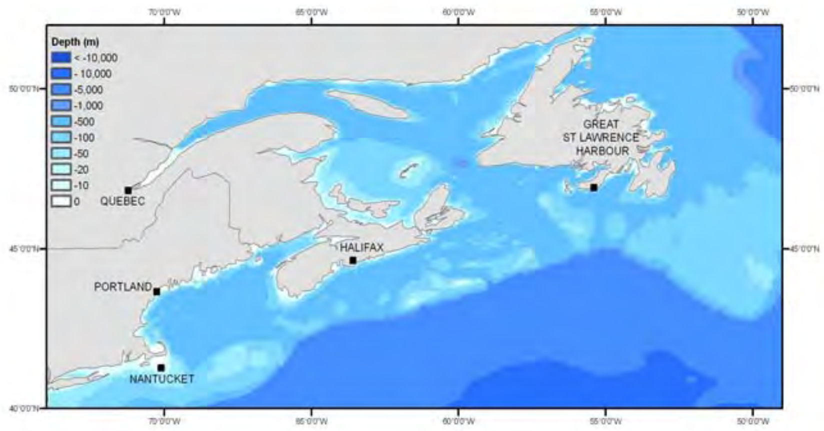


Figure 27 Map of the Scotian Shelf.

7.2 E&P industry activity

Production The oil & gas industry off Nova Scotia has been active since exploration began in 1959. Production within the area is relatively small, with only two offshore projects historically producing oil & gas; the Cohasset-Panuke project producing oil from 1992 to 1999, and the Sable Offshore Energy Project producing natural gas since 1999. Offshore oil & gas activity has been predominantly in the Sable Island area (Figure 28), which lies close to the marine protected area of The Gully. Up until 2000, of the wells that had been drilled, all significant and commercial discoveries have been located in the Sable Island area, approximately 150 km offshore (Canada-Nova Scotia Offshore Petroleum Board 2000). There has been an interest in exploiting the south western area, the Georges Bank, however, a moratorium within this area has been in place since 1988, and has been extended until 2012. More recently, exploration activity has also occurred off the deepwater Scotian Shelf.

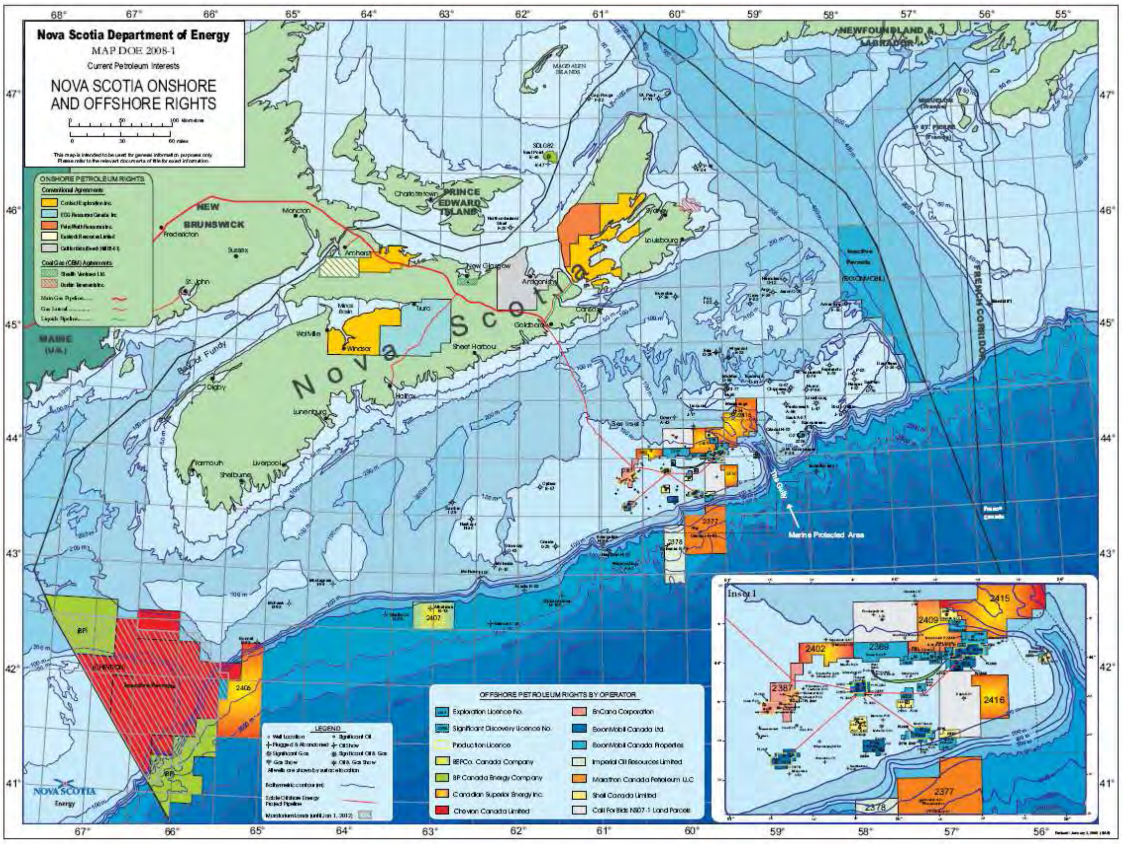


Figure 28 Map of offshore petroleum activity in the Nova Scotia area (source: www.cnsopb.ns.ca/).

The first well drilled on the Scotian Shelf was an exploratory well drilled by Mobil in June 1967, with the first offshore discovery at Sable Island in 1971. Since then, a further 203 wells have been drilled, the vast majority of which (62%) have been exploratory wells (Figure 29). The drilling of development wells began in 1991 and, of the 79 wells drilled since then, 50 have been development wells. The total depth of the wells drilled along the Scotian Shelf varies in depth from 829 m (Shell: Fox) to 6,676 m (Marathon Canada: Crimson).

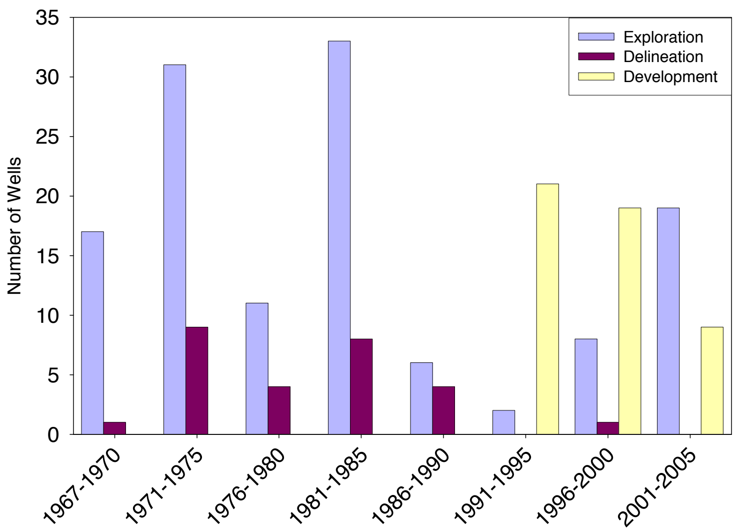


Figure 29 Number of wells drilled along Scotian Shelf 1967-2005.

Exploration Seismic exploration of the Scotian Shelf using 2Dimensional methods first began in 1960 (Figure 30). By 2004, approximately 400,034 km had been covered using 2D seismic mapping techniques. In that time there were three peaks of seismic exploration activity. These were during 1969 to 1972, 1981 to 1984 and 1998 to 1999, when data acquisition covered 96,805 km, 112,058 km and 71,144 km, respectively. Seismic exploration using three-dimensional methods did not begin until 1985 and around 30,000 km^2 had been covered by 2004. The peak of 3D seismic surveying occurred between 1999 and 2001, when 19963.97 km^2 were covered. During 1992 and 1995, no seismic exploration or either sort was recorded.

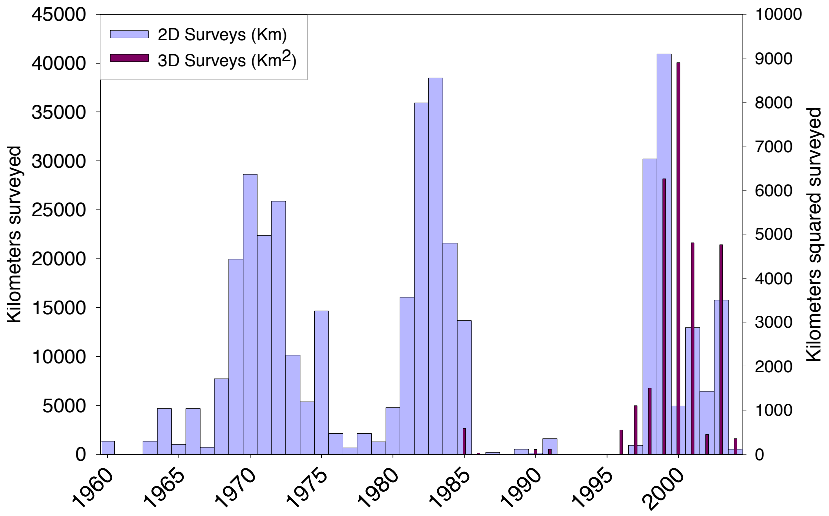
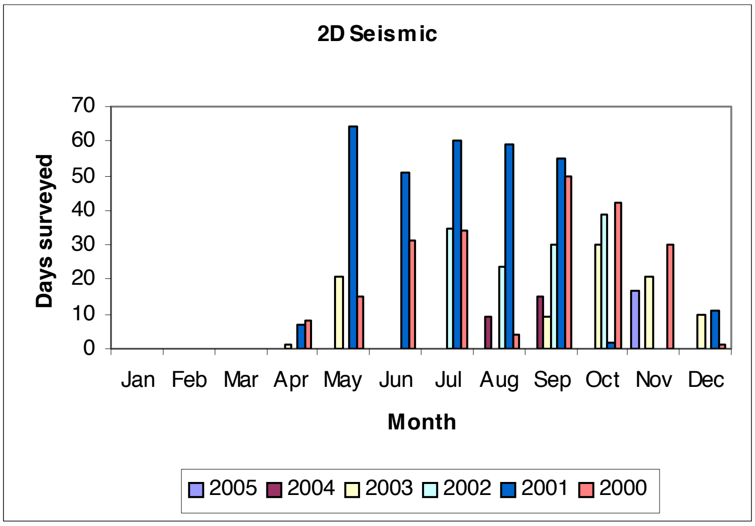


Figure 30 Kilometres of reflection seismic data acquired along the Scotian Shelf 1960-2004.

Seasonal variation in recent seismic activity can be determined using detailed seismic data available from the Nova Scotia Offshore Petroleum Board. By averaging out the days spent to complete a reported survey, and averaging the km recorded during a survey, an indication of seasonal peaks in activity can be determined. Figure 31 shows the days spent surveying per month.



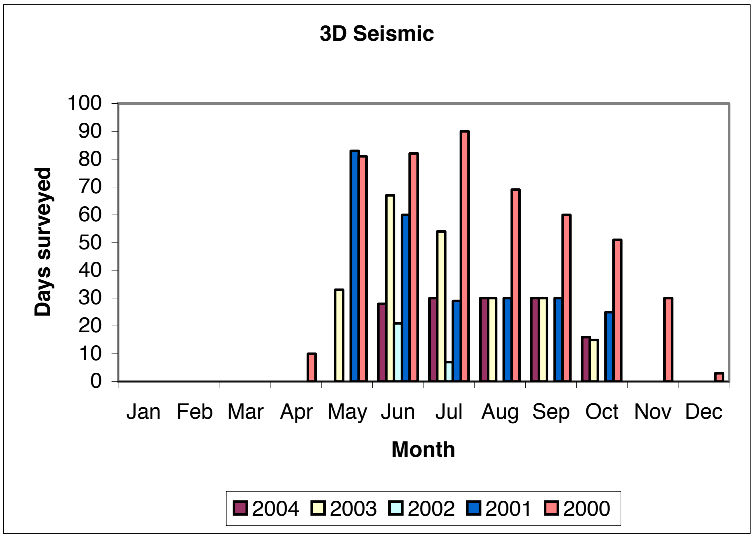
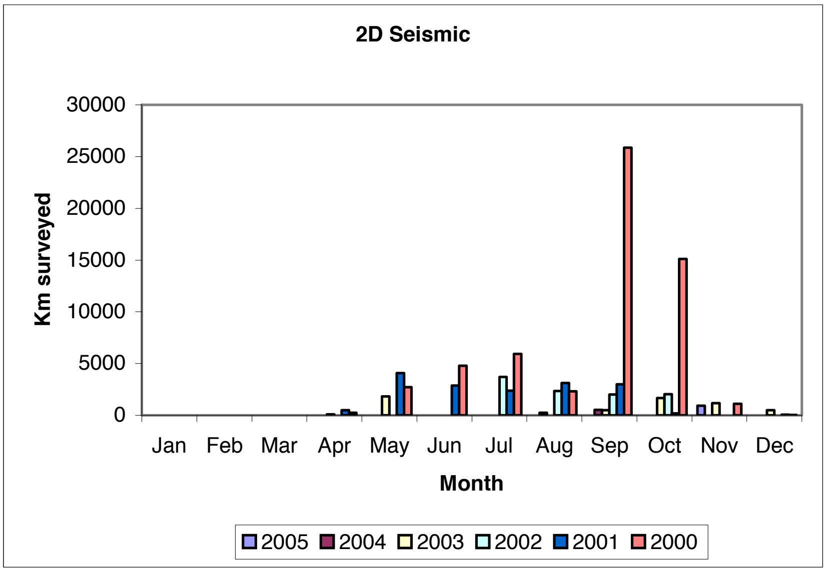


Figure 31 Seasonal variation in seismic 2D days surveyed (2000 – 2005) and 3D days surveys (2000 – 2004) (Adapted from data provided by the Canada – Nova Scotia Offshore Petroleum Board).

Peaks in activity for both 2D and 3D surveys can be seen in 2000 and 2001, showing the highest number of days spent surveying. It can also be seen that little or no activity occurred during the winter months, with high levels of seismic activity occurring over early summer to late autumn. The highest total of survey days occurred during May 2001, with 64 days spent surveying by three vessels for 2D seismic data, and during July 2000, with 90 days spent surveying by three vessels for 3D seismic data.

The total distance of seismic data can be averaged out over the duration of the survey to provide an indication of the distance acquired each month (Figure 32).



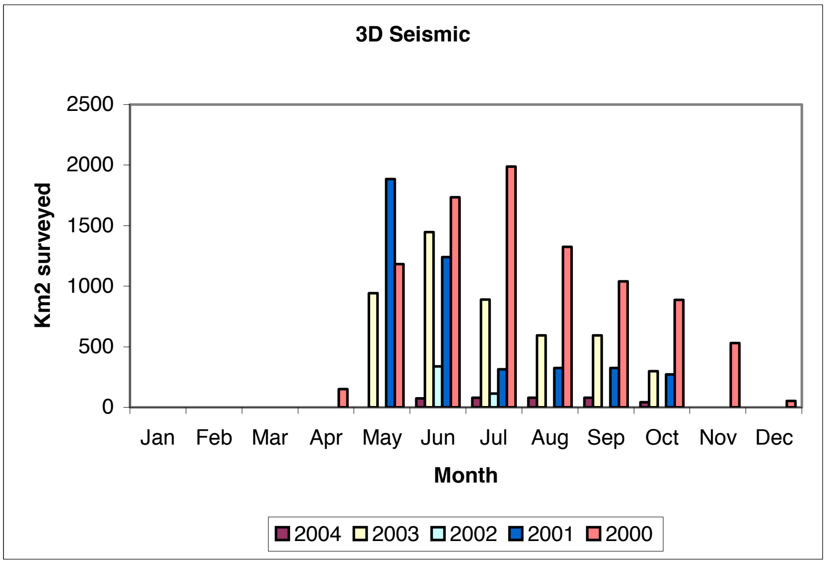


Figure 32 Seasonal variation in distance surveyed, 2D km (2000 – 2005) and 3D km^2 (2000 – 2004) (Adapted from data provided by the Canada – Nova Scotia Offshore Petroleum Board).

Looking at the distance covered within surveys conducted per month, significant peaks in activity can be seen in 2D seismic survey data during 2000, where approximately 25846 km and 15123 km of data were obtained in September and October, respectively. The quantity of 3D data obtained appears to be more evenly spread with the years, with 2000, 2001 and 2003 obtaining the largest area of 3D data.

7.3 Overview of cetacean species off Nova Scotia

A variety of cetacean species are regularly present over the Scotian Shelf, albeit with some seasonal differentiation. The list includes 10 odontocetes and six baleen whales (overview

Table 16 Overview of cetacean species regularly occurring in the Scotian Shelf (Blaylock *et al.* 1995; Davis *et al.* 1998 and therein; Lawson *et al.* 2000; Simard *et al.* 2006; NOAA 2007).

Species	Range	Timing	Number
Odontocetes			
Sperm whale (*Physeter macrocephalus*	Shelf edge and Gully in part.	Year round	Unknown (~10-30 in Gully)
Northern bottlenose whale (*Hyperoodon ampullatus*)	Throughout; core resident area: Gully	Year round	160 in Gully (50% of total; 2005)
Killer whale (*Orcinus orca*)	Throughout but only occasionally	Year round	Unknown
Long-finned pilot whale (*Globicephala melas*)	Throughout shelf edge and slope	Year round except winter	Unknown
Short beaked common dolphin (*Delphinus delphis*)	Throughout and Gully in part.	April-August	1,600 (1995)
Atlantic white-sided dolphin (*Lagenorhyncus acutus*)	Throughout and Gully in part.	Year round; peak in summer	12,000 Gulf of St. Lawrence (Aug. Sep. 1995)
White-beaked dolphin (*Lagenorhyncus albirostris*)	Throughout	Unknown	Unknown
Striped dolphin (*Stenella coeruleoalba*)	Shelf edge and deeper water (Gully)	Summer	Unknown
Bottlenose dolphin (*Tursiops truncatus*)	Throughout but occasionally	Late summer	Unknown
Harbour porpoise (*Phocoena phocoena*)	Throughout, local concentrations	Spring - fall	Unknown
Mysticetes			
Northern right whale (*Eubalaena glacialis*)	Throughout but higher in southern shelf feeding area	April - November	Part of Western NA population (~300, 2007)
Humpback whale (*Megaptrea novaengliae*)	Throughout and unpredictable	April - November	Part of Western NA population (5000-7,000 2000)
Blue whale (*Balaenoptera musculus*)	Throughout	January - November	Part of Western NA population unknown (~1,000-2,000)
Fin whale (*Balaenoptera physalus*)	Shelf edge, offshore and throughout	April - November	Part of Western North Atlantic (2,200, 2007)

Species	Range	Timing	Number
Sei whale (*Balaenoptera borealis*	Southwestern Shelf and slope	May- October	Nova Scotia stock 207, (2006)
Minke whale (*Balaenoptera acutorostrata*	Throughout	Unknown	300-400 (1998)

As can be seen in Table 16, information on the abundance of the different species varies, with some residency of the sperm whale and the northern bottlenose whale and a designated Nova Scotia stock of the sei whale. One important area within the Scotian Shelf is The Gully, located approximately 40 km east of Sable Island, on the eastern Scotian Shelf. The Gully is a submarine canyon, 70 km long, up to 20 km wide and more than 2,000 m deep at its mouth. On a wider scale, the Gully ecosystem comprises an upper trough area, smaller canyons, the relatively shallow banks on either side of the canyon and parts of the Scotian Slope. As a result, The Gully ecosystem contains many diverse habitats and is highly productive (details in Davis *et al.* 2000; Gully Marine Protected Area Regulation 2003). The Gully is of special importance for a small and probably resident population of northern bottlenose whales, the only ziphiid (beaked) whale group studied on a long-term basis. The Gully is probably of importance for other cetacean species as well, but abundance estimates and other parameters necessary for the present assessment are only available for the former. The present case study will therefore concentrate on northern bottlenose whales in The Gully. The development of other cetacean stocks / populations that represent parts of stocks will be discussed separately.

7.4 Northern bottlenose whales stock assessment

7.4.1 Life history of northern bottlenose whales

Northern bottlenose whales belong to the family of beaked whales (Ziphiidae) and can reach 6 - 9 m in length. One of their characteristics is their large, bulb-shaped forehead and short, dolphin-like beak. northern bottlenose whales are found in the North Atlantic, from the coast off Spitzbergen south to Nova Scotia and the southwest coast of Spain / Portugal, including the Azores (Culik 2004). The population size is unknown with around 40,000 individuals estimated in the eastern part of the North Atlantic. The species is gregarious, with school sizes of at least four and occasionally more individuals. The species is primarily adapted to feeding on squid, although fish, sea cucumbers, starfish and prawns are also taken (Culik 2004).

There are no published data on the hearing ability of northern bottlenose whales. Hooker & Whitehead (2002) recorded clicks between 2 and 24 kHz (man 11 kHz, CV 59%) with some differences between clicks emitted by socialising whales at the surface and those heard by whales presumably foraging at depth. Earlier reports by Winn *et al.* (1970) of whistles between 3 and 16 kHz and burst pulses were challenged by Hooker & Whitehead (2002) as potentially coming from pilot whales. The click frequencies and interclick intervals recorded by Hooker & Whitehead (2002) indicate that clicks are used to forage on the squid *Gonadus steenstrupi* (see also Hooker 1999; Hooker *et al.* 2001 and below). The study indicates that northern bottlenose whales are able to hear at the least sounds between 2 and 24 kHz. Sensitivity to higher frequencies is a possibility, as the recording system was limited to a maximum frequency of 35 kHz (Hooker & Whitehead 2002). It is difficult to discern the hearing range from this limited number of studies, but there is reason to assume that northern bottlenose hearing covers a rather wide range of frequencies, very similar to other odontocetes of same or comparable size such as white whales (*Delphinapteras leucas*) and killer whales

(*Orcinus orca*; Southall *et al.* 2007). Southall *et al.* (2007) provisionally place the species in their mid-frequency category (functional hearing range 150 Hz - 160 kHz). It is therefore reasonable to assume that they are able to perceive a considerable amount of E&P industry related sound.

7.4.2 Population structure and trends

A rather distinct group of northern bottlenose whales has been studied since the 1980s in The Gully (Nova Scotia, see above). Published results are based on field data collected between 1988 and 2003 and the dataset has been analysed with a variety of highly sophisticated statistical methods, resulting in precise and defensible population estimates (Whitehead *et al.* 1997a,b; Whitehead *et al.* 1997b; Hooker 1999; Gowans *et al.* 2000; Whitehead & Wimmer 2005). Studies have also dealt with social organisation (Gowans & Rendell 1999), seasonal trends and movement patterns (Gowans *et al.* 2000; Wimmer & Whitehead 2005), dietary preferences (Hooker 1999; Hooker *et al.* 2001), diving behaviour (Hooker & Baird 1999) and genetics (Dalebout *et al.* 2006) and provide a detailed picture of the bottlenose whales of The Gully and adjacent regions. The comprehensiveness of the studies makes it possible to analyse the population before the background of at least six years of oil & gas exploration, some years of construction activities and - looking at very recent data - the early stages of operation of oil & gas platforms in the region.

Whitehead *et al.* (1997a and b), were the first to note that northern bottlenose whales are present year round in The Gully, that there is a residency in some individuals and that the whales in The Gully are morphologically different from bottlenose whales in other regions. They also expressed their concern that the start of oil & gas exploration and construction activities in the Scotian Shelf would negatively affect the presumably distinct northern bottlenose whale population in The Gully. In her thesis, Hooker (1999), found fluctuations in sighting rates and hence abundance of whales in different years (1988 - 1998) but no overall positive or negative trend. She found indications that the whales in The Gully feed predominately on squid of the species *Gonatus steenstrupi*, which are moderately sized (mantle ~ 10 cm), and are thought to live around the sea floor on continental slopes. The diving behaviour of bottlenose whales in The Gully - the animals dive to depths of over 800 m every 80 min with diving durations of up to 70 min - is consistent with benthic or bathypelagic foraging behaviour (Hooker 1999; Hooker & Baird 1999; Hooker *et al.* 2001). Hooker (1999) also found little displacement of individuals over time and concluded that the apparent lack of movement indicates that the canyon provides the bottlenose whales with an important and sustainable food resource.

Based on these results, Hooker *et al.* (1999) suggested that The Gully should be designated as a marine protected area, which was implemented by the Canadian Government in 2004 (for more information see www.dfo-mpo.gc.ca). Later investigations confirmed the residency of the whales in The Gully, but also showed that northern bottlenose whales are also present in two other underwater canyons in the vicinity (Shortland, 50 km east; Haldiman, 100 km east) and there are movements of individuals between canyons, especially by males (Wimmer & Whitehead 2005). The population in The Gully appears to be genetically distinct. Since no indications for bottlenecks were found, The Gully population is probably not a relic of a historically wider distribution. Instead, the rather unique ecosystem appears to have long provided a stable year-round habitat for a distinct population of northern bottlenose whales (Dalebout *et al.* 2006).

Table 17 summarises the results of population estimates for different periods since the study has started. Whitehead *et al.* (1997a and b) estimate that the abundance is higher than both the following calculations purely for methodological reasons, for example, due to the percentage of animals used as marked in the mark-recapture analysis, and it should be noted that the latter estimates seemed to be more accurate. The differences between Gowans *et al.* (2000) and Whitehead & Wimmer (2005) are probably also methodological, as the higher numbers in the latter study are due to animals whose primary habitat is outside The Gully and who rarely visit it (Whitehead *et al.* 1997a and b; Gowans *et al.* 2000; Whitehead & Wimmer 2005). Looking at the documented trends, it can be seen that all the values are non significant: the population of northern bottlenose whales seems to have remained the same over the course of the study. If we assume that Gowans *et al.* (2000) estimates are closest to reality, we conclude that app. 130 (range ~ 100 - 160) northern bottlenose whales were present between 1988 and 2003 in The Gully, with no change in the overall trend. Mortality - as estimated by a combination of mortality, emigration and mark-change - is 12% per annum, with no means of allocating the value between the three causes, yet, much of the 12% are probably due to mark changes (COSEWIC 2002).

Table 17 Overview over the results by different studies on the abundance of northern bottlenose whales in the Gully.

Study period	Method	Estimate	Trend	Source
1988 - 1995	Mark-recapture based on photo-identification	230 (95% CI = 160 - 360)	Not investigated	Whitehead *et al.* 1997a,Whitehead *et al.* 1997b)
1988 - 1999	Mark-recapture based on photo-identification*	Left side: 133 (95% CI = 111 - 166)	Left side: -0.13% per year (95% CI = -3.4% to 3.9% (n.s.)	Gowans *et al.* 2000
		Right side: 127 (95% CI = 106 - 160)	Right side: -0.43% per year (95% CI = -4.5% to 3.1% (n.s.)	
1988 - 2003	Mark-recapture based on photo identification**	163 (95% CI = 119 - 214)	= + 0.7 - + 2.5% per year (n.s.)	Whitehead & Wimmer 2005

Looking at the results from the different methods of estimation, we might conclude that if effects of E&P sound exist, they have eluded detection in the process of population estimates. Yet, we have to be careful with drawing too firm conclusions, as CI's were rather high, so trends are difficult to discern. However, looking at the sighting rate / hour searching between 1988 and 1999, it can be seen that the values are extremely stable between years, especially between 1996 and 1999 (Gowans *et al.* 2000; Fig. 2) further indicating that numbers of whales have remained relatively stable throughout the study period.

7.5 Other factors potentially affecting the stock

Information on other factors potentially affecting northern bottlenose whales on the Scotian Shelf is sparse. Whitehead *et al.* (1997a) provide an overview. *Whaling* - no threat any more - might have lead to a reduction of up to 40% of the original population of northern bottlenose whales off the Scotian Shelf. Between 1962 and 1967, 87 northern bottlenose whales have been killed by whalers from Blandford, Nova Scotia, with most individuals taken from within and around The Gully. Current threats are presumably *collision with ships*, *entanglement in fishing gear*, effects from *marine debris* (for example litter), *fishing* (groundfish = shallow areas bordering The Gully; Redfish = mid water draggers in and around the Gully), and chemical pollution. Yet, Whitehead *et al.* (1997a) provide no further information on the exact or assumed impact of these factors on the population. It is interesting to note that the major east-west trans-Atlantic shipping lane is located only 30 km south of The Gully (Whitehead *et al.* 1997a; COSEWIC 2002). What follows is an assessment of the different factors based on some additional data provided from different sources.

7.5.1 Fisheries

There are extensive reports on the activities of the fishing Industry on the Scotian Shelf (Davis *et al.* 1998; Harrison & Fenton 1998; CNSOPB 2003) and these should be referred to for more detail. The following paragraph will outline the major implications of the fishing industry for the northern bottlenose whales. Fisheries can affect cetaceans in several ways: 1) directly, as animals might be caught incidentally in fishing nets, 2) directly, through sound emissions that affect the behaviour of the animals, and 3) indirectly, through over fishing and therefore the depletion of food resources. By catch or entanglement in fishing gear is noted by Whitehead *et al.* (1997a) as a potentially limiting factor as 'a number of northern bottlenose whales in The Gully show evidence of encounters with fishing gear' (see also Figure 1 in Whitehead *et al.* 1997a). Yet this is the only source that mentions direct mortality through entanglement, and no further evidence is provided. It is therefore impossible to assess the importance of this factor. Disturbance by sound is a potential threat if we consider that fishing vessels can be quite noisy, particularly when towing bottom gear (140 - 160 dB re 1 μPa, 10 Hz - 10 kHz, most below 1 kHz, Trawler data, Richardson *et al.* 1995). We should also note here that the fishing effort on the Scotian Shelf has been huge, targeting groundfish (Atlantic cod, pollock, haddock, hake redfish etc), pelagic species (Atlantic herring, Atlantic mackerel etc.), crustaceans (American lobster, northern shrimp, snow crab) and molluscs (clams and scallops). Yet we have to bear in mind that the ground fishery has been greatly reduced during the 1990s (closure of some areas from 1993 on) and that most of the remaining fisheries takes place in the south-western part of the Scotian Shelf (years 1995/1996, maps in Davis *et al.* 1998). The Gully itself remains important for long line fisheries for halibut (2001 catch = 47 tons; CNSOPB 2003). It is likely that fishing vessels are detected by whales at considerable distances. Thomsen *et al.* (2006b) calculated transmission loss (with ~ 16 log R) for ship sound, taking the values of Richardson *et al.* (1995) into account (Table 18).

Table 18 1/3rd octave sound pressure levels of sound emitted by a fishing vessel at different distances from the source calculated with ~ 16 log R (after Thomsen *et al.* 2006b).

	Ship sound (dB re 1 μPa RMS	
Distance to source (m)	**0.25 kHz**	**2 kHz**
1	160	150
10	145	133
50	135	122
100	130	117
1,000	115	100
10,000	99	80

It can be seen that vessel sound at 10 km distance is barely above the ambient noise levels reported for the Scotian Shelf above. Received levels at 1 km are also relatively low and it might be concluded that sound from fishing vessels will have a behavioural effect - if any - on northern bottlenose whales only at comparably close ranges. Depletion of food resources is probably not an issue with regards to northern bottlenose whales in The Gully, since their preferred prey is not targeted by the fishing industry. Remaining issues with regard to direct impacts from fisheries are litter and large debris from fishing vessels, and both seem to occur in The Gully at comparably high levels (Lucas 1992; Dufault & Whitehead 1994). More indirect effects such as impacts of sound on prey species are highly unlikely, as the squid the whales hunt for is probably not very sensitive to sound and also too far down in the water column to be affected by high sound levels.

7.5.2 Shipping

The Gully is only 30 km away from one of the major shipping lanes of the east coast of North America: the east-west trans- Atlantic shipping route (COSEWIC 2002 see Figure 25). Ship strikes are possible, yet the COSEWIC (2002) report notes that there are no known reports of northern bottlenose whale fatalities due to ship strikes (see also Whitehead *et al.* 1997a; Hooker *et al.* 1997). Sound from ships can lead to an increase of ambient noise over a wider region which, in principle, might affect the ability to hear biologically relevant sound in cetaceans (Richardson *et al.* 1995)[18]. Zakarauskas *et al.* (1990) reported high ambient noise levels for the Scotian Shelf region between 90 - ~ 103 dB re 1μPa (measurements in 1/3rd octave band levels, recording range = 30 - 900 Hz; wind speeds 11 and 20 kts). These levels are very typical for areas located in heavily-used shipping lanes (Wenz 1962; Urick 1983) and are very similar to the ones Thomsen *et al.* (2006b) described in their review for the German North Sea under comparable wind speeds. However, in coastal areas with a lot of traffic to and from ports, ambient noise levels can be much higher than that (Nedwell *et al.* in press). It is important to note here that the water depths in the Gully are probably sufficient to cut-off sound transmission from large distances, as sound transmission will probably shift from cylindrical (or nearly-cylindrical 10 log R) to spherical transmission (20 log R: Urick 1983). Reportedly, The Gully can be 'exceptionally quiet' at times (noted by Davis *et al.* 1998). Nevertheless, without systematic measurements, it is difficult to assess the effects of ambient noise in reaction to other sound sources.

7.5.3 Pollution

Contamination is an issue as marine mammals are top predators and might accumulate pollutants over time (see Vos *et al.* 2003 for an overview). Very recently, Hooker *et al.* (2008) analysed biopsy samples from northern bottlenose whales from The Gully (periods 1996 / 1997 and 2002 / 2003) and the Davis Strait, Labrador, taken in 2003. They documented blubber contaminants and concentrations consistent with other North Atlantic species. The levels found were also lower than those that are thought to cause health problems in more contaminated cetacean species. Scores for CYP1A1 expression - which is thought to reflect recent exposure to contaminants - were low in the sampled whales, with most samples scoring zero. From the few animals that expressed CYP1A1, those sampled in 2002 / 2003 had higher concentration than those sampled in 1996 / 1997.Hooker *et al.* (2008) also detected a range of PCB congeners and organochlorine compounds with PCB showing no differences; HCHs and endosulfans showing significant decreases, and DDT and chlordanes showing significant increases over time. These changes are attributed to a temporal change of contaminant levels in the water and / or prey species, although it was not likely that the contaminants had been released by nearby oil rigs or during seismic exploration, Hooker *et al.* (2008) did not rule out the possibility that oil & gas

[18] However, in the case of Northern bottlenose whales, the spectrum of vocalisations used by them in lower frequencies is unknown (see Hooker and Whitehad 2002).

activities have led to the remobilisation of persistent contaminants from sediments on the Scotian Shelf. However, these conclusions should be interpreted with caution as - except in one case - different animals were analysed between 1996 / 1997 and 2002 / 2003. It is true that the one animal sampled for both periods showed the same trend as reported for the whole dataset. Yet, contaminant levels of different individuals are difficult to compare over time, as many other factors could be responsible for the observed 'changes'[19]. The authors also provide no explanation on the decrease in other contaminants. Finally, it should be remembered that sample sizes - at least for the CYP1A1 part of the study - were too small to draw any conclusions on temporal trends. Therefore, the results of this study are very difficult to assess.

7.6 Trends in other cetaceans of the Scotian Shelf

As we could show earlier, the Scotian Shelf is an area with relatively high cetacean diversity (Table 16). Yet, deciphering trends for the populations of other cetacean species that appear consistently in the Scotian Shelf is difficult. Sperm whales are common on the Shelf and they seem to be regularly present in The Gully as well. Whitehead (1998) estimates that between 10 and 30 sperm whales might be present in The Gully at any given time. Most of the individuals observed in the Scotian Shelf region are maturing or adult males (Whitehead 1998). According to NOAA (2007), the North Atlantic stock of sperm whales is comprised of 4,800 animals (CV = 0.38) with abundance estimates of several hundred animals from surveys off northeast US / Bay of Fundy and Scotian Shelf region. The data are insufficient to conclude about possible trends. Yet, mortality is reportedly low, and the 2000 NOAA stock assessment report estimated 4,700 sperm whales from Florida to the Gulf of St. Lawrence, indicating that the population is neither growing or declining significantly (Waring *et al.* 2000). Sperm whales were commonly sighted during the seismic monitoring studies compiled by Lee *et al.* (2005) indicating that the usage of The Gully and adjacent waters is continuous despite the exploration activities being undertaken in the region. Moving on to the low-frequency cetaceans (Southall *et al.* 2007), the humpback whale is commonly observed along the Scotian Shelf (Davis *et al.* 1998; Lawson *et al.* 2000; see reports in Lee *et al.* 2005). The whales seen in the Shelf area probably belong either to the Gulf of Maine (847 individuals; NOAA 2007) or to the Gulf of St. Lawrence and Labrador Newfoundland subpopulations, respectively; all are part of the North Atlantic population which comprises 11,500 animals (NOAA 2007). Current data suggest that the Gulf of Maine stock is steadily increasing in size which is consistent with an estimated average recovery trend of 3.1% in the North Atlantic population overall for the period 1979-1993 (NOAA 2007). It is difficult to decipher any trends for subpopulations, yet, if human activities affected individuals, this factor was not influencing the overall positive trend in population growth.

The case of the Northern right whale Northern right whales use the Scotian Shelf frequently, especially the south-western part and the adjacent Bay of Fundy (Browns, Roseway, Lahane and Emerlad Banks; Davis *et al.* 1998). The species appears to be of particular interest for this investigation since 1) the summer feeding areas of individuals at least partly overlap with E&P activities (see maps in Davis *et al.* 1998, Figure 5, 6), 2) it uses sounds between < 500 Hz to 1,500 Hz to communicate with conspecifics (Clark 1983) and is therefore probably quite sensitive to low-frequency sound (see Southall *et al.* 2007), and 3) the stock from which animals visit the Scotian Shelf between April and November is extremely endangered, numbering only about 300 animals with little signs of recovery since the cessation of whaling (see

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[19] In mature females there is also the possibility of downloading of lipophilic contaminants to offspring and therefore reduced contaminant levels.

www.noaa.gov for further SAR's). In line with these results, Clapham *et al.* (1999) conclude that the North Atlantic right whale stock is one of the most critically endangered populations of large whales in the world. The stagnation of the stock is even more intriguing since its sister species (southern right whale (*Eubalaena australis*) is making a remarkable comeback in other parts of the world, for example off South Africa and Argentina (Kenney 2002).

It should be noted here that the range of the North Atlantic stock of right whales only very partially overlaps with E&P activity and that most of the whales are probably not exposed to E&P industry sound. Yet, in terms of which factors are affecting the recovery of cetaceans, the North Atlantic stock of Northern right whales is an interesting case, which should be outlined here.

NMFS (2005) lists several threats to the Northern right whale population including *vessel interactions*, *entrapment* and *entanglement* in fishing gear, *habitat degradation*, *sound*, *contaminants*, *underwater explosives*, *climate and ecosystem change*, and - from a more historic viewpoint - *commercial exploitation*. As it is likely that these factors act cumulatively, both vessel interactions and entrapment / entanglement in fishing gear seem to be the major contributors to the apparently high rate of mortality (27% of individuals die before reaching 4 years of age). From the 45 confirmed deaths of western North Atlantic right whales, 16 are known to have been caused by ship strikes, three could be directly linked to entanglement and a further eight were suspected to be caused by entanglement. Further, an alarming 60% of all right whales bear scars and injuries indicating fishing gear entanglement (NMFS 2005). Sound might cause injuries at very close ranges and behavioural reactions at larger ranges. However, as a playback study by Nowacek *et al.* (2004) indicated, right whales might tolerate shipping sound, at least to a certain extent. Contaminants might not be much of a problem since levels in Northern right whales are comparatively low, due to their plankton-based diet. The effects of climate and ecosystem change are difficult to assess, as this might be a rather broad category including a wide range of different phenomena. At the least, it has been shown that Northern right whales are very sensitive to shifts in their prey, switching to areas of higher productivity within short periods of time (NMFS 2005). Additional factors that come to mind here are predation by killer whales (see Ford & Ellis 1999), competition with other species feeding on the same prey, such as sei whales or disturbance by whale watchers (NMFS 2005). In conclusion, many factors are affecting this particular group of whales with disturbance by sound being only one of them.

7.7 Responses of cetaceans to E&P industry activity in the Scotian Shelf

If long-term trends are absent, we should look at short-term changes in behaviour due to seismic activity in the studied species. Perhaps most relevant for the issue of potential disturbance of Northern bottlenose whales by seismic surveys are findings from various field studies undertaken in 2003 in The Gully and adjacent waters and compiled by Lee *et al.* (2005). In general, these studies dealt with acoustic monitoring and marine mammal surveys in The Gully and Scotian Shelf both before and during seismic surveys. Of particular value were the studies by Austin & Carr (2005) dealing with received sound pressure levels at distances of up to 55 km from a 3D seismic operation. They found received levels of 152, 167 and 175 dB re 1μPa SEL, RMS and peak respectively at 2.6 km from the source. At 55 km, the corresponding values were 130 dB re 1μPa (SEL), 133 dB re 1μPa (RMS) and 143 dB re 1μPa (peak) for 77 m and 123 dB re 1μPa (SEL), 126 dB re 1μPa (RMS) and 136 dB re 1μPa (peak) at 180 m water depth. Most energy was at frequencies below 100 Hz (Austin & Carr 2005).

McQuinn & Carrier (2005) provided a whole range of far-field measurements at different water depths that are depicted in Table 32 . The received sound level was measured in The Gully while the seismic vessel was surveying outside The Gully at distances 30 - 100 km from the recording site. As can be seen in Table 32, received sound pressure levels can be as high as 147 dB re 1μPa (peak) at 100 km, approximately 50 dB above the ambient noise level typical for The Gully. The authors concluded that the 'worst case' sound level in The Gully when an exposed animal would be 0.8 km away from the source was 178 dB re 1μPa. In another study, Simard *et al.* (2005) reported received sound pressure levels at water depths of 190 and 210 m to be between 91 and 103 dB re 1μPa. at 91 - 31 km ranges, confirming the trend also found in the other two investigations that received sound pressure levels decrease with water depth. Finally, in the same volume, Potter *et al.* (2005) confirmed earlier observations that some of the sound from seismic surveys has energy at higher frequencies, up to 4 kHz. However, they also showed that most energy was emitted below 500 Hz (Potter *et al.* 2005).

Looking at potential short term disturbance, the studies reported in Lee *et al.* (2005) are difficult to assess as they seem to suffer from methodological pitfalls, especially small sample sizes, and they cover our target species to only a very limited degree. For example, Moulton & Miller (2005) monitored marine mammals before and during seismic activity (on-off) from a 3D seismic survey vessel. They found some indications of avoidance by whales due to seismic activities, judging by the number of animals seen on/off and the distance of the observation to the seismic vessel during on/off. However, sample sizes were too small to demonstrate this unequivocally. Received levels were measured during this survey (see above mentioned results by Austin & Carr (2005) and modelling exercises indicated that they could be as high as 190 dB re 1μPa at 150 m from the vessel. northern bottlenose whales were only observed once, so no conclusions could be drawn. Potter *et al.* (2005) reported avoidance by cetaceans towards a 3D survey vessel at distances up to 100 m, yet the overall number of marine mammals in the observable radius did not change significantly when the seismic source was on compared to when it was off. Marine mammals were observed in larger groups and became less vocal when the array was on. However, the authors also noted that bias might have been introduced, as no distinction was made in the analysis between baleen and toothed whales. Gosselin & Lawson (2005) investigated the distribution and abundance of marine mammals in The Gully before and during seismic surveys based on line transect surveys. However, the observed trends couldn't be attributed to sound and most likely represented seasonal changes that have been found in other studies as well.

7.8 Impact analysis

The above-mentioned studies indicate that effects by anthropogenic activities are difficult to assess in the case of northern bottlenose whales in The Gully and adjacent waters. Looking at the impact analysis in Table 19 we see that fisheries interactions and pollution might affect parts of the population (s) of bottlenose whales in The Gully and adjacent waters. The behavioural response due to sound from exploration and construction activities is of medium severity yet, given the decrease of exploration and the limited numbers of platforms being built, the likelihood for the factor playing a role is low at present.

Table 19 Impact analysis for northern bottlenose whales off Nova Scotia (Range: Short: < 100m, medium > 100 m < 5,000 m, long: > 5,000 m; Duration: Short: short-term, Long: long-term; intensity: Low (L), medium (M), high (H); severity, uncertainty(U) and likelihood(LH): Zero, low (L), medium (M), high (H), very high; likelihood U: unknown; for explanations, see chapter 2.2; dark grey: potential impacts on parts of population; light grey: measurable effects above normal fluctuations).

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	L
E&P industry sound	Seismic exploration	Masking	M	Short	L	L	H	M
		Response	Long	Short	M	M	H	M
		TTS	Close	Short	M	L	Very H	L
		PTS	Close	Long	H	H	Very H	L
	Construction	Masking	M	Short	L	L	H	L
		Response	Long	Short	L	M	H	L
		TTS	Close	Short	M	L	Very H	L
		PTS	Close	Long	H	H	Very H	L
	Drilling	Masking	Close	Short	L	L	M	M
		Response	Close	Short	L	L	M	M
Fisheries Interactions	Entanglement in gear, driftnet	Injury	Close	Long	M	M	M-H	M
		Death	Close	Long	H	H	M	M
Shipping interactions	Ship strikes	Injury	Close	Long	M	M	M	M
		Death	Close	Long	H	H	M	L
	Shipping sound	Masking	M	Short	L	L	H	M
		Response	M	Short	L	L	H	M
Pollution	Contamination	Reduced health	Long	Long	M	H	H	M - H
Military	MF sonar	Masking	M	Short	L	L	H	U
Military	MF sonar	Response	M	M	Short	L	H	U
Military	MF sonar	Injury	Close	Long	M	M	H	U

7.9 Conclusions

E&P activity has been present off Nova Scotia, especially during the late 1990s, with widespread seismic exploration, and construction and production activities since the beginning of this century. It is likely that sound levels from the E&P industry were audible over considerable distances to most cetacean species inhabiting the Scotian Shelf, especially the ones sensitive to low-frequencies. As case studies in this and other regions have shown, behavioural reactions are also likely at ranges up to several kilometres. The Scotian Shelf is home to a variety of cetacean species, with northern bottlenose whales being resident in a particular confined area, The Gully. Field studies undertaken between 1988 - 2003 indicate that the population in The Gully has remained relatively unchanged during this period, indicating that E&P industry sound and other human impacts such as shipping sound; interactions with fisheries, and contamination haven't affected the population significantly. Yet, due to the relatively short history of field studies and variability in abundance estimates, further studies are required to clarify the demographic features and their development in the northern bottlenose whales in The Gully and adjacent waters. Other cetacean species that occur frequently in the region are sperm whales and humpback whales, with populations of the former species unchanged on a large scale and the latter increasing. Parts of the Scotian Shelf form an important summer habitat for the northern right whale, which is endangered and whose population is not recovering despite the cessation of whaling. Observations from confirmed deaths indicate that ship strikes and entanglement in fishing gear are major factors inhibiting recovery, and that sound is one of many other factors potentially affecting this vulnerable stock as well.

8 Case study 4: UK East Coast - harbour porpoises and minke whales

8.1 Introduction to the area

This case study will focus on the UK East Coast, in particular the southern North Sea area. The whole North Sea extends to about 625,000 km^2. There are deep regions to the north, especially where the sea borders Norway, but otherwise it is a shallow shelf sea, generally with depths of less than 200 m, and an average depth of just 25 - 35 m in the southern North Sea (Figure 33).

Figure 33 Overview of the southern North Sea.

The shallow depth means that the water column is well mixed by tidal and wind forcing. The North Sea is influenced by inflow of Atlantic water through the Dover Straits to the southwest, and to a lesser extent by Atlantic water from the north. The North Sea is a heavily utilised area, with fishing grounds, shipping lanes, and oil & gas activity all extending across this area, and potentially conflicting with not just each other, but also the cetaceans found in this region.

8.2 E&P activity off the UK East Coast

Production Oil & gas exploration began on the UK Continental Shelf (UKCS) in 1964 with the first licenses being granted and the first well being drilled in the central North Sea soon after (see www.ukooa.uk) Exploration drilling continued and the first North Sea gas field began production in 1967 (BERR 2008). Drilling activity has remained high in the North Sea with the number of exploration wells drilled peaking in 1990 at

159. Development drilling activity has remained high in recent years with 201 wells drilled in 2006 after a development drilling peak of 289 wells in 1998 (BERR 2008). Figure 24 shows the principal infrastructure off the UK east coast, including all oil & gas terminals, pipelines and fields, licensed areas, and windfarm sites as of 2008 (courtesy of BERR 2008). This map highlights the vast extent of this industry in a small area of the North Sea.

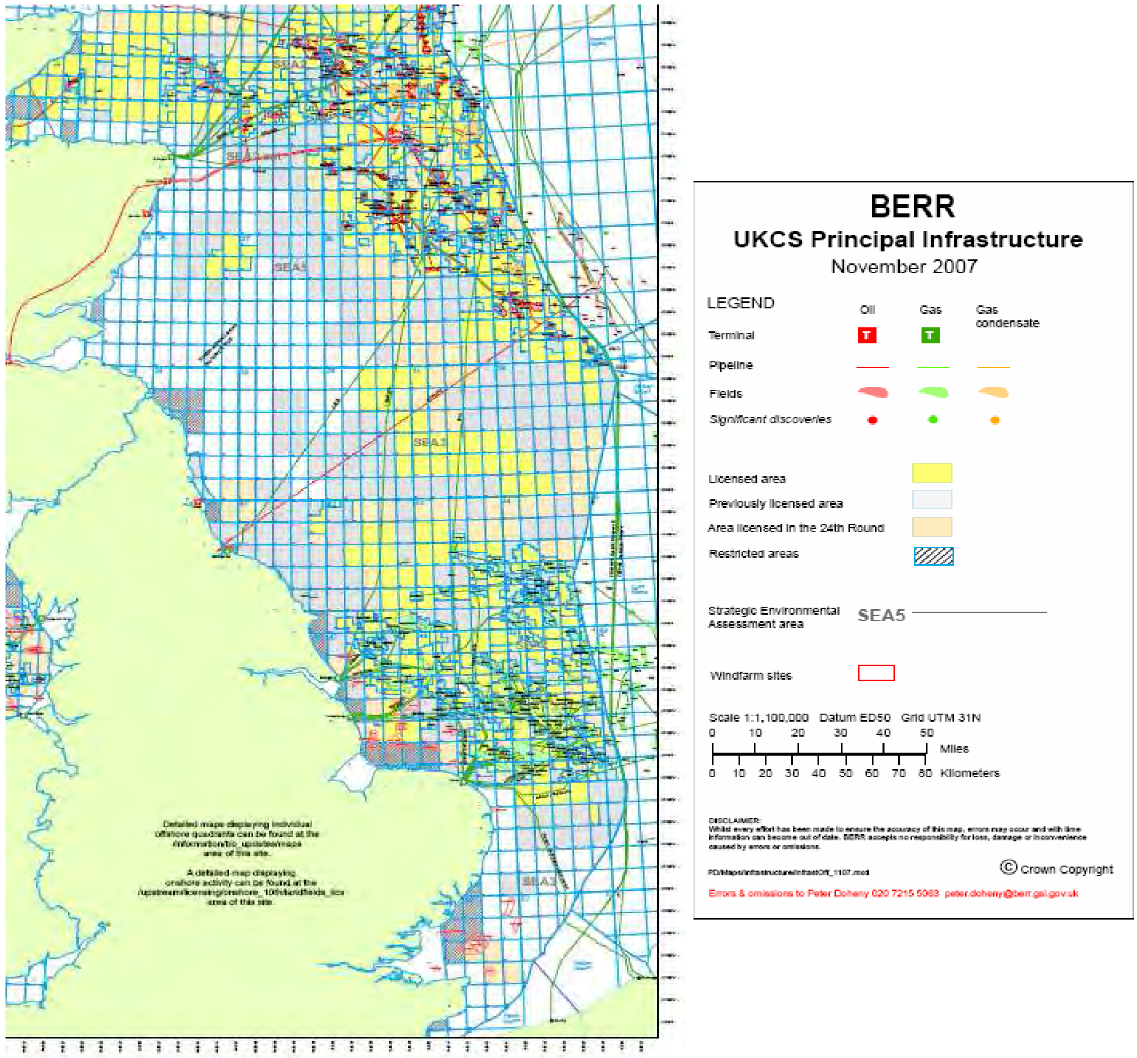

Figure 34 UKCS Principle Infrastructure (BERR 2008. Crown Copyright; cropped to show UK east coast structures.

Currently, there are 284 UKCS installations in production (Table 20). The first platform installations were predominantly in the southern North Sea, followed later by increased activity in the northern North Sea, the Moray Firth and the Irish Sea. The largest increase in platform numbers occurred during the late 1980s, with over 80% of current platforms in production by 1997. Most recently, activity has moved into the central North Sea and to the west of the Shetland Islands, with a 65% and 200% increase, respectively, in platform numbers over the last 10 years.

Table 20 Cumulative totals by area of installations in production on the UK Continental Shelf between 1997 and 2007 (BERR 2008).

Area	**Cumulative Platform Total by First Production Date**			
	1977	**1987**	**1997**	**2007**
Northern North Sea	7	21	34	34
Central North Sea	8	12	26	43
Southern North Sea	71	83	139	168
West of Shetland	0	0	1	3
Irish Sea	0	7	15	17
Moray Firth	3	8	17	19
Total	89	131	232	284

Over the last forty years, production off the east coast of the UK has shown a steady increase. The cumulative total number of platforms within the Moray Firth, central and southern North Sea has risen accordingly (Figure 35). The southern North Sea has seen the greatest activity in terms of platform numbers reaching a cumulative total of 168 by 2007. The greatest increases were seen in 1967 - 1973 and 1987 – 1990, when platform totals rose from 5 to 68 and 83 to 115, respectively.

The central North Sea has seen a smaller number of platforms built, with a cumulative total of 43 in place by 2007. A steady rise in the number of platforms began in 1993 when numbers rose from 14 to 38 in 2002. The Moray Firth also saw a similar increase; albeit on a smaller scale in terms of numbers, during this period, with the most a notable increase of 13 to 19 platforms between 1996 and 1999 (Figure 35).

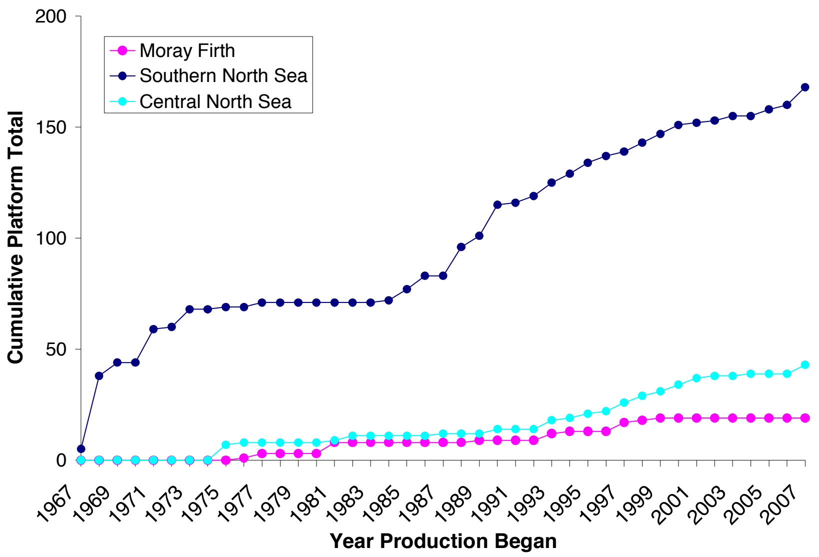

Figure 35 Cumulative Platform numbers within the Moray Firth, Central Northern Sea and Southern North Sea from 1967-2007 (BERR 2008).

Exploration Seismic surveys have been carried out in the North Sea since 1963, with the majority being 2D line transects. With the developing 3D technology, surveying began in 1978 with high numbers of 3D surveys concentrated in the southern North

Sea and northern central North Sea. Over the last 10 years, activity has begun moving into areas west of the Shetland Islands and into the Irish Sea (Figure 36).

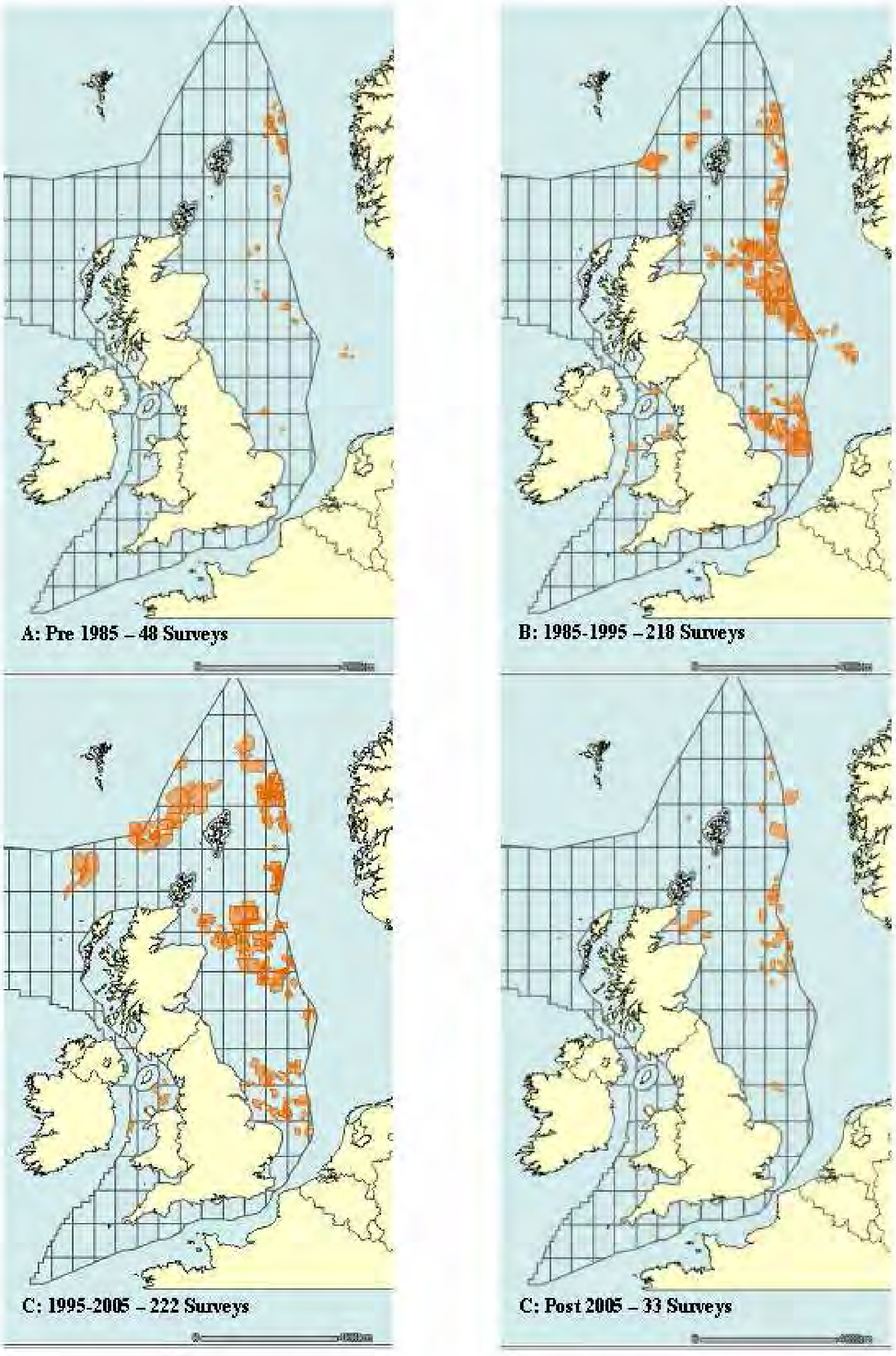

Figure 36 Historical 3D Seismic Activity of UK Coast (taken from map queries run within UK Deal (www.ukdeal.co.uk); map A: Pre 1985 – 48 surveys; map B: 1985-1995 – 218 surveys; map C: 1995-2005 – 222 surveys; map C: Post 2005 – 33 surveys).

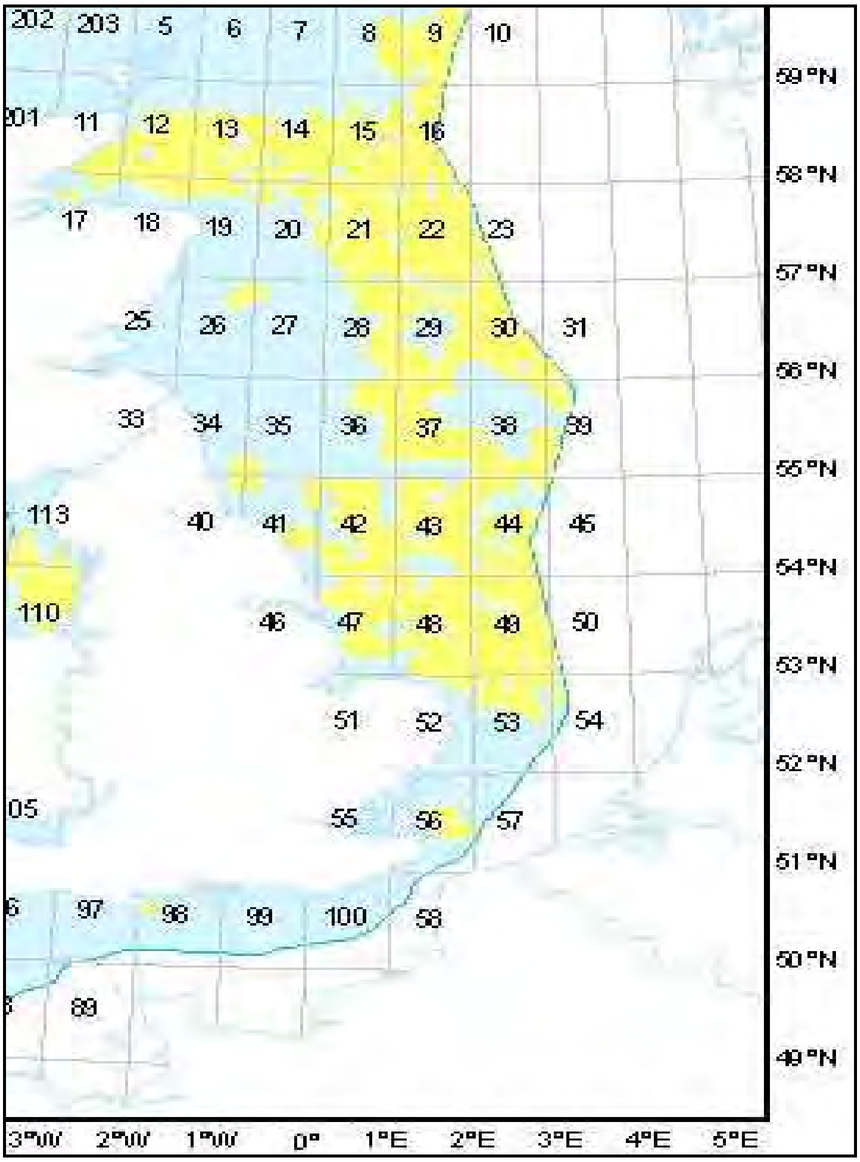

Figure 37 Map of UK east coast showing quadrant numbers used by the industry, and the areas in yellow that are currently under licence (BERR 2008).

The industry splits areas of the UK coast up into quadrants for reference (Figure 37), and it is these quadrants that are referred to in the following text. The amount of seismic activity within quadrants 11 - 57 has varied between 1997 and 2003 (Figure 38). The greatest activity was seen in 1997 when 10,705 km and 6,441 km^2 of 2D and 3D surveys were made, respectively. Overall, 2000 was the “quietest” year in terms of surveys, with only 210 km and 463 km^2 of 2D and 3D seismic activity respectively.

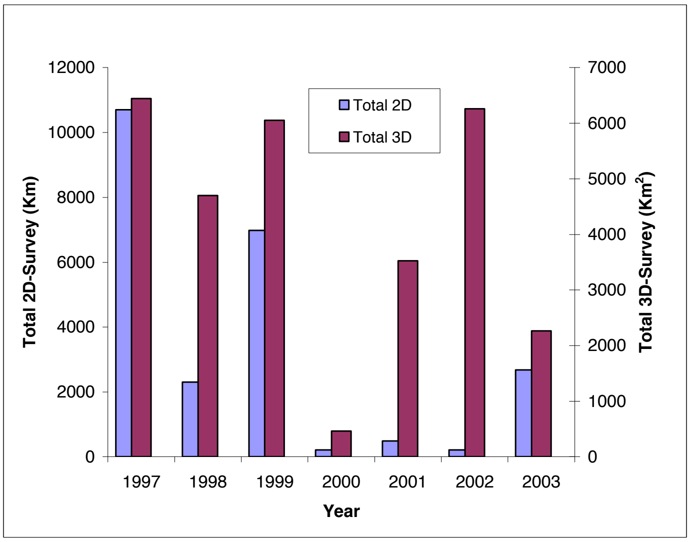

Figure 38 Total km of 2D-Survey and Total km^2 of 3D-Survey carried out within Quadrants 11-57 of the UK Continental Shelf between 1997 & 2003. (Adapted data from ASCOBANS 2005).

Between 1997 and 2003, quadrants numbers 12, 20, 21, 29 and 30 experienced the greatest seismic activity (figure 6). The greatest level of activity was seen in quadrant 30 with 2,421 km and 5,663 km^2 of 2D and 3D survey work being carried out. Quadrants 20 and 21 saw high levels of 2D survey activity (2,441 and 2,345 km respectively) but relatively lower levels of 3D surveying (1,534 and 454 km^2 respectively). In contrast quadrant 12 saw 5,046 km^2 of 3D surveying but only 376 km of 2D surveying.

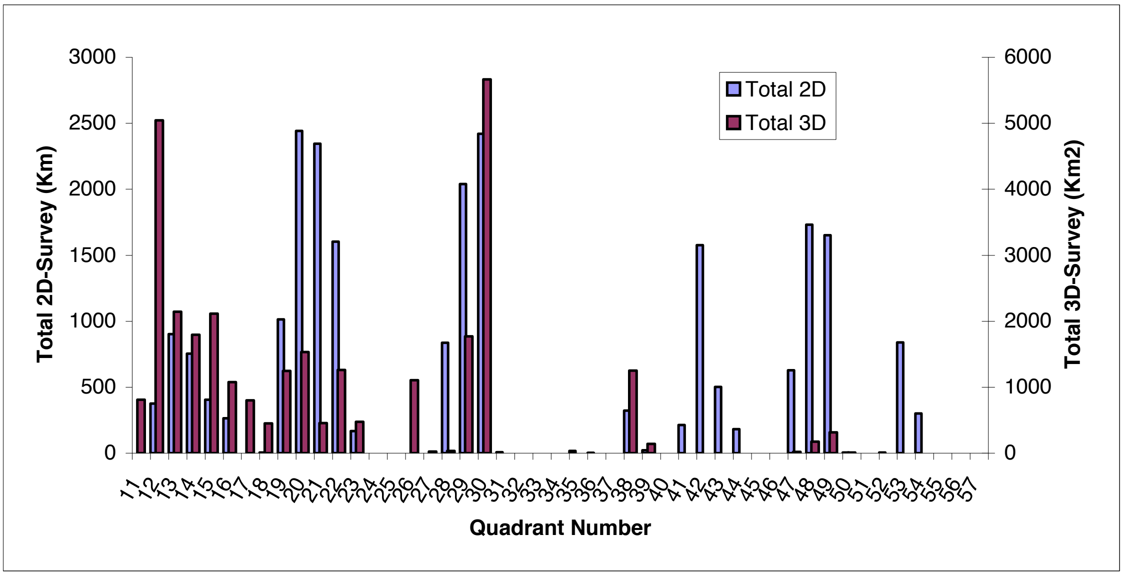

Figure 39 Total km of 2D-Survey and Total km^2 of 3D-Survey carried out between 1997 and 2003 within Quadrants 11-57 of the UK Continental Shelf. (Adapted data from ASCOBANS 2005).

8.3 Cetaceans off the UK East Coast

The waters of north-west Europe house a rich diversity of cetaceans species; 28 species of cetacean have been recorded (overview in Reid *et al.* 2003). Although not all of them have been found in the North Sea, the following have all been recorded sightings over the last 25 years (Reid *et al.* 2003): humpback (*Megaptera novaeangliae*), minke (*Balaenoptera acutorostrata*), pygmy sperm (*Kogia breviceps*), killer (*Orcinus orca*), and long-finned pilot whales (*Globicephala melas*); common bottlenose (*Tursiops truncatus*), short-beaked common (*Delphinus delphis*), white-beaked (*Lagenorhynchus albirostris*), Atlantic white-sided (*Lagenorhynchus acutus*), and Risso's dolphins (*Grampus griseus*); and also harbour porpoise (*Phocoena phocoena*).

The two species that are found most frequently off the UK east coast are the harbour porpoise and minke whale. The harbour porpoise is the smallest and by far the most numerous of the cetaceans found in north-western European continental shelf waters and typically they occur in small groups of one to three animals (Reid *et al.* 2003). Figure 40 shows the distribution of harbour porpoises around the UK coast from data collected prior to 2003 (taken from Reid *et al.* 2003). They are commonly seen around most of the coast, with smaller numbers in the southern North Sea and the English Channel area. Minke whales are the smallest of the baleen whales, and are the most common mysticete occurring in these waters; Figure 41 shows their distribution around the UK coast from data collected prior to 2003 (taken from Reid *et al.* 2003). They are not sighted as commonly as harbour porpoise, and their distribution is not as extensive. They are most frequently seen in the northwest region of the North Sea, close to the UK east coast, but become rare south of approximately 54°N, and also in the central and eastern parts of the North Sea.

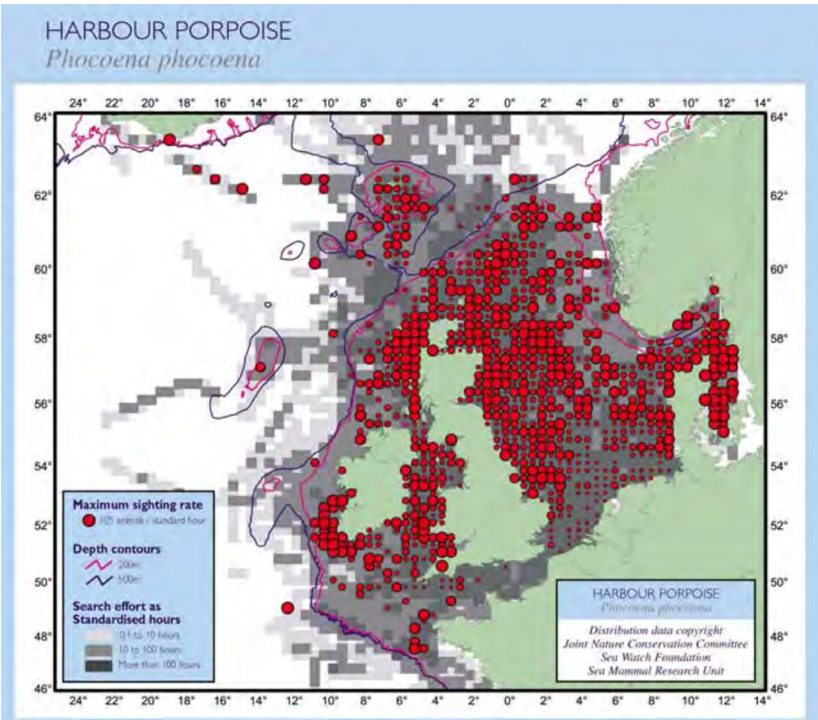

Figure 40 Distribution of harbour porpoise sightings around the UK (Reid *et al.*2003).

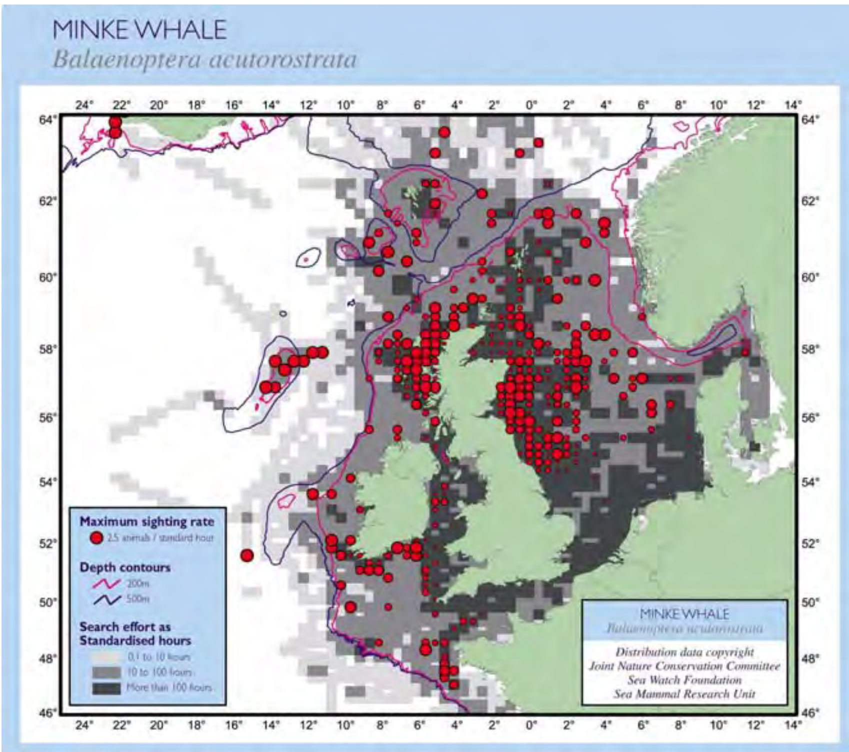

Figure 41 Distribution of minke whale sightings around the UK (taken from Reid *et al.* 2003).

8.4 Harbour porpoise stock assessment

8.4.1 Population structure

The question of whether harbour porpoises from the North Sea and Channel can be split into sub-populations / stocks, and where these divisions should occur, has long been contested in the literature. Based on mitochondrial DNA analysis, Walton (1997) suggested a division of the North Sea animals into northern and southern stock areas, as a result of the large genetic differences found between them, while no differences were identified between animals from the Dutch and English coasts. Conversely, Tolley *et al.* (1999) and Andersen *et al.* (2001) suggested a division of the northern North Sea into eastern and western sub-populations.

In 2000, IWC / ASCOBANS divided the harbour porpoises occurring in the North Sea for practical management purposes into a northern North Sea stock, a central and southern North Sea stock and an additional one located in the western English Channel (ASCOBANS 2006; Eisfeld 2006).

8.4.2 Population size

The most comprehensive population estimates are the SCANS surveys undertaken during summer 1994 and 2005, respectively (for the 1994 survey blocks see Figure 42). The survey blocks of the North Sea that we are interested in, and that were used during the SCANS survey in 1994, are blocks C (bordering the UK east coast), F (northern central North Sea), and G (southern central North sea). However, interest in possible southward shifts in porpoises (see below) leads us also to investigate block B (far south of North Sea and Channel; of interest due to the southern North Sea area).

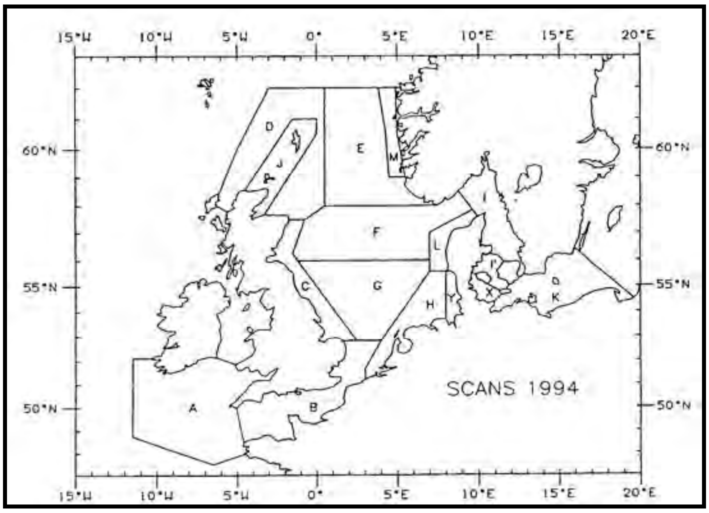

Figure 42 Scans 1994 survey blocks (taken from Hammond *et al.* 2002).

Changes to SCANS survey blocks for SCANS-II in 2005, means we also have to incorporate block H (coastal German waters) to enable comparisons to be drawn between results.

Table 21 gives the estimated abundances for these areas. The SCANS survey was repeated in 2005 (Hammond 2006b) and, although the blocks were not labelled in the same way (see Hammond *et al.* 2002; Hammond 2006b), the same areas were surveyed once again. The absolute densities are also given in Table 21. An approximate number of ~ 250,000 and ~ 230,000 animals were estimated for the North Sea and English Channel in the 1994 and 2005 surveys, respectively (Hammond 2006a). When separating out our areas of interest (the North Sea, south of the Moray Firth, and consequently the English Channel due to the survey block) the corresponding estimates were 152,106 in 1994, and approximately 180,000 in 2005, so there was an overall increase in the number of porpoise in this area. This is reflected well in the density plots (Figure 43), showing harbour porpoise numbers per km^2.

Table 21 SCANS I and II survey results by area for harbour porpoise (taken from Hammond *et al.* 2002 and Hammond 2006a).

Survey Year	Survey Block	Animal Abundance (CV)	Animal Density (animals km^2)
1994	B (far south and channel)	0	0
1994	C (coastal waters east UK)	16,939 (0.18)	0.387
1994	F (northern central NS)	92,340 (0.25)	0.776
1994	G (southern central NS)	38,616 (0.34)	0.340
1994	H (German coast)	4,211 (0.29)	0.095
	Total 152,106		
2005	V (northern NS) (ship)	47,100 (0.37)	0.335
2005	U (southern NS) (ship)	88,100 (0.23)	0.483
2005	B (far south and Channel) (aerial)	40,900 (0.38)	0.331
2005	H (German coast) (aerial)	3,900 (0.38)	0.335
	Total 180,000		

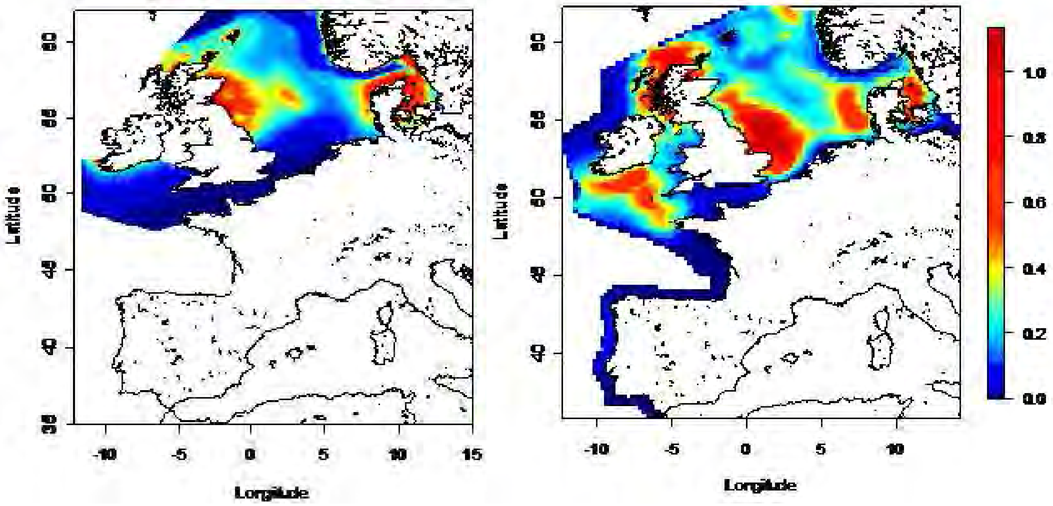

Figure 43 Density surface of harbour porpoise abundance (animals per km^2) from the SCANS 1994 (left frame) and SCANS II 2005 (right frame), which highlights the southern shift of porpoises to the southeast UK coast (ICES 2007)[20].

8.4.3 Demographic variables

Lockyer & Kinze (2003), examined the age structure of approx. 1,645 stranded and by caught harbour porpoises from Danish waters. With the movements of the animals between these waters and the North Sea, it is likely that the reported age frequency distributions provide a good estimate of that seen in the North Sea animals; and this suggestion was echoed by Lockyer & Kinze (2003) who believed that the following findings were almost exactly the same as the age structure seen in British harbour porpoise. Lockyer & Kinze (2003) found that the largest age group was 0 years of age in both sexes, indicating an especially high mortality in the first year, with a greater decline seen in males. The age class frequency declines rapidly from birth to age 2, and then declines more slowly. Longevity was 22 –23 years regardless of sex, with less than 5% of animals living beyond age 12 years. The maximum observed age was 24 years (Lockyer 2003).

From studies of directly caught, by caught and stranded animals in the North Atlantic, Lockyer & Kinze (2003) found that the sex ratio is biased to males throughout life: 1.1-1.2 males : 1.0 females at the foetal stage. Ólafsdóttir *et al.* (2003) also reported a bias to males with a ratio of 1.2 : 1.0 in foetuses. This male bias persists with ratio from 1.1-1.7 males : 1.0 females post-natal (Lockyer 2003). The stranded animals indicated a consistent ratio with that at birth, indicating that males are slightly at more risk of being by caught than females, suggesting that this may be a result of the seasonal segregation of the sexes and the area of fishing operations (Lockyer & Kinze 2003).

8.4.4 Migrations / Seasonality

As discussed earlier, it appears that there has been a shift of porpoises towards the southern North Sea. However, their annual and seasonal movements are a little more

[20] Using data from a variety of sources including: Hammond 2006b; Hammond PS and Macleod K., 2006. SCANS II - Report on Progress. Document for ASCOBANS Meeting of Parties, Egmond aan Zee, September 2006; SCANS II newsletters (www.biology.st-andrews.ac.uk/scans2); Hammond 2006a.

ambiguous. Northridge *et al.* (1995) reported that, at the start of the year, porpoises in the North Sea formed two major groupings, one to the west of Denmark in the eastern North Sea, and another, more scattered, in the deeper waters of the north-western North Sea. During the second quarter, in May and June, the main area of distribution is from Yorkshire to the Shetlands along the western North Sea margin, where animals are possibly joined for the calving season by animals from the eastern North Sea and those from farther north; during this time the sighting rate increases, but is superseded by sightings in the third quarter that extend over most of the North Sea north of 55°N (Northridge *et al.* 1995). However, given the reported southern shift in distributions, this information has to be reviewed to incorporate recent trends.

The theory that porpoises return to breed close to the coast has also been considered within ASCOBANS (2006) who believed that, despite the high probability of mixing in the middle of the North Sea, porpoises may be associated with separate breeding areas near the coast. Such a division in sub-populations may be created by philopatric behaviour of females (Andersen 2003).

Siebert *et al.* (2006), found evidence for a strong seasonality of harbour porpoise occurrence off the German coast, with the highest numbers being seen during the summer months. Scheidat *et al.* (2004) also found that, during the summer, harbour porpoises did not distribute uniformly, with the highest densities found off northern Frisia close to the Danish border.

8.4.5 Population trends

Results from large-scale surveys (SCANS I and II in 1994 and 2005) indicate that the population size of harbour porpoises in the North Sea has remained largely unchanged. It is true that population trends for harbour porpoise are quite difficult to assess given their extensive distribution, movements and the fact that studies other than SCANS have been limited to relatively small areas. However, the SCANS surveys of 1994 and 2005 enable us to decipher the large-scale trend. When considering the North Sea and English Channel area as a whole, the approximate estimates were ~ 250,000 and ~ 230,000 for 1994 and 2005, respectively, suggesting a slight decrease in numbers, although this was not statistically significant. When looking at the sectors that we are concerned with in this study, i.e. the North Sea area south of the Moray Firth (blocks B, C, F, G and H in 1994 and corresponding areas in 2005), the figures are 152,106 in 1994 and approximately 180,000 in 2005, representing an overall increase in numbers of porpoise. When the larger SCANS survey area is split between north and south, it appears that harbour porpoise distribution has undergone a southward shift, with a two-fold increase in the number of porpoises in the southern North Sea strata (from 102,000 to 215,000) while porpoise numbers in the northern North Sea strata have halved (from 239,000 to 120,000); yet the overall abundance estimates have not changed (ICES 2007)[21]. It is difficult to make definitive statements about long-term shifts in movements of harbour porpoise given the ‘snapshots’ in time that these surveys provide. Yet, smaller scale studies confirm the trend of a southward shift in distribution. In the light of human factors presumably affecting the population, leading to 'recovery' plans for the North Sea (see below), this is a quite remarkable result.

In line with the SCANS results, recent studies, using mainly stranding data and observations from seabird surveys, indicate a comeback of harbour porpoises in the southern North Sea, most notably along the Dutch and Belgian coast (Camphuysen

[21] See footnote 20for data sources.

1994, Camphuysen 2005; Witte *et al.* 1998; Haelters *et al.* 2004). However, these studies provided no estimates for the absolute densities of porpoises in that area. The results of a systematic and quantitative aerial line transect study in an area off Eastern Frisia, southern North Sea, by Thomsen *et al.* (2006a) supported the above-mentioned findings. Based on their results, Thomsen *et al.* (2006a) found it questionable whether the southern North Sea should be considered as a 'region of concern' to be included in a recovery plan for the species. Probably, the situation will not change considerably within the next years, since both in Germany and the Netherlands bycatch rates are at present relatively low (Reijnders *et al.* 1996; ASCOBANS 2006, see below). However, it is unlikely that the recent comeback of harbour porpoises in the southern North Sea is explained by a recovery of a 'local population'. First, it is still under debate whether a separate sub-population exists in the southern North Sea (Andersen 2003, see above). Second, the annual increase of 40% in sighting-rates observed by Camphuysen (2005) exceeds by far the maximum potential rate of increase of 10% for the species (Stenson 2003; Camphuysen 2005).

To summarise, the North Sea stock of porpoises seem to have remained at a relatively constant level, but has probably undergone drastic distributional shifts in recent years. It is very likely that changes in occurrence of the species in parts of the North Sea might not result from a population recovery, but rather from a recruitment of porpoises from other areas, which might in turn be caused by environmental factors such as the reduced local availability of prey (Camphuysen 2005). The current status of harbour porpoises in the North Sea could probably only be investigated thoroughly using a combination of surveys, genetic studies and satellite telemetry (for recent findings in the central North Sea, see Thomsen *et al.* 2007).

8.5 Other factors potentially affecting harbour porpoises

Human activities, such as discharge of contaminants, shipping and hydrocarbon exploration and production, and on a more localized scale, e.g. sewage discharge, constructions (including wind farms), aquaculture, mineral extraction (sand and gravel), recreational activities, competition for prey by fisheries and military use, which may all indirectly affect harbour porpoise health through changes in the quality of their habitat (ASCOBANS 2006). Table 22 shows the approximate distribution and scale of human uses in the North Sea, all of which can impact upon the health, activities and habitat of harbour porpoises. This table indicates that harbour porpoises from the central and southern North Sea are more at risk and exposed to higher levels of these activities than those in the northern North Sea.

Table 22 Approximate distribution and scale of human uses in the North Sea in relation to the harbour porpoise sub-populations, +++ = major use, ++ = medium use, + = minor use (adapted from ASCOBANS 2006).

	Northern North Sea	Central and Southern North Sea
Fishing	+++	+++
Contaminant discharge	+	++
Shipping	+	+++
Hydrocarbon exploration	+++	+++
Sewage discharge	+	+++
Construction	+	+++
Aquaculture	++	+
Mineral extraction		++
Recreation	+	+++
Military	+	+

8.5.1 Fisheries

Hunting occurred in many parts of the range of porpoises (e.g. Bay of Fundy, Labrador, Denmark, Faroe Islands, Greenland), but in recent years it has been confined to a few areas such as Greenland and the Faroe Islands (Stenson 2003). There is no deliberate taking of harbour porpoises in the North Sea, however, almost all fishing gear and, in particular, gill and tangle nets, bear the risk of incidental entanglement of harbour porpoises (ASCOBANS 2006).

In the past, harbour porpoises were harvested for their meat and blubber but, at present, porpoises are given legal protection in nearly every country (Bjørge & Tolley 2002). Large numbers of harbour porpoises were taken by hunters in Danish waters from the 14th century until 1892 and again between 1916 - 1919 and 1941 - 1944 (Stenson 2003).

The **incidental catches** of harbour porpoise in the North Sea are a topic of high sensitivity and often discrepancy, given the intense and lucrative fishing effort intersecting harbour porpoise distributions in these waters. ASCOBANS (2006) and Stenson (2003) have reviewed the incidental catches in the North Sea. Table 23 is an amalgamation of these bycatch estimates.

Table 23 Incidental catches of harbour porpoises in the North Sea taken from Stenson 2003 and ASCOBANS 2006 (for detailed references, see Stenson 2003).

Year	Catch	Country	Estimation Method
1980-81	91	Denmark	Collections
1986-89	105	Denmark	Collections
1986-89	<5/yr	Netherlands	Reports
1990-95	66	UK	Collections
1990-94	23	Germany	Collections
1994-98	6,785/yr	Denmark	Observer program
1987	5,322/6,630	Denmark	Observer program
1988	5,938/6,727	Denmark	Observer program
1989	4,973/5,230	Denmark	Observer program
1990	5,191/5,257	Denmark	Observer program
1991	6,312/6,573	Denmark	Observer program
1992	6,543/7,099	Denmark	Observer program
1993	6,709/7,421	Denmark	Observer program
1994	7,366/7,566	Denmark	Observer program
1995	6,737/7,308	Denmark	Observer program
1996	5,991/6,762	Denmark	Observer program
1997	5,308/5,731	Denmark	Observer program
1998	5,206/4,974	Denmark	Observer program
1999	4,227/3,840	Denmark	Observer program

Year	Catch	Country	Estimation Method
2000	4,149/3,266	Denmark	Observer program
2001	3,887/2,867	Denmark	Observer program
1995	818	UK	Observer program
1996	624	UK	Observer program
1997	627	UK	Observer program
1998	490	UK	Observer program
1999	436	UK	Observer program
2002-2003	25-30 (annual estimate)	Germany	Observer program
2004	7	Belgium	Strandings
2004	3-10	Belgium	Strandings
2003-04	100 (annual estimate)	Netherlands	Strandings
1990-2001	17	Germany	Strandings

Table 23 highlights the extent of incidental mortality due to fishing in the North Sea, by many of its bordering countries.

ASCOBANS (2000) defined a total anthropogenic removal above 1.7% of the estimated harbour porpoise abundance as unacceptable and adopted the intermediate precautionary objective to reduce bycatch to less than 1% of the best available population estimate (ASCOBANS 2000), however, the total known bycatch in the central and southern North Sea (at least 3% of the population) has exceeded this level (Stenson 2003). This led to the adoption by the EU of a regulation laying down measures concerning incidental catches (EC 812/2004) to alleviate the problem (ASCOBANS 2006). One way to mitigate against bycatch is the use of acoustic harassment devices (pingers) that scare porpoises away from nets and these devices are mandatory in some sectors of the Danish North Sea. In addition, fishing effort in the Danish and UK set net fisheries has decreased sharply since the mid 1990's, leading to reduced bycatch rates (Stenson 2003).

However, exact rates of bycatch are difficult to assess at present and management procedures are in place to deal with this problem. The goal is to set bycatch limits that allow populations to recover and/or to maintain 80% of carrying capacity in the long term. Hammond (2006b) calculated examples of bycatch limits based on the SCANS II data for two management procedures (Potential-Biological-Removal, PBR; Catch-Limit-Algorithm, CLA) that were tuned according to different scenarios. For the southern North Sea example, bycatch limits are 1,127 and 2,124 (PBR, CLA respectively; tuning: median population status after 200 years is 80% of carrying capacity; details see Hammond (2006b).

8.5.2 Shipping

The predominant effect of shipping on harbour porpoises is the sound that emanates from the ship's propellers, machinery, the hull's passage through the water and the use of sonar; this sound may impede communication between individuals[22] and cause behavioural and distributional changes (ASCOBANS 2006). Yet, results on the effects of shipping are highly equivocal: Herr *et al.* (2005), comparing vessel traffic density and harbour porpoise sightings in the German North Sea found that neither ships nor porpoises were evenly distributed, with a concentration of ships in the southeast and porpoises in the northwest of the region. They described a negative correlation between both, and concluded that porpoises were avoiding areas with dense vessel traffic. However, the authors do point out that in the survey grid there are a large number of blank values, which may have limited interpretation of the data. The establishment of a cause-effect relationship, identified by the authors on the basis of correlations, seems to be rather unjustified[23]. Evans (2003) reported previous studies undertaken by the same authors, indicating avoidance of oncoming vessels by harbour porpoises in the Shetland Isles. It was found that porpoises were more likely to respond negatively to speedboats and a large ferry, both of which they experienced only infrequently, compared with sailing boats and a small daily ferry, with some habituation occurring later in the summer season. They were also more likely to respond negatively when occurring singly or as adult-calf pairs than when in groups (Evans 2003). Further avoidance of ships by porpoises to a distance of up to 1 km has been shown by Palka & Hammond 2001).

Dolman *et al.* (2006) indicated that ship strikes of harbour porpoises have occurred in the North Sea, yet no exact numbers were given. Non-fatal propeller cuts have been identified on harbour porpoises (Evans 2003). In addition, Evans (2003) does highlight that harbour porpoises are a species at risk in the North Sea due to the frequent high-speed ferry crossings.

8.5.3 Pollution

Harbour porpoises, being high in the food chain and having a low metabolic capacity for degradation, accumulate high concentrations of lipophilic and persistent organic compounds through their diet (Law *et al.* 1998), and as such are at high risk from contaminants. These are also conserved within the population to a great degree as mothers download a large proportion of their body burdens of these compounds to their offspring during parturition and (particularly) lactation. Within the UK marine mammals stranding programme, possible associations between contaminant concentrations in tissues and infectious disease mortality were investigated; statistically significant associations were found for elevated levels of PCBs in blubber, and mercury in liver (Jepson *et al.* 1999; Bennett *et al.* 2001; Law *et al.* 2002). Mercury contamination has also been reported by Siebert *et al.* (1999) to present a risk to harbour porpoises. They found that porpoises from the German North Sea were carrying a significant burden of mercury, while those from the Baltic were not so much at risk, and these higher loads of mercury were associated with a higher prevalence of parasitic infection and the incidence of certain pathological diseases such as pneumonia.

[22] However, the use of low frequencies at or below 2 kHz for communication in harbour porpoises remains speculative (see Thomsen *et al.* 2006b for a disucssion on this).

[23] For, example, it is well known that the major shipping lanes in German waters are outside high-density areas of porpoises; yet, it is completely unknown, if both are related in any ways. Porpoises seem to target areas of northern Frisia in spring and summer, probably due to environmental favourable conditions and not because they would avoid busy shipping lanes (for distribution in German waters, see Scheidat *et al.* 2004; for habitat modelling see Skov & Thomsen in press).

Further studies of contaminants found in stranded harbour porpoises by Law & Whinnett (1992) and Law *et al.* (2006b) have endorsed the susceptibility of harbour porpoise to environmental contaminants, with low level but detectable concentrations of 2 – 4 ring polycyclic aromatic hydrocarbons (PAH) being found in muscle tissue, and elevated levels of a range of flame retardant compounds in blubber. Law *et al.* (2006a) investigated the levels of brominated flame retardants in the blubber of stranded harbour porpoises from the UK. Hexabromocyclododecane (HBCD) dominated and was detected in all samples and the maximum concentration was about double that reported in earlier U.K. studies; this may be a result of changing patterns of use of HBCD following limitations on the production and use of two polybrominated diphenyl ether (PBDE) products (the penta- and octa-mix formulations) within the EU.

Bull *et al.* (2006) explored the relationship between parasitic load (nematodes) and contaminant burdens in harbour porpoises stranded on UK coasts using a 15-year data set. Positive association between 25 PCB's and cardiac stomach nematodes was observed and PCB-related immunosuppression is discussed as one of the possible explanations; there was evidence to suggest a threshold concentration level for the sum of 25 PCB congeners beyond which cardiac stomach nematodes become significantly more abundant.

Many international instruments and regulations (e.g. OSPAR, Water Framework Directive, MARPOL) aim to reduce or eliminate the discharge of contaminants (ASCOBANS 2006), which may improve the levels of contaminant discharge in the future, however, it is those that are already in the environment that still pose a threat to harbour porpoises, given their properties that allow them to bioaccumulate and remain in the sediment and also in the food chain for many decades.

8.5.4 Environmental changes

Harbour porpoises have been reported to be opportunistic feeders (e.g. Lockyer *et al.* (2003) and Vikingsson *et al.* (2003), who found more than 40 prey taxa in stomachs of Icelandic harbour porpoises), and diet composition may be dependent upon local availability and abundance of prey, which is likely to vary between regions and seasons. For instance, Lockyer & Kinze (2003), found some dietary differences between harbour porpoises from the North Sea and inner Danish waters, and considerable seasonal variations in the diet of harbour porpoises off Iceland have been identified (Vikingsson *et al.* 2003). Even though a wide range of species has been recorded in the diet, porpoises in any one area tend to prefer two to four main species (e.g. whiting (*Merlangius merlangius*) and sandeels (*Ammodytidae*) in Scottish waters) (Santos & Pierce 2003).

Literature on porpoise diets in the northeast Atlantic suggests that there has been a longterm shift from predation on clupeid fish (mainly herring *Clupea harengus*) to predation on sandeels and gadoid fish, possibly related to the decline in herring stocks since the mid-1960s (Santos & Pierce 2003).

It is difficult to assess whether food depletion might play a role for porpoises in the southern North Sea. One the one hand, the species is an opportunistic forager, which indicates that porpoises might quickly adapt to changes in prey abundance (see above). On the other hand, not all prey is of equal energetic value and porpoises have a seasonally fluctuating, but overall very high metabolism, resulting in the more or less constant need for sufficient and nutritious food (Kastelein *et al.* 1997). MacLeod *et al.* (2007b) investigated stomach contents from stranded porpoises in Scottish waters, and found substantially smaller proportions of sandeels in 2002 / 2003 when compared to a baseline period (1993 - 2001). They also reported an increase in the proportion of animals that have died due to starvation between the periods (1993 - 2001: 5%, 2002 / 2003: 33%). It has to be noted here that the sample size for the later period was relatively small (16 individuals) and details on how starvation was identified were not given. However, the study indicates that porpoises might be very susceptible to changes in food abundance in some regions including the UK East coast. Consequently, the shift of porpoises from the northern to the southern north Sea has been linked to changes in prey abundance (see above discussion and Camphuysen 2005; Thomsen *et al.* 2006a).

8.5.5 Marine construction and industrial activities

Pile-driving is undertaken in harbour works, bridge construction, oil & gas platform installations, and in construction of offshore wind farm foundations. Most recent published work has concerned this last activity. Source levels vary (Table 24) depending on the diameter of the pile and the method of pile driving (impact or vibropiling). The frequency spectrum ranges from less than 20 Hz to more than 20 kHz with most energy around 100 - 200 Hz (for an extended overview see Nedwell *et al.* 2003; Nedwell *et al.* 2004; Madsen *et al.* 2006b; Thomsen *et al.* 2006b).

Table 24 Overview of some studies measuring sound from impact pile driving.

Activity	Pile driving method	Measurement	Report	Source
Construction of aviation fuel receiving facility	Impact pile-driving	dB RMS at various distances from source	> 170 dB re 1 μPa rms at 250 m	WÜRSIG *ET AL.* 2000
Offshore wind farm construction	Impact pile-driving Ø = 3 m	SEL at various distances in Sweden	~ > 200 dB re 1 μPa^2 · s at 1m	McKenzie-Maxon 2000
Oakland Bay Bridge Construction	Impact pile-driving	dB peak and rms at various distances from source	185 - 196 dB re 1 μPa rms at 100 m 197 - 207 dB re 1 μPa peak to peak	CALTRANS 2001
Offshore wind farm construction	Impact pile-driving Ø = 1.5 m	dB zero peak and SEL at various distances in German North Sea	228 dB re 1 μPa zero to peak at 1 m	THOMSEN *ET AL.* 2006B
Offshore wind farm construction	Impact pile-driving Ø = 4.0 - 4.7 m	dB peak to peak at various distances and four different sites in the UK	243 - 257 dB re 1 μPa peak to peak at 1m	NEDWELL *ET AL.* IN PRESS

Of particular relevance here are the results of the recent empirical studies by Tougaard *et al.* (2003a,b); Tougaard *et al.* (2005) and Carstensen *et al.* (2006) during the construction of the offshore wind farms at Horns Reef (North Sea) and Nysted (Baltic). At Horns Reef, acoustic activity of harbour porpoises (*Phocoena phocoena*) decreased shortly after each ramming event and went back to baseline conditions after 3 - 4 hrs. This effect was not only observed in the direct vicinity of the construction site, but also at monitoring stations approx. 15 km away, indicating that porpoises either decreased their acoustic activity or left the area during ramming periods (Tougaard *et al.* (2003b). It was also found that densities of porpoises in the entire Reef area during ramming were significantly lower than during baseline conditions. During ramming, porpoises exhibited more directional swimming patterns compared to observations obtained on days without construction, when more non-directional swimming patterns were observed. This effect was found at distances of more than 11 km and perhaps also up to 15 km from the construction site (Tougaard *et al.* 2003a). Similar effects were found during the construction (combination of pile-driving and vibropiling) of the Nysted offshore wind farm. There was no return to baseline levels after construction was completed (Carstensen *et al.* 2006; Tougaard *et al.* 2005). However, since absolute abundance of porpoises was low from the start, this finding might be incidental and is difficult to attribute to the construction activity (Tougaard *et al.* 2005). Further, both studies should be interpreted with caution, as there was no documentation of received sound pressure levels and there were also other methodological limitations[24]. Future investigations, modelling or measuring received sound pressure levels, should give a better understanding of the effects of pile driving sound on porpoises and other marine mammals.

Mineral extraction is restricted to relatively small areas in the North Sea, however in the central and southern North Sea, for example off the coast of Suffolk and Norfolk, it is carried out to some extent. Therefore, this will intersect with harbour porpoise distribution in particular. The main concern from this activity is the removal of the top layer of the seabed that may affect habitat for prey species (e.g. sandeels) of the harbour porpoise (ASCOBANS 2006) and, as mentioned earlier, also prey species of minke whales in the North Sea. Another concern is the underwater sound emitted during dredging, yet studies so far show lower source sound pressure levels compared to other activities (see Defra 2003), indicating that behavioural disturbance, if any, will be limited to close or medium ranges.

8.5.6 High-frequency sonar (military, fish finders)

Military high-frequency sonar used in shallow waters like the North Sea in offensive or defensive systems is potentially not as harmful as mid- or low-frequency sonar, due to the rapid absorption of higher frequencies, and disturbance to harbour porpoises can be further minimised by the use of monitoring systems and other mitigation measures (see ICES-AGISC 2005; ASCOBANS 2006). In addition, their usage is generally restricted to more or less confined exercise areas (ICES-AGISC 2005). As high-frequency cetaceans (see Southall *et al.* 2007), porpoises might be susceptible to high-frequency sonar. However, the supposingly limited application and the points mentioned above might reduce the overall impact.

[24] For example, in both areas, pingers and seal-scarers were used before ramming. Tougaard *et al.* (2003b)and Tougaard *et al.* (2005) mention that both were used intentionally as a mitigation measure to deter porpoises and seals from the vicinity of the construction sites. They also note that the rather large scale behavioural effects could not have been attributed to the mitigation measures employed, since source levels of the deterrent devices were much lower than the ones from pile-driving. However caution has to be taken in comparing source levels without reference to frequency. As we saw earlier, pile-driving noise is broadband, however, with most energy below 1 kHz and therefore below ranges of best hearing in porpoises. Especially the seal scarers might have caused avoidance response in porpoises at larger distances than expected, since the source levels used were reportedly rather high with carrier frequencies well within good hearing abilities of porpoises (SL = app. 189 dBp-p re 1 µPa; carrier frequencies of 13 – 15 kHz; Lofitech, Norway, pers. comm.). Since harbour porpoises have very acute hearing in that frequency range, it cannot be ruled out that effects were caused by a combination of the mitigation measures employed, along with the pile-driving. On the other hand, decrease of acoustic activity was also found during pile-driving in a harbour close to the Nysted site, with no mitigation measures employed. This might speak in favour of the interpretation by the authors (see also Carstensen *et al.* 2006).

Fish finders, used in commercial and recreational fisheries operate typically between 24 and 200 kHz, well within the range of optimum hearing of porpoises. Yet, the power signal is comparably low, the beam relatively narrow and pulses are rather short, indicating that effects on porpoises might be moderate (ICES-AGISC 2005). Their very wide application in the North Sea also throughout the year might lead to a closer look on potential impacts in the near future.

8.6 Overlap between harbour porpoise distribution, platforms and seismic surveys off the UK East Coast

Before we explore distribution patterns of porpoise with regards to oil & gas platforms and seismic surveys in more detail, we should raise a note of caution: Investigations of cetacean distribution with regards to the distribution of industrial activities are important, but are hampered somewhat by the lack of knowledge on what governs the movements of the animals in any given area. A lack of overlap therefore doesn't necessarily mean avoidance and high usage of an 'industrialised' area doesn't indicate that animals are unaffected. The following investigation is aimed at a very first step that might lead to a more detailed spatial analysis including a number of covariates (see, for example, Skov & Thomsen in press).

Another point to consider is that the following distribution patterns are valid only for the time of the surveys (four weeks in summer 1994 and 2005). However, additional studies in many parts of the North Sea have confirmed the sightings distributions of the SCANS surveys, indicating that the observed distribution patterns are quite comprehensive (see for example Reid *et al.* 2003; Scheidat *et al.* 2004; Camphuysen 2005;Thomsen *et al.* 2006a;Thomsen *et al.* 2007).

As shown earlier (Figure 40, Figure 43), harbour porpoises are more prevalent in the coastal waters of the northern UK and, like minke whale, were generally found north of 54°N. To the south of this, sightings significantly decreased, and the SCANS 1994 survey found zero animals in the far south of the North Sea and the English Channel. This distribution didn't match the major areas of oil & gas production and exploration, just touching upon the aggregation of fields east of Grimsby (53 - 54°N) to the south, and again having some limited overlap with the fields running diagonally south, east of Peterhead 57°50' N. The quadrants (refer to Figure 37) in which the animal density was at its highest in the 1994 SCANS survey are 19, 25 - 27, 34 - 35 and 40 - 41(Figure 43). The number of platforms in production overlapping this distribution is zero. When looking at seismic activity in these areas, there is also very little seismic surveying being carried out. Of these eight named quadrants, only three of them have had 3D surveying carried out from 1997 - 2003, with quadrants 19, 26 and 27 having 1247, 1107, and 24 km^2 surveyed respectively. Also just three have had 2D seismic surveying carried out, with quadrants 19, 35 and 41 having 1013, 18 and 214 km^2 surveyed respectively. This may have indicated that perhaps the porpoises were more frequent in areas with less oil & gas activity, if not for the case that the SCANS II 2005 survey, which showed a dramatic southward shift in harbour porpoise distribution (Figure 43, right panel).

When reassessing the 2005 harbour porpoise distribution against the oil & gas activity, a slightly different pattern emerges, with overlaps between porpoise sightings and the oil & gas industry becoming more prevalent. The overall density of animals is much greater and more widespread across the southern North Sea. Table 20 and Figure 35 show that the southern North Sea is home to by far the largest number of platforms, a cumulative total of 168 as of 2007. From the SCANS (1994) survey to the SCANS II (2005) there was an increase of 29 platforms. The quadrants in UK waters that encompass this southward shift in distribution are shown in Figure 37. This shows that harbour porpoises are present in some very high areas of activity, with a lot of platforms in production, and large numbers of surveys being carried out (1997-2003 figures) e.g. quadrants 48 and 49, as well as those which are still relatively free from E&P industry. The actual distribution will spread out further into the southern North Sea, and overlap more with the large oil & gas fields and industry in this area but we cannot give figures relating to this; as the quadrant map shows, UK waters do not extend across the whole North Sea.

Table 25 Quadrants in which harbour porpoise density is high (Hammond 2006a) and their relative oil & gas activity and infrastructure (period 1994-2005).

Quadrant Number	3D km^2 surveyed	2D km^2 surveyed	Number of Platforms in Production
27	24	0	0
35	0	18	0
41	0	214	0
42	0	1,577	6
43	0	503	8
47	18	628	11
48	176	1,731	35
49	313	1,651	94
51	-	-	0
52	0	4	1
53	0	839	3
54	0	300	0
55	-	-	0
56	-	-	0
57	-	-	0

To summarize: it appears that highest densities of harbour porpoises found in the North Sea have made a southward shift from 1994 to 2005, from a region with almost no oil & gas structures, and little seismic surveying, to higher overlaps with an area which has regions of very intensive E&P industry activity. At least, these spatial information hint that porpoises did not actively avoid areas of high E&P activity; however, as the rules that govern the movements of harbour porpoises are very poorly understood, no further conclusions can be drawn.

8.7 Impact analysis and conclusions for porpoises

Table 26 indicates that fisheries interactions, pollution and climate change are the effects that could have population level consequences for harbour porpoises off the UK coast. Climate change is difficult to mitigate against, as it cannot be addressed at the local scale or reduced overnight by banning certain actions. Contamination is difficult to assess, as the physiological consequences for individuals are just only beginning to be understood. There are some indications that, due to monitoring and mitigation programmes, bycatch numbers have been reduced. Other factors that could have negative influences on parts of the population include ship strikes and interspecific competition, with medium or low likelihoods of occurrence.

Table 26 Impact analysis for harbour porpoises of the UK east coast and North Sea. (Range: Short: < 100m, medium > 100 m < 5,000 m, long: > 5,000 m; Duration: Short: short-term, Long: long-term; intensity: Low (L), medium (M), high (H); severity, uncertainty(U) and likelihood(LH): Zero, low (L), medium (M), high (H), very high; likelihood U: unknown; for explanations, see chapter 2.2; dark grey: potential impacts on parts of population; light grey: measurable effects above normal fluctuations).

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
E&P industry sound	Seismic exploration	Masking	Long	Short	L	M	Very H	M
		Response	Long	Short	L	M	H	M
		TTS	Close	Short	M	L	M	M
		PTS	Close	Long	H	H	H	L
	Construction	Masking	Long	Short	L	M	Very H	L
		Response	Long	Short	L	M	H	L
		TTS	Close	Short	M	L	M	L
		PTS	Close	Long	H	H	H	L
	Drilling	Masking	Close	Short	L	L	M	M
		Response	Close	Short	L	L	M	M
Fisheries	Entanglement in gear	Injury	Short	Long	M	M	M	M
		Death	Short	Long	H	Very H	M	M
Shipping	Ship strikes	Injury	Short	Long	M	M	H	L
		Death	Short	Long	H	H	M	L
	Shipping sound	Masking	M	Short	M	M	H	H
		Response	M	Short	M	M	H	H
Pollution	Contamination	Reduced health	Long	Long	M	H	H	M
Environment	Climate Change	Emigration	Long	Long	H	Very H	Very H	H
		Starvation	Long	Long	H	Very H	Very H	H
Competition	Food-depletion by fisheries	Emigration	None				L-M	
		Starvation	None				L-M	Zero
	Interspecific competition	Emigration /avoidance	M	Long	H	H	Very H	L
		Starvation	M	Long	H	H	Very H	L
		Response	M	Short	L	M	M-H	L
Industrial activities	Aggregate dredging	Masking	M	Short	L	L	H	M
		Response	M	Short	L	M	H	M
	Construction – bridges,	Masking	M	Short	L	L	H	M
		Response	Long	Short	L	M	H	M

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
	turbines etc.	TTS	Short	Long	M	M	H	M
High-frequency sonar	HFS / Fishfinder	Masking	M	Short	M	M	H	H
		Response	M	Short	M	M	H	H

Conclusions The North Sea houses a large amount of oil & gas industry activity. Currently, this relatively small body of water has 284 platforms in production, with 201 wells drilled in 2006. The southern North Sea has seen the greatest increases in industry, with 168 platforms in 2007. The North Sea has a large amount of seismic surveying occurring there too, with over 2,000 km^2 3D surveying and over 2,500 km^2 2D surveying occurring in 2003 (quadrants 11 - 57 only). The harbour porpoise was chosen as the species of study as it is the most abundant cetacean in these waters, because of the huge interest which surrounds this species, and because of the many pressures they face in the North Sea. Yet, results from large-scale surveys indicate no significant changes in abundance between 1994 and 2005. Numbers of porpoises in the southern North Sea - the area with the highest concentration of platforms - have doubled between 1994 and 2005, most likely due a shift in distribution for animals from the north, which in turn might have been caused, by shifts in prey distribution. Bycatch numbers have decreased recently, possibly as a result of declines in commercial fisheries, improvements in nets, and mitigation measures. The impact matrix indicates that the main threats to this species are fisheries interactions, pollution and climate change. Sound from construction and seismic surveys will potentially lead to short-term displacements of porpoises, yet effects on populations are not apparent. The movement of harbour porpoises farther into areas more densely populated with oil & gas industry activities and structures is difficult to interpret as it might as well be that animals are forced to move into these areas due to environmental pressures. As it appears that, despite the many man-made pressures, harbour porpoise abundance in the mid- southern North Sea has been relatively stable over the past decade, ongoing surveys will provide a more detailed picture on the development of the population.

8.8 Minke whale stock assessment

8.8.1 Population structure

In 1977 the IWC split the North Atlantic minke whale population into four areas for management purposes; the British Isles minke whales were grouped with minke whales of Svalbard and Norway, and named the Northeastern stock; however, the information supporting these divisions was weak even for management purposes (Horwood 1990). More recent data from genetic, mark-recapture and other types of studies tend to support these divisions (NAMMCO 2008). Genetic studies indicate that the west Greenland and central Atlantic minke whales do not belong to the same stock as the north-eastern Atlantic minke whales (NAMMCO 1999). Mark-recapture analyses of animals tagged in the central and northeast Atlantic stock areas show little evidence of mixing between these two areas (IWC 1991). This north-eastern stock area is a much larger area than we are concerned with in this case study, so abundance estimates of these large geographically diverse stocks makes it difficult to infer any real population estimates for minke whales in the North Sea. The main concentrations of minke whales off the UK coast were recorded off the north-east coast of England, from Flamborough Head northward to the Orkneys (Northridge *et al.* 1995).

8.8.2 Population Size

In 1989, the second of the NASS surveys was conducted, which calculated abundance estimates for minke whales in the Northeastern stock area. Their estimate was 67,380 (95% CI 46,572 - 97,485) (Schweder *et al.* 1997). The NASS survey of 1995 repeated these estimates and numbers rose to 112,125 (95% CI 91,498 - 137,401) (NAMMCO 1998b), however there was no statistically significant difference between the two estimates. The SCANS surveys also provided abundance estimates for minke whales. Using the same blocks and regions of the North Sea designated above for harbour porpoise, gives the figures obtained. Despite the numbers for this area appearing much greater, it must be noted that the area for 2005 was larger given that an estimated abundance was calculated for the whole area of the far south North Sea, Channel, German and Danish coastline. In the 1994 survey, this area was separated out, and the German and Danish coasts did not have abundance estimates calculated for them given the lack of sightings.

In total, 18,600 minke whales were estimated for the whole of the SCANS-II survey area, this is much more than the estimate of 8,445 in 1994; however, the two surveys cannot be directly compared given the much larger survey area studied in 2005 (1,370,000 km^2 compared to 1,040,000 km^2, see above). Despite the larger abundance estimates and clear increase in densities (Figure 44) the total estimate of minke whale abundance for the North Sea of 10,500 (2005) animals was not significantly different from the figure of 7,300 obtained in 1994 (Hammond 2007 Table 27).

Table 27 SCANS I and II survey results by area for minke whales (taken from Hammond *et al.* 2002and Hammond 2006a).

Survey Year	Survey Block	Animal Abundance (CV)	Animal Density (animals km^2)
1994	B (far south and channel)	0	0
1994	C (coastal waters east UK)	1,073 (0.42)	0.0245
1994	F (northern central NS)	1,354 (0.36)	0.0114
1994	G (southern central NS)	1,001 (0.70)	0.0088
1994	H (German coast)	0	0
2005	V (northern NS) (ship)	4,450 (0.45)	
		Total 3,428	
2005	U (southern NS) (ship)	3,520 (0.69)	
2005	B (far south, Channel German and Danish coast) (aerial)	1,200 (0.96)	
		Total 9,170	

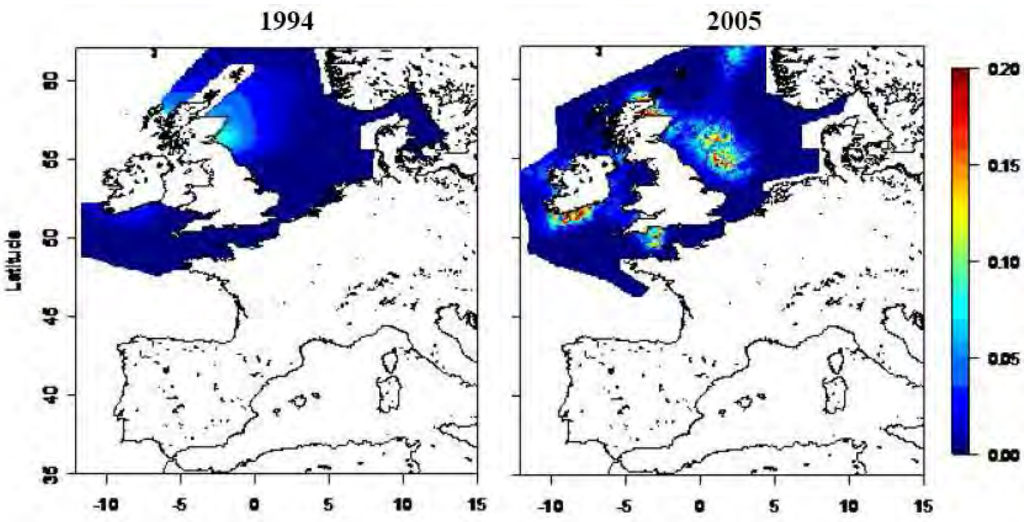

Figure 44 Density surface of minke whale abundance (animals per km^2) from the SCANS (left frame) and SCANS II (right frame; taken from Hammond 2007).

8.8.3 Demographic variables

Walton (1997) believed that minke whales appear to be segregated by **age/sex classes** more than any other baleen whale. This segregation coupled with, probably, changes to age class structures due to whaling, means that age classes are difficult to determine, and also makes historic tables from whaling catches (see for example in Horwood 1990) unreliable. For minke whales, much of the biological information comes from whaling records. This in itself presents problems, given that the whalers often targeted one sex as a result of its size, and also segregation of the sexes often meant biased catches of large numbers of one sex. Therefore biological data derived from whaling records needs to be viewed with caution. shows the minke whale catch by month by Icelandic whalers (1974-1978) along with the percentage of females in that catch (Horwood 1990). This trend however, **is the opposite sex ratio trend to that observed by English catches**, where in September and October, the catch was mainly mature females (Horwood 1990 Table 28).

Table 28 Percentage of minke whales caught by month from Iceland (1974 to 1978), and percentage of females in the catch (Taken from Horwood 1990).

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
% of minke whales caught by month	1.6	8.2	10.8	14.9	30.3	18.5	10.5	4.5	0.6
% of females in the catch	76.9	65.2	58.2	54.3	41.6	38.4	34.3	44.4	66.7

Horwood (1990) found that estimates of average and age-specific **mortality** from whaling records were unreliable, but the least worst of these estimates at this time was 0.13/year (using a geometric model and catch at age summed across a few earlier years). Further data indicated a natural mortality rate of about 10% per year; yet, as there was inadequate evidence to argue for any age-specific trend in natural mortality rate, it is likely that juvenile mortality rates are higher than adult mortality rates, leading to relatively high overall values (Horwood 1990).

8.8.4 Migrations / Seasonality

Northridge *et al.* (1995) reported minke whales to be rare in British waters during the first quarter of the year but, during the second quarter, minke whales move into coastal waters off north-east England and the Hebrides, and are then joined by more animals during the third quarter in the Hebrides and off the east coast of Scotland. In the fourth quarter there are still some minke whales present in the Hebrides, and a few off the east coast of Scotland (Northridge *et al.* 1995).

Weir *et al.* (2007) found that minke whales were only sighted off the Aberdeenshire coast during the month of August. A little farther north, a study of minke whales in the outer Moray Firth by Robinson *et al.* (2007) was conducted from 2001 - 2006 between the months of May and October. They found that minke whales were recorded during all survey months, the peak occurrence was during July and August. Additionally, the temporal distribution of whales suggested an inshore movement of animals across the summer months, with the whales being recorded in deeper, offshore waters in May and June, followed by increasing numbers of encounters with animals in more shallow, inshore waters from July onwards. However, these results did not hold true for all years. In 2004 the whales were completely absent from the study area, while 2005 and 2006 saw the highest abundances (Robinson *et al.* 2007).

Further seasonal studies of minke whale distributions in the UK and adjacent waters were made by MacLeod *et al.* (2007a) who collated ferry sightings data for a number of regions. In the northern North Sea, data were available from April to September from 2002 to 2006. Sightings of minke whales increased from April to July before falling rapidly in August and September; however, in April to June, sightings were primarily in more open waters away from the coast while in July to September they were restricted to more coastal waters (MacLeod *et al.* (2007a). The authors then suggested that sightings fell in July and August as a result of the minke whales moving into coastal waters, where the ferry route does not run. These findings seem to corroborate those of Robinson *et al.*(2007), with the movement of minke whales in the summer months in this area.

8.8.5 Population trends

As mentioned earlier, minke whale densities and abundance have been increasing between 1994 and 2005, yet the data are too variable to confirm this statistically. Despite minke whales from the North-eastern stock being targeted by whalers in the past and to a limited extent still in the present (see whaling section later on), surveys indicate that minke whale abundance in the Northeast Atlantic in general is stable or increasing and may be approaching pre-exploitation levels (NAMMCO 1999).

8.9 Other factors potentially affecting minke whales

8.9.1 Whaling industry

Horwood (1990) reported on the catches on minke whales around the UK coast. Norwegian whalers caught many minke whales in the North Sea, and in the 1940s there was a regular industry along the Scottish and English coasts; the Scottish whaling took place in July and August to the east of the Shetland Islands and moved to offshore of the English coast in September and October. The larger Scottish whaling operation took mainly males, whereas the English industry took mainly mature females (Horwood 1990).

From 1977 to 1982, the North-eastern stock of minke whales had an annual quota of 1,790 placed upon it by the IWC. No catch limit was agreed for 1983, and for 1984 a quota of 635 was set in order to halt the decline and stabilise the stock. In 1986, the IWC gave it protected status with a zero catch limit, however this was rejected by Norway (Horwood 1990).

Table 29 shows the catches made of minke whales from the North-eastern stock. All of these were made by the Norwegians, and after 1985, this was done under objection of the IWC.

Table 29 Catches of minke whales from North-eastern stock by Norwegians. 1978-1985 (figures from www.nammco.no.; post 1985 catches were made under the objection of the IWC; catch figures from 1986-2006 courtesy of IWC (http://www.iwcoffice.org/_documents/table_objection.htm)).

Year	Number of Minke Whales Taken
1978	1383
1979	1786
1980	1807
1981	1771
1982	1782
1983	1688
1984	630
1985	634
1986 (86/87)	379
1987 (87/88)	373
1993	157
1994	206
1995	218
1996	388
1997	503
1998	625
1999	591
2000	487
2001	552
2002	634
2003	647
2004	544
2005	639
2006	545

Minke whales are also infrequently entangled in fishing gear (NAMMCO 2008), albeit not reported for UK waters. VanWaerebeek & Reyes (1994) reported on the accidental fishing mortality of two minke whales in artisanal gill nets in 1991, off Peru.

8.9.2 Shipping

Minke whales are likely to be affected by acoustic disturbance from vessels, in the same way as other cetaceans. In the St. Lawrence estuary, Edds and Macfarlane (1987; cited in Evans 2003) found that minke whale vocalizations were masked by high-frequency outboard motor sound. However, not all reports demonstrate avoidance behaviour by minke whales towards ships. Evans (2003) reports that, in the Hebrides, minke whales, after increased exposure to vessels, exhibited little or no reaction. Also, a much greater number of whales seem to interact with whale watching vessels compared to when the industry started twelve years ago, which might be the result of habituation. Evans (2003) suggests, that if high-speed ferries were introduced in the Hebrides or Northern Isles of Scotland, the minke whale in particular might be affected, and the same applies to routes crossing the northern North Sea.

Minke whales are infrequently struck by vessels (NAMMCO 2008). However, there have been a number of such deaths reported in the literature with most observations having anecdotal character (Dolman *et al.* 2006). From the UK, reports have been received of direct observation of collisions of ships with minke whales (Evans 2003). According to sources cited in Dolman *et al.* (2006)[25], minke whales are the fourth most likely great whale to be involved in a vessel collision, with 6% of collision deaths involving this species. However, the sources of this claim are not of much relevance to the North Sea, where fewer species of great whale occur, and different vessel traffic densities are found.

8.9.3 Pollution

There is no evidence that contaminants are presently affecting minke whales in the North Atlantic (NAMMCO 2008). However, a study by Kleivane & Skaare (1998) analysing blubber samples from 72 minke whales from the northeast Atlantic, found the following organochlorines to be present: the industrial chemicals PCBs (polychlorinated biphenyls), and the organochlorine pesticides DDTs (dichlorodiphenyltrichloroethanes), HCHs (hexachlorocyclohexanes), HCB (hexachlorobenzene) and CHLs (chlordanes). Interestingly, concentrations of three major pollutants varied with sex; mature males had higher concentrations than mature females or juveniles. As suggested by the authors, this may be a consequence of geographic separation, and changes in diet with years/areas which may influence the levels of contaminants in these whales[26]. Also, males cannot download any of their body burdens of lipophilic contaminants to offspring and so their burden continues to increase as they age. Their findings were supported by a study by Hobbs *et al.* (2003) who analysed blubber from 155 minke whales from seven different regions of the North Atlantic, one of which was the North Sea. Minke whales from the North Sea did not have the highest concentrations of PCBs, but did have higher loadings of more highly chlorinated PCBs and recalcitrant OC pesticides than animals from Greenland (Hobbs *et al.* 2003). However, general similarities in contaminant levels suggests that the whales are quite mobile and may feed in multiple areas within the north-eastern Atlantic (Hobbs *et al.* 2003).

[25] A review of strandings databases for the US Atlantic Coast [1975-1996], Italy [1986-97], France [1972-98] and South Africa [1963-98], cited in Koschinski, 2002

[26] Lower levels in females might also be related to the transfer of contaminats during lactation.

8.9.4 Environmental changes

Historically, the distribution of minke whale catches by whalers followed that of the fishery for migratory herring that thrived at the time and minke whales were frequently observed among the herring shoals (Horwood 1990). However, given the decline of herring fisheries around the UK coast, it is likely that this species will also have been forced to switch their prey choice. In the North Atlantic, minke whales consume mainly krill (*Thysanoessa* spp. and *Meganychtiphanes* spp.), herring (*Clupea harengus*), capelin (*Mallotus villosus*), sandeel (*Ammodytidae*), cod (*Gadus morhua*), polar cod (*Boreogadus saida*), and haddock (*Melanogrammus aeglefinus*), as well as other species of fish and invertebrates (NAMMCO 1998a). Prey choice will vary spatially and temporally and is dependent upon availability. Many of these commercially important species have seen dramatic decreases in the North Sea in recent years, leading to the increased likelihood that the minke whales in this area will have either to switch prey species or move out of the area.

Pierce *et al.* (2004) found that in the North Sea, sandeels comprised the principal prey item for minke whales, constituting approximately 70% by weight of their diet. This was supported by a study by Robinson & Tetley (2007) in the outer Moray Firth, who believe that schooling mackerel perform the role of compacting targeted sandeel prey into concentrated bait balls during summer, on which the minke whales forage. If this is the case, minke whales in this area are reliant on not just one species (their prey) being present, but also on facilitators being present in the same area at the same time; making them twice more at risk of declining fisheries and other environmental impacts which may affect these fish species. It is possible that the absence of either of these fish species during the summer of 2004 was liable for the total absence of minke whale sightings that year (Robinson & Tetley 2007).

8.9.5 Military

Thiele (2001; cited in Evans 2003) found no avoidance responses of minke whales to a vessel throughout the time the EK 500 echo sounders were operating; whales were seen in close proximity and none of them appeared to move away even though the echo sounders are audible to them several miles away from the vessel. In the Bahamas in 2000, two minke whales live stranded in the presence of 2.6 - 8.2 kHz active sonar sounds generated during military exercises (reviewed in ICES-AGISC 2005), providing evidence that may link military sonar with negative behavioural responses in minke whales.

8.10 Overlap between minke whale distribution, platforms and seismic surveys off the UK east coast

For this analysis, the same precautions shall be kept in mind as mentioned in chapter 8.6.

In the North Sea, minke whales are present from approximately 54°N in the south of their distribution, northwards to the Moray Firth and Shetlands (Figure 41). Their distribution indicates a coastal preference, with numbers decreasing substantially farther offshore in the central North Sea. In this case, their distribution has relatively little overlap with the oil & gas industry, with almost no infrastructure occurring in this region close to shore. The amount of 3D seismic surveying is also very small in this region (Figure 36). However, it appears that there may have been an offshore movement of minke whales farther into the central North Sea (see Figure 44) during the most recent SCANS II survey. It is unlikely that this is a consequence of seasonal movements, as, during the summer, when the SCANS surveys occurred, minke whales have generally been found to move inshore (Northridge *et al.* 1995; MacLeod *et al.* 2007a; Robinson *et al.* 2007). Consequently, this increase in density in the central North Sea during 2005 means the whales will be under increased exposure to the activities of the E&P industry.

The central North Sea currently has 43 platforms, of which 23 have been installed in the last 10 years, showing a 65% increase since 1997 (Table 20, Figure 35). The main quadrants that correlate to the 2005 minke whale distribution in the central North Sea are 28 - 30, 36 - 38 and 43 - 44. Within these quadrants there are 28 platforms in production. The largest amount of seismic surveying occurs in 29, 30 and 38, with 1769, 5563 and 1249 km^2 3D surveying (1997 - 2003) and 2040, 2421 and 322 km^2 of 2D seismic surveying (1997 - 2003) respectively. However, this relatively high level of surveying appears to have decreased post 2005 (see Figure 36).

To summarise, in the central North Sea, there has been a 65% increase in platforms over the last 10 years, coupled with which there would have been a large rise in sound levels during construction etc, and also seismic 3D and 2D surveys occurring in relatively high densities within some central North Sea quadrants. Yet the minke whales appear to have moved away from their mainly coastal distribution (Figure 41, Figure 44) where there are no platform structures and almost no seismic activity occurring, to an area with high E&P activity.

At least in the summer, minke whales are concentrated in the Moray Firth (Hammond 2006a; Hammond 2007; Robinson *et al.* 2007). Simultaneously, the oil & gas activity in this area has been increasing. Table 20 shows that, as of 2007, there were 19 installations in the Moray Firth area, growing from just three in 1977 (BERR 2008). This rise has however remained relatively stable with few installations being emplaced since 1999. In contrast, the amount of seismic activity in this area has risen sharply. Before 2005, the amount of 3D seismic activity in the Moray Firth was very small, however, from 2005 onwards, there was an increase in the number of seismic surveys (Figure 36). Quadrants 17 and 18 (refer to Figure 37 for quadrant locations) encompass the southern edge of the outer Moray Firth, and the region studied in Robinson *et al.* (2007). In these quadrants, there are no platforms in production and there has been a negligible number of 2D seismic surveys, but 800 and 451 km^2 were surveyed for 3D in quadrants 17 and 18, respectively (from 1997 - 2003). However, the largest amount of 3D seismic surveying occurred in quadrant 12 in the outer Moray Firth, where between 1997 - 2003, 5046 km^2 were surveyed. This trend appears to have continued into 2005 and beyond (see Figure 36).

Given the increased level of seismic surveying occurring in the region, and the installation of a further six platforms between the SCANS I and II surveys, it appears that the minke whales are not adversely affected, at least enough to have caused them to have moved into other areas. In fact, the density maps (Figure 44) show quite the opposite, with more minke whales being found in this area in 2005 than in 1994. As indicated in the previous exercise on porpoises, this trend shouldn't be interpreted in a way that E&P activity didn't affect the whales as there might be pressures that lead the animals to use an area even under adverse conditions (see below).

8.11 Impact analysis and conclusions for minke whales

Table 30 highlights the factors and effects faced by minke whales in this area. Concurrent with the other case studies, climate change is the factor that has potentially the most severity upon these animals and could result in population wide consequences. As discussed earlier, climate change is not exclusive to this species in this area, and cannot be mitigated against on a short-term basis. Fisheries interactions resulting in death are also coupled with a very high severity, however, the lack of historical documentation of minke whales being bycaught indicates that this is unlikely to occur, and certainly not to an extent that would affect the population. Ship strikes, contamination and interspecific competition are also highlighted as factors that could have negative consequences for the population, however these have a medium likelihood of occurring and scientific documentation does not support them to have had negative effects at the population level in the past, and no evidence is emerging to suggest they may in the future.

Table 30 Impact analysis for minke whales of the UK east coast and North Sea. ((Range: Short: < 100m, medium > 100 m < 5,000 m, long: > 5,000 m; Duration: Short: short-term, Long: long-term; intensity: Low (L), medium (M), high (H); severity, uncertainty(U) and likelihood(LH): Zero, low (L), medium (M), high (H), very high; likelihood U: unknown; for explanations, see chapter 2.2; dark grey: potential impacts on parts of population; light grey: measurable effects above normal fluctuations).

Factor	Source of impact	Effect	Range	Duration	Intensity	Severity	U	LH
E&P industry sound	Seismic exploration	Masking	Long	Short	L	M	H	M
		Response	Long	Short	L	M	H	M
		TTS	Close	Short	M	L	H	L
		PTS	Close	Long	H	H	H	L
	Construction	Masking	Long	Short	L	M	H	L
		Response	Long	Short	L	M	H	L
		TTS	Close	Short	M	L	H	L
		PTS	Close	Long	H	H	H	L
	Drilling	Masking	Close	Short	L	L	M	M
		Response	Close	Short	L	L	M	M
Fisheries	Entanglement in gear	Injury	Close	Long	M	M	M	U
		Death	Close	Long	H	H	M	U
Shipping	Ship strikes	Injury	Close	Long	M	M	H	U
		Death	Close	Long	H	H	M	U
Pollution	Contamination	Reduced health	Long	Long	M	H	H	M
Environment	Climate Change	Emigration	Long	Long	H	Very H	Very H	U
		Starvation	Long	Long	H	Very H	Very H	U
Tourism	Whale watching sound	Masking	M	Short	L	M	H	L
		Response	M	Short	L	M	M-H	L
		TTS	Close	Long	M	M	H	L
Industrial activities	Aggregate dredging	Masking	M	Short	L	M	H	M
		Response	M	Short	L	M	H	M
	Construction – bridges, turbines etc.	Masking	Long	Short	L	M	H	M
		Response	Long	Short	L	M	H	M
		TTS	Close	Short	M	L	H	L
		PTS	Close	Long	H	H	H	L
Marine transport	Shipping sound	Masking	Long	Short	L	M	H	M
		Response	M	Short	M	M	M	M
		TTS	Close	Long	M	M	Very H	M
Military	HF sonar	Masking	None					U
		Response	M	M	Short	L		U
		Injury	Close	Long	M	M		U

Conclusions As stated earlier, the North Sea is densely populated with oil & gas industry surveying and structures. The minke whale was chosen for study as it is the most abundant low-frequency cetacean in these waters. The outlook for minke whales appears to be relatively positive in the Northeast Atlantic. No large increases in strandings have occurred recently, and survey results seem to indicate an increase in numbers overall, with localised fluctuations mostly likely a result of changes in prey distribution. Minke whales remain the most abundant balaenopterid in the North Atlantic, and may be approaching pre-exploitation levels (NAMMCO 1999). Their healthy numbers in this region and movements into and around busy areas of the North Sea, indicate that this species is not significantly threatened from the number of factors affecting them, including the oil & gas industry.

8.12 Remarks on studies on effects of seismics on cetaceans in the area

A study by Stone & Tasker (2006) on seismic survey effects on cetaceans found that, between 1998 - 2000, 37 sightings of harbour porpoises occurred (111 individuals) and they were found to remain further from the source when it was active, and also their orientation was affected. Minke whales did not exhibit the same response. Sightings on 79 occasions (103 individuals) found that no effects on the occurrence or behaviour of minke whales were observed.

The lack of response exhibited by minke whales in the Stone & Tasker (2006) study would seem to correlate to their movements, which do not seem to actively avoid or remain farther from oil & gas industry production and exploration activity, especially in recent years. Although harbour porpoise showed some avoidance to sound sources associated with the industry, it does not appear to have shifted the distribution permanently out of areas of intensive activity and, in fact, the southwards shift in distribution that they have exhibited actually showed more animals closer to areas of higher activity than was the case in 1994.

9 General discussion

This investigation provided new insights into trends of some selected cetacean stocks that are exposed to E&P industry sound and a variety of other man-made factors. In doing so, we were mainly guided by a *conservation level approach* by looking at population level trends in relation to exposure to human impacts, although we also dealt with consequences on an individual level (see chapter 3 Whitehead *et al.* 2000)). We have tried to discuss population trends and attempted to weight the various factors affecting stocks in the case studies. Here, we try to wrap everything up by reflecting on the main outcomes of this study.

9.1 The overall picture

Large-scale uncertainty regarding cetacean stocks From what we described in chapter 4, it becomes apparent that there are very large gaps in our understanding of the distribution and abundance of cetaceans in areas of high E&P activity. The data on long-term trends is only sufficient for areas off the Northwest European coast and off North America; but, even here, only a very few number of stocks lend themselves to more detailed study with regard to exposure to E&P industry sound. The lack of adequate data becomes especially apparent if we look at areas off Africa, Indonesia and South America. This is a serious gap, as these areas are under increasing focus by the E&P industry for future exploitation (Table 31), and regulatory frameworks as well as mitigation measures are probably very different from the ones in more 'developed' areas. We have already mentioned that one important future research task should be a more comprehensive mapping of cetacean stocks worldwide and a fostering of case studies, particularly off the West coast of Africa but also off Asia. This is also important if we consider that exposure to stresses / threats can vary greatly across regions making extrapolations on effects of human activities from one area to the other quite challenging. Yet, this is probably difficult to achieve through a fund such as the JIP, as the data that needs to be gathered should be of high temporal resolution, preferably spanning at least 10 years (Whitehead *et al.* 2000).

Limited information on E&P exploration activity Another confounding factor in this analysis was the lack of open-access data on oil & gas platforms and even more so on the number of seismic surveys in almost all parts of the world. Without any additional funds, it was very difficult to quantify the impact from seismic surveys (on the difficulties in quantifying sound budgets in different regions, see below). It should be in the own interest of the industry to provide data if needed, to foster transparency and research on its potential impacts.

9.2 A closer look

Trends in the case study species In this study we took a closer look at the development of stocks / populations of seven cetacean species in different parts of the world that are heavily used by the E&P industry. We should mention here that - even if we chose a rather representative set of case studies - our overview is far from providing a complete picture and should be viewed rather as a first necessary step to outline major points that might be then addressed in further investigations. However, despite these limitations, some interesting results can be shown.

Two of the stocks we have analysed in more detail have been increasing in numbers or surveys indicating population growth (Californian humpback whales, and UK minke whales, respectively). This is especially intriguing, since both represent low-frequency cetaceans (Southall *et al.* 2007) who should principally be affected to a larger extent by E&P sound than other cetaceans (but see also discussion in chapter 3). Three of the investigated stocks seem to be at least stable (northern bottlenose whales off Nova Scotia, harbour porpoises off the UK east coast, fin whales off California). One seems to remain unchanged, yet trends are difficult to assess due to the magnitude of error in abundance estimates (Gulf of Mexico sperm whales). Finally, individuals of one stock - the blue whales off California - show a decrease in numbers of sighted animals; however, as outlined in chapter 6, this is probably due to a shift in whale distribution that is in turn rather related to shifts in prey distribution than to man made effects. The apparent lack of negative population level consequences of human disturbance is at first sight stunning as we were able to identify and weight a variety of factors that potentially affect each of the stocks in addition to E&P sound exposure.

Possible explanations McGregor (2007) discusses three possible explanations for the lack of response in sound playback studies that are applicable to this investigation. We have amended them only slightly and shall discuss them in more detail below:

Measures are too crude to detect differences This is an important argument that is often raised when studying potential impacts on population level trends in cetaceans. For example, Whitehead & Weilgart (2000) argue that looking at the published studies on cetacean distribution and abundance, CI's of more than 0.20 are too high to indicate population level trends over the comparably short periods that most stock assessments are undertaken. Looking at our case studies, uncertainties persist for the sperm whales off the Gulf of Mexico, and we should also apply caution in drawing firm conclusions regarding minke whales off the UK (see above). However, for harbour porpoises, data in some survey blocks of the SCANS I and II surveys were relatively robust and density surface modelling allowed for a comparison between surveys with no overall changes observed, but a significant shift in distribution from North to South (Hammond *et al.* 2002; Hammond 2006b). Large-scale trends were also confirmed by smaller scale investigations that allowed for statistical comparisons between surveys (Thomsen *et al.* 2006a, 2007). Yet, given the relatively large size of the population and the overall high statistical variability in the density estimates, we should be somewhat cautious in over interpreting the results of SCANS I and II. Given that - under a worst-case scenario - bycatch numbers were approximately 3,000 - 4,000 individuals per year between 1994 and 2005, the resulting 36,000 - 48,000 extra-deaths might have lead to an overall decrease of the population of < 10% in that period might not be identified due to statistical variability. On the other hand, Scheidat & Siebert (2003), modelled the impact of bycatch and other human factors on harbour porpoises in the German North Sea and found a decrease of ~ 20% over the course of 10 years, calculating with an annual bycatch of 4.29%. Further studies will help to shed light on the trends of the harbour porpoise population in the southern North Sea. Furthermore, the abundance estimates of two of the three species of baleen whales we looked at off California – humpback whales and blue whales - comprise reasonable CI's, and the observed trends might also be viewed as rather robust[27]. The same might be said about the Northern bottlenose whales in The Gully[28]. A possible way to reduce the uncertainty in assessing trends in cetacean populations would be the development of better data collection systems, perhaps allowing also for shorter survey intervals and a higher number of transects per survey (see Thomsen *et al.* 2006a). One should also consider a combination of methods, for example passive acoustic tracking and visual line transect counts. Finally, the application of power analysis should foster the investigation of long term population trends (for a recent review see Diederichs *et al.* 2008, see recommendations below).

Populations experience no difference even when individuals are affected Looking at the sound profiles from the E&P industry on the one hand and the hearing systems of cetaceans on the other, we might say that cetaceans perceive E&P industry sound over comparably large areas and PTS and TTS might happen at some distance from the source (see chapter 3)[29]. We have also documented published disturbance reactions for each case study species (chapters 5 - 8). One alternative explanation for a lack of negative response at the population level might be that the factors we discussed are either not severe enough, or that individuals are able to adapt to changes in their environment to compensate for negative effects. One might argue that the oceans are rather noisy places and that cetaceans are adapted to deal with relatively high received sound pressure levels (Wahlberg 2007). It is true that there are a variety of sources of sound in the marine environment that occur naturally, such as vocalisations of marine mammals, fish and certain crustaceans, sounds that are induced by rain, wind and waves, as well as sub-sea volcanic eruptions, earthquakes and lighting strikes. Some of them can reach quite high levels, for example source sound pressure levels of click sounds that are used by toothed whales in navigation and foraging can be as high as 235 dB re 1mPa peak to peak (sperm whale clicks Møhl *et al.* 2003). Another example is snapping shrimp, which influence ambient noise

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[27] In general, mark-recapture estimates based on photo-identification yield better results in terms of statistical power than line transect surveys (see results in Table 13).

[28] Yet, C.V's are not given but only confidence intervals.

[29] We should keep in mind that for most cetaceans, no audiograms are available.

levels in tropical and subtropical waters to a high degree and might contribute to ambient noise levels in some areas of higher latitudes as well (Wenz 1962; NRC 2003; Hildebrand 2005). Yet, the story might be more complicated as, in the case of biosonar, the emitted sound is highly directional and the chances of being 'hit' are less than when compared to man-made sonars (Møhl 2003). Furthermore, many biological sounds are seasonal and the ocean is therefore not *per se* a noisy environment. We should also remember that many areas are rather quiet, especially during nighttimes, when human activity is low (own observations). Finally, man made sound *adds* to the sound that is already out there and it can't be ruled out that even moderate levels are enough to increase ambient noise profiles considerably (Ross 1993; NRC 2003; McDonald *et al.* 2006 see below).

If sound bothers cetaceans, they should have developed mechanisms to compensate for negative effects. Indeed, these are manifold and can include altering the timing and the design of social signals as well as a wide range of behavioural reactions (Miller *et al.* 2000; Foote *et al.* 2004). It should be remembered that this mechanism might be relatively straightforward as the direct costs of sound production in cetaceans are presumably low (for review on sound production mechanisms, see Frankel 2002). It should also be remembered that many cetaceans principally cover large distances during any given day (see species chapters in Perrin *et al.* 2002) and that slight changes in behaviour such as startle responses or changes in swimming pattern due to sound exposure might be negligible (see Southall *et al.* 2007). Studies that suggest otherwise (e.g. Williams *et al.* 2006) are, as yet, highly speculative[30].

Different response is inappropriate - This argument stems from evolutionary biology and basically infers that animals might not react to unwanted signals just because there are other things more important to them at the time of exposure. We should consider here that animals have evolved in such a way that there is a trade-off between individual costs (reduced survival, reduced short term well being) and benefits (value of the habitat / foraging etc) to optimise their fitness (Krebs & Davies 1997). In other words: man-made sound might be unwanted, disturbing and / or unpleasant, but the rewards to stay in the habitat outweigh the costs (McGregor 2007; Barnard 2007).

It is difficult to assess the value of the habitat for each of our case study species, as the areas we were looking at are quite large. But at least it seems that Northern bottlenose whales seem to rely on deep-water channels like The Gully, as they are specialised foragers on bottom dwelling prey (see chapter 7). It is, therefore, likely that their threshold for disturbance is much higher than in other species that use their habitat on a much more opportunistic basis, such as the blue whales off California or porpoises off the UK, that have shown rather drastic changes in response to prey availability (see chapter 6, 8). We should therefore be cautious in interpreting the lack of a negative trend in Northern bottlenose whales as showing that man-made factors have no effects on them.

This is even more important when we envision that individuals might be disturbed only to a certain level: It would be interesting to find out if there is a level at which populations change due to human factors: A very good case study - albeit not within the range of the oil & gas industry - are the resident killer whales off British Columbia and Washington State. Since the beginning of the field studies in the 1970s, both northern and southern resident communities have been increasing at a rate that is at or close to the maximum reported for the species (2 - 3%); and they have been doing so

[30] Studies that actually show a decline in the study objects like the bottlenose dolphins observed by Bejder *et al.* 2006b et al are highly resident.

despite a variety of human impacts. Yet recently, numbers have levelled off in the northern and decreased in the southern community (Ford *et al.* 2000). This can at least theoretically be attributed to man made effects such as over fishing, contamination and disturbance by vessels; yet, it might also only indicate that both populations have reached their respective carrying capacity (see Ford *et al.* 2000 for a more detailed discussion).

9.3 Short term vs. long term impacts

In this review, we were able to identify a number of factors that potentially lead to negative effects on individual cetaceans. We were also able to divide effects according to their temporal, spatial and biological characteristics. Looking at the factors inducing change, we should take a closer look on those that are long lasting, as it is the potential effects of those that might be of greatest concern. Climate change seems to be the overarching sword of Damocles on the marine environment: It can impact cetacean populations both directly (e.g. reduced sea ice) and indirectly (changes in the distribution and abundance of prey; reviews by Whitehead *et al.* 2000; Moore 2005; Learmonth *et al.* 2006). However, at present, it is very difficult to assess the effects of climate change on cetaceans as the whole research field seems to be still very much in its infancy: Lusseau *et al.* (2004) report that climate change affects grouping behaviour in both wild killer whales and bottlenose dolphins. However, as the authors themselves point out, they were not able to establish causal relationships, but rather looked at very indirect links between a 'critical group size' and parameters indicating prey availability. The same is true for MacLeod *et al.* (2007b) who investigated stomach contents of stranded harbour porpoises found in two arbitrarily selected 'periods' 1993 - 2001 and 2002 / 2003, and drew very wide-ranging conclusions on the potential effects of climate change on sandeel distribution based on a very limited number of samples. On the other hand, very convincing seem to be the investigations by Trites *et al.* (2007) and Guenette *et al.* (2006), who investigated the decline of Steller sea lions in the Gulf of Alaska and the Aleutian Islands with a variety of methods and could show that ocean climate played a role in the decline; but they also found, that other factors contributed too (see below). Investigations on environmental factors that are governing the distribution of cetaceans are just emerging (see for example Skov & Thomsen in press)) and it will be probably only a matter of time until the way climate changes affect cetaceans is better understood.

9.4 Cumulative effects

It is very likely that none of the factors we identified in the case studies is harmful enough to cause a decline in cetacean stocks, but together they may create conditions which lead to reduced productivity and survival. In their investigation on Steller sea lions, Guenette *et al.* (2006) found that predation, prey availability, ocean climate changes and interspecific competition all played a role in the drastic decline of the Alaskan stock of sea lions. They were also able to quantitatively weight the different factors in a modelling exercise. Cetologists, on the other hand, are far from quantitatively weighting factors that affect whales and dolphins (see NRC 2005). Yet, it should have become clear from what we said above, that sound is only one factor impacting cetaceans and it might be not the most severe one: For example, Read *et al.* (2006) estimate that worldwide fisheries kill several hundreds of thousands of cetaceans as bycatch each year. It is therefore evident that the potential impacts of sound have to be looked upon in a wider perspective, addressing the consequences of acoustic disturbance on populations in conjunction with other factors (see NRC 2005). This concert of factors might be expanded to migratory species such as our three baleen whales off California that are not only affected by human and other activities on their summer feeding grounds but also during migrations and on their wintering grounds. Previous research indicates that individuals - especially females with calves - might be more prone to disturbance during this time of the year compared to other periods.

9.5 Regulation and mitigation

A discussion of regulatory approaches and mitigation measures is not the primary concern of this review and details shall be looked up elsewhere (for overviews, see Richardson *et al.* 1995, Würsig & Richardson 2002, OSPAR in press). Here, we should only outline some basic principles.

One way to regulate noisy activities is to set **criteria for sound exposure** that should not be exceeded (see chapter 3.1 for details Southall *et al.* 2007)). It should again be noted that these values are discussed controversially within the scientific community as they are based on very limited data sets with respect to sound-induced injury in marine mammals. There have been similar attempts to define exposure criteria for fish, yet none have been published to date. Another way for regulation to proceed is to set **safety zones** within which no marine mammals should be present during sound intensive activities. For example, for marine mammals, the Joint Nature Conservation Committee (U.K.) recommends an exclusion zone of 500 m for the start of seismic surveys (JNCC 2004). Besides setting sound exposure criteria and safety zones, there are several other measures to mitigate against potential impacts of underwater sound, both dealing with the **source of sound** as well as the **receiver**. Looking at the source, there are several mitigation options currently in place or proposed, the design of the equipment used in an activity can be altered so that noise is significantly reduced. There is also the option of a restriction of noisy activities during 'critical' phases, such as breeding in marine mammals. Operational procedures can also be applied to reduce noise, for example 'soft-start / ramp-up' procedures can be undertaken during pile driving by slowly increasing the energy of the emitted sounds and thereby alerting marine life to the sound. Looking at the receiver, acoustic harassment devices have been used both for seals and harbour porpoises and have proven to be effective in scaring the animals away from the source at close ranges (Yurk & Trites 2000; Culik *et al.* 2001; Cox *et al.* 2001).

9.6 Future areas of research

Looking at the issue of effects of underwater sound in more general terms, Southall *et al.* (2007)and IACMST (2006) provide a detailed list of recommendations for future research. In our opinion, there are several areas where research on the effects of E&P industry sound on cetacean stocks shall specifically focus in the future:

Better data on cetacean stocks focussing on particular areas We have already highlighted the need for comprehensive datasets in certain areas (see above).

Transformation of activities into quantities of sound exposure The question of how activities such as km transect of seismic surveys can be transformed into 'noise budgets', providing units that are quantifiable, is a very important issue that is still in its infancy. Yet, without noise budgets, the exposure that animals face is not quantifiable, and therefore comparing effects can only be done in rather broad terms (see Hildebrand 2005; Miller *et al.* 2007).

Development of finer impact analysis methodology As mentioned earlier (see chapter 1), NRC (2005) developed a population consequence of acoustic disturbance model (PCAD model) that involves different steps from sound source characteristics through behavioural change, life functions impacted, and effects on vital rates to population consequences. Yet, most of the quantitative variables of the PCAD model are currently unknown. Challenges to fill gaps can come in many ways, due to uncertainties in population estimates for several species / regions, difficulties in weighting noise against other stressors (see above), difficulties in quantifying noise impacts etc. (see NRC 2005 for a detailed discussion). Despite the uncertainties, models like the PCAD one shown above are essential in understanding the possible impacts of man-made sound and should be further developed.

Development of further methodologies to measure change in cetacean populations There are a wide variety of methodologies available that can be refined or combined to adequately measure change in cetacean populations. This includes visual monitoring using distance line-transect sampling, including new techniques for estimation of correction factors (g(0); Buckland *et al.* 2001; Thomsen *et al.* 2005a), passive acoustic monitoring (PAM) (see Thomsen *et al.* 2005b). New approaches also include using habitat modelling (Skov & Thomsen in press) and a refinement Before-After Control Impact design (BACI design; Diederichs *et al.* 2008), as well as density surface modelling (Hammond 2006b).

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12 Appendix

Table 31 Overview of E&P industry and cetacean stocks – a – Number of platforms (GESAMP 2007, MMS 2008, BERR 2007), b - Average active drilling rigs per month current (2007 yr average) activity (Baker Hughes rig count 2008), c – Average active drilling rigs per month – Historical Peak during 1982-2007 (Baker Hughes rig count 2008) d – Current Rig Fleet (RIGZONE accessed Jan 2008), e – Current rig utilisation (RIGZONE accessed Jan 2008)

Area	**E&P Activity**							**Number of species**	**Most abundant stocks (N)**	**Source for cetacean stocks**	**Data Assessment**
	Activity started	***a***	***b***	***c***	***d***	***e***	**Seismic**				**NS / S**
				Africa							
Africa – West Coast	1938 – seismic exploration 1958 - production	~380 (2000)	15	54 (1982)	69	89.9%	Seismic vessel count – 9 (1995)	> 20	<u>Gulf of Guinea:</u> bottlenose dolphins and humpacks <u>All coast:</u> Atlantic humpback dolphin	Picanço *et al.* 2006	NS
Nigeria			6				21,000 km 2D seismic lines 21,500 km 3D seismic lines (1993 – 1998) *NNPC(2008)*				
Angola			3				94,758 km 2D (~2007) *Western Geco*	21	Sperm and humpback whale	Weir 2006c, a, b, 2008	
Gabon			1				47,429 km 2D (~2007) *Western Geco*				
Congo			1				2,426 km 2D (~2004) *Western*				

Area	E&P Activity							Number of species	Most abundant stocks (N)	Source for cetacean stocks	Data Assessment
	Activity started	*a*	*b*	*c*	*d*	*e*	Seismic				NS / S
							Geco				
Asia Pacific											
Overall		~ 950 (2000)	107	109 (2006)	219	42.5%	Seismic vessel count - 29 (1995)				
Indonesia	1962 – Joined OPEC		20				15,854 km 2D seismic lines 2,877 km 3D seismic lines (2003) MIPGAS (2007)	Indonesia: 29 (sperm whales) ; Sulawesi: sperm whales Kalimantan: 10 species mostly *Delphinidae*	Not sufficient information; potentially sperm whales (regional) and *Delphinidae*	Indonesian oceanic cetacean program, Kalimantan: Kreb & Bodiono 2005	NS
Malaysia & Philippines			15				3,524 km^2 3D (1997/98) 5,740 km 2D (2002) *Western Geco*	Phillipines: 21	-	Alava *et al.* 1993	
Thailand & Vietnam			15					Vietnam Gulf of Tonkin: ~ 6; mostly *Delphinidae*	*Delphinidae*	Smith *et al.* 2003	NS
West Australia			11		21	90.5%	23,875 km 2D (1996-1997) *CGG Veritas* Seismic vessel count – 6 (1995)	-	Humpback and blue whale	Jenner & Jenner 1992; Jenner & Jenner 1994; Jenner *et al.* 2001	Suffient for humpback whale LFC
South Asia (India)			29		51	88.2%		-	-	-	-
China			19								
Middle East											
Overall	1960 – Arabian Gulf and south Caspian Sea		30	66 (1982)			Seismic vessel count – 12 (1995)	Western tropical Indian Ocean incl. Gulf of Oman: 21 species	Regional differences; mostly small odontocetes, less mysticetes	Ballance & Pitman 1998 Baldwin *et al.* 1998; Baldwin *et al.* 1999;	NS

Area	E&P Activity							Number of species	Most abundant stocks (N)	Source for cetacean stocks	Data Assessment
	Activity started	***a***	***b***	***c***	***d***	***e***	**Seismic**				**NS / S**
								spinner dolphins and sperm whales: Arabian Peninsula: 23 (6 mysticetes) All areas 28 species all groups with regional differences		Baldwin *et al.* 2000; Baldwin *et al.* 2002; WDCS 2002; Oman 2003, 2004	
Caspian Sea					25	68%					
Persian Gulf (UAE, Qatar, Saudi Arabia)			27		16	73.8%		3 + unidentified	Indian ocean bottlenose dolphin	Preen 2004	NS
Red Sea (Egypt)			11		16	100%		~ 10	Bottlenose dolphin	Baldwin *et al.* 1999	NS
Russia Offshore activity confined to areas of Sakhalin Island and Barents Sea.	1998 – Shakalin Island construction 1999 – Production 1982 – O&G discovered in the Barents Sea	3 – Shakalin Island					Seismic vessel count – 13 (Commonwealth of Independent States –1995)	Barents Sea: 15 (marine mammals); minke whales and humpbacks white whales migratory Sakhalin: ~ 23	Barents Sea: Minke whales, humpback wahles Sakhalin: killer whales, minke whales, gray whales (identified individuals)	Barents Sea: Zabavnikov *et al.* 2005 Skaug & Oien 2005 Schweder & Volden 1994; Lindstrøm *et al.* 1999; Lindstrøm *et al.* 2001; Lindstrøm & Haug 2001; Haug *et al.* 2002Sakhalin: Kato *et al.* 2005; Burdin *et al.* 2007	Barents Sea: Sufficient for minkes and humpbacks Sakhalin: Sufficient for killer whales and gray whales
			South America								
Overall		~ 340		87			Seismic vessel				

Area	**E&P Activity**							**Number of species**	**Most abundant stocks (N)**	**Source for cetacean stocks**	**Data Assessment**
	Activity started	***a***	***b***	***c***	***d***	***e***	**Seismic**				**NS / S**
		(2000)	71	(1982)			count – 10 (1995)				
Venezuela	1920 – Offshore activity around Lake Maracaibo		17		46	89.8%		21	Bryde's whale and common dolphin wintering Humpback whales	Romero *et al.* 2001; Silva *et al.* 2006 Oviedo & Silva 2005	NS
Brazil	1967 – Offshore activity began		22		49	67.4%	27,531 kms 2D (~1999) *CGG Veritas* 21,0000 km 2D 27,000s km^2 3D *Fugro Reprossed*	43 (35 odontocetes, 8 mysticetes)	-	IWC progress reports, Freitas Netto & Barbosa 2003; Parente & De Araújo 2005; Parente *et al.* 2006	Only presence / absence data
Mexico			28		68	76.5%					
Other & Carib.			4		14	71.4%		-	Humpback whales (regional)	NOAA	NS
			North America								
Overall		~ 3889 (2008)	75								
Gulf of Mexico	1947 – Production began	3,847 (MMS Feb 2008)	71	231 (1981)	276	54.7%	1,800,144 km CDP (2D) 234,590 km High Res. 269,962 km 258,202 km CDP Interpretation 549,277 km^2 3D DST 3 wells 1968-02, OCS Report	19	Sperm whale bottlenose dolphin	IWC, NOAA (1995-2005) SWSS (2002-2006)	Sufficient for sperm whales (MFC)
North Atlantic Shelf (U.S. Waters)	1976 – Exploratory drilling		3		3	100%	127,788 km CDP (2D) 0 km^2 3D				

Area	E&P Activity							Number of species	Most abundant stocks (N)	Source for cetacean stocks	Data Assessment
	Activity started	*a*	*b*	*c*	*d*	*e*	Seismic				NS / S
							1968-97, OCS Report				
Eastern Canada – Scotian Shelf and Labradour – Newfoundland Shelf	1960 - Seismic exploration began,	8 (July 2007 – Deloitte Petroleum Services)					400,034.33 km 2D 29,511.86 km² 3D	11	White beaked, white sided dolphin, harbour porpoise, minke whales <u>Gully:</u> Northern bottlenose whales	NOAA (1995-2007), Hooker *et al.* 1997; Hooker 1999; Hooker & Baird 1999; Hooker *et al.* 1999; Gowans *et al.* 2000; Hooker *et al.* 2001; Hooker & Whitehead 2002; Hooker *et al.* 2002	<u>Gully</u>: Sufficient for Northern bottlenose whale, <u>MFC</u>
Offshore California, Washington, to Oregon		23 (MMS Feb 2008)	2				246,022 km CDP (2D) 56,638 km High Res. 78,460 km CDP Interpretations 867 km^2 3D 1968-97, OCS Report	23	Humpback whales, blue whales	NOAA (1995-2007)	Sufficient for Humpback whales Blue whales Fin whales and perhaps others (odontocetes, small) <u>LFC</u>
U.S. Alaska (Beaufort Sea)		11 (August 2007 – Deloitte Petroleum Services)			4	25%	815,212 km CDP (2D) 110,851 km High Res. 156,833 km CDP Interpretations 550 km^2 3D DST 14 wells 1968-02, OCS Report		beluga whale, bowhead whale	NOAA (1995-2007), Fraker & Bockstoce 1980; Richardson *et al.* 1986; da Silva *et al.* 2000	Sufficient for bowhead whales <u>LFC</u>
Cook Inlet							38,892 km CDP	15	Gray whale	NOAA (1995-	Beluga

Area	**E&P Activity**							**Number of species**	**Most abundant stocks (N)**	**Source for cetacean stocks**	**Data Assessment**
	Activity started	***a***	***b***	***c***	***d***	***e***	**Seismic**				**NS / S**
							(2D) No 3D surveys 1968-02, OCS Report		Humpback whale Cook Inlet Beluga	2007)	Gray whale (with reference to seismic) LFC / MFC
				North West Europe							
Overall		~ 562 (2008)	48	89 (1985)	160	98.1%					
UK	1964 – First E&P licences 1967 – Production began	284 (BERR 2008)	25				23582 km (2D) 29708 km^2 (3D) 1997 - 2007 ASCOBANS Report (2005)	25	Harbour porpoise, whitebeaked dolphin and minke whale	Hammond *et al.* 2002; Hammond 2006b; Hammond 2006a; Hammond 2007 Reid *et al.* 2003	Sufficient for harbour porpoise and minke whale HFC / LFC
Norway		96 (OPL 2001)	18					Diverse Southern Norway up to Trondheim: SCANS II T&M: Harbour porpoise, Minke whale, Whitebeaked dolphin Northern Norway North of Nordkap: Harbour porpoises, sperm whales killer whales	Southern Norway: Harbour porpoise Northern Norway: harbour porpoises	Bjørge & Øien 1995; Hammond *et al.* 2002; Hammond 2006a; Hammond 2006b; Hammond 2007	Southern Norway: Sufficient for harbour porpoise HFC Northern Norway: insufficient
Netherlands		135 (OPL 2001)	3					Harbour porpoises		Hammond *et al.* 2002; Hammond	

Area	E&P Activity							Number of species	Most abundant stocks (N)	Source for cetacean stocks	Data Assessment
	Activity started	*a*	*b*	*c*	*d*	*e*	Seismic				NS / S
										2006a; Hammond 2006b; Hammond 2007	
Other Europe N. Sea		47 (OPL 2001)									

Table 32 Results of the measuremnt of McQuinn and Carrier (2005) on seismic airguns in different distances

Station	Recording Date (yyyy-mm-dd)	Latitude N (deg.dec)	Longitude W (deg.dec)	Distance to Source (km)	Hydrophone deployment Depth (m)	Bottom Depth (m)	Sound Speed (ms^{-1})	No. of Seismic Pulses	Peak (dB re 1μPa)	SPL_{rms} (dB re 1μPa)	SEL (dB re 1μPa)	Interpulse Difference Mean (dB)	Interpulse Difference Max. (dB)	Pulse Time Window (sec)
A1	2003-07-05	44.0967	59.2807	64.5	50	60	1463.3	47	138.2	121.3	122.6	3.9	10.4	2.6
A2	2003-07-14	44.1656	59.1917	96.1	90	230	1456.4	28	134.0	117.9	123.0	6.6	11.7	6.3
A3	2003-07-05	44.1884	59.0216	71.2	90	190	1454.9	27	131.0	117.0	126.1	3.3	9.8	7.2
A4	2003-07-05	44.2244	58.8934	90.9	45	56	1458.3	103	144.5	134.3	134.6	3.9	12.1	1.4
B1	2003-07-06	44.0057	59.2232	51.7	35	43	1463.0	150	144.1	137.6	135.4	3.2	8.4	0.6
B2	2003-07-06	44.0454	59.0843	50.9	90	300	1447.3	4	139.1	123.3	128.5	2.4	3.1	3.6
B3	2003-07-14	44.0896	58.9681	67.2	90	230	1453.6	20	142.6	131.2	129.7	3.3	8.0	0.8
B4	2003-07-05	44.1368	58.8318	101.3	75	90	1455.6	91	147.3	134.4	133.8	3.7	12.2	1.8
C1	2003-07-06	43.9176	59.1649	53.9	45	59	1456.0	66	150.7	136.1	140.6	2.7	7.4	3.7
C2	2003-07-06	43.9589	59.0428	74.7	90	292	1448.8	145	147.7	131.8	131.0	4.1	8.8	1.2
C3	2003-07-14	43.9976	58.9147	70.9	90	193	1447.9	79	145.3	134.6	136.0	3.2	10.9	2.7
C4	2003-07-14	44.0329	58.7862	89.1	90	106	1450.3	105	148.6	138.8	132.8	5.3	13.7	1.4
D1	2003-07-07	43.8273	59.1138	66.7	85	91	1449.4	95	149.9	131.5	130.9	4.5	11.4	2.1
D2	2003-07-13	43.8696	58.9862	75.7	90	550	1452.3	36	151.7	138.4	131.5	5.7	14.1	1.1
D3	2003-07-13	43.9045	58.8528		90	252	1449.3							
D4	2003-07-06	43.9447	58.7299	82.8	90	196	1448.0	82	152.0	132.6	139.5	1.7	5.5	5.2
E1	2003-07-07	43.7341	59.0547	50.7	90	309	1446.0	159	154.7	133.6	138.3	3.3	7.4	3.1
E2	2003-07-07	43.7727	58.9339	50.9	90	1300	1447.5	104	155.9	145.1	137.6	4.3	14.6	0.3
E3	2003-07-13	43.8171	58.8014	58.9	90	1100	1447.0	156	156.5	145.1	136.9	3.3	13.3	0.2
E4	2003-07-08	43.8535	58.6877	79.6	90	1220	1447.8	154	153.7	139.5	135.6	2.7	9.2	1.7
F1	2003-07-08	43.6420	59.0143	30.8	90	1250	1473.4	161	160.5	140.2	143.7	1.0	2.5	2.2
F2	2003-07-13	43.6893	58.8891	50.2	90	1300	1462.4	150	150.8	132.9	138.1	1.8	10.5	3.9
F3	2003-07-08	43.7247	58.7593	60.3	90	2500	1452.5	74	155.2	139.1	138.9	1.3	4.7	1.1
F4	2003-07-08	43.7655	58.6283	72.1	90	2000	1448.0	163	153.1	136.8	134.6	4.0	14.8	1.5
Min				30.8				4	131.0	117.0	122.6	1.0	2.5	0.2
Mean				67.9				96	152.2	137.7	136.3	3.4	9.8	2.4
Max				101.3				163	160.5	145.1	143.7	6.6	14.8	7.2

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