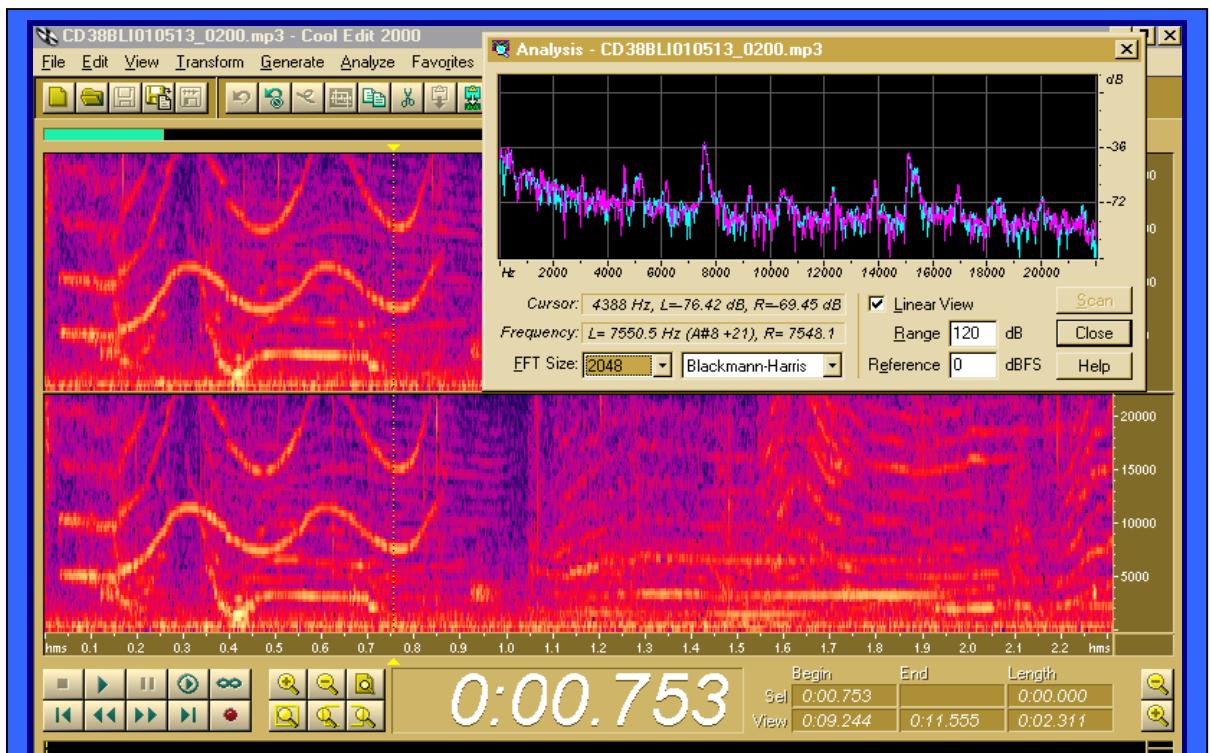


Cetaceans and Seabirds of Ireland's Atlantic Margin

Volume III

ACOUSTIC SURVEYS FOR CETACEANS



COASTAL & MARINE RESOURCES CENTRE
ENVIRONMENTAL RESEARCH INSTITUTE
UNIVERSITY COLLEGE
CORK



Cetaceans and Seabirds of Ireland's Atlantic Margin

Volume III **ACOUSTIC SURVEYS FOR CETACEANS**

Natacha Aguilar de Soto *

Emer Rogan **

Oliver Ó Cadhla *

Jonathan C.D. Gordon †

Mick Mackey *

Niamh Connolly *

*** COASTAL & MARINE RESOURCES CENTRE,**

**Environmental Research Institute,
University College, Old Presentation Building,
Western Road, Cork.
IRELAND**

**** DEPARTMENT OF ZOOLOGY, ECOLOGY & PLANT SCIENCE**

**Environmental Research Institute,
University College, Lee Maltings,
Prospect Row, Cork.
IRELAND**

† SEA MAMMAL RESEARCH UNIT

**Gatty Marine Laboratory,
University of St. Andrews, St. Andrews,
Fife KY16 8LB.
SCOTLAND**

Citation:

Aguilar de Soto, N., Rogan, E., Ó Cadhla, O., Gordon, J.C.D., Mackey, M. & Connolly, N. (2003). *Cetaceans and Seabirds of Ireland's Atlantic Margin. Volume III - Acoustic surveys for cetaceans.* Report on research conducted under the 1997 Irish Petroleum Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6, 99/38 and 00/13. 54pp.

CONTENTS

	Page
Summary	3
Introduction	5
Background	5
Rationale	6
Acoustic and cetacean population ecology	7
Characteristics of cetacean sounds	8
Man-made sound in the marine environment	9
Underwater noise and cetaceans	10
Research objectives	14
Study area	15
Materials and methods	16
Equipment & software	16
Acoustic survey protocol	19
Analysis of cetacean vocalisations	19
Spatial and numerical analysis	22
Results	25
Acoustic survey effort	25
Equipment performance	27
Individual survey results	28
Probable acoustic record of Cuvier's beaked whales	40
Acoustic detection of seismic and drilling activities	42
Discussion	46
Use of acoustic methods	46
Distribution of cetaceans detected acoustically	46
Noise and cetaceans in the Irish Atlantic Margin	48
Conclusion	50
Acknowledgements	51
References	52

SUMMARY

The island of Ireland and its territorial waters are home to a wide variety of cetacean and seabird species. This report presents detailed findings from research conducted under the Petroleum Infrastructure Programme set up by Ireland's then Department of the Marine and Natural Resources in 1997. The initial three-year *Cetaceans & Seabirds at Sea* research programme, which commenced in 1999, has now been completed and is presented in three volumes under the title "Cetaceans and Seabirds of Ireland's Atlantic Margin". The volume presented here summarises the results of a cetacean acoustic monitoring programme that, between July 2000 and September 2001, was carried out to complement visual surveys for cetaceans. This acoustic research was made possible by a grant to University College Cork from the Petroleum Affairs Division of the Department of Communications, Marine and Natural Resources for necessary hydrophone equipment.

Acoustic methods greatly enhance information on cetacean distribution, allowing approximately three times more survey-line coverage than visual surveys alone. This is particularly important when just one cetacean observer is stationed on board the survey vessel.

The results of the acoustic survey programme are summarised below:

- A total of 90 days of effective acoustic survey were completed, 85 days along Ireland's Atlantic Margin between July 2000 and July 2001.
- This report presents the first analysis of 1,190 hours survey time, under a sampling protocol measuring 20 seconds of acoustic monitoring every 2 minutes. Detections of cetacean species were contained in a total 238.42 hours of recording over a total survey track-length of 14,478.98 km.
- The towed hydrophone array was first deployed during the *SIAR* survey, conducted over a three-week period in July-August 2000. This intensive visual and acoustic survey was conducted in the deep waters of the Rockall Trough and extended to continental shelf waters to the west of Ireland (see Volume II). A total of 1,873.3 km of track-line were surveyed acoustically and visually, and an additional 781.8km of track-line was covered using acoustic methods alone. This resulted in 210 acoustic encounters.
- Acoustic surveys in Ireland's Atlantic Margin were also carried out on board the Irish Naval Service vessel L.E. *Eithne* and on the National Seabed Survey vessels S.V. *Bligh*, and S.V. *Siren*. Since all of these ships were originally constructed as naval vessels, they were designed to minimise noise production and thus constituted good platforms for acoustic monitoring.
- A total of 249.8 km of track-line was surveyed acoustically aboard the L.E. *Eithne*, 10,952.98 km on the S.V. *Bligh* and 511.50 km on the S.V. *Siren*. The average towing speed during acoustic surveys was 8.5 knots, while the maximum towing speed was 16 knots.
- These surveys resulted in 671 acoustic encounters with at least seven odontocete species recorded. These included detections of Cuvier's beaked whale (possibly the first record of this species' pulsed vocalisations), sperm whale, long-finned pilot whale, bottlenose dolphin, common dolphin, striped dolphin and white-sided dolphin, plus other unidentifiable vocalisations. The total number of recordings by species were as

follows: 110 sperm whale encounters, 124 long-finned pilot whales, 435 dolphin species and two beaked whale encounters.

- Other underwater noise was also detected during surveys for cetaceans, most notably a seismic survey off northwest Ireland that was recorded 490km away from the seismic source. This and other monitoring confirmed the wide-scale zone of influence of seismic activities. Man-made noise from the Corrib Field drilling platform was also detected.
- Trial survey data showed that acoustic monitoring of cetaceans is possible near seismic vessels and could be helpful in mitigating the impact of intense man-made sound on cetaceans.
- During the acoustic survey programme several areas were identified as being of special importance on the basis of their higher relative abundance of cetaceans. These include (i) continental slope areas to the west and northwest of the Porcupine Shelf and (ii) at an approximate latitude of 57° N, (iii) waters overlying the Feni Ridge, (iv) the Porcupine Seabight and (v) an unnamed canyon approximately situated at 53° 30' N, 19° 0' W.
- Acoustic recordings from waters > 1500m depth indicated a higher presence of cetaceans than expected and suggested that the Rockall Trough may be an important habitat for deep-diving species such as sperm whales. The distribution of such cetacean species may indicate the presence of oceanographic or physical features that have a wider biological significance, e.g. submarine canyons, areas of high benthic biomass, spawning sites, etc.
- The acoustic survey results represent an important contribution to the information gathered under the overall research programme. The data gathered served to strengthen and expand information on cetacean distribution collected by visual survey methods, while new areas such as cetacean vocal behaviour and the influence of man-made sound in the Irish marine environment were also explored.
- Further laboratory analysis is recommended in order to extract and examine information from the collected dataset and to further explore the biological and management significance of findings to date.

INTRODUCTION

BACKGROUND

Ireland's offshore territory has been explored for its hydrocarbon resources since the 1970s. This marine research and the associated drilling operations have largely focused on government-granted licence blocks located along the Irish Atlantic Margin (Fig. 2). Among the diverse marine fauna which may be detrimentally affected by such exploration (including seismic survey activity) and its associated developments (e.g. transportation of hydrocarbon products) are those at the top of marine food webs including seabirds and cetaceans (i.e. whales, dolphins and porpoises). While the immediate impact of oil pollution on seabirds and marine mammals has been well documented in a number of cases (e.g. *Braer*, *Erika*, *Exxon Valdez* and *Sea Empress* oil spills), there are other impacts from hydrocarbon exploration and exploitation which are harder to evaluate, particularly where background data on distribution and abundance of these species are lacking.

Information on cetacean populations in the Atlantic waters off western Ireland have historically been sparse and, until now, surveys were conducted in a few selected areas (see Evans, 1990; Leopold *et al.*, 1992; Gordon *et al.*, 1999). The latter study, which occurred off County Mayo in 1993, combined acoustic and visual methods and, although relatively small in scale, the study demonstrated how acoustic monitoring could greatly improve the detection rate for odontocetes (toothed cetaceans). More recently, detections collected remotely from bottom-mounted military hydrophones situated on the Atlantic Margin have become available (Clarke & Charif, 1998; Charif *et al.*, 2001). These studies summarised data on the vocalisations of fin, blue and humpback whales (*Balaenoptera physalus*, *B. musculus* and *Megaptera novaeangliae*) over twelve and 24-month periods and yielded important findings on seasonal distribution of these large whales in Irish waters.

Against this backdrop of relatively limited information, a study was formulated as part of an overall drive to deliver detailed scientific information on the physical and biological resources of the Irish Atlantic Margin and its hydrocarbon exploration areas. The acoustic survey programme presented here represents the first consistent study of its kind in offshore Irish waters and formed part of the three-year *Cetacean & Seabirds at Sea* project undertaken by the Coastal & Marine Resources Centre at University College Cork. The research was performed on behalf of the Rockall Studies Group (RSG) and Porcupine Studies Group (PSG) under the Petroleum Infrastructure Programme set up in 1997 by Ireland's Department of the Marine and Natural Resources (Murphy, 2001).

Under the overall *Cetaceans & Seabirds at Sea* project, a number of parallel studies were conducted. These consisted of (i) "Seabirds-at-sea" sighting surveys; (ii) Cetacean sighting surveys, and (iii) Acoustic surveys for cetaceans. These are presented in three volumes under the title "Cetaceans and Seabirds of Ireland's Atlantic Margin". The present volume focuses on the results of the acoustic project, which studied a range of species from dolphins to medium and large toothed whales. This volume contributes to our knowledge of poorly studied species, which are difficult to survey due to their intrinsic evasive behaviour and the inaccessibility of their habitats. In conjunction with Volume II it may provide sufficient data to contribute to a more comprehensive picture of cetacean distribution in the waters of Ireland's Atlantic Margin.

RATIONALE

Cetaceans are almost always difficult subjects to view at sea. This is particularly the case when sea conditions are sub-optimal, when visibility is poor, and at night. However, many species

make loud and distinctive vocalisations and can often be detected more readily using passive acoustic systems rather than by visual means. There are a number of generic advantages to using an acoustic approach in combination with visual methods to detect cetaceans at sea:

1. For some species the acoustic range of vocalisations can be measured and predicted more precisely than the visual range. Underwater acoustics is a sophisticated and well-developed branch of science. If the source level of the vocalisations is known, the propagation conditions can be modelled and noise level measured to enable prediction of the range at which the vocalisations can be detected. It is often possible to calculate range directly using arrays of hydrophones (Greene & McLennan, 1996). In contrast, there is little theoretical understanding of the complex factors that affect a human observer's ability to detect cetaceans visually. An observer's ability to detect animals can often vary with subtle changes in physical conditions, sometimes in unexpected ways.
2. Acoustic range is less affected by meteorological conditions than is visual range. The range at which cetaceans can be spotted is reduced rapidly with a deterioration in sea conditions. Consequently, visual surveys for cetaceans are rarely continued under sea states exceeding Beaufort force 3 to 4. Although the level of background noise increases with sea state, and this masking noise can reduce the range of detection in acoustic surveys, the effect is measurable and resultant range reductions are predictable. In practice, therefore, acoustic surveys can usually continue in higher sea states than visual surveys.
3. Acoustic range covers 360° around the survey platform. Most visual surveys are conducted in a -90° to +90° sector in front of the vessel. Using the standard methodology combining seabird and cetacean visual observation (see Vols. I & II), the range for visual observations classified as "on transect" is confined to 300 m (0.16 nm) in a 90° arc in front of and to one side of the survey vessel.
4. Many cetacean species can be detected acoustically at a greater range than they can be seen particularly when small research vessels are being used as observation platforms. The range at which cetaceans can be seen or heard varies from species to species and with the sophistication of the acoustic equipment being used. For example, dolphins can be detected at ranges of up to 2 km and sperm whales can be reliably heard at ranges of 5-9 km using simple hydrophones (Jonathan Gordon, University of St. Andrews, *pers. comm.*) while Sparks *et al.* (1993) reported detecting sperm whales at ranges of 18km using a towed linear array. Some of the large baleen whales can be heard with near-surface hydrophones tens of kilometres away (Clark & Fristrup, 1997).
5. Acoustic surveys are less onerous than visual surveys. Searching for whales and dolphins is both physically and mentally demanding, and requires constant vigilance by experienced observers. Furthermore, observers have to be rotated regularly and rested in order to maintain performance levels. Consequently large field teams are required, which incurs a greater logistical and financial burden.
6. Acoustic monitoring can be conducted 24 hours a day without any restriction due to daylight. In contrast, sighting surveys become impossible in poor light conditions and at night. Most cetaceans are thought to continue vocalising both day and night, although allowances may have to be made for diurnal variation in acoustic output.
7. A complete and permanent record can be made of acoustic survey cues. A high quality CD recording provides a remarkably full record of the acoustic information within the band of sensitivity. This is then available for further analysis and can be reanalysed in the future if techniques improve.

8. There is a great potential for automation of data collection and detection. Modern digital processing techniques allow aspects of acoustic analysis, such as distinguishing, classifying, counting and timing vocalisations, to be performed automatically (Potter *et al.*, 1994; Gillespie, 1997; Chappell & Gillespie, 1998). While laboratory or field verification of detections is necessary in order to detect positive and negative error incurred by software-automated triggers, two distinct advantages stem from automating the initial detection process. Firstly, it further reduces the amount of human effort required to conduct a survey. Secondly, and most importantly, it removes sources of human error associated with an individual's ability to accurately detect all vocalising animals in the surrounding environment.

ACOUSTICS AND CETACEAN POPULATION ECOLOGY

An understanding of cetacean vocal behaviour is relevant to many aspects of cetacean ecology:

- **Animal abundance and distribution**

Although traditional methods for estimating cetacean abundance rely on visual methods, acoustic information may assist in the development of models to predict the occurrence and number of animals in an area. It may be important to know, for example, the vocal behaviour for deep-diving species in order to determine the relative detectability of such species by visual means. Vocal dialects and signature calls can be used to identify species, populations and even distinct groups of animals within populations (e.g. Deecke *et al.*, 2000; Miller & Bain, 2000).

The use of acoustics allows for a relatively non-invasive method to determine the degree of isolation of a population or its relatedness to other sub-populations. Furthermore, age and sex-related segregation can be studied by vocal means for some species. For example, the mechanism of sound production in sperm whales described by Norris & Harvey (1972) allows for the calculation of the size of the vocalising individuals (Gordon, 1991), which itself is related to their age and sex.

- **Behavioural ecology**

Since sound is theoretically the most important sense for cetaceans and an animal's activity at a given moment may be related to its vocal behaviour, it may be possible to identify aspects of a species' ecology by its vocalisation patterns. For example, three known behavioural categories of sperm whales (i) feeding, (ii) travelling and (iii) socialising, can be identified by the animals' vocal pattern. Several studies have been carried out which correlate the click rhythms of sperm whales with various activity categories. Thus the vocalisation patterns incorporating distinctive "creaks" by sperm whales have been used to identify areas of enhanced feeding activity (Drouot *et al.*, 2000; Jacquet *et al.*, 2001), allowing the use of cetaceans as potential bio-indicators.

- **Conservation ecology**

There are many conservation issues to which cetacean acoustics may make a contribution. While the responses of cetaceans to waterborne noise are very variable, for example, it has been shown that some species such as pilot whales and bottlenose dolphins increase their rate of vocalisation during periods of significant anthropogenic disturbance (Rendell & Gordon, 1999; Scarpaci *et al.*, 2000), while, in contrast, sperm whales may become silent (Watkins, 1986). In spite of the complexity of the discipline, acoustics can play a major role in understanding and mitigating against the effects of man-made noise and other impacts from human activity (e.g. to solve conflicts between cetacean and fisheries -- Notarbartolo di Sciara & Gordon, 1997; Culik *et al.*, 2001) by presenting a very useful tool with which to study the animals in their natural environment.

CHARACTERISTICS OF CETACEAN SOUNDS

Cetaceans rely on sound as their main sense for communication, navigation, prey detection and capture. Other functions such as individual animal recognition (via "signature" whistles) or prey immobilisation have been strongly suggested by some researchers.

Cetaceans have evolved anatomical features in order to produce particular signals (see Evans, 1987; Richardson *et al.*, 1995). Perhaps the most relevant of these is the development of a complex system of nasal sacs through which air circulates for sound production. Sounds are produced by the passage of air in the form of small bubbles through tight, myo-elastic structures near the blowhole called the "monkey lips". The sounds produced are divided into three categories. These are (i) tonal frequency modulated calls; (ii) pulsed modulated sounds, and (iii) broadband frequency clicks. Tonal calls are used primarily for communication and individual recognition purposes. They include a great variety of sounds, such as whistles, squeals, moans, etc. Pulsed modulated sounds are also used for communication. Finally, echolocation clicks act as a powerful echo sounder with high resolution to assist in navigation and in the identification and location of prey underwater.

Not all cetaceans have the same acoustic abilities. Species of sperm whale (Family *Physeteridae*) and porpoises (Family *Phocoenidae*) use clicks for communication purposes, since they do not produce tonal sounds. In contrast, the use of echolocation has not been found in baleen whales (mysticetes), although short sound pulses have been recorded in the presence of some species such as grey whales (*Eschrichtius robustus*) and minke whales (*Balaenoptera acutorostrata*) (Evans, 1987). Further research is required on this subject.

Typical sounds produced by odontocetes (toothed whales, dolphins and porpoises) are mainly clicks, which are intense broadband pulses, and whistles, which are narrow band-frequency modulated sounds, usually with harmonics. The maximum detection distance of cetacean vocalisations depends on the intensity at which they are emitted by the animals and the frequencies that are used (high frequencies are absorbed at shorter distances than are low ones). The relative position of the listener also influences the maximum distance at which the sounds can be perceived, since clicks are highly directional. Tonal sounds themselves also influence directionality, although to a lesser extent (Kaschner *et al.*, 1997; Notabartolo di Sciara & Gordon, 1997).

The typical sounds produced by mysticetes are low frequency tonal pulses. There have been some interesting experiments for military purposes on transmission of sound through special channels created by specific temperature and salinity conditions in deep waters (Thurman & Burton, 2000). These SOFAR (Sound Fixing and Ranging) channels can allow communication across whole oceans, whereby sound rays trapped by refraction propagate close to horizontally within these channels. The reductions in spreading loss and limited surface/bottom losses maintain the acoustic pressure. Thus, if cetaceans use them for communication, their vocalisations may be detected over ranges yet unknown. Such long-range low frequency sound transmissions have been recorded over distances greater than 1000 km (Bowles *et al.*, 1991). This may theoretically be useful as a communicative tool over large distances for species living solitarily or in small groups, or for animals segregated by age and sex during certain times of the year.

Table 1 describes the diverse modes of vocalisation produced by several odontocete species. Dolphin echolocation clicks extend from the audible range for humans into the ultrasonic region and most species are detectable by standard hydrophones, such as that used in the present study. However, most standard equipment's lower frequency limit for cetacean detection is set by incorporating a low-pass (200 Hz) filter, in order to mask background noise (e.g. engine noise). Unfortunately, this usually prevents the detection of baleen whales since these species typically vocalise on frequencies below 1,000 Hz (1 kHz). Similarly, at high

ultrasonic frequencies, such as those produced by harbour porpoises, specialised hydrophones are required. Therefore no one system offers yet the ability to detect simultaneously all cetacean species in the marine environment.

TABLE 1. Frequency range and source level of the vocalisations for the most common odontocete species occurring in the studyarea.

Species	Sound type	Dominant Frequencies (kHz)	Source level dB re 1µPa at 1m
Sperm whale (<i>Physeter macrocephalus</i>)	Click	<0.1 - 30 E, R 2-4 & 10-16 bands R	160-180 R 220 M
Long finned Pilot whale (<i>Globicephala melas</i>)	Whistle Click	1-8 R , 2.8-4.7 E 1-18 R	No data available
Atlantic white-sided dolphin (<i>Lagenorhynchus acutus</i>)	Whistle Clicks	8.2-12.1 E	No data available
White-beaked dolphin (<i>Lagenorhynchus albirostris</i>)	Squeal	8-12 E	No data available
Short-beaked common dolphin (<i>Delphinus delphis</i>)	Whistle Chirps, barks	2-18 R , 4-16 E 0.5-14 R	No data available
Bottlenose dolphin (<i>Tursiops truncatus</i>)	Whistle Click Bark	0.3-24 R , 4-20 E 0.2 to >300 E 0.2-16 E	125-173 R
Harbour porpoise (<i>Phocoena phocoena</i>)	Click	41-160 E	100 R

(E reviewed in Evans, 1987; R reviewed in Richardson *et al.*, 1995; M Møhl *et al.*, 2000)

MAN-MADE SOUND IN THE MARINE ENVIRONMENT

The biological significance of fish sounds has been studied since the 1950s (Winn, 1964), while other marine animals (e.g. invertebrate crustaceans) also create sound. Cetaceans are predominantly aural animals that rely on sound as their main sense. They are more vulnerable when their hearing sensitivity is well developed in the frequency ranges at which man-made sounds are emitted. Broadly speaking, small cetaceans (e.g. dolphins and porpoises) are more sensitive to high frequencies (measured in kHz) and larger species (e.g. baleen whales) to lower ones (measured in Hz), consistent with the characteristics of their respective vocal repertoires. Acoustic intensities even below lethal levels can still cause permanent and temporary auditory shifts affecting their communication, navigation, prey detection or predators avoidance and, thus, their overall survival.

Man-made sources of noise (see Fig. 1) contribute increasingly to ambient noise in the oceans, adding to natural noise sources (such as waves, thermal noise, etc.). Noise was first officially recognised as a pollutant at the 1971 United Nations Conference on the Human Environment. Since then there has been an increase in international concern, resulting, for example, in the introduction of guidelines on noise pollution in countries such as Great Britain and USA. Resolutions addressing this issue include (i) Articles 192, 194 (2, 3), 206 and 235 of UNCLOS 1982; (ii) UNCED 1992; (iii) the EC Conservation of Natural Habitats Directive (1992) and a

number of UK laws including the Wildlife and Countryside Act 1981, the Control of Pollution Act 1974, the Water Resources Act 1991 and the Environment Act 1995 (Ward *et al.*, 1998).

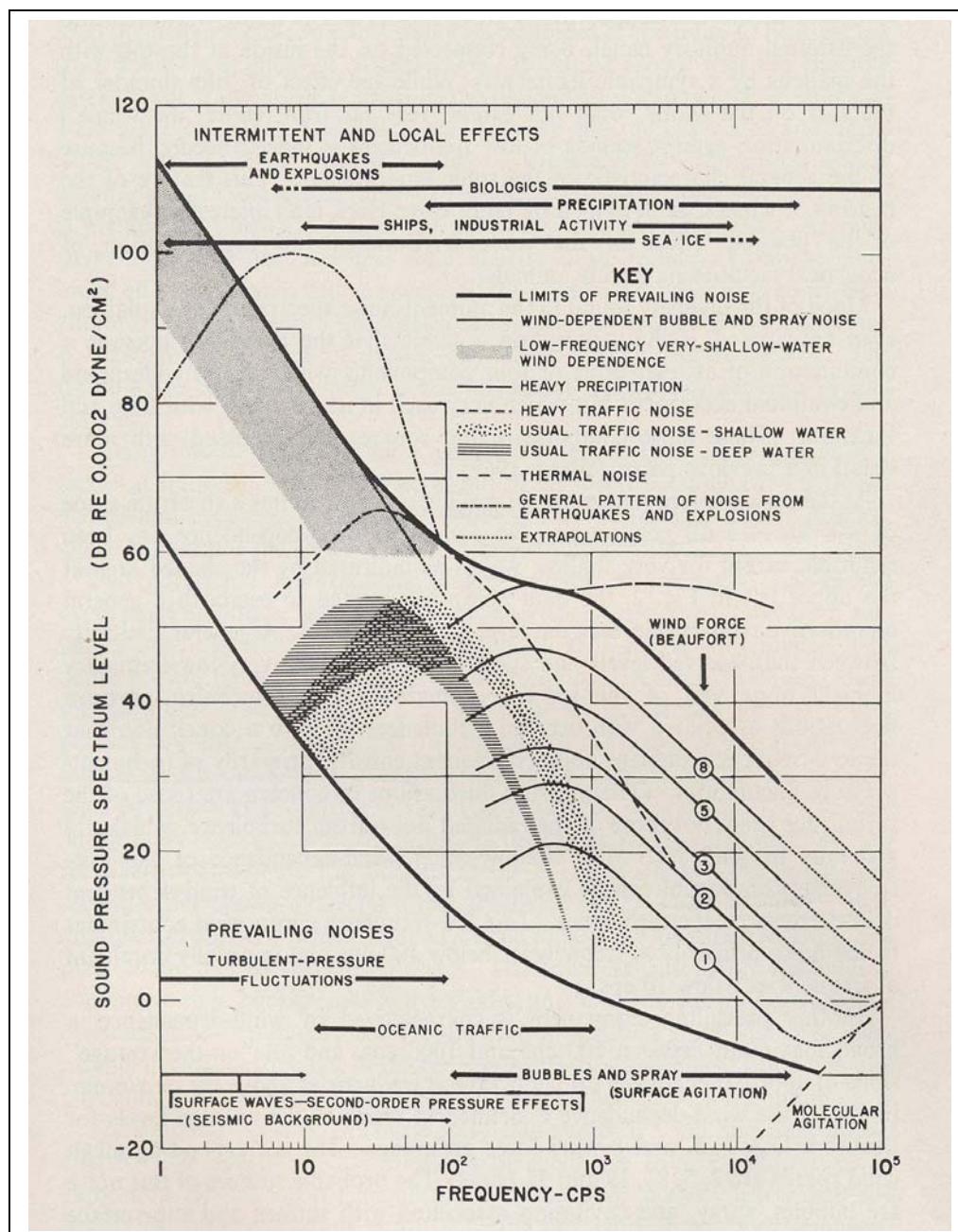


Figure 1. Summary of sound spectra, probable sources and mechanisms of ambient noise in the marine environment. Horizontal arrows show the frequency band of influence of various sources (*from Wenz, 1964*).

UNDERWATER NOISE AND CETACEANS

The composition of typical ambient noise in the marine environment during the 1960s is described graphically above (Fig. 1). Anthropogenic noise sources span a wide range of frequencies (Goold, 1996) and are often emitted at intensities above the widely adopted 180 decibel (dB, re 1 μ Pa at 1m) criterion for harm to marine mammals. Scientific evidence indicates that lower received source levels can cause both temporary and permanent auditory shifts

resulting in damage to marine mammals (Richardson *et al.*, 1995), even causing mass strandings in some cases (e.g. military sonar - Balcomb & Claridge, 2001). Consequently, a source intensity of 120 dB has been suggested, by Whitehead (2001), as the precautionary threshold above which underwater noise may have an impact on marine mammal populations.

Shipping activity, seabed studies and military practices all constitute important sources of noise (or acoustic) pollution. It had been estimated that the intensity of noise in the oceans would increase by 15 dB from shipping activities alone between 1950 and 2000 (Notarbartolo di Sciara & Gordon, 1997). During this period, seismic exploration and the use of airgun arrays have increased significantly, particularly in the last 30 years of the 20th century. Underwater industrial developments such as those for hydrocarbon exploitation, pipes or cable-laying, harbour construction, are also more numerous. Many of these developments require blasting activities, whose acute impacts on fish and cetaceans are well documented (Myrberg, 1990; Ketten *et al.*, 1993; Richardson *et al.*, 1995). The indirect impact of long-term exposure to deleterious levels of sound is also well documented (Todd *et al.*, 1996). In addition, some modern ship designs increase the range of frequencies at which they contribute to the noise in the sea. For example, fast ferries increase the volume of displaced water from the hull and result in an increased acoustic output in the 10-20 kHz region (Browning & Hartland, 1997).

There has been relatively little research to date into the effects of large-scale marine industrial activities on cetaceans. Studies related to hydrocarbon exploration and exploitation usually focus on the impact of noise pollution produced by 2-D and 3-D seismic prospecting. Less research effort has been invested on other related activities such as drilling and the removal of bedrock. Yet playback experiments of drilling sounds in the presence of cetaceans have shown avoidance reactions and reduction of calling rates by various baleen whale species (Richardson *et al.*, 1995). While many such studies focus on behavioural changes as a consequence of man-made noise, the potential exclusion of cetaceans from important habitats may be equally important.

Several studies on the responses of marine mammals to anthropogenic noise, such as that from seismic surveys, have identified the following factors as influencing the degree of response given by the animals: (a) source intensity levels; (b) degree of background noise; (c) distance to the source; (e) species involved; (f) behavioural state/season; (g) prior degree of exposure to noise; (h) age/sex/time of day (Myrberg, 1990). Sources of acoustic pollution located in shallow waters may have an increased effect on cetaceans at a local level, while those produced in continental slope and oceanic waters will cover a wider spatial range and potentially affect deep-diving species, some of which are rare and poorly studied.

There are intra- and inter-specific variations in the sensitivity and response of the animals to the same kind of sound. The "habituation" effect, suggested by the different responses of animals of the same species in different regions where they are more or less used to man-made noise, does not necessarily indicate reduced physical damage, as if frequently postulated. It is equally possible that habituation may result in reduced avoidance and thus increased exposure to potentially harmful noise levels.

In view of research in Irish waters and the requirements of legislation (e.g. EC Habitats Directive 1992, Irish Wildlife Act 1976, 2000) the Atlantic Margin area may be considered a sensitive region in which precautionary regulation of human activities is even more appropriate. Consequently, the present study set out to examine for the first time the acoustic environment inhabited by cetaceans along Ireland's Atlantic Margin.

In discussing the effects of seismic sources on marine mammals, several important points should be taken into account:

1. Avoidance responses to seismic sources start at received sound levels from 110 to 164 dB re 1µPa (from 20 dB over ambient noise) (Myrberg, 1990);
2. Distances at which marine mammals may actively avoid seismic sources range widely from 3 to 24 km (Richardson *et al.*, 1995);
3. Responses to single airguns or airgun arrays evoke different responses (Harris *et al.*, 2001);
4. Deep diving species such as beaked whales and sperm whales can be more sensitive to man-made sounds (Gordon *et al.*, 1998; Whitehead, 2001);
5. The received source levels for marine mammals from seismic activity can be less than the peak intensities used by the animals in their vocalisations (Richardson *et al.*, 1995);
6. Scientifically-determined responses of marine mammals include short-term behavioural changes, avoidance of seismic areas and variation in migratory routes. Some species show a greater reaction to continuous sources than to impulsive ones operating at the same intensity. This may be related to the greater total pressure level involved in a continuous source (Richardson *et al.*, 1995).

The distances at which seismic pulses are received will directly influence the degree of impact on marine mammals. The effects of impulse noise on cetaceans vary depending on the received levels. Some of the potential direct effects are described below:

- **Physical damage and safe distances**

UK guidelines to minimise acoustic disturbance of marine mammals (Tasker, 1998) require the suspension of seismic activity when one or more cetaceans are detected inside a 500m radius of the seismic vessel. The aim is to guarantee that the animals do not become exposed to a received source level higher than 180 dB re 1µPa-m, believed to be the limit above which temporary damage may be caused to a cetacean's auditory system. However, recent studies propose a reduction in the intensity which can cause damage to 160 dB re 1µPa-m. This source level may be received by the animals at distances up to 4.9 km from a fully-operating array. In the UK, "Incidental Harassment Authorisation" (IHA) is given to seismic survey operators, allowing disturbance to marine mammals but not serious injury or death. In order to ensure the protection of the animals, it set an initial security radius of 150m around the seismic vessel, on the basis of a critical 190 dB received level. This was later reduced to 160 dB, and consequently the radius was increased to 250m (Harris *et al.*, 2001). However, experts in the field have also suggested a precautionary level of 120 dB re 1µPa-m as the maximum allowable received level for cetaceans, in consideration of (i) recent mass stranding events during use of low frequency military sonar and (ii) improved knowledge of species thought to be particularly sensitive to acoustic pollution (Whitehead, 2001).

- **Habitat degradation**

Several studies have clearly shown avoidance behaviour by cetaceans away from areas of seismic activity. Such behaviour includes circling the noise source at certain distances. This could result in a change in migratory pathways and increased energetic expenditure or exclusion from important habitats which have become impacted by anthropogenic noise (Richardson *et al.*, 1995).

- **Stress**

Noise was first considered a pollutant on land, and only later in the marine ecosystem. Studies on terrestrial wildlife have demonstrated the physiological responses including increased heart rate and alteration to metabolism and hormone balance. The coupling of these effects has the potential to cause bodily injury, energy loss, a decrease in food intake,

habitat avoidance and abandonment, and reduced reproductive success (Busnel & Fletcher 1978).

▪ Behavioural and communicative disruption

Studies of the vocalisations of humpback whales showed that boat noise can affect humpback whale song structure at the most basic level by altering the rhythm or increasing the tempo of songs (Norris, 1994). Other studies have shown increasing levels of vocal activity in response to potentially disturbing activities such as sonar or approaching vessels (Gordon *et al.*, 1998; Scarpaci *et al.*, 2000).

Noise pollution may also affect cetaceans by indirect means. For example, the man-made source levels may cause changes in the availability of prey for foraging animals. Although marine fish typically have less acute hearing than marine mammals, their auditory abilities are most sensitive to frequencies between 100 and 500 Hz, the range at which most seismic sound is produced. At these frequencies, their hearing is certainly more sensitive than that of the odontocetes studied to date. Effects of airgun pulses on fish range from serious injury at short ranges, to avoidance behaviour, possibly at the range of many kilometres (Turnpenny & Nedwell, 1994). Reduced catch rates have been reported for several species of fish in areas of seismic survey activity. In a series of controlled experiments, Skalski *et al.* (1992) demonstrated a 50% decline in catch per unit for rockfish (*Sebastes* spp.) during exposure to noise from airguns. The authors attributed this to changes in behaviour that made fish less likely to be caught in fishing gear rather than to a dispersion reaction by fish. The authors did not indicate, however, how long the effects lasted. Bohne *et al.* (1985) reported a decrease in average fish abundance, measured acoustically, during a 3-D survey in the North Sea. Populations were reduced by 36% for demersal species, 54% for pelagic species, and 13% for small pelagic species, compared with pre-shooting abundance. Engas *et al.* (1993) found an average 50% reduction in catch and availability of cod and haddock within a 20-mile radius of an operating seismic vessel, and showed a 70% reduction for both these species within the seismic shooting area. Other studies describe avoidance behaviour and the Mauthner cell reflex (involuntary muscular flexion) in direct response to airgun sounds up to 125 m away (Wardle & Carter, 1998).

MITIGATION MEASURES TO PROTECT CETACEANS

Measures can be taken in order to minimise the direct and indirect effects of seismic activity on cetacean populations. The most obvious solutions to reduce the impacts on cetaceans involve time and area closures, namely the effective control of static and mobile noise sources to avoid seasons and/or areas in which higher concentrations of cetaceans occur. A logical planning procedure to avoid the overlapping of seismic activities in certain areas would diminish the total amount of sound pressure introduced on the environment at a particular time.

A further measure to mitigate against significant impact would be to allow certain noise sources (e.g. seismic or underwater blasting) to operate only when following the most strict guidelines (e.g. Tasker, 1998 - JNCC), incorporating elements such as the "soft-start" approach and the use of adequate post-sighting buffer times prior to the commencement of seismic shooting. While such measures may be adopted by UK vessels operating in Irish waters, as is often reportedly the case, the "JNCC" measures are adhered to on a purely voluntary basis, are often not fully implemented and marine mammal monitoring is often carried out by non-trained personnel. In the context of results presented herein, in Vol. II and elsewhere, such an approach falls short of effective monitoring and management.

There is no doubt that in-depth studies are required on this matter to properly manage disturbing activities such as seismic or underwater explosions. However, at the outset, the proper assessment of environmental impact on marine mammals should include modelling by marine acousticians to assess the effects of underwater sound on marine mammals, fish and human beings (e.g. divers, swimmers). The distribution of received sound levels and critical distances for marine mammals can vary enormously with the composition of local water masses, seabed

features and physical composition (Ketten, 1995), thus increasing or diminishing their impact on the marine fauna.

In order to calculate sound pressure levels and consequently the critical range at which sound may impact on marine mammals, site-specific models are required which describe with reasonable accuracy the likely noise conditions in a particular location (Ward *et al.*, 1998).

RESEARCH OBJECTIVES

The chief research objectives of the acoustic survey programme for cetaceans in Ireland's Atlantic Margin were as follows:

1. To use acoustic methods to study cetacean distribution and abundance in areas where no prior or only scarce information existed.
2. To identify critical areas of cetacean concentration in the context of the information required by the new activities of the oil companies
3. To enhance knowledge of the acoustic behaviour and the acoustic environment of cetaceans, and how this may be affected by oceanographic parameters, seabed features and anthropogenic activities.
4. To enhance the effectiveness with which cetaceans can be monitored in the Rockall Trough and other offshore areas of interest to oil companies by providing an automated acoustic monitoring system.
5. To provide the research team at University College Cork with acoustic equipment, enhancing the effectiveness of ongoing monitoring work and providing training for the long-term capacity of the team to develop acoustic research on cetaceans.
6. To study the possibility of improving methods to minimise the impact of noise produced by seismic survey ships in the presence of cetaceans.
7. To provide high quality independent scientific information essential for conservation and management purposes.

STUDY AREA

The primary study area for the project consisted of the offshore waters to the southwest and west of Ireland, commonly termed "Ireland's Atlantic Margin" (Naylor *et al.*, 1999). This area stretches from the Goban Spur through the Rockall Trough and includes the adjoining Rockall Bank and continental shelf areas, including the prominent western "Porcupine Shelf", a bathymetric high which contains the relatively shallow Porcupine Bank. Research effort during the study extended into waters north and east of this region (Fig. 2), considering the potential for large-scale cetacean movement through the region in space and time.

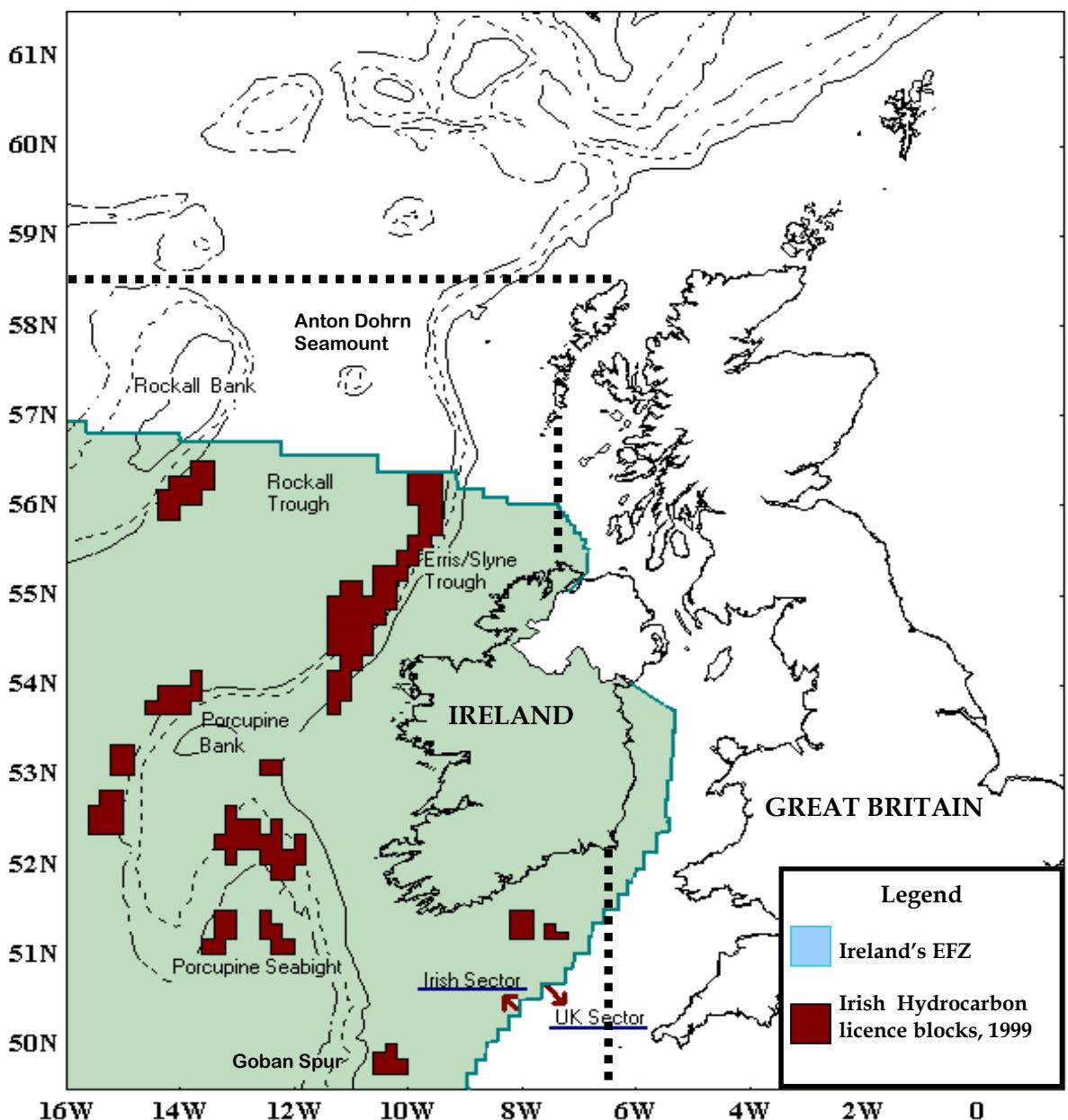


Figure 2. Project study area (to left of dotted line ■■■■) showing territorial waters comprising the Republic of Ireland's Exclusive Fishery Zone (EFZ) (shaded) and licence blocks for hydrocarbon exploration. [_____ 200m isobath; - - - 500m isobath; —— 1000m isobath.]

MATERIALS AND METHODS

EQUIPMENT & SOFTWARE

The acoustic monitoring method used during the research programme consisted of equipment and techniques developed over a decade in an international context. The system allowed:

- Real-time monitoring of the marine acoustic environment while the survey vessel was underway;
- Automatic recording of acoustic data to the hard disk, to be stored on writable CD media for later analysis;
- Real-time tracking of pulsed sounds from sperm whales and pilot whales, and clicks of echolocating species;
- Automatic real-time detection of odontocete whistles;
- Collection of GPS data into a relational database;
- Collection of cetacean detection information into a single database which can be used to assess cetacean abundance along the vessel's track-line;
- Acoustic data forms for input into a relational database for cetacean sightings. Environmental information such as wind speed and direction, hydrophone depth, water temperature, etc. could also be entered.

A description of the acoustic equipment (Fig. 3) begins with the 300m-long towed hydrophone array that is deployed from the stern of the vessel. The hydrophone tube is linked directly to an on-board PC with an in-built CD-writer for storing acoustic data generated during the survey:

1. HYDROPHONE ARRAY

The array consists of 2 Benthos AQ-4 hydrophones with a bandwidth connected to preamplifiers with 30x gain and 200Hz low frequency roll-off filters. The equipment has an approximate flat response between 200Hz and 22kHz and is omni-directional in the perpendicular plane. The hydrophones are mounted 3m apart in a 10m-long oil-filled polyurethane tube with an in-built depth sensor. The array is neutrally buoyant. Previous experiments (e.g. Barlow & Taylor, 1998) showed that a 3m distance between the elements is optimal since it allows good angular resolution without ambiguity between signals from different animals.

2. CABLE

The 300m long cable has an external water insulation of polyurethane surrounding a kevlar strain member. The cable contains the wires that conduct power to the preamplifiers and signals from both the hydrophone and the depth sensor. The array and cable system is made negatively buoyant by the weight of the cable in order to tow it under the surface at a depth of between 7-15m. Other designs including armoured cable would have provided more protection from damage as a result of entanglement or excess tension when pulling, but they would also have been more expensive, difficult to transport and less flexible for deployment and recovery for the range of vessels used during the study period.

3. AMPLIFIER BOX

During the first research deployment on the *SIAR* survey (*see* below) the research team used an amplifier box with filters up to 5.6 kHz and an external transformer but this proved sensitive to electrical noise. Since then the device includes a stereo monitor unit with an in-built transformer

designed specially for this project. It has a set of analogue high pass low frequency filters up to 440 Hz. The power input of +/- 12 Volts (V) is provided by a set of two 12V marine gel batteries.

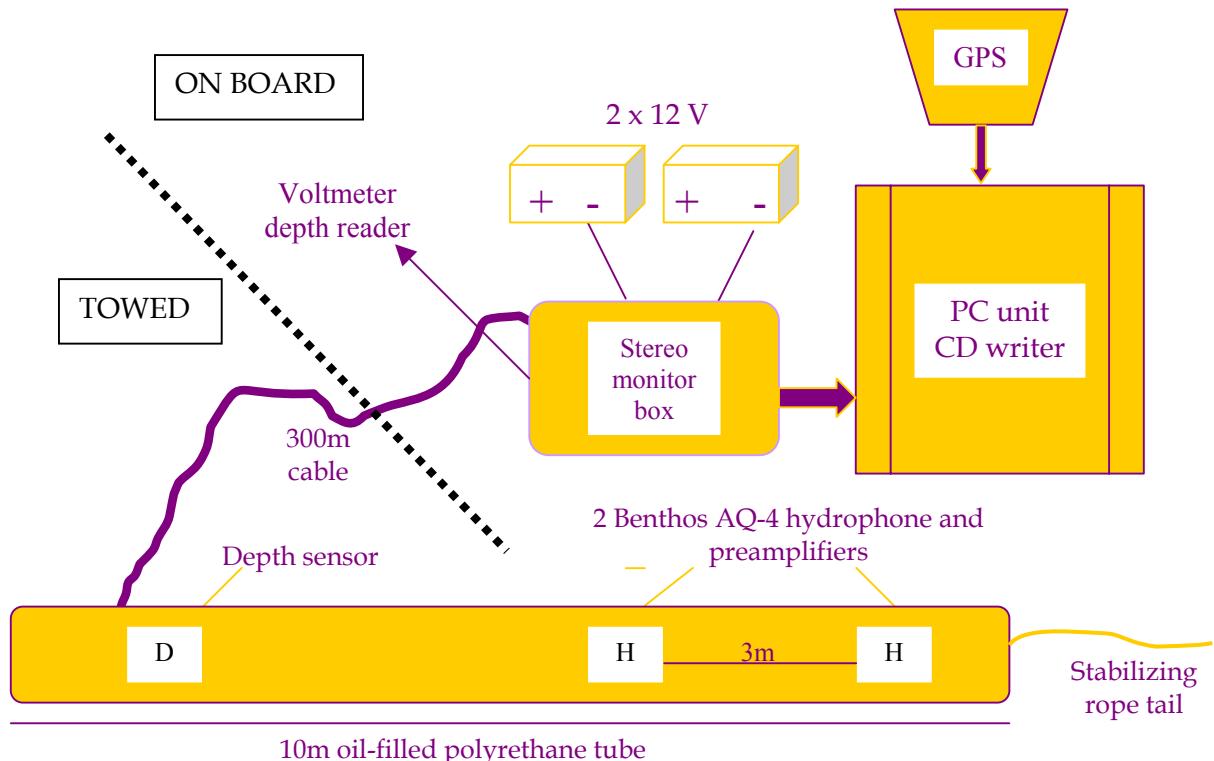


Figure 3. Schematic diagram of the equipment used on all acoustic surveys for cetaceans.

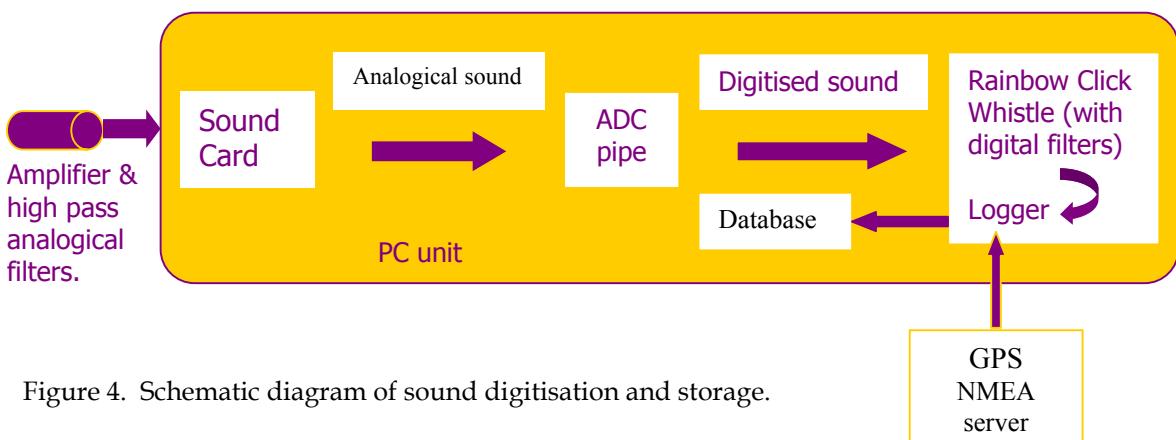


Figure 4. Schematic diagram of sound digitisation and storage.

4. DEPTH SENSOR

An inbuilt depth sensor is read by a voltmeter that was calibrated *in situ* and whose reading is translated to depth in meters by the following formula:

$$\text{Hydrophone Depth} = \left[\frac{\text{Voltage} - 4}{0.221} \right] \times \left[\frac{100}{16} - 10 \right]$$

5. SOFTWARE

Dedicated software, previously developed by Douglas Gillespie and Oliver Chappell under funding from the International Fund for Animal Welfare (IFAW) and Shell UK, was provided to the research team. The data acquisition software runs in real time and is composed of the following elements (Fig. 4):

- ***ADC pipe***

The transducers analogue signal from the hydrophone tube passes via an amplifier box with a high pass analogue filter and is digitised by a standard PC sound card (*Sound Blaster Live Platinum*). The *ADC pipe* program makes this single data stream available to several other programs running concurrently (*Rainbow Click*, *Whistle* and *Logger*).

- ***Rainbow Click***

Rainbow Click detects transient sound (such as cetacean clicks) and calculates the bearing at which they arrive at the hydrophone pair by comparing the time delay for each detected transient signal between channels. Adjustable digital filters are used to reduce noise and triggered transient signals go through a two-stage detection and characterisation process. At the first stage, transient signals of an appropriate duration which exceed a threshold (which is adjusted dynamically to be n standard deviations above the mean noise level), are marked. In the second phase the transient signal's spectral characteristics are examined before being accepted as putative cetacean clicks. The program attempts to identify clicks likely to have come from the same individual on the basis of their relative bearing and spectral characteristics. These "individual" clicks are coloured and displayed as appropriate.

- ***Whistle***

The *Whistle* program detects tonal sounds such as dolphin whistles or the lower frequency moans of baleen whales and incorporates a variety of noise reduction algorithms. Once noise has been reduced, time slices are calculated for each data block. These can be depicted in a standard spectrogram format. Within each time slice the program searches for the peak frequencies of detected signals. The program identifies those with most energy and searches for peaks at similar frequencies in adjoining slices in order to join them. If a sufficient number of such peaks are found, indicating a tonal sound exceeding a certain length, then a "likely whistle" is triggered. The contours of the whistle are depicted on a second display window and data summarising the whistle signal are stored in a *Logger* database.

- ***Logger***

This program acts as a central user interface and integration program. It receives data from a number of sources and stores this in an integrated relational database. Navigational data are received automatically via an NMEA interface from instruments such as the vessel's Global Positioning Systems (GPS) and other navigation and weather instruments. *Logger* receives data from the operator via pre-prepared forms and may prompt for such data at regular intervals. Checks on the integrity and accuracy of data entered in this way are run. *Logger* also receives data from the acoustic detection programs described above. Finally, the program incorporates a sound-recording module, which can make acoustic recording to the hard disk as required, or automatically on a pre-determined schedule. Data are stored in an access database. A plotting module plots data such as the vessel's track, locations of sightings and acoustic detections on a topographical map of the area.

All data obtained via these software programs are categorised into files (*.*) as follows:

***.wav**

Sound files recorded directly onto computer from the hydrophone/preamplifier output. These could be fixed length files recorded automatically at set intervals or variable recordings of

specific sounds of interest to the researcher. These are full data files that can be monitored aurally and analysed with any professional acoustic software.

***.clk**

Files containing the waveforms and summary data for all transient sound detected by a program *Rainbow Click*, which was developed by IFAW. These might commonly be sperm whales clicks and those of killer whales (*Orcinus orca*) and pilot whales (*Globicephala* spp.), in addition to the echolocation clicks other species. These files are recorded continuously, thus allowing the relative movement of vocalising animals to be tracked and revealing variation in the pattern of vocalisations.

***.wsl**

These files summarise data for detected tonal vocalisations (i.e. whistles).

***.mdb**

Microsoft™ Access® files, whose data fields can be designed by the researcher. All such files contained an index to link with a positional database from the vessel's Global Positioning System (GPS).

ACOUSTIC SURVEY PROTOCOL.

With the exception of the *SIAR* survey on board the M.V. *Emerald Dawn* (see also Vol. II), acoustic surveys were conducted primarily on vessels of opportunity (e.g. research vessels, fishery protection vessels), which are able to provide a spare berth for a scientific observer. The use of vessels of opportunity as research platforms limits the opportunity for determining the design of the survey lines but enhances the total area of coverage at low cost.

Sea surface temperature data were also recorded during some surveys. They were also collected along the transect route of the *SIAR* survey. In addition, the Geological Survey of Ireland allowed the use of temperature data collected at several stations during the S.V. *Bligh* surveys in 2000 and 2001, and S.V. *Siren* survey in 2001. The acoustic dataset was analysed using a point sample approach, with the equipment automatically recording 20-second samples every two minutes. At an average ship speed of 8.5 knots, the equipment therefore sampled every 510 m, as the vessel moved along transect lines through the study area.

Recordings were made both during the visual watch of the researchers and also when off visual effort. For example, on the *SIAR* survey, recordings were made when drifting at night or on transit to transect lines. On the other surveys, recordings were made when travelling at night or during periods where the vessel was resting in one location. Whenever possible, the hydrophone array was towed and collected data over a 24-hour period.

With the exception of the *SIAR* survey, only one CMRC researcher was normally on board a particular vessel to collect both visual and acoustic data on all acoustic surveys. Since visual observations were recorded only during daylight, the acoustic equipment was set to automatic sampling during the day, with the researcher performing periodic checks to guarantee the correct performance of the equipment. Ideal conditions would allow two researchers on board to keep both visual and acoustic watches simultaneously.

ANALYSIS OF CETACEAN VOCALISATIONS

Tonal sounds were detected automatically by *Logger* and their physical properties stored on a database linked with position and time data.

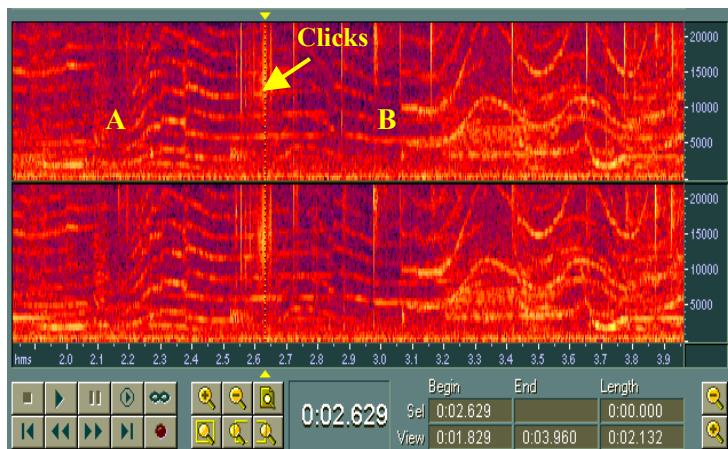


Figure 5. Sample sonogram of dolphin vocalisations

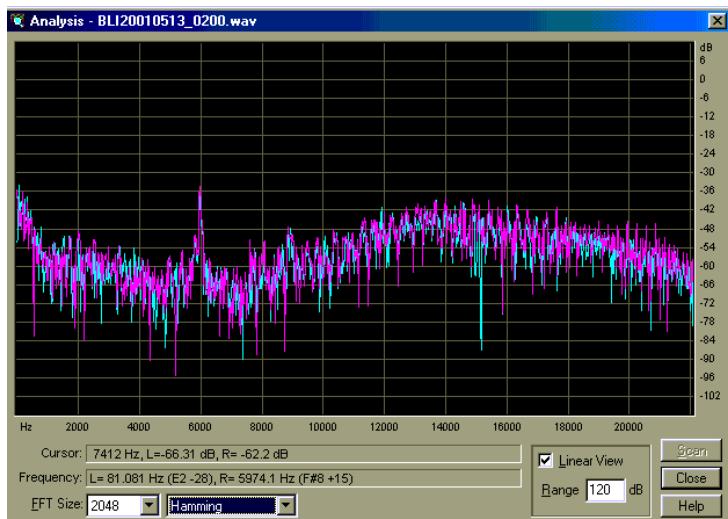


Figure 6. Power spectrum of echolocation clicks above.

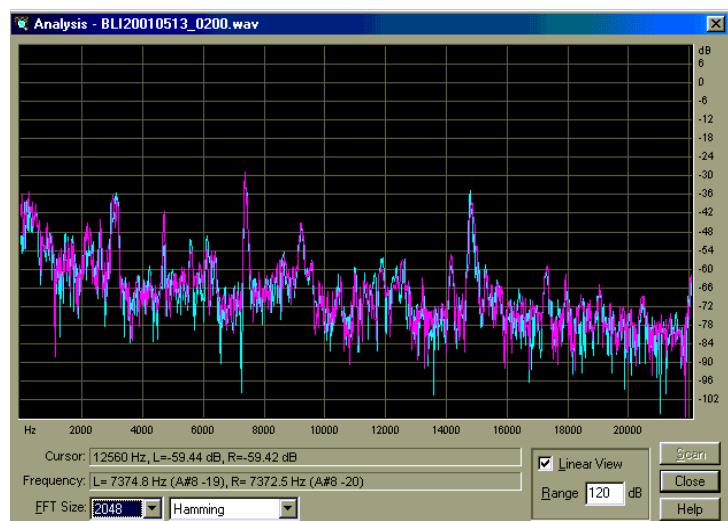


Figure 7. Power spectrum of a cetacean whistle.

The acoustic characteristics recorded were (i) maximum and average amplitude; (ii) start, end, maximum, minimum and average frequencies; (iii) the number of peaks and troughs and their

maximum and minimum frequencies; (iv) bearing, duration and estimated range to the vocalising animals.

Pulsed sounds of sperm whales, pilot whales and dolphins were also recorded and summarised in "click events" with the following characteristics (i) mean amplitude; (ii) mean, first and last inter-click interval; (iii) mean, first and last bearing; (iv) the number of clicks and their duration. In addition to all files recorded over the predetermined sampling interval (i.e. 20 seconds every two minutes), continuous click (i.e. *.clk) files were recorded. These enabled the recreation of detected signals from their physical properties and allowed for the continuous tracking of clicking animals.

Tonal and pulsed sounds were recorded and preliminary analysis carried out using the acoustic software packages *Whistle* and *Rainbow Click* and the commercial software program *Cool Edit®* (Syntrillium Corporation™). High-resolution colour spectrograms were calculated using a Hamming smoothing window and 2048 point FFT (fast Fourier transform) analysis. Pulsed sounds were analysed to determine their power spectrum, inter-click intervals, inter-pulse intervals, etc.

Figure 5 above is a sonogram presenting a series of dolphin echolocation clicks (as vertical lines) and whistles (as waveforms) in graphic form. The upper yellow arrow shows the point at which the power spectrum of the clicks has been analysed (Fig. 6), showing a peak frequency of approximately 6 kHz. Two distinct whistles (A and B) are shown (Fig. 5) having seven and two harmonics respectively. The first (A) has one peak and two troughs. The second (B) has two peaks and three troughs. Figure 7 shows the power spectrum of whistle B with 2 harmonics measured at the middle trough. It shows signal amplitudes at 7,374 kHz and 14,750 kHz with the maximum energy output concentrated in the lower harmonic. It is also possible to distinguish a third, smaller peak situated at 3.5 kHz. This corresponds to the detection of a "pinger" device being used on the vessel by the Geological Survey of Ireland during the National Seabed Survey.

■ *Species identification*

The mode in which acoustic surveys were conducted aboard vessels of opportunity introduced uncertainty in species identification, since vocalising animals were often recorded for short periods or at low intensities, and it was not possible to approach them to identify the species and estimate accurately the number of individuals. However, multi-parametric statistical analysis of whistle frequency parameters can allow for the identification of vocalisations to species level (Rendell *et al.*, 1999). While this analysis was beyond the scope of the present report, it may be carried out subsequently.

For the purposes of this report, the authors set three cetacean identification categories as follows: (i) sperm whale; (ii) pilot whale; and (iii) dolphin (Family *Delphinidae*). The latter category included both identified dolphin vocalisations and un-identified whistles resembling those produced by dolphin species. Only when the characteristic vocalisations of, for example, Short-beaked common dolphins (*a.k.a.* Common dolphins) or Atlantic white-sided dolphins (*a.k.a.* White-sided dolphins) were detected, or when the animals were also detected visually, was the third category divided up to species level.

■ *Proportion of time vocally active*

All acoustic detections were allocated into separate cetacean encounters. It was possible to calculate the proportion of the total recorded time in the encounter that the animals were vocally active. In the case of sperm whales, whose clicks can be separated for each individual, the calculation was done up to the level of individual whales. This was not possible for grouped animals such as dolphin species and a mathematical model has yet to be developed to correct for group size.

- **Determination of sperm whale body-length**

The specialised sound production mechanism of sperm whales, described in detail by Norris & Harvey (1972), allows for age determinations from individual vocalisations (Gordon, 1991). In this species, the animal's sound producing tissues (monkey lips) are situated at the front end of the head. The initial click pulse is emitted directly into the water. A series of secondary echoes from successive reflections of the click on the frontal sac (situated close to the skull) also occur. These sounds are detectable acoustically as measurable, regularly spaced pulses and the interpulse interval (IPI) may be directly related to the length of the head and thus to the total length of the whale, according to a formula developed by Gordon (1991):

$$\text{TL (Total Length)} = 4.883 + 1.453 \text{ IPI} - 0.001 \text{ IPI}^2$$

While the analysis of sperm whale vocalisations to determine the age profile of animals in Irish waters was beyond the scope of the present report, it could be carried out subsequently and would be worthwhile.

SPATIAL AND NUMERICAL ANALYSIS

1. SPATIAL ANALYSIS

The data were analysed spatially using the Geographic Information System *ArcView®* 3.2 software with depth data taken from the GEBCO 1997 digital atlas (Natural Environment Research Council, UK).

The *Logger* databases provided a list of acoustic samples linked to GPS positional data. The samples were listened to and the relative distance of cetaceans in every acoustic detection was allocated a scale/index of intensity from 0 (silence) to 5 (in very close proximity to the hydrophone array). This index was allocated by aural methods yet it was possible to use detections determined by the *Whistle* program, which colour codes to different intensities, as a means of ground-truthing the scale. The commercial acoustic software packages *Cool Edit®* and *Sound Forge®* (Sonic Foundry™) were also used in the analyses.

Noise levels and presence/absence of other acoustic events such as seismic survey activity, "pinger" and multi-beam sonar emissions, were also assigned to each recording with an aural scale from 0 to 5. To assess noise levels, power spectrum analyses were performed on random examples of recordings representing all noise levels using *Cool Edit®*. The seismic samples recorded were listened to and aurally assigned a level of intensity of their pulsed sounds from 0 (silence) to 5.

The presence of other sound associated with submarines, simultaneous seismic surveys, drilling platforms, and general background noise, were also scored on a scale from 1 to 5. The dataset was plotted using *ArcView®* 3.2 software. Distances from the points where seismic pulses were detected to the seismic source were measured on the maps. The relevant oil companies and governmental agencies provided details of the dates, location and intensity of the seismic sources working at the time in the survey area.

2. ANALYSIS OF ABUNDANCE

Many of the techniques used to estimate cetacean abundance from sighting surveys are potentially applicable to acoustic survey data. As a result of their characteristic vocalisations, sperm whales seem to be particularly suitable candidates for such approaches. The coverage and number of acoustic encounters obtained in some surveys allows for the calculation of density and abundance of some species or clusters of species. However, this is a complex

process that begins with an analysis of the physical components of the acoustic data. As a result, the analysis is ongoing and it is hoped that the results may be available at a later stage. During the present study a number of surveys also presented the opportunity for the collection of data on water temperature, salinity and sound velocity at various depths. These data were obtained by the Geological Survey of Ireland on surveys aboard the S.V. *Bligh* and S.V. *Siren* and they may add important information in future analyses of cetacean acoustics.

In order to apply the appropriate statistical methods for estimating animal abundance and population density, firstly the **number of animals** in every encounter and the **effective area** of survey coverage (Buckland *et al.*, 1993) must be obtained. For vocalising animals, the latter is related to the range at which animals may be detected by acoustic means.

- ***The number of individuals***

Acoustic survey methods may be more capable than visual ones of recording all the animals in a group as the animals can be detected over a greater range and also when diving. Line-transect methods typically used in visual surveys tend to underestimate group size unless the sighted animals are approached for better identification of group size, or unless time is given to be certain that all animals have surfaced and are seen.

In the present study, estimates of sperm whale group size were made aurally, aided by software analysis. Due to the nature of sperm whale sounds and a great deal of research thereon, it is possible to distinguish between the clicks of different sperm whales according to (i) the intensity and (ii) type of clicking, together with (iii) observed differences in the calculated bearings to clicking animals and (iv) the inter-pulse interval (IPI) of pulsed calls.

Other species present greater difficulties since their numbers have to be accounted for on the basis of aural perception. For example, the use of calculated bearings is not a reliable method for fast swimming cetaceans, such as many dolphin species. Further difficulties arise with species where research has not yet revealed the proportion of time spent vocalising, relative to an animal's sex, age, behaviour and time of year.

- ***Maximum audible range***

The range at which cetacean vocalisations can be detected depends on factors related to (i) the animals themselves, such as the *source level* (i.e. the intensity at which the sound is transmitted), the direction of emissions and the range of frequencies used. Other extrinsic factors are also involved. These are related to (ii) sound pathways and include physical attributes of the aquatic medium, such as water temperature, salinity, depth and the level of background noise, including that produced by the research vessel itself. The range of detectability also depends on (iii) the sensitivity of the acoustic equipment to signals on various frequencies.

The source level varies for different species of cetaceans, thereby affecting the detectability of the animals. This occurs even within the same species where source level can be adapted by the animal to various environmental conditions (Rasmussen *et al.*, 1999). Sperm whale source levels are reported to be in the range 160-180 dB (re 1 µPa) (Richardson *et al.*, 1995), although Møhl *et al.* (2000) recorded source levels up to 210 dB using hydrophones situated at 1,000m depth, in close proximity to vocalising whales. Source levels produced by dolphins typically range from 108-173 dB (Richardson *et al.*, 1995). Janik (2000) measured intensities up to 169 dB for wild bottlenose dolphins in the Moray Firth, estimating that their whistles could be heard over 5 km in a homogeneous environment. Larger toothed whales such as killer whales and pilot whales are thought to emit sound at intensities between 160 dB and 180 dB (Richardson *et al.*, 1995). However, echolocation clicks may contain higher sound pressure levels than those produced in whistles. For example, white-beaked dolphins have been recorded producing clicks at source intensities of 219 dB (Rasmussen *et al.*, 1999).

In a normal acoustic survey, vessel noise is the main factor limiting detection range (Leaper & Scheidat, 1998). One problem arises where survey coverage is not homogeneous along the transect lines due to the variation in noise levels. If background noise operates at a high source level it can mask cetacean signals. The received signal intensity is reduced by transmission loss as a function of distance to the animal. Thus the range at which a signal can be detected is limited not only by the distance of the animal from the vessel but also by the distance at which its intensity can surpass the background noise within a critical frequency band.

RESULTS

ACOUSTIC SURVEY EFFORT

Since the acquisition of the acoustic equipment in July 2000, five combined acoustic and visual surveys were carried out in offshore waters along Ireland's Atlantic Margin and one in the Irish Sea. The five Atlantic Margin surveys were conducted in an area stretching from southeastern margin of Rockall Bank to the Goban Spur and westwards beyond the western limit of the Rockall Trough (Fig. 8). In general, acoustic surveys covered the transect lines where the researcher was also on visual effort for seabirds and cetaceans (see Vols. I & II). This allowed the integration of both acoustic and visual survey datasets in most cases.

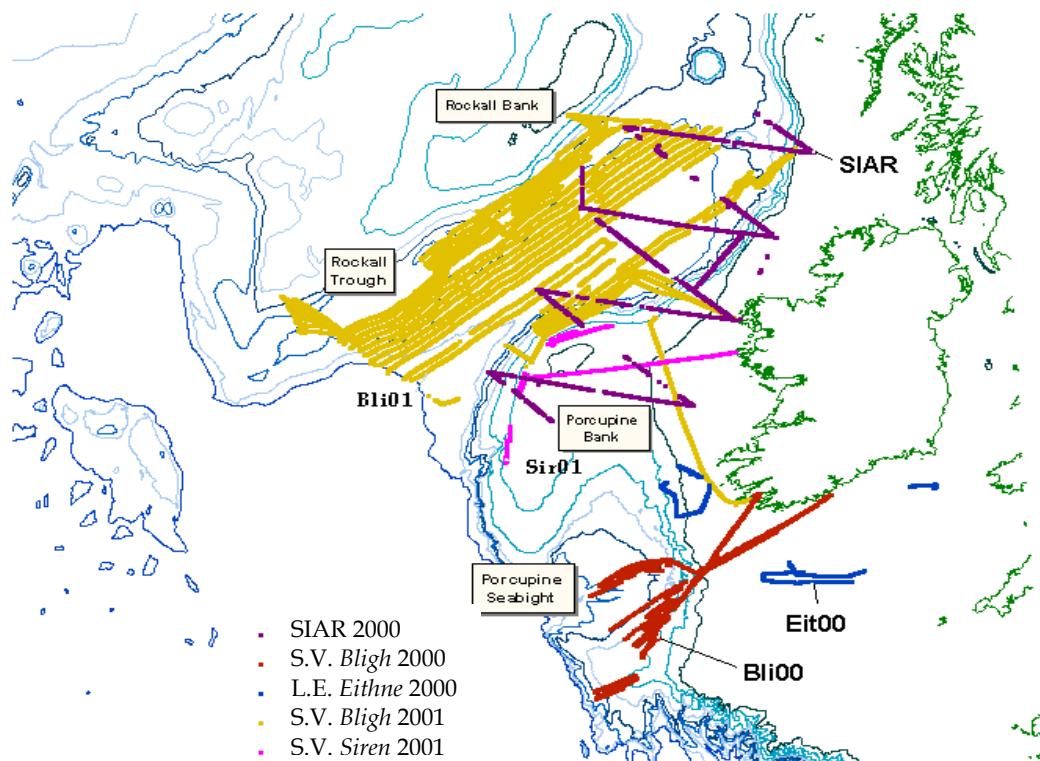


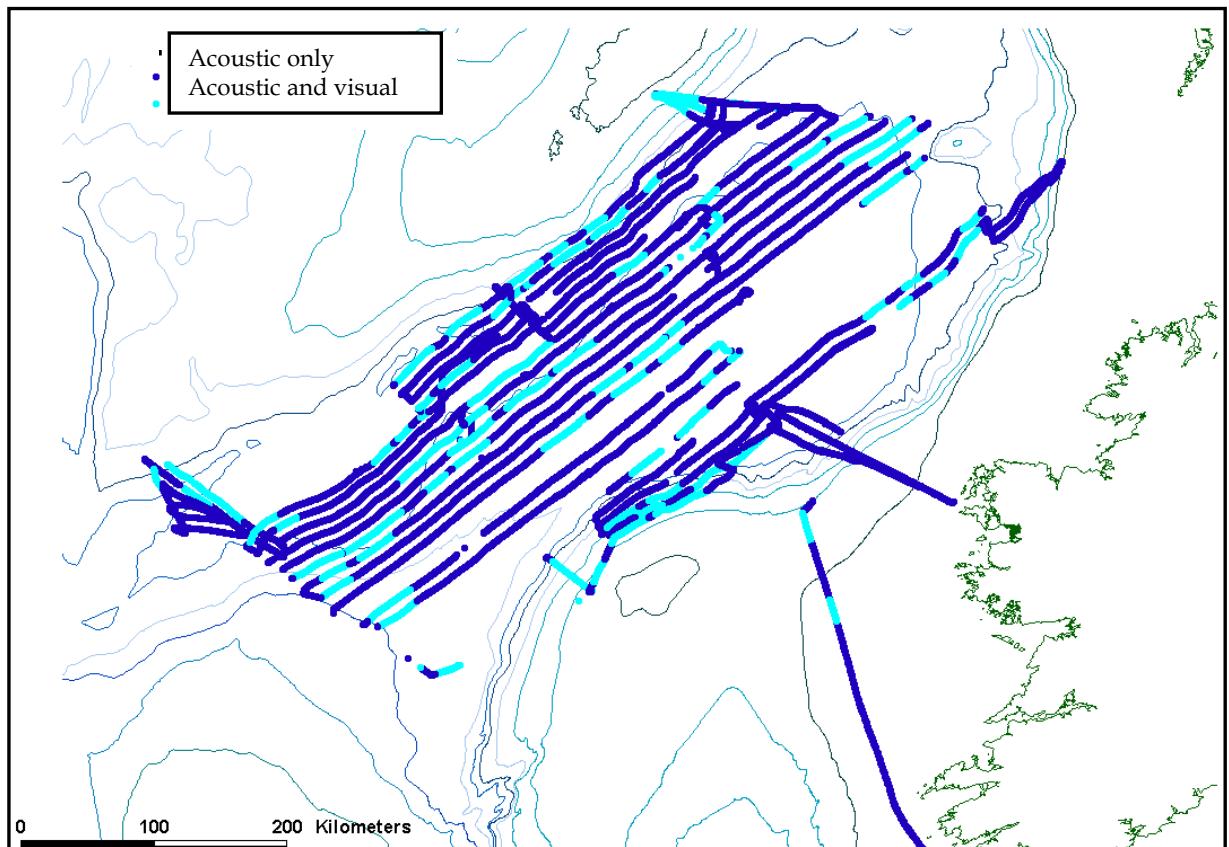
Figure 1.3: Acoustic surveys carried out by UCC from July 2000 to July 2001. Figure 8. Plotted tracklines of acoustic surveys for cetaceans carried out by the Cetaceans & Seabirds at Sea team along Ireland's Atlantic Margin between July 2000 and July 2001.

Effective acoustic monitoring was achieved on ninety days at sea. The first acoustic trials, conducted prior to and during the SIAR survey in 2000, allowed for a short "troubleshooting" period and the solving of minor technical and deployment problems. In this and subsequent surveys, the principal cause of variation in survey effort between research trips was unsuitable weather conditions, which made deployment and recovery of the hydrophone equipment hazardous or risked the entanglement of cable around the vessel's propellers. Survey effort was also curtailed on occasion when the survey vessel was operating at speeds in excess of 16 knots. Successful deployment of the gear resulted in a total of 1,190 hours of acoustic surveying and an acoustic record spanning 238.42 hours (Table 2).

TABLE 2. Summary of effective days, hours surveyed and recorded in the study period.

Survey	Survey dates	Survey track-length (km)	Survey time (hours)	Recording time (hrs)
SIAR survey	30/07/00 to 22/08/00	2,764.70	337.40	78.18
L.E. Eithne '00	18/09/00 to 22/09/00	249.80	27.40	5.44
S.V. Bligh '00	14/10/00 to 25/11/00	1,232.80	76.10	26.27
S.V. Bligh '01	29/04/01 to 08/06/01	9,720.18	694.30	118.84
S.V. Siren '01	30/06/01 to 06/07/01	511.50	54.90	9.69
TOTAL		14,478.98	1,190.10	238.42

Up to four times more time can be spent monitoring for cetaceans during an acoustic survey than during a visual one. An example of this is shown in Figure 9, where significantly greater coverage was achieved aboard the S.V. *Bligh* by acoustic means than by combined acoustic and visual means (only 22% of the total acoustic trackline was also covered using visual methods). This is due to the ability of the acoustic equipment to record automatically, for example, through a wider range of weather conditions than can be utilized for visual surveying. It also allows the recording of acoustic data in poor light conditions or while the observer is resting at night.

Figure 9. Survey coverage by single and combined methods on the S.V. *Bligh* survey, 2001.

EQUIPMENT PERFORMANCE

The acoustic signature of each vessel, together with other parameters such as the average vessel speed and water depth, led to differences in the performance of the acoustic monitoring system. Such differences were based on the high intra-survey and inter-survey variability in noise levels. Thus the received levels required to detect cetacean vocalisations varied somewhat, affecting the range at which the animals were detected and, consequently, the effective acoustic coverage.

On a number of surveys, the effect of background noise from broadband low frequency sources (e.g. engine noise) was less significant than targeted man-made signals on specific high frequencies (e.g. sonar). The latter narrow-band interference occurred on surveys aboard the S.V. *Bligh* and S.V. *Siren*. These vessels were engaged in mapping the Irish seabed territory under the Geological Survey of Ireland's National Seabed Survey programme. This survey required the use of two acoustic devices:

- *Pinger*

This acoustic device is used to analyse the seabed composition up to approximately 30 m below the substrate surface. It emits pulses on a peak frequency of 3.5 kHz (Fig. 10) with variable inter-pulse intervals depending on the water depth. The characteristics of the pinger echoes received from the seafloor vary according to the seabed composition.

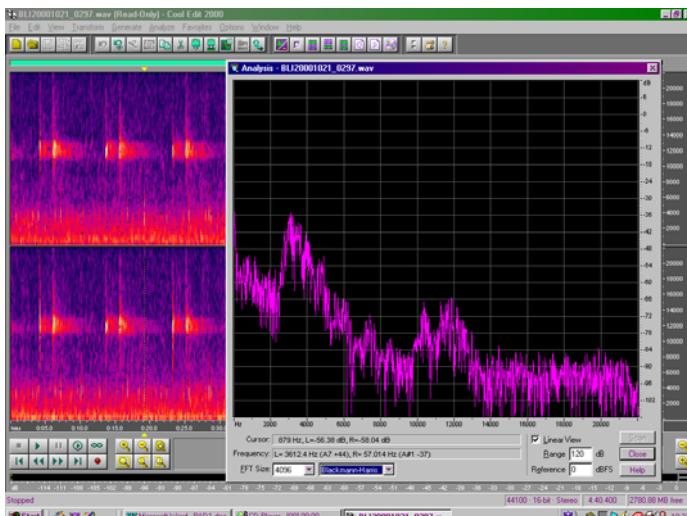


Figure 10. Sample spectrogram & power spectrum of pinger emissions

- *Multibeam*

This sonar device is used to map the water depth and derive accurate contours for the seabed. It emits pulses at various frequencies. A peak frequency of 12 kHz was used in deep waters aboard the S.V. *Bligh* (Fig. 11), while a peak frequency of 95 kHz was used in shallower waters (<300m depth) aboard the S.V. *Siren*.

Since the operational frequency of the pinger overlaps directly with that of sperm whale clicks and the multibeam frequency overlaps with the whistles of several cetacean species, the devices triggered the detection of the cetacean acoustic monitoring software. As a result, numerous false-positive detections were made and entered on the relevant databases. However this was anticipated and aural analysis of the samples by the researcher allowed the highly distinctive sounds of the pinger and multibeam devices to be distinguished from detections of the cetacean vocalisations.

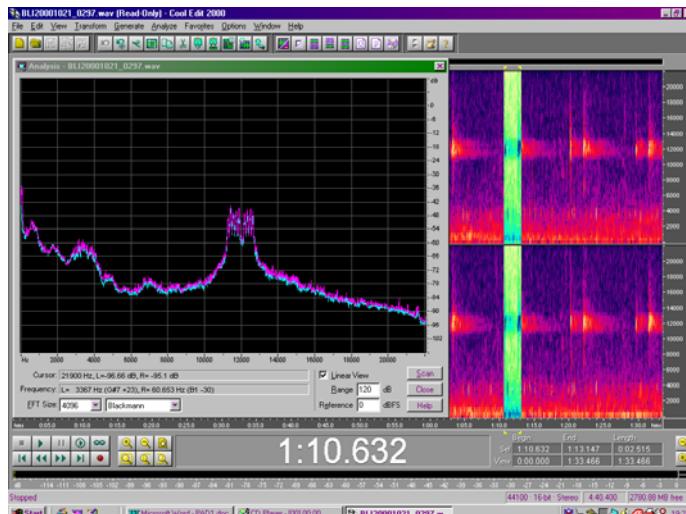


Figure 11. Sample spectrogram and power spectrum of the multi-beam sonar used on the S.V. Bligh.

INDIVIDUAL SURVEY RESULTS

A summary of the results of acoustic monitoring across all surveys in the Irish Atlantic Margin region is shown below:

TABLE 3. Summary of the total number of cetacean encounters recorded by the *Cetaceans & Seabirds at Sea* team during acoustic surveys in Ireland's Atlantic Margin.

Survey	Sperm whale encounters	Pilot whale Encounters	Dolphin encounters	Beaked whale encounters	TOTAL
SIAR survey	18	3	187	2	210
L.E. Eithne	0	0	8	0	8
S.V. Bligh '00	2	3	46	0	51
S.V. Bligh '01	89	114	175	0	378
S.V. Siren	1	4	19	0	24
TOTAL	110	124	435	2	671

1. SIAR SURVEY (30 July to 22 August, 2000)

Within the scope of the research programme carried out by the *Cetaceans & Seabirds at Sea* team, funding was allocated for a dedicated three-week cetacean and seabird survey aboard a chartered vessel (*see Vol. II*). The rationale behind the proposed survey was to allow the investigation of a key region within the broader study area, while also filling gaps in survey coverage caused by the usual reliance on vessels of opportunity in the overall project. In addition to its spatial objectives, the planned *Survey In Western Irish Waters And The Rockall Trough (SIAR)* aimed to greatly enhance the data gathered under the overall research programme. This would be achieved by systematically surveying the target region using more

powerful visual and acoustic survey methods in tandem with the standard single-observer approach. The combination of both visual and acoustic survey methods provided an optimal set of data for cross calibration of the visual and acoustic detections to assess more accurately the range of detection, received sound levels at various distances, etc.

The vessel chartered for the *SIAR* survey was the 35m M.V. *Emerald Dawn*, a deep-water trawler based in Dingle, County Kerry. Analysis of the sound produced by the vessel itself determined that the vessel was relatively noisy, especially as it detuned its variable pitch propeller to adjust boat speed. This made acoustic surveys difficult in areas of steep bottom relief or in shallow waters, where reflection of sound from the seafloor was increased.

The survey area allocated for the *SIAR* survey was a block of approximately 120,000 km², running in a southwest to northeast direction and stretching up to 360 km offshore from the Porcupine Bank towards the Outer Hebrides (Fig. 12). The target area was transected by a series of seven full transect legs approximately 143 nautical miles in length, and by two shorter legs at the northern and southern margins measuring approximately 55 and 60 nautical miles respectively. The survey extended from latitude 56° N to 52° N. The northern half of the survey (from 54° N) covered deep waters of the Rockall Trough and continental slope. In contrast, the southern half concentrated in waters less than 500 metres deep.

The hydrophone was deployed successfully during most of the visual transect lines and also when off visual effort. A total length of 1,878.3 km visual survey effort was also covered acoustically. An additional 781.8 km were surveyed solely using acoustic methods with a further 104.6 km covered by transit-type surveys.

The *SIAR* survey was the first occasion on which the newly made acoustic equipment was used. Thus it acted as an experimental survey and enabled the authors to identify any software or technical problem. Electrical noise, high on the survey due to a faulty provisional connection from the amplifier box to the PC, was subsequently resolved. Such initial problems with the hydrophone equipment reduced the system's sensitivity, occasionally affecting the detection range of the equipment. This would theoretically lead to variations in the effective survey coverage and, as a result, the effort data require further in-depth analysis if abundance estimates for particular species are to be derived by acoustic means.

All acoustic detections made during the *SIAR* survey, some of which were hours long, were grouped into 210 separate acoustic encounters (Table 3). This categorisation of the data was based on a minimum time interval of ten minutes between encounters of dolphins. At an average vessel speed of 8.5 knots this corresponds to 2.96 km of transect line which approximates the audible range of dolphin vocalisations. This method followed a recent abundance estimation method used for dolphins in the Ligurian Sea (Gordon *et al.*, 2000). While drifting at night the "silent-time" period to separate encounters was increased to 30 minutes. To separate sperm whale encounters, a silent-time interval of one hour was considered appropriate, corresponding to nearly 16 km travelled.

There were 21 distinct detections of sperm whale groups: (i) nine in waters >2,500m deep (Rockall Trough), (ii) one in waters <500m deep, south of the Porcupine Shelf, and (iii) eleven in waters overlying the continental slope (Fig. 12). These corresponded to 18 separate sperm whale encounters. Just three of these encounters were detected visually, all occurring in the northern (Rockall Trough) part of the survey area.

There were three distinct acoustic encounters of long-finned pilot whales (Fig. 12), two of them on the continental slope and one in the continental shelf. Two encounters on the continental slope were detected visually, while one acoustic encounter was not detected by visual means.

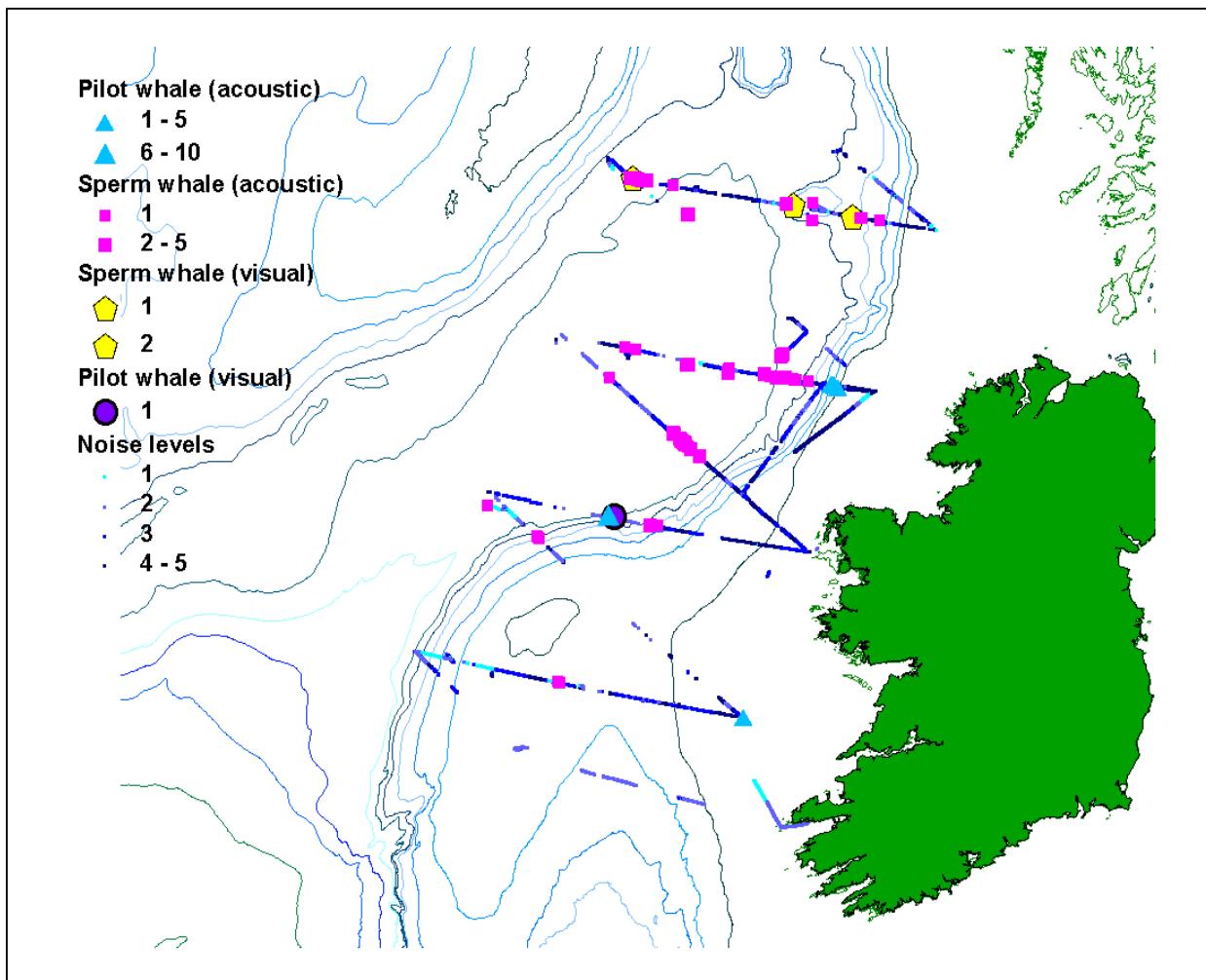


Figure 12. Long-finned pilot whale and sperm whale visual and acoustic detections made during the SIAR survey. Estimated group sizes are described. Transect lines are assigned a graduated colour according to the noise level present in samples (1 = minimum, 5 = maximum).

There were 187 acoustic encounters with various dolphin species (Fig. 13). The detection of dolphins appeared to show a latitudinal bias towards the southern half of the survey area, which comprised continental slope and shallower waters. Common dolphins were found to be the more abundant species in the deep waters of the Rockall Trough while white-sided dolphins appeared to show a preference for the areas overlying steeper continental slopes. Acoustic detections were also made while in transit between transect lines and on the way to Dingle harbour where some whistles of the resident dolphin "Fungi" were recorded amidst the high background noise typical of shallow waters.

The total number of acoustic encounters is greater than the number of visual records if all the recordings (both on and off visual effort) are taken into account. However, the numbers of acoustic and visual detections, independent of one another, are very similar if off-effort periods are discounted. While it may be tempting to assume therefore, that visual survey methods, if conducted properly, may approximate acoustic survey methods, it must be remembered that several factors must be considered when analysing visual and acoustic data together. For example, the detectability of cetaceans may be highly species-dependent. A significantly higher number of sperm whales, which are deep-diving species easily missed by a passing vessel, were recorded acoustically during the SIAR survey than were observed on visual effort. Conversely, it is also common for several sightings of one or more dolphin species to be made within a single continuous acoustic detection. In addition, various physical properties of the

medium through which the sound is transmitted may also play a role in acoustic detection rate (e.g. oceanographic conditions). Needless to say, further analysis of sound spectra, amplitude and bearings associated with all detections are required. Such analysis should provide a more accurate determination of encounter characteristics, of detection range and of the number of species.

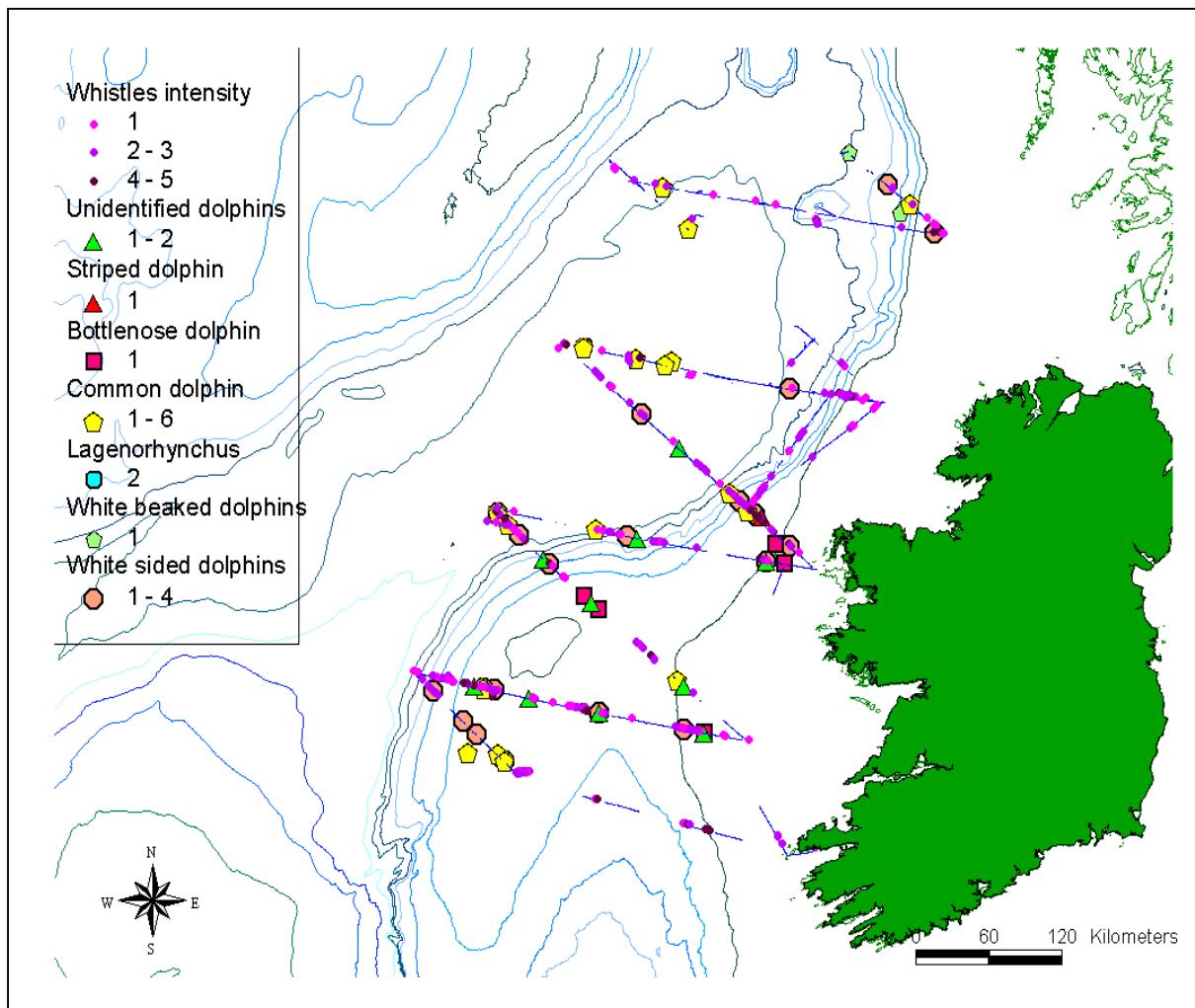


Figure 13. Summary of all acoustic detections of dolphins and visual encounters made during the SIAR survey. Detections are classified to species level where possible and estimated group sizes are given. Transect lines are assigned a graduated colour according to the intensity of whistles present in samples (1 = minimum, 5 = maximum).

2. L.E. EITHNE (18 to 22 September, 2000)

A combined acoustic and visual survey was carried out on the Irish Naval Service flagship L.E. *Eithne*. The vessel provides a good platform for acoustic studies since it was designed to be a quiet ship. However, the vessel's ability to travel at relatively high speeds (15-20 knots) occasionally affected the detection range of the hydrophone as the array was occasionally skimming the water surface. As a result, background noise at medium frequencies, generated by increased water flow, was higher than in other surveys conducted during the research programme. Although weighting the cable could have reduced this component of the background noise, it would have increased the risk of losing or damaging the equipment at high speeds. An added difficulty arose when the equipment had to be recovered during boarding operations associated with fishery protection activities, as the frequent changes of course could potentially damage the array.

Nevertheless, the hydrophone array was towed along a total of 805.8 km at spaced intervals during the survey, which took place mainly in continental shelf waters to the southwest of Ireland (Fig. 14). Some data were lost due to the unforeseen use of faulty CD's. Thus only 249.8 km (corresponding to 13.5 hours) of survey effort could be analysed. A total number of 381 valid samples totalling 2.19 hours of recordings were detected by the acoustic equipment. The distribution of the acoustic detections is summarised in Table 4 and represented graphically in Figure 14. In calculating the percentage of cetacean detections per recording, samples with high level of water noise (noise level 5) were not considered.

TABLE 4. Summary of survey coverage and cetacean acoustic encounters during the L.E. *Eithne* survey.

Area	Trackline covered (km)	% Coverage	% recordings with cetacean detections	Number of encounters
Continental Slope	37.2	16%	16%	3
Continental Shelf	212.6	84%	9%	5
TOTAL	249.8	100%	25%	8

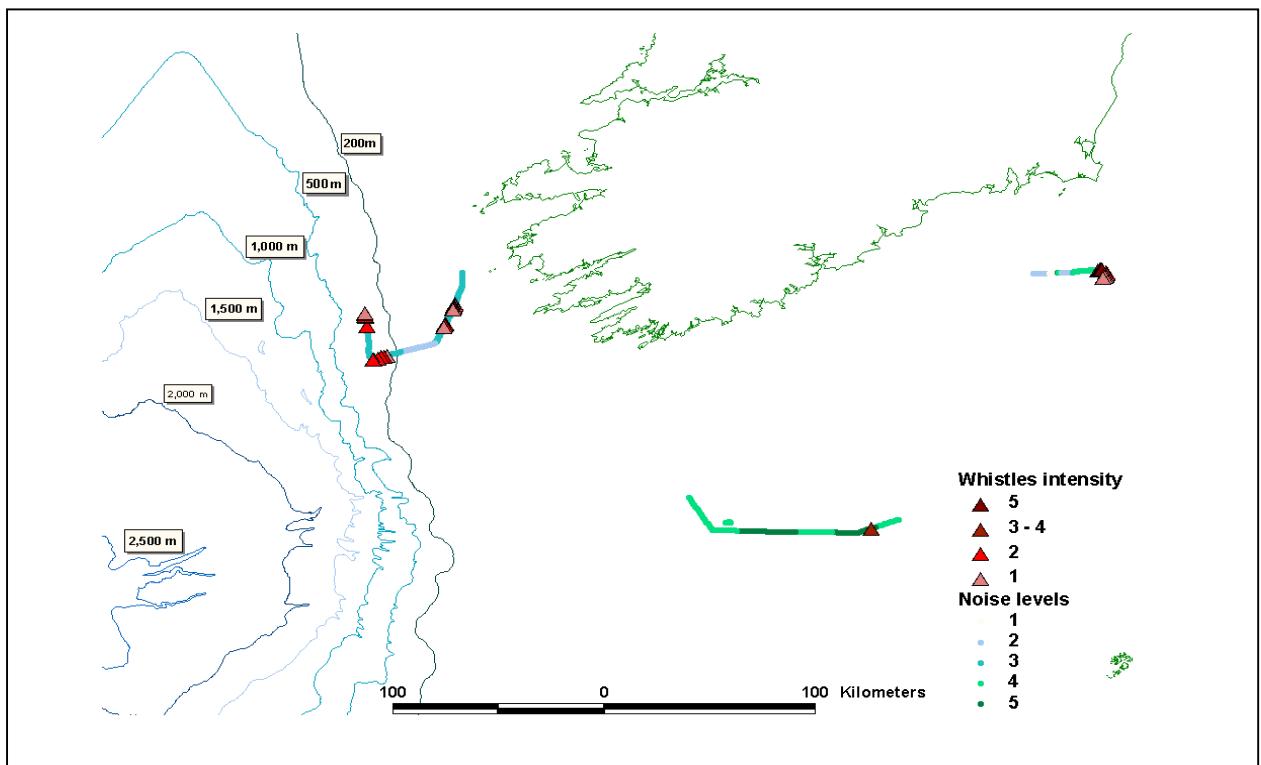


Figure 14. Acoustic detections of cetaceans and noise levels recorded on the L.E. *Eithne* survey.

A total of eight separate acoustic encounters of dolphin species were made during the survey (Fig. 14). All encounters were recorded at night, when the observer was off visual effort. This is not surprising since, during the day, the fishery protection activities of the vessel limited the use of the hydrophone. Aural identification and the relatively long duration of the encounters suggested that the species were mostly common dolphins.

The number of detections was small when compared to other surveys, which may be related to the difficulties with CD equipment and the contribution made by high frequency components

of the background noise. Acoustic detection rates per km of transect line appeared to be comparatively higher in waters overlying the continental slope with fewer detections in the Celtic Sea portion of the survey area (Fig. 14). While the levels of background noise were higher in the Celtic Sea, a brief comparison between the continental slope and shelf within the western portion of the survey area, where the levels of noise were similar, still showed a higher concentration of encounters over the slope.

The use of Irish Naval Service vessels as acoustic research platforms offers some potential. The wide coverage, continuous patrolling activity and favourable acoustic characteristics make them suitable for the long-term monitoring of cetacean abundance in Irish waters. The principal limitation is introduced by the relatively high cruising speeds that result in shallow hydrophone deployment and elevated levels of noise. The use of added weight and/or a depressor could increase tow depth and alleviate the latter problems.

3. S.V. BLIGH 2000 (14 October to 25 November 2000)

The surveys on board the S.V. *Bligh* resulted in the best geographic coverage using the acoustic equipment. This acoustic survey was the first of three acoustic surveys for cetaceans carried out on board the vessels chartered by the Geological Survey of Ireland for the National Seabed Survey. A total of 1,232.8 km of track-line was covered over the course of 76.1 hours during the survey. The average vessel speed was 9.1 knots.

The survey lines overlapped on several occasions. This was due to the repeated transit of the ship to the coast to gain shelter from the gale-force winds that occurred frequently during the survey period. The separation in time between the transits made them useful for presence/absence analysis, although they did not increase the survey area covered. Although background noise from the water turbulence, waves, etc, increases with higher sea states, this survey verified the effective performance of the equipment in adverse weather conditions. The high number of cetacean encounters recorded in conditions up to Beaufort force 9 was noteworthy.

A total of 4,528 automatic detection samples were taken spanning 26.27 hours of recording and 61.3% of the total number of recording samples contained cetacean vocalisations. A total of 51 acoustic encounters were recorded during the survey, comprising two sperm whale encounters, three pilot whale encounters and 46 encounters with various dolphin species. Comparison of the detection rate along survey lines inside the continental shelf (Area B: depth < 200m) and on the steep slope of the Goban Spur and Porcupine Seabight (Area A) indicated differences in cetacean distribution (Area A: 67% of 3,286 samples contained cetacean vocalisations; Area B: 41% of 1,213 samples contained cetacean vocalisations; Fig. 15)

Common dolphins were the most frequently recorded species on this survey. The comparatively high acoustic encounter rate may be related to a southern shift in the distribution of cetaceans in the winter season. The number of encounters may also be related to the complex seabed relief of the survey area. The continental slope in the area that encompasses the Goban Spur and Porcupine Seabight is very steep and includes a complex system of canyons where important meso-scale processes may enhance local productivity. Further evidence of this is indicated by the presence of carbonate mounds associated with deep-water corals in the area.

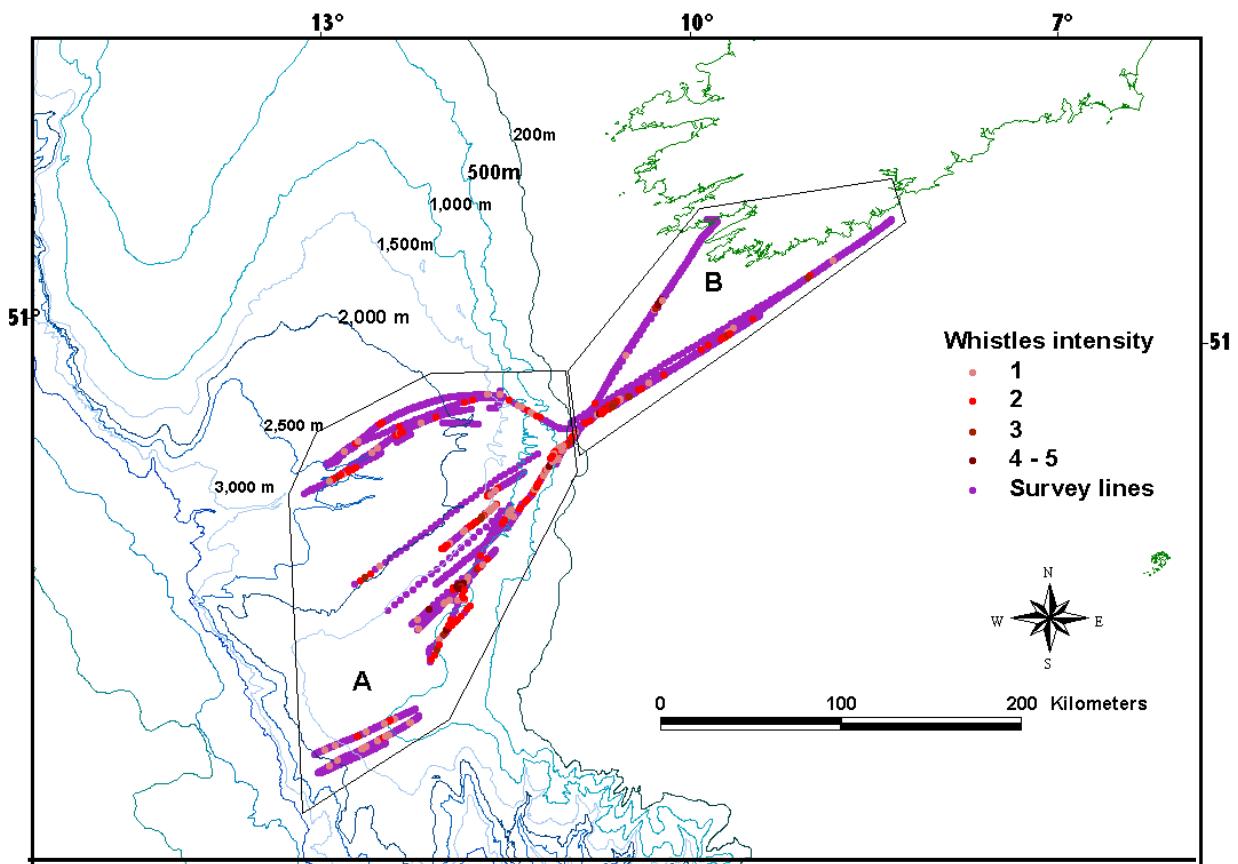


Figure 15. Distribution of cetacean vocalisations recorded on the S.V. *Bligh* 2000 survey, separated into areas A (continental slope) and B (continental shelf).

4. S.V. BLIGH 2001 (29 April to 8 June 2001)

This survey intensively covered the Rockall Trough over a six-week period in the spring of 2001. A total of 40 days were effectively surveyed, totalling 694.3 survey hours. During the survey 19,997 samples (corresponding to 118.83 hours of monitoring) were recorded. The average vessel speed was 8.7 knots. As in the previous S.V. *Bligh* 2000 survey, the vessel's activity did not interfere with the deployment of the acoustic equipment, as it was possible to tow the magnetometer (used by the GSI for mapping magnetic anomalies) and the hydrophone array simultaneously. This allowed for the comparison of the survey capabilities of a single observer on visual effort and on acoustic effort.

Visual effort covered only 22% of the total acoustic trackline covered. All visual sightings, apart from those of baleen whales, were also detected and recorded by the acoustic equipment. The incidence of background noise during the survey (Fig. 16) were recorded as follows: level 1 - 0.03%; level 2 - 37.6%; level 3 - 45.2%, level 4 - 15 % and level 5 - 1.7% and a graphical representation is shown

Based on experience and the vessel speed, encounters were defined by a silent period separation of fifteen minutes between dolphin and pilot whale encounters and forty-five minutes between sperm whale encounters. This separation between encounters was very conservative (4km for dolphins and pilot whales and 12 km for sperm whales) as the deep waters of the Rockall Trough and the silent characteristics of the vessel allowed for a wider range of detection than usual. The data will require further analysis to separate encounters on the basis of relative bearings to the animals. However this may allow the authors to produce retrospective density and abundance estimates for sperm whales in the Rockall Trough in the spring of 2001.

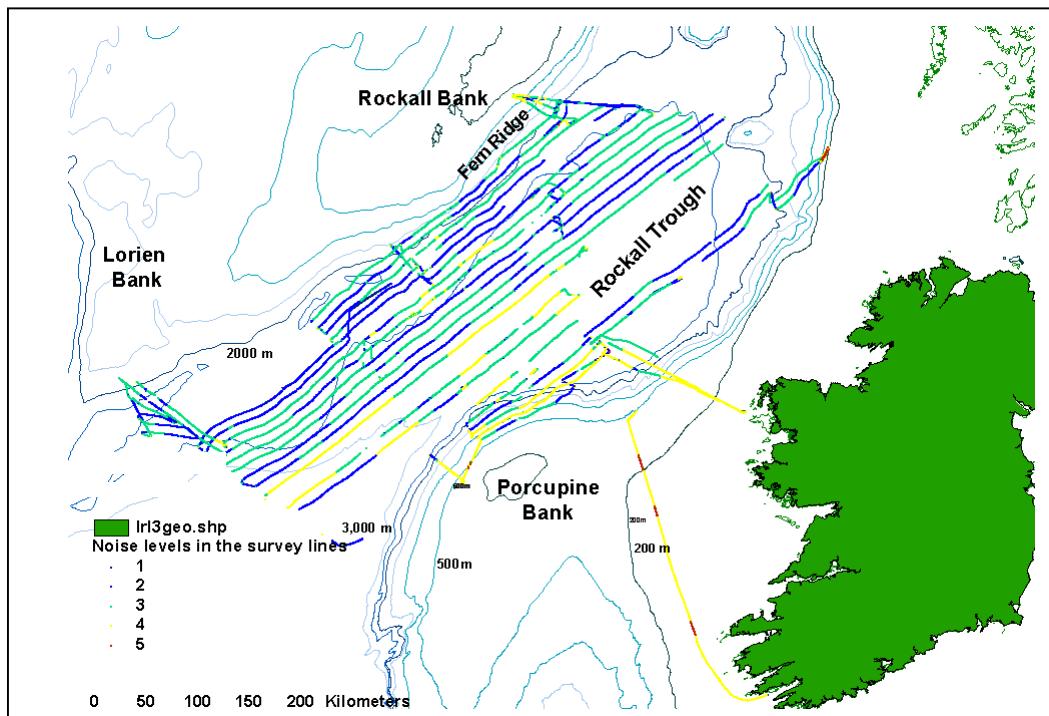


Figure 16. Noise levels (1 = minimum, 5 = maximum) recorded among acoustic samples recorded on the S.V. *Bligh* 2001 survey.

The distribution of the acoustic detections during the survey is shown in Figures 17 and 18. A total of 378 acoustic encounters were recorded during the survey. These could be separated into 175 encounters with various dolphin species, 114 encounters with pilot whales and 89 encounters with sperm whales. 89 encounters with sperm whales were detected on the survey (Fig. 17), with a minimum duration <2 minutes, and a maximum recording of four hours and eight minutes' duration. Counting of the number of individuals within sperm whale groups, which may be corrected with further acoustic analysis, yielded group sizes from one to seven animals.

On the majority of occasions, sperm whales were recorded acoustically before they were seen and only once was an animal sighted first as it rested on the surface before it dived and began vocalising. The analysis of detection distances is not complete, but a detection distance of approximately 16 km was derived from a number of recordings in which clicking individuals were acoustically monitored for periods of over an hour.

To investigate the influence of slope on cetacean distribution, the authors selected polygons of containing tracklines from the northwestern margin of the Porcupine Shelf across the Rockall Trough (Fig. 19). This allowed the comparison of the distribution of acoustic detections between polygons situated throughout the Rockall Trough area. The polygons were distributed randomly along the Rockall Trough on the basis of selecting areas with minimum slope and maximum survey coverage. The results are given as percentages to correct for the non-homogeneous coverage in the different polygons. In addition to this analysis, two small polygons were situated to cover survey lines that crossed the continental slope. Another small polygon was positioned over a particular basin-like indentation (C) within the survey area, which is situated along the southwestern margin of the Rockall Trough.

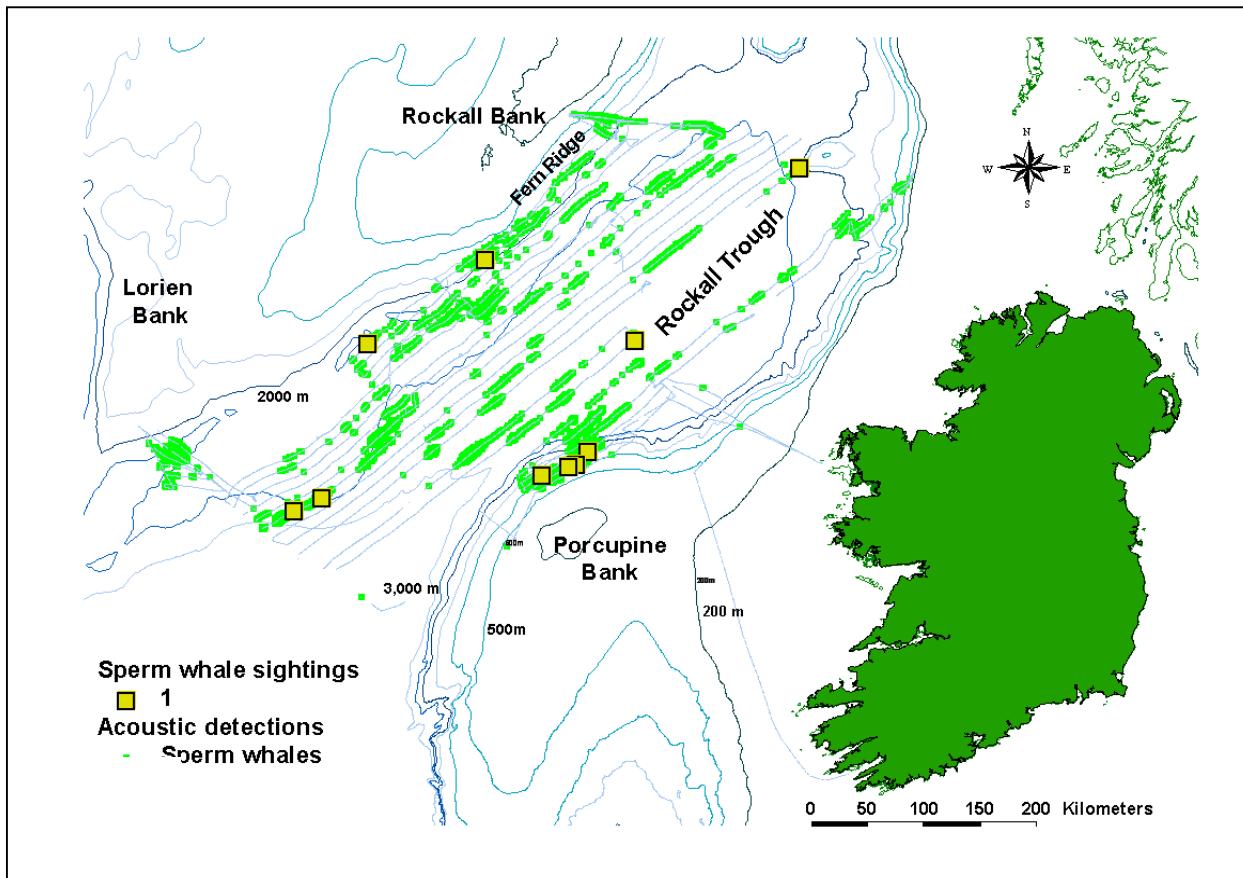


Figure 17. Distribution of sperm whale visual and acoustic detections during the S.V. *Bligh* 2001 survey.

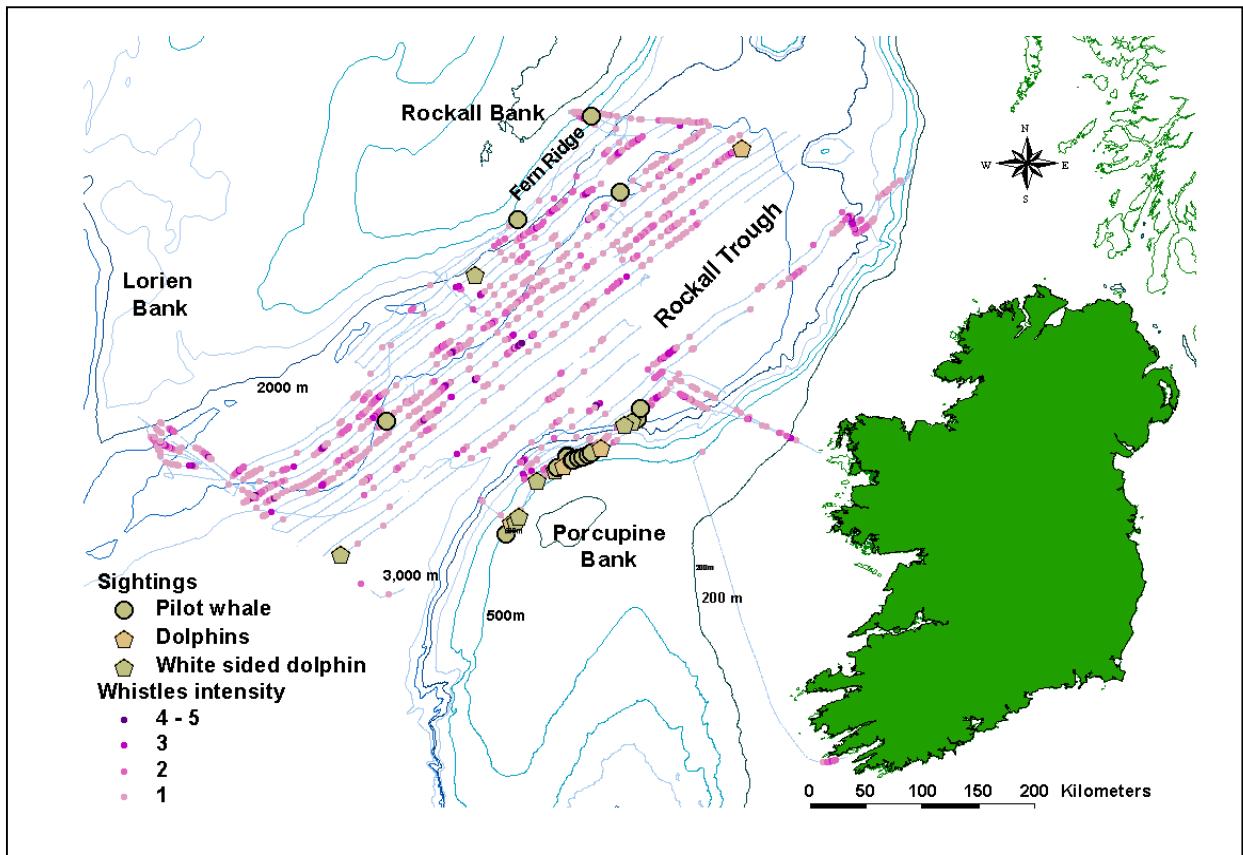


Figure 18. Distribution of long-finned pilot whale and dolphin visual and acoustic detections during the S.V. *Bligh* 2001 survey.

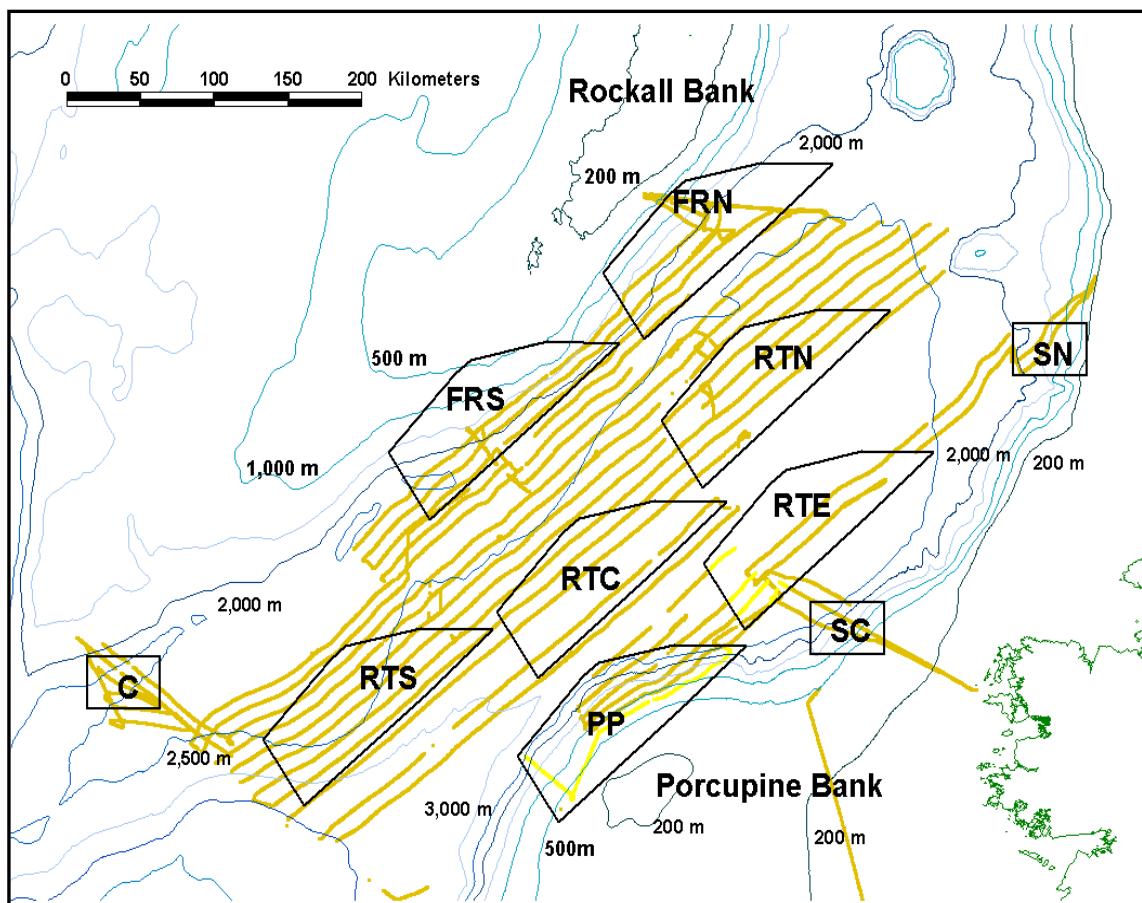


Figure 19. Tracklines of the S.V. *Bligh* 2001 survey showing area polygon sub-samples used in the distribution analysis.

TABLE 5. Summary of the distribution and frequency of occurrence for acoustic detections of cetaceans from S.V. *Bligh* 2001 survey. Detection data described are from selected area polygons (see Fig. 19).

Area	Total no. of samples	Cetacean detections	Whistle detections
NW Porcupine Shelf (PP)	1,112	35.7%	12.6%
Rockall Trough South (RTS)	1,508	25.7%	14.2%
Rockall Trough Centre (RTC)	961	29.0%	5.4%
Rockall Trough North (RTN)	1,144	19.0%	10.3%
Rockall Trough East (RTE)	846	15.4%	9.8%
Feni Ridge South (FRS)	945	26.7%	5.2%
Feni Ridge North (FRN)	1,335	29.8%	13.8%
Unknown seabed feature (C)	479	40.3%	16.7%
Continental Slope North (SN)	194	43.81%	32.5%
Continental Slope Centre (SC)	221	9.0%	8.1%

Results from these analyses show that area C and the northern Irish continental slope (SN) areas had a higher percentage of cetacean detections than any other region (Table 5). These areas are small in comparison with other polygons. In contrast a similar area of steep slope (SC) selected off northwestern Ireland contained very few cetacean detections (9% of samples).

Of the larger polygons analysed, the northwestern Porcupine area (PP) contained the highest number of detections. This region is an area of considerable ecological importance, according to recent findings. The map below (Fig. 20) indicates the distribution of seabed carbonate mounds from the Geological Survey of Ireland data and also from recent *Geomound* and *Ecomound* research projects, in which the Coastal & Marine Resources Centre was also involved (see Hovland *et al.*, 1994; Henriet *et al.*, 1998; Wheeler *et al.*, 1998). The map also shows surface water temperature taken at several locations along the survey track. Sea surface temperature ranged from 10.2 - 12.7°C, with colder water located in the northern sector.

In the northwestern Porcupine region these mounds are situated at water depths ranging from 500 to 1,000 metres and are found in areas of dynamic hydrology. They are related to the presence of the deep-water reef-forming coral *Lophelia pertusa*. This coral has a highly diverse associated fauna and diversity (Rogers, 1999). Coral mounds are also known to be located in relatively high concentrations in the Porcupine Seabight and along the southern margin of the Feni Ridge. Such areas appear to be coincident with areas of relatively high cetacean abundance (see Vol. II). This underlines the significance of such areas from many physical and biological perspectives and warrants further detailed investigation of these habitats, their oceanographic conditions and the biological species that aggregate therein.

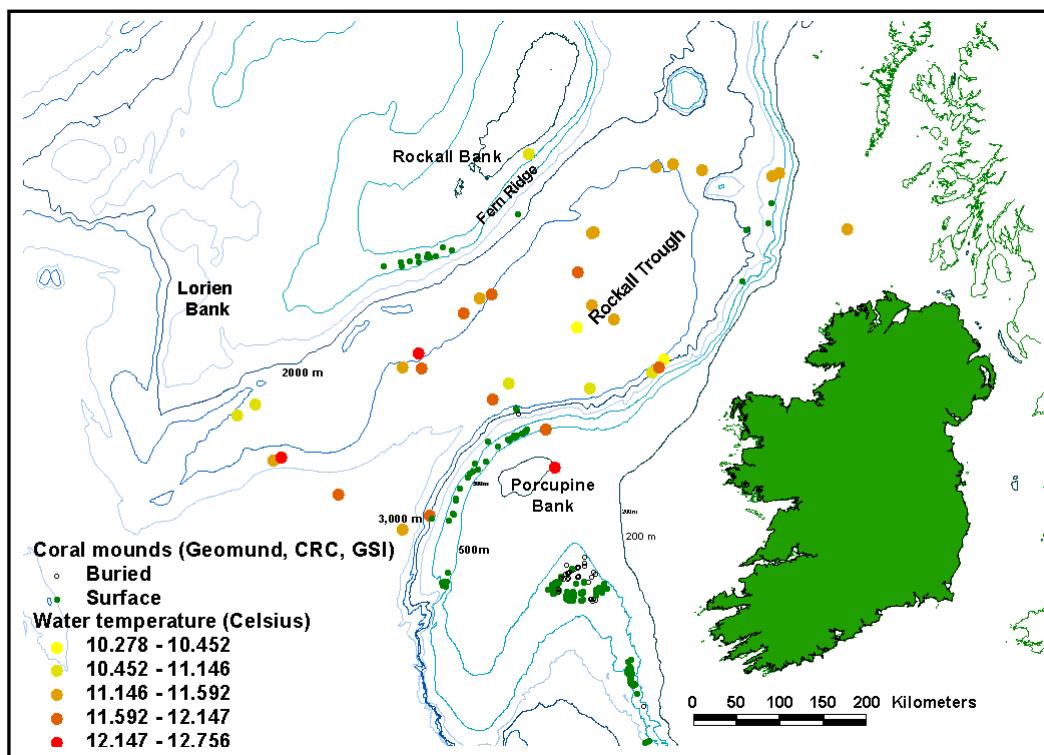


Figure 20. Distribution of location data for seabed carbonate mounds (several sources) and GSI sea surface temperature records obtained during the S.V. *Bligh* 2001 survey.

5. S.V. SIREN 2001 (30 June to 6 July 2001)

This relatively short trip covered part of the 500 m isobath fringing the Porcupine Shelf and a transect ashore to coastal County Galway (Fig. 21). The vessel was chartered by the Geological Survey of Ireland under the National Seabed Survey. It was thus using similar acoustic devices (i.e. pinger and multibeam sonar) to those utilised aboard the S.V. *Bligh*. The multibeam's operating frequency on this survey was 95 kHz, which lies beyond the frequency range of the hydrophone equipment used in cetacean research. The inter-pulse interval of the pinger was relatively short in duration, due to its use in comparatively shallow waters. This, vessel noise,

and the water depths being surveyed combined to create a relatively noisy environment on the survey. As a result, the acoustic survey range for cetaceans was quite limited.

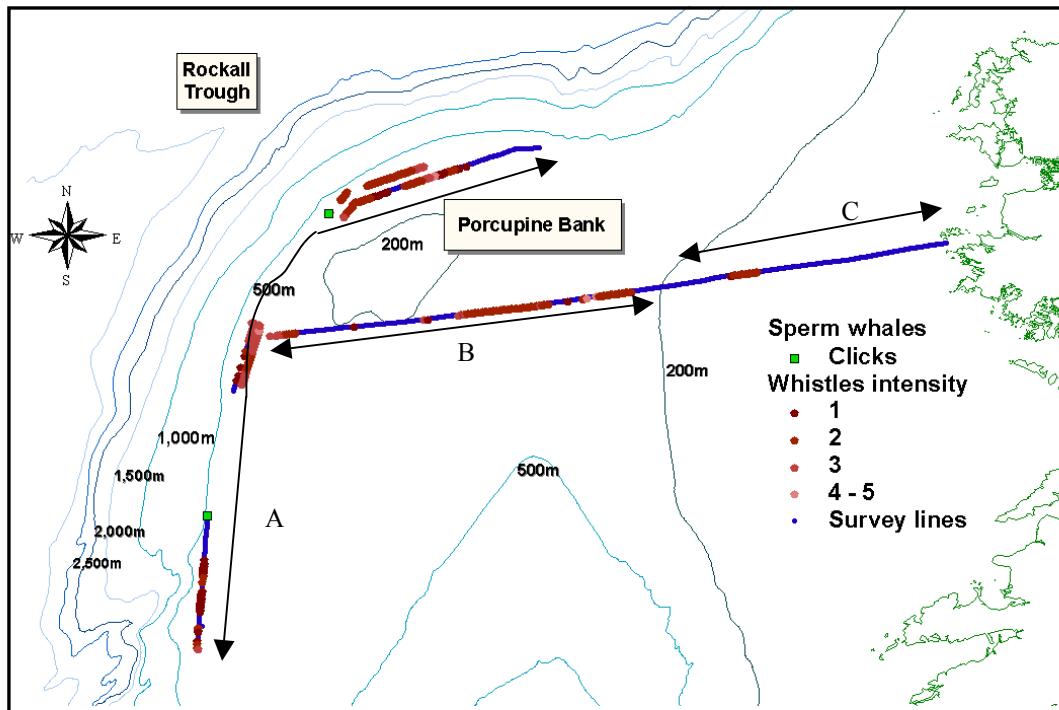


Figure 21. Summary of survey lines and acoustic detections of cetaceans recorded on the S.V. *Siren* survey. Survey lines were divided (A to C) for analysis purposes on the basis of their proximity to the continental slope.

A total of 54.9 hours of effective acoustic survey were achieved at an average vessel speed of 9.4 knots. This yielded a total acoustic transect length of 511.5 km, as shown in Figure 21. The total number of acoustic encounters was 29, consisting of one encounter with sperm whales, four encounters with pilot whales and nineteen encounters with dolphin species.

In spite of the high background noise, a relatively high number of detections were made during the survey, with 39.8% of all acoustic samples containing cetacean vocalisations. When divided into separate areas, the detection rate within samples was highest along the western margin of the continental shelf (Fig. 21). In transect A, 45% of samples contained cetacean vocalisations. This was followed by a similarly high rate of cetacean detections within samples taken through the Porcupine Shelf region (transect B = 41.2%). This contrasted sharply with acoustic samples from waters less than 200 m depth (transect C) in which 10% of samples contained cetacean vocalisations.

The acoustic information gathered on this survey supported the results of dedicated visual surveys during the SIAR survey and those aboard vessels of opportunity (see Vol. II), in addition to acoustic data collected aboard the S.V. *Bligh* in 2001, all of which indicate the importance for cetaceans of waters in the Porcupine region. Together, the data further underline an apparently high density of cetaceans, particularly odontocete (i.e. toothed cetacean) species, along the continental slopes fringing southern, western and northern margins of the Porcupine Shelf.

PROBABLE ACOUSTIC RECORD OF CUVIER'S BEAKED WHALES

During the course of the SIAR survey seven sightings of members of the beaked whale family (Family *Ziphiidae*) were made throughout the chosen survey area (Fig. 22). These consisted of groups of Cuvier's beaked whale (*Ziphius cavirostris*), Sowerby's beaked whale (*Mesoplodon bidens*) and Northern bottlenose whale (*Hyperoodon ampullatus*), in addition to sightings of beaked whales that could not be identified to species level (see Vol. II).

The acoustic behaviour of beaked whales is poorly known. MacLeod (1999) reviewed the limited information available on this subject and suggested that beaked whale vocalisations may be categorised by (i) pulsed sounds ranging from 300 Hz to 129 kHz, and (ii) non-pulsed sounds from 2-10 kHz up to 16kHz (the latter identified as that of the Northern bottlenose whale *Hyperoodon ampullatus*). Furthermore, anatomical evidence appears to indicate that the auditory system of beaked whales may be sensitive to high frequencies in the ultrasonic range, in addition to low frequency sound (MacLeod, 1999).

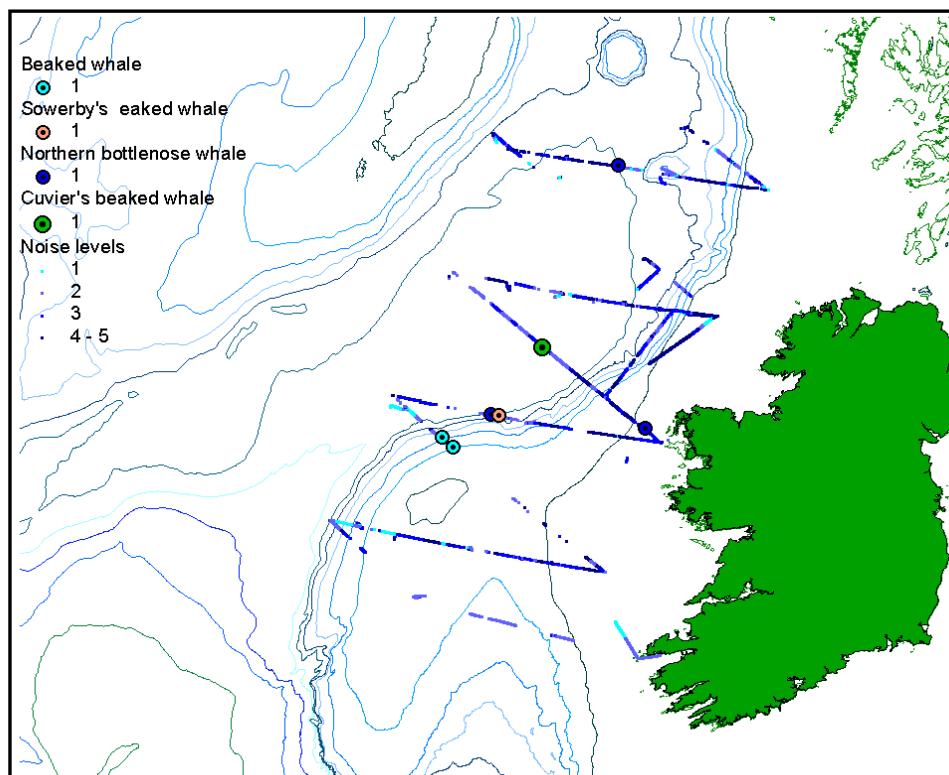


Figure 22. Sighting positions for groups of beaked whale species recorded during the SIAR survey in 2000. Background noise intensity levels are given on an ascending scale from 1 (minimum) to 5 (maximum).

During the SIAR survey, both pulsed and tonal sounds were recorded in the presence of beaked whale species. On one occasion, pulsed sounds were recorded simultaneous to one northern bottlenose whale encounter. However, these were greatly masked by the background noise. Further pulsed sounds were also recorded during sightings of other identified and unidentified beaked whales. However, the quality of recordings was very poor due to high levels of background noise.

Only two of the simultaneous visual and acoustic recordings of beaked whales presented data of sufficient acoustic quality for further analysis. Both were during an encounter with a single group of five Cuvier's beaked whales that approached within 30 metres of the survey vessel as

it lay adrift and on standby. Seven observers were mobilised upon first sighting of the animals and no other cetaceans were seen nor heard in the area within one hour of the sighting.

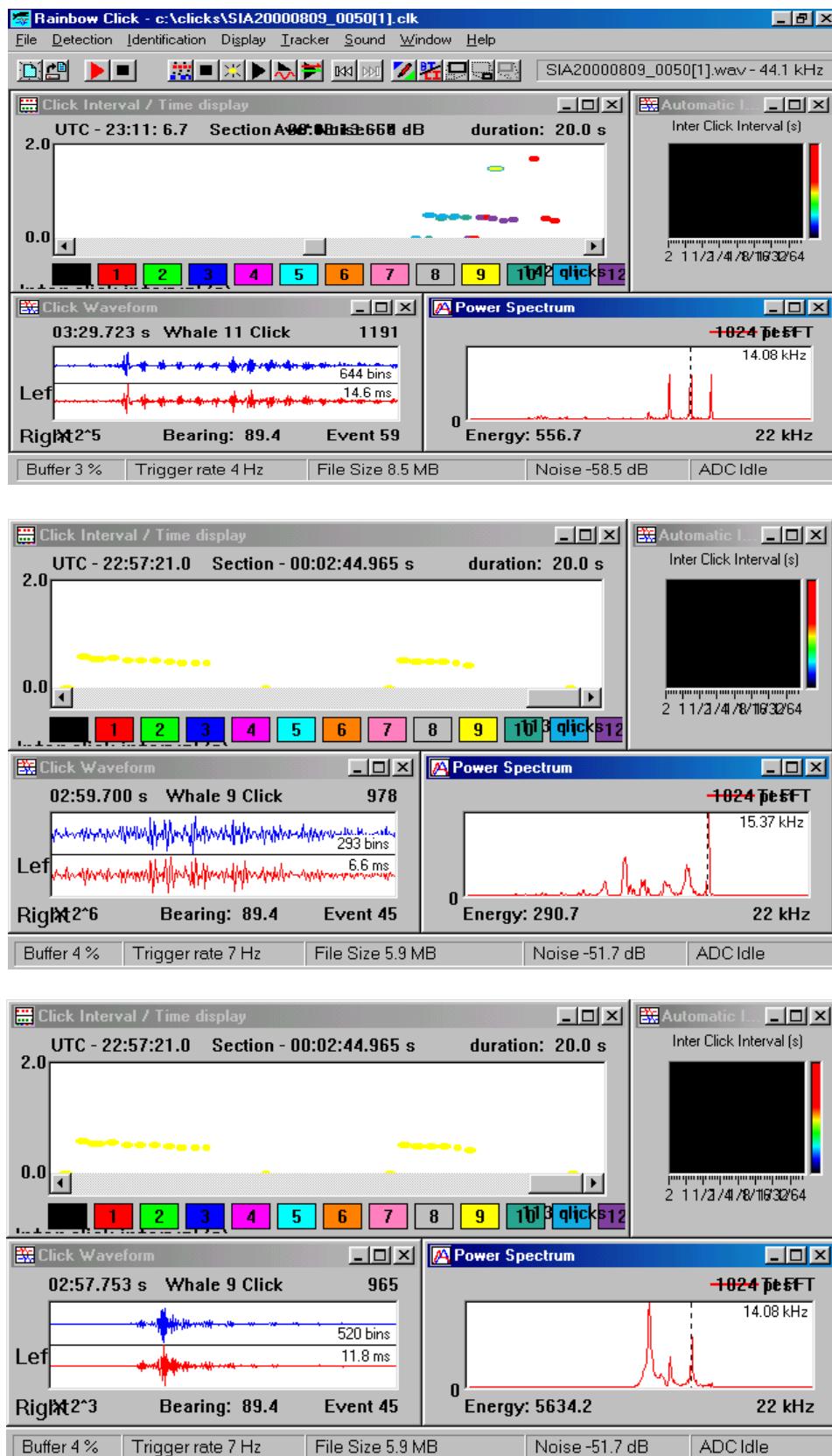


Figure 23. Stereophonic displays of three click waveforms and their power spectra, recorded in the presence of five Cuvier's beaked whales during the SIAR survey.

Analysis of the first click's power spectrum showed peak frequency levels within those postulated by MacLeod (1999): 15.46 kHz, 14.08 kHz and 12.75 kHz (Fig. 23). The analysis of several other clicks showed the same peak frequencies, although these did not always occur together, plus other peaks at 15.37 kHz, 12.46 kHz and 11.46 kHz. Most of the clicks showed regular echoes and it appeared that variable inter-pulse intervals occurred for different vocalising individuals. This might have some relationship to the individual animal's size, as determined for sperm whales (Gordon, 1991). The measurement of several inter-pulse intervals in the recordings yielded an average duration of 0.7 milliseconds. However, an exhaustive analysis of all clicks is required to properly characterise the acoustic data obtained in these recordings.

Beaked whales are widely acknowledged as rare and notoriously inconspicuous cetacean species. Most beaked whale species tend not to approach boats or perform aerial displays. Furthermore, these animals are believed to occur singly or in small groups in offshore waters, in which they are deep-diving species, all of which makes them difficult to detect and observe in the field. To our knowledge, there is only one published recording of the Cuvier's beaked whale tonal sounds (i.e. Manghi *et al.*, 1999) and no published records exist of pulsed sounds such as those recorded in the present study. It is possible that other cetaceans were present in the region during this simultaneous visual and acoustic recording and that the sounds recorded were of another species. However, this is unlikely due to the observer effort and the proximity of the observed Cuvier's beaked whales to the acoustic equipment deployed beneath the survey vessel during the encounter.

It is also possible that, in the course of other acoustic surveys, other pulsed sounds of beaked whales were confused with those of sperm whales, for example, thus underestimating their presence. The rarity of simultaneous visual and acoustic detections of many beaked whale species makes interpretation of the limited data gathered in the present study relatively difficult and the subject area certainly requires considerably more research.

ACOUSTIC DETECTION OF SEISMIC AND DRILLING ACTIVITIES

Pulses from seismic survey vessels engaged in hydrocarbon exploration off northwest Ireland were detected on the SIAR and S.V. *Bligh* 2001 surveys. It was found that higher received sound levels were detected using the hydrophone equipment when the relevant vessel for cetacean research approached the continental shelf area to the west of County Mayo. Contact between the authors and the Petroleum Affairs Division (PAD) of the Department of the Marine and Natural Resources confirmed the identity of seismic vessels and the nature of exploratory activities in the area.

During the SIAR survey in 2000, the hydrophone equipment was being used in cetacean detection for the first time. High levels of background low frequency noise necessitated the use of high pass filters from 200 Hz up to 5.6 kHz, in order to optimise cetacean acoustic detection. This prevented the continuous monitoring of seismic sources in the survey area. However, on several occasions seismic pulses, could be heard in spite of the filtering process. Upon further investigation, the received sound levels increased dramatically with a change towards lower frequency settings or in the absence of filters. In view of the presence of seismic sound pulses in the acoustic environment of cetaceans these sources were monitored opportunistically during the SIAR survey (e.g. when off survey effort, on standby or adrift at night).

Monitoring for seismic activity during the SIAR survey showed that seismic sound pulses from the M.V. *Polar Princess*, which was conducting a 3-D seismic survey off the County Mayo coast, could be recorded at distances exceeding 250 km (Fig. 24). Clearly, therefore, the entire study

area covered by the SIAR survey was prone to background noise from various sources, including noise from seismic exploration. The acoustic intensity of this seismic source was relatively high in the shallower continental shelf waters adjacent to the seismic vessel (Fig. 24).

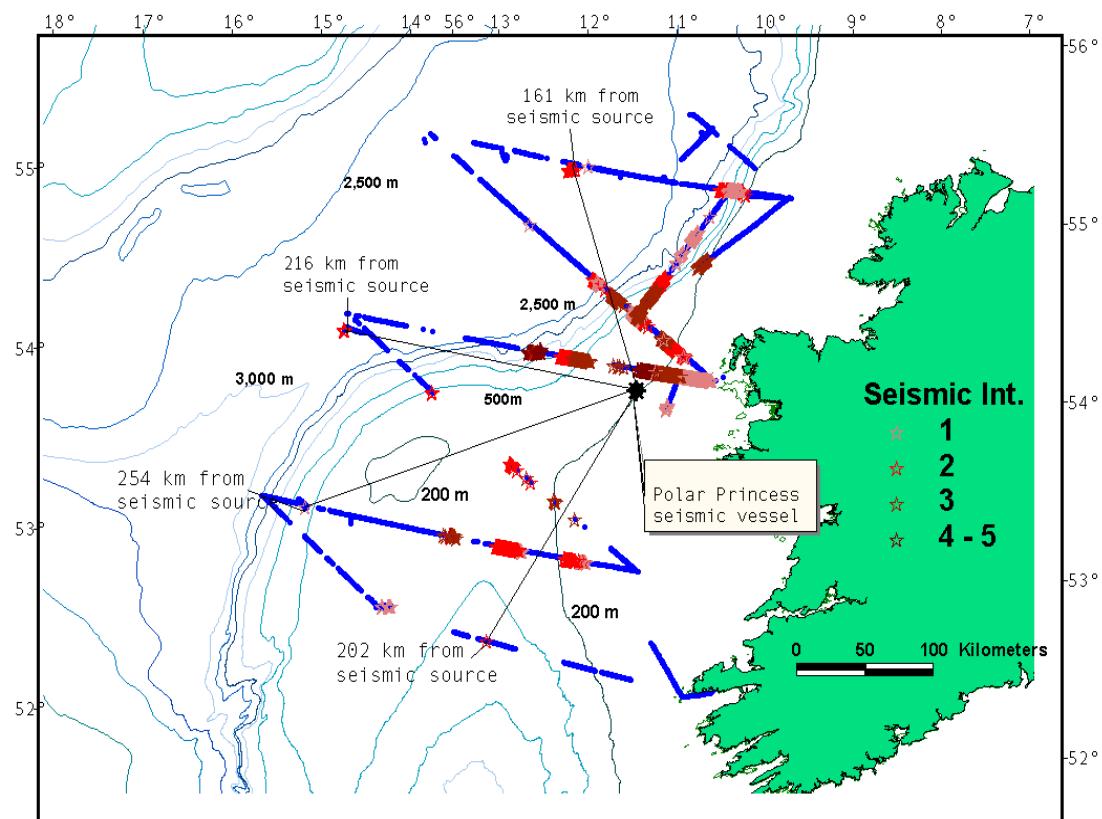
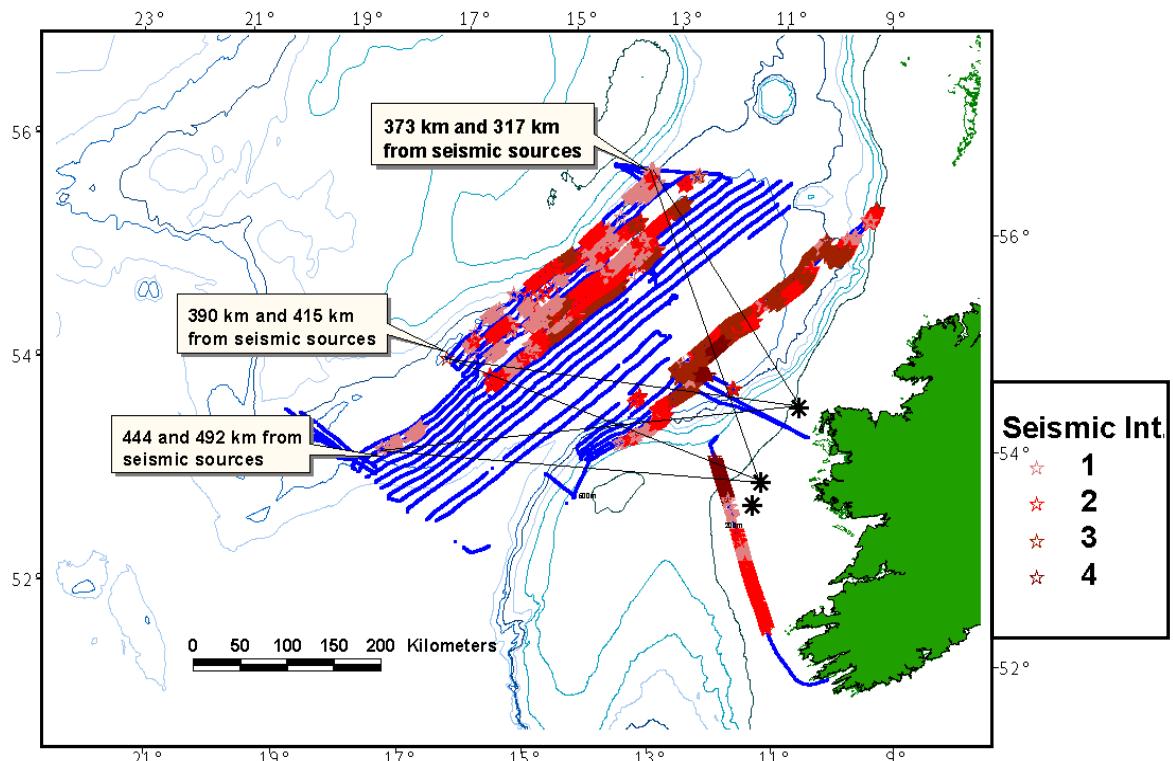


TABLE 6. Summary of seismic operations coincident with acoustic and visual surveys for cetaceans aboard the S.V. *Bligh* (2001). Data were made available by PAD.

Vessel Name	Contracting company	Survey Date and Area	Seismic Sources	Location centre
M.V. <i>Geopacific</i>	Statoil	15 May - 9 July 500 km ²	Airgun array 3,460 x 2 sources = 6,920 in ³	S. Erris Trough 54° 32' 20" N 10° 47' 25.9" W
M.V. <i>Seisquest</i>	Enterprise Energy Ireland	17 May - 4 June 300 km ²	Airgun array 3,450 in ³	Central Slyne Trough. 53° 57' 32" N 11° 15' 39.2" W
M.V. <i>Seisquest</i>	Marathon Petroleum	4 June - 13 June 240 km ²	Airgun array 3,460 in ³	S. Slyne Trough. 53° 34' 47.6" N 11° 22' 05.2" W

During the period of the S.V. *Bligh* 2001 survey, three seismic surveys were carried out off northwest Ireland, all using airgun arrays (Table 6). Seismic emissions in all surveys were produced at an array depth of 6 metres. On this occasion, acoustic and visual survey effort for

cetaceans had seen the completion of a number of acoustic survey lines prior to the commencement of seismic activity. When the S.V. *Bligh* 2001 survey and seismic activities were being conducted simultaneously, seismic pulses were detected at the observer's furthest possible distance from the source (Fig. 25). This indicated that sound produced during 3-D seismic activity are probably detectable underwater at distances greater than 500km from the source.



on an ascending scale of 1 to 5.

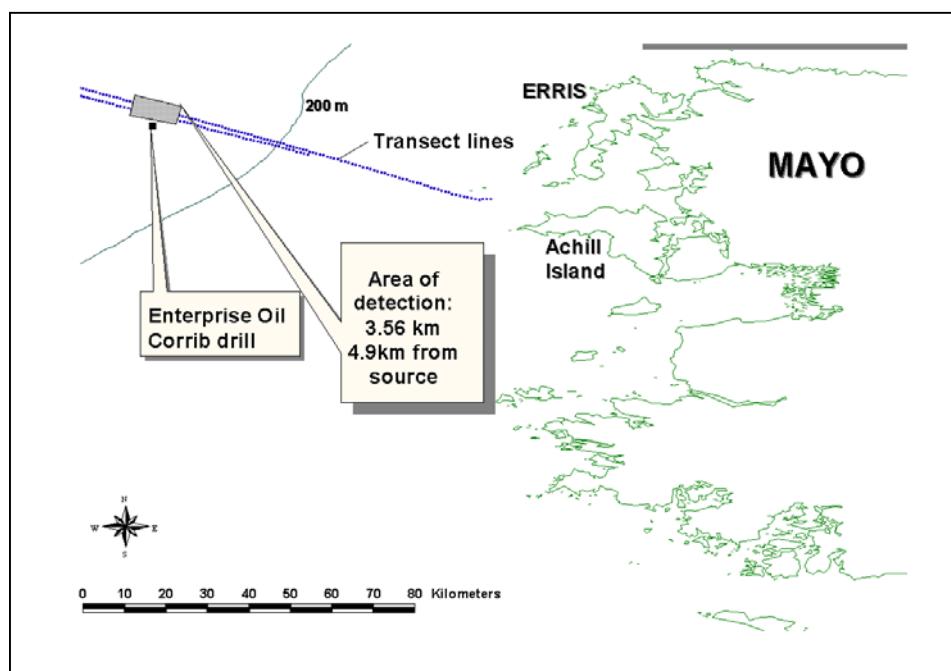


Figure 26. Location of the detection zone for drilling activity off western Ireland during the S.V. *Bligh* 2001 acoustic and visual survey. Vessel transect lines and the 200m depth contour are shown.

In the case of the S.V. *Bligh* 2001 survey, seismic pulses from vessels operating off the west coast of Ireland were detected in waters overlying the continental shelf, the Rockall Trough and as far west as the Feni Ridge. Received sound levels were logically dependent on the distance to the source, but other factors such as water depth and bottom slope have to be taken into account when accounting for the range at which seismic activities can be detected.

In addition to noise associated with seismic operations, the hydrophone equipment used in cetacean detection also recorded sound associated with subsurface drilling activity off western Ireland on two occasions. The focal point for this activity was the Enterprise Energy Ireland 18/25-3 Corrib Appraisal Well, situated in the Slyne Basin ($54^{\circ} 19' 14.467''$ N, $11^{\circ} 04' 09.378''$ W). Two transect lines aboard the S.V. *Bligh* (2001) passed at distance of 3.56 km and 4.9 km from the anchored semi-submersible drilling rig on consecutive days (4, 5 May) (Fig. 26).

Recorded sound from these drilling operations was in the form of continuous pure tones at a peak frequency of 9.4 kHz. The maximum distance at which this sound could be detected using the acoustic equipment was significantly lower (<5km from the source, Fig. 44) than the distances at which seismic activities in the area could be detected, yet was in the order of several kilometres.

DISCUSSION

USE OF ACOUSTIC METHODS

The acoustic equipment used throughout the surveys reported on here, was operational on a 24-hour basis, in sea states up to Beaufort force 9 and at vessel speeds of up to 16 knots, although the average survey speed was 8.5 knots. Other instruments, such as a magnetometer, were simultaneously towed on two surveys without any damage to the acoustic equipment.

This kind of acoustic survey, using a towed hydrophone array, proved to be very efficient for studying sperm whales and several other toothed cetaceans. The equipment failed to detect these animals only when they were beyond the detection range or when animals were not vocalising (e.g. sperm whales on the surface). In the case of sperm whales, members of a group do not dive simultaneously, thus it is usually possible to detect non-solitary animals by acoustic means. Our results showed that out of 110 sperm whale encounters just three were of whales seen at the surface before they dived, after which they could be detected acoustically. However, the equipment was not as efficient a detection tool for dolphin species, as their vocalisations are less powerful and resting and travelling animals may often remain silent. Nevertheless, the proportion of dolphin detections recorded by acoustic means is often higher than that by visual means (Gannier, 1999).

It is noteworthy that, during the SIAR survey, a team of five visual observers operating simultaneously was required to achieve a similar detection level to that derived from acoustic methods. This further underlines the high probability that cetacean occurrence is underestimated by a single-observer sighting survey, as normally carried out under the standard "Seabirds at Sea" methodology (*see Vol. II*). Consequently, acoustic methods present an opportunity to improve upon the accuracy of data gathered by a sole observer.

However, the time required to operate acoustic equipment and monitor alongside full visual survey effort suggests that future cetacean surveys in the Irish Atlantic Margin using vessels of opportunity should see the deployment of two observers instead of one (*see Vol. II*). This would make the most practical sense and allow for the shared responsibility for visual and acoustic survey duties on board the survey vessel.

An analysis could be done separately for the different surveys with sufficient data, to compare spatial and temporal variations of the distribution of some species. Such analyses could not be included in this report due to the large acoustic dataset collected and the short time-frame available for analysis. In addition, false positive detections introduced by pinger and multibeam sonar devices increased the handling time for acoustic samples from individual surveys.

DISTRIBUTION OF CETACEANS DETECTED ACOUSTICALLY

Some cetacean species' attraction to or deterrence from the vessel may introduce an element of bias in the analysis in areas where these species were predominant. For example, surveys in the southern Atlantic Margin area tended to be dominated by encounters with common dolphins. The frequent presence of this species, members of which commonly bow-ride survey vessels, may influence the overall detection rate by acoustic means, masking the presence of species which are not attracted to or actively deterred by vessels. This source of false positive or negative error is also studied on visual surveys and needs to be accounted for in determining true detection rates. Thus a degree of caution must be applied in interpreting the results of acoustic data without the empirical determination of sources of bias.

The acoustic system detected a minimum of seven species of cetacean: sperm whale, pilot whale, Cuvier's beaked whale, common dolphin, striped dolphin, bottlenose dolphin and Atlantic white-sided dolphin. In addition, vocalisations were recorded of animals not identified to species level. Sperm whales were detected on all surveys and were recorded in all the deep sea areas, both slope and trough. However, care needs to be taken when interpreting the acoustic detections in the deeper trough areas; Detection range tends to increase with water depth due to lower levels of background noise and a higher range of transmission of the signals.

During the acoustic research programme the *Cetaceans & Seabirds at Sea* team recorded sperm whales in a total of 110 encounters, some up to four hours long. Several studies have been carried out correlating the different click rhythms and other sound production of sperm whales with various activity categories. The rate of vocalisations such as the "creaks" of sperm whales have already been used to identify areas of enhanced feeding activity (Drouot *et al.*, 2000). Further analysis of the data gathered in the present study could allow areas with concentrated feeding activity to be identified.

Ongoing analysis would also provide information on the acoustic repertoire of the different cetacean species occurring in Ireland's Atlantic Margin. This baseline data is important in order to allow future identification of populations and their degree of interrelation with other areas. Further analysis may also allow the better identification of encounters to species level, since differences in the calls of closely related species (e.g. pilot whales *Globicephala melas* and *G. macrorhynchus*; Rendell *et al.*, 1999) may be demonstrated with dedicated research efforts. Acoustic analysis to determine sperm whale body-length may provide tangible proof of the presence of juvenile individuals in northern latitudes and Ireland's Atlantic Margin. Although the sighting records of juvenile sperm whales in Ireland's Atlantic Margin (*see Vol. II*) are unequivocal, acoustic analysis would provide quantitative data on the size distribution of the sperm whale population inhabiting Ireland's Atlantic Margin, be it seasonally or throughout the year.

The greatest numbers of acoustic detections in all surveys were in areas where the seabed has a high slope gradient. These detections occurred both at the continental slope and in separate formations such as deep submarine canyons and basins, confirming the biological importance of these areas. This is consistent with results from various studies in the northeast Atlantic (Evans, 1998). The apparent tendency for cetacean species to aggregate in continental slope areas may be related to feeding activity, as some such areas are known to be rich in biological productivity. However, combined acoustic and visual surveys in the present study showed that not all areas of steep gradient display a high occurrence of cetaceans and ongoing studies will be required along Ireland's Atlantic Margin to further determine those areas of principal importance and the factors which make them so.

Acoustic detections of cetaceans indicated that a north-south gradient in cetacean abundance may occur within the Ireland's western continental shelf area, with generally higher numbers of animals detected acoustically in the southern half of Ireland's Atlantic Margin. This gradient appeared to vary, depending on the season. For example, in the southern shelf area, there appears to be a greater abundance of cetaceans in the winter than in the summer.

The results of acoustic surveys also suggested that waters overlying the northwestern margin of the Porcupine Shelf, the Porcupine Seabight and Goban Spur regions and, generally speaking, the continental slope are areas of relatively high cetacean abundance. The area with the greatest proportion of acoustic detections was a deep basin along the southwestern edge of the Rockall Trough (53.5° N, 19° W). The higher concentration of cetaceans associated with certain bathymetric features, such as submarine canyons and banks, may be related to the fact that these features promote, retain and concentrate productivity from the base of the food chain to higher trophic levels. The increased turbulence, local up-welling and water mixing in these

areas favour phytoplankton and thus zooplankton production. These resources are exploited by local predators that are, in turn, preyed upon by pelagic species such as cetaceans and seabirds (Hyrenbach *et al.*, 2000).

While such physical seabed features may assist in the identification of areas of importance for cetaceans, variability in the distribution of species observed in the present study may also relate to other features. For example, ephemeral hydrographic features with a more limited spatial and temporal extent may also occur seasonally with great biological significance. These may attract transient aggregations of cetaceans and other predators to exploit the increased productivity generated. While the highly dynamic pelagic systems require a different management scheme to those applicable in stable terrestrial situations (Hyrenbach *et al.*, 2000), both systems share the need to protect specific sites on the basis of their importance for the biology of a particular species. Such sub-areas include breeding and nursery areas for cetaceans, feeding grounds and important migratory routes.

The hydrocarbon exploration blocks allocated along the continental slope to the northwest of the Porcupine Shelf are coincident with concentrations of cold-water coral mounds and areas of high cetacean abundance and species diversity. The relationship between the presence of cold-water corals and diverse cetacean species may be related to a coincidental exploitation by both cetacean and corals of the biological processes that have resulted from dynamic oceanography in areas of steep slope and strong currents. The co-incident relationship may also be more simply based on an increased biodiversity in the area due to the presence of coral reefs, providing a habitat for fish and cephalopod prey species of cetaceans. In any case, the data collected by acoustic means and visual methods (*see Vol. II*), certainly indicate that the northwestern Porcupine Shelf and most of its continental slope represent an important habitat that should be the focus of further research. The information gathered in this study also indicate that this region should be effectively managed in order to guarantee the continuation of the ecosystem function at all levels.

NOISE AND CETACEANS IN THE IRISH ATLANTIC MARGIN

Areas of importance for cetaceans, identified in the present study and in visual surveys (*see Vol. II*) (e.g. parts of the Porcupine Shelf, Porcupine Seabight and Rockall Bank), may be directly and indirectly affected by seismic activity, since many have also been designated for hydrocarbon exploration. Drilling noise was detected during acoustic surveys along sections of transect line through the Slyne Trough. These track-lines were devoid of cetacean detections when compared with other zones of the continental slope and shelf but there is presently not enough information to study any correlation between these results. Commercial drilling activities were also being carried out during the present study on the Porcupine Shelf and in the Porcupine Seabight, both areas of relative importance for cetaceans. Airgun pulses from seismic surveys were recorded in the present study up to almost 500km away from the source, confirming the long-range propagation of these signals. This is a particular concern for deep-diving species such as sperm whales and beaked whales, which are thought to be more sensitive to acoustic pollution (Gordon *et al.*, 1998).

This potential impact of man-made sound on cetaceans was starkly illustrated in a number of mass strandings of beaked whales, which have been directly associated with military acoustic experiments and the use of specialised low-frequency military sonar (Simmonds & Lopez Jurado, 1991; Frantzis, 1998; Balcomb & Claridge, 2001). Such deep-water species were not thought to be threatened by the direct impacts of seismic explorations until investigations began in earnest in the late 1980s. However, there is now an increased technical capability to explore acoustically and drill in water depths of more than 3,000m. This is highlighted by an almost 3,000% increase in oil production and 3,500% increase in natural gas production from deep-

water areas since 1990 (Roden & Mullin, 2000). The expansion of hydrocarbon exploration into the deeper oceanic waters of Ireland's Atlantic Margin through which low frequency sound readily propagates, represents a concern for the proper conservation of deep-water species in the region.

It is important to balance the potential impact of seismic activities on cetaceans and on the fishing industry, for example, with the potential benefits of the hydrocarbon exploitation, while restricting these impacting activities to areas where the natural and economical resources of the Atlantic Margin and northeast Atlantic are not compromised. In this context it is strongly advised that, as a precautionary measure (i) seismic and drilling and other high-level acoustic activities in the Irish Atlantic Margin should see the formal adoption of international guidelines for the protection of cetaceans during operations, and (ii) these guidelines should be used by the hydrocarbon and marine exploration industries as soon as possible.

Ongoing research will certainly be necessary (i) to accurately determine existing and potential areas of direct and indirect impacts to cetaceans in Ireland's Atlantic Margin and (ii) to improve upon measures to mitigate against such impacts from seismic activities and other sources.

CONCLUSION

The present study utilised acoustic survey methods for surveying cetacean populations on a large geographic scale in Irish Atlantic Margin waters for the first time. The use of acoustic methods proved highly successful in operational and informational terms. This was particularly the case where weather and light conditions did not allow visual survey methods to be used and where critical monitoring was being carried out aboard vessels producing relatively high levels of underwater noise.

Key conclusions from the study may be summarised as follows:

1. Acoustic surveys for cetaceans enhanced significantly the data collected under the overall research programme, supported many findings of cetacean research conducted by visual means and providing a platform for the improvement of survey methods in these waters.
2. The use of acoustic methods in the present study have also enhanced the potential of gathering valuable information on rare species inhabiting Ireland's Atlantic Margin, such as data on the acoustic repertoire of beaked whales, whose ecology is poorly known.
3. The relative abundance of several cetacean species, derived from acoustic survey data, appeared to be correlated in parts of Ireland's Atlantic Margin with certain physical seabed features such as the continental slope. This supported several findings determined from visual surveys for cetaceans (see Vol. II)
4. Cetacean acoustic behaviour, in combination with visual survey data, might provide a useful supporting indicator of the distribution of vertebrate and invertebrate prey species along Ireland's Atlantic Margin.
5. Noise from seismic explorations was detected almost 500 km from the sources. Low frequency pulses from airgun arrays were shown to span both continental shelf and slope waters, and oceanic basins, expanding the potential impact range of seismic activities.
6. Measures for mitigating the impacts of man-made sound on cetaceans and other marine mammals occurring along Ireland's Atlantic Margin are currently adopted on a voluntary basis by seismic survey vessels. Considering data gathered in the present research programme, it is considered that these should be compulsory and consistent with recognised international guidelines and future at-sea monitoring aboard seismic vessels in Irish waters should be conducted by trained, dedicated marine mammal observers.
7. The acoustic and visual survey systems developed during the project may be used to monitor cetacean occurrence during seismic surveys and other potentially-detrimental acoustic activities in order to minimise their impact on the animals, and to assess induced changes in cetacean behaviour. Indeed it was for this purpose that some components of the hydrophone system were developed.
8. Priority research areas for the future include the furthering of knowledge of the acoustic repertoire of species of the Atlantic Margin, development of automated species identification, improved knowledge of acoustic behaviour of cetaceans in Ireland's Atlantic Margin, in particular proportion of time they are vocal, knowledge of source levels and directionality of vocalisations. An ongoing analysis of acoustic data gathered in the study should be performed. If done, estimates of the relative abundance and density of sperm whales, long-finned pilot whales and various dolphin species in the areas of Ireland's Atlantic Margin could be derived for comparison with visually-obtained data.

ACKNOWLEDGEMENTS

The overall *Cetaceans & Seabirds at Sea* programme was undertaken on behalf of the Rockall Studies Group (RSG) and Porcupine Studies Group (PSG) of the Irish Petroleum Infrastructure Programme. The survey was initially funded by RSG project 98/6 in 1999 and later extended through RSG project 00/13 and comprised: Agip (UK) Ltd (RSG), Agip Ireland BV (PSG), Anadarko Ireland Company (RSG), ARCO Ireland Offshore Inc (RSG), BG Exploration & Production Ltd (RSG), BP Exploration Operating Company Ltd (RSG), British-Borneo International Ltd (RSG), Chevron UK Ltd (PSG), Elf Petroleum Ireland BV (both groups), Enterprise Energy Ireland Ltd (both groups), Marathon International Hibernia Ltd (PSG), Mobil Oil North Sea Ltd (RSG), Murphy Ireland Offshore Ltd (RSG), Phillips Petroleum Exploration Ireland (RSG), Phillips Petroleum Company United Kingdom Ltd (PSG), Saga Petroleum Ireland Ltd (RSG), Shell EP Ireland B.V. (RSG), Statoil Exploration (Ireland) Ltd (both groups), Total Oil Marine plc (RSG), Union Texas Petroleum Ltd (RSG) and the Petroleum Affairs Division (PAD) of the Department of the Marine and Natural Resources (both groups). The survey also utilised acoustic monitoring equipment funded by project 99/38 of the programme's Offshore Support Group (OSG), which is managed by the Petroleum Affairs Division.

We would like to specifically acknowledge the role of the Petroleum Infrastructure Programme and PAD in providing funding to UCC for the cetacean acoustic equipment and in providing the research team with the opportunity to advance acoustic cetacean research in Ireland. We are also very grateful to RSG/PSG and Agnes McLaverty (Enterprise Energy Ireland, Ltd.) for support, help and advice in logistics and project management. We also extend our thanks to Mr Martin Davies (CSA) for his management assistance and help with vessel allocations. We would also like to thank Dr Mark Tasker and Dr Eugene Nixon for their assistance as members of the project's Steering Committee. Thanks also to Oliver Chappell, Thomas Gordon and Douglas Gillespie for indispensable assistance with the acoustic equipment and advice on acoustics software and data analysis.

The research covered in this report was greatly assisted by the National Seabed Survey programme under the GEOLOGICAL SURVEY OF IRELAND (GSI, Beggars Bush, Haddington Road, Dublin 4), to whom we are grateful for the opportunity to work alongside the seabed mapping programme.

The CMRC would also like to warmly thank all primary contacts and host organizations that provided platforms for the surveys and some people that have played an important role in facilitating our work on the vessels. These are Lt. Comdr. Hugh Tully & Lt. Cdr. Gerald O'Flynn and Commodore Frank Lynch of the Irish Naval Service, Commander Eugene Ryan of the L.E. *Eithne* and Capt. Jim Robinson, Prof. Jean-Pierre Henriet, Veerle Huvenne and Dr Ben de Mol (University of Gent), Helen Gwinnutt, Deepak Inamdar and Mick Geoghegan and Ciarán Lawless from the Geological Survey of Ireland (GSI), Mr. Hanley, Mr. Pavel Chubar, Mr. Igor and Alan O'Flynn of the S.V. *Bligh* and Bryan O' Flynn of the S. V. *Siren*. Thanks also to Xavier Monteys and Thomas Furey (GSI) for helping with data which set an ecological context for cetacean information obtained in the field.

We are also sincerely grateful to Michael Flannery, Andrew Lecher, the crew of the M.V. *Emerald Dawn* and Benjamin Roe for their enormous help and flexibility in undertaking, provisioning and successfully completing the *SIAR* survey. The authors would like to thank Dr Phil Hammond, Dr Jonathan Gordon, Dr Sharon Hedley and Prof David Borchers (U. of St. Andrews) for their helpful advice during the survey's planning stages. Of course the survey would not have been the success it was without the efforts of Agnes McLaverty (Enterprise Energy Ireland Ltd.) and our hard-working co-observers: Julia Carlström, Valerie Cummins, Dr Simon Ingram and Dr Emer Rogan. Thanks also to Joe Silke, Fisheries Research Centre, Marine Institute for use of the temperature probe and interpretation of data.

Finally thanks to the CMRC team that gave invaluable advice on GIS: Valerie Cummins, Max Kozachenko, Vicky O'Donnell, and Gerry Sutton. Martin Davies (CSA), Michelle Cronin and Anneli Englund kindly provided assistance with earlier drafts of this document.

Go raibh mile maith agaibh go léir.

REFERENCES

- Balcomb, K.C. & Claridge, D. (2001). A mass stranding of cetaceans caused by naval sonar in the Bahamas. *Bahamas J. Science* **5**: 2-12.
- Barlow, J. & Taylor, B.L. (1998). Preliminary abundance of sperm whales in the northeastern temperate Pacific estimated from a combined visual and acoustic survey. *Report to the Scientific Committee of the International Whaling Commission SC/50/CAWS 20*.
- Bohne, B.A., Thomas, J.A., Yohe, E.R. & Stone, S.H. (1985). Examination of potential hearing damage in Weddell Seals (*Leptonychotes weddelli*) in McMurdo Sound, Antarctica. *Antarctic J. U.S.* **20**: 174-176.
- Bowles, A.E., Smulter, M., Würsig, B., DeMaster, D. & Palka, D. (1991). *Biological survey effort and findings from the Heard Island Feasibility Test 19 January - 3 February, 1991*. Report from Hubbs/Sea World Inst., San Diego, Ca. US. 102pp.
- Browning, L. & Hartland, E. (1997). Cetacean disturbance by high-speed ferries: a preliminary assessment. *Proc. Inst. Acoustics* **19 (9)**: 85-95.
- Buckland, S.T., Anderson, D.R., Burnham, K.P. & Laake, J.L. (1993). *Distance sampling. Estimating abundance of biological populations*. London, Chapman & Hall. 446 pp.
- Busnel, R.G. & Fletcher, J. (eds.) (1978). *Effects of Noise on Wildlife*. New York. Academic Press.
- Chappell, O. & Gillespie, D. (1998). Cetacean detection software development in 1997/1998. *Unpublished report to Birmingham Research and Development Ltd.*
- Charif, R.A., Clapham, P.J. & Clark, C.W. (2001). Acoustic detection of singing humpback whales in deep waters off the British Isles. *Mar. Mamm. Sci.* **17 (4)**: 751-768.
- Clark, C.W. & Fristrup, K.M. (1997). Whales '95: a combined visual and acoustic survey for blue and fin whales of Southern California. *Rep. Int. Whal. Commn.* **47**: 583-599.
- Clark, C.W. & Charif, R.A. (1998). *Acoustic monitoring of large whales to the west of Britain and Ireland using bottom-mounted hydrophone arrays, October 1996-September 1997*. Joint Nature Conservation Committee, Peterborough.
- Culik, B.M., Koschinski, S., Tregenza, N. & Ellis, G.M. (2001). Reactions of harbour porpoise *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. *Mar. Ecol. Prog. Ser.* **211**: 255-260.
- Deecke, V.B., Ford, J.K.B. & Spong, P. (2000). Dialect change in resident killer whales: implications for vocal learning and cultural transmission. *Anim. Beh.* **60**: 629-638.
- Drouot, V., Gannier, A. & Goold, J. (2000). Underwater vocalisations for assessing sperm whale habitat. In P.G.H. Evans, R. Pitt-Aiken & E. Rogan (eds.). *European Research on Cetaceans 14: Proceedings of the 14th Annual Conference of the European Cetacean Society*: 29-32.
- Engas, A., Lokkeborg, S., Ona, E., & Sodal, A.V. (1993). Effects of seismic shooting on catch and catch-availability of cod and haddock. *Fiskeri Og Havet* **9**: 1-177.
- Evans, P.G.H. (1987). *The natural history of whales and dolphins*. London, Academic Press.
- Evans, P.G.H. (1990). European cetaceans and seabirds in an oceanographic context. *Lutra* **33 (2)**: 95-125.
- Evans, P.G.H. (1998). Biology of cetaceans of the Northeast Atlantic (in relation to seismic energy). In M. Tasker & C. Weir (eds.). *Proceedings of the Seismic and Marine Mammals Workshop*. UKOOA. London.
- Frantzis, A. (1998). Does acoustic testing strand whales? *Nature* **392**: 29.
- Gannier, A. (1999). Comparison of the distribution of odontocetes obtained from visual and acoustic data in northwestern Mediterranean. In P.G.H. Evans & E.C.M. Parsons (eds.) *European Research on Cetaceans 12: Proceedings of the 12th Annual Conference of the European Cetacean Society*.
- Gillespie, D. (1997). An acoustic survey for sperm whales in the Southern Ocean Sanctuary conduct from the R.V. *Aurora Australis*. *Rep. Int. Whal. Commn.* **47**: 897-907.
- Goold, J.C. (1996). Broadband characteristics and propagation of air gun acoustic emissions in the southern Irish Sea. *Report to Chevron UK, Aran Energy and Repsol*.
- Gordon, J.C.D. (1991) Evaluation of a method for determining the length of sperm whales (*Physeter catodon*) from their vocalisations. *J. Zool. Lond.* **224**: 301-314.
- Gordon, J.C.D., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M.P & Swift, R. (1998). The effects of seismic activity on marine mammals. In M. Tasker & C. Weir (eds.). *Proceedings of the Seismic and Marine Mammals Workshop*. UKOOA. London.
- Gordon, J. Berrow, S.D., Rogan, E. & Fennelly, S. (1999). Acoustic and visual survey of cetaceans off the Mullet Peninsula, Co. Mayo. *Ir. Nat. J.* **26 (7/8)**: 251-259.
- Gordon, J.C.D., Matthews, J.N., Panigada, S., Gannier, A., Borsani, J.F. & Notabartolo di Sciara, G. (2000). Distribution and relative abundance of striped dolphins (*Stenella coeruleoalba*), and distribution of sperm whales (*Physeter catodon*) in the Ligurian Sea cetacean sanctuary: results from a collaboration using acoustic monitoring techniques. *J. Cet. Res. Manage.* **2(1)**: 27-36.

- Greene, C.R. & McLennan, M.W. (1996). *Passive acoustic localisation and tracking of vocalising marine mammals using buoy and line arrays*. Unpublished report of the Biodiversity Group of Environment Australia. Hobart, Tasmania, Australia.
- Harris, R.E., Miller, G.W. & Richardson, W.J. (2001). Seal response to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. *Mar. Mam. Sci.* **17** (4): 795-812.
- Henriet, J.P., De Mol, B., Pillen, S., Vanneste, M., Van Rooij, D., Versteeg, W., Croker, P.F., Shannon, P.M., Unnithan, V., Bouriak, S., Chachkine, P. and the Porcupine-Belgica '97 shipboard party. (1998). Gas hydrate crystals may help build reefs. *Nature* **391**: 648-649.
- Hovland, M., Croker, P.F. & Martin, M. (1994). Fault-associated seabed mounds (carbonate knolls?) off western Ireland and northwest Australia. *Mar. Pet. Geol.* **11**(2): 232-246.
- Hyrenbach, K.D., Forney, K.A. & Dayton, P.K. (2000). Marine protected areas and ocean basin management. *Aquat. Conserv: Mar. Freshw. Ecosyst.* **10**:437-458.
- Jacquet, N., Dawson, S. & Douglas, L. (2001). Vocal behaviour of male sperm whales: why do they click? *J. Acoust. Soc. Am.* **109** (5): 2254-2259.
- Janik, V.M. (2000). Source levels and the active space of bottlenose dolphin (*Tursiops truncatus*) whistles. In P.G.H. Evans, J. Cruz & J. A. Raga (eds.) *European Research on Cetaceans 13: Proceedings of the 13th Annual Conference of the European Cetacean Society*.
- Kaschner, K., Goodson, A.D., Connolly, P.R. & Leaper, P. A. (1997). Species characteristic features in communication signals of cetaceans: source level estimates for some free ranging north Atlantic odontocetes. *Proc. Inst. Acoustics* **19**: 217-226.
- Ketten, D.R., Lien, J. & Todd, S. (1993). Blast injury in humpback whale ears: Evidence and implications. *J. Acoust. Soc. Amer.* **94**(3) 2: 1849-1850.
- Ketten, D. (1995). Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In R.A. Kastelein, J.A. Thomas & P.E. Nachtigal (eds.) *Sensory systems of Aquatic Mammals*. De Spil Publishers, Woerden, The Netherlands.
- Leaper, R. & Scheidat, M. (1998). An acoustic survey for cetaceans in the Southern Ocean Sanctuary conducted from the German government research vessel *Polarstern*. *Rep. Int. Whal. Commn.* **48**: 431-437.
- Leopold, M.F., Wolf, P.A. & Van Der Meer, J. (1992). The elusive harbour porpoise exposed: strip transect counts off southwestern Ireland. *Neth. J. Sea Res.* **29** (4): 395-402.
- MacLeod, C.D. (1999) A review of beaked whale acoustics with inferences on potential interactions with military activities. In P.G.H. Evans, J. Cruz & J.A. Raga (eds.). *European Research on Cetaceans 13: Proceedings of the 13th Annual Conference of the European Cetacean Society*: 35-38.
- Manghi M., Montesi G., Fossati, Pavan G., Priano M. & Teloni V. (1999). Cuvier's beaked whales in the Ionian Sea: first recordings of their sounds. *European Research on Cetaceans 13: Proceedings of the 13th Annual Conference of the European Cetacean Society*: 39-42.
- Miller, P.J.O. & Bain, D.E. (2000). Within-pod variation in the sound production of a pod of killer whales, *Orcinus orca*. *Anim. Beh.* **60**: 617-628.
- Møhl, B., Wahlberg, M., Madsen, M.T., Miller, L. A. & Surlykke, A. (2000). Sperm whale clicks: Directionality and source level revisited. *J. Acoust. Soc. Am.* **107** (1): 638-648.
- Murphy, N.J. (2001) PIP - Meeting the challenge of new frontiers. In Murphy, N.J. & Davies, M. (eds.) *Ireland's Deepwater Frontier: Results from the Petroleum Infrastructure Programme*. p 2-5. Conference proceedings. Petroleum Affairs Division, Department of the Marine and Natural Resources, Dublin. 139pp.
- Myrberg, A.A. (1990). The effects of man-made noise on the behaviour of marine animals. *Env. Inter.* **16**: 575-586.
- Naylor, D., Shannon, P. & Murphy, N. (1999). *Irish Rockall region – a standard structural nomenclature system*. Petroleum Affairs Division, Department of the Marine and Natural Resources, Dublin. Special Publication 1/99.
- Norris, K.S. & Harvey, G.W. (1972). A theory of the function of the spermaceti organ of the sperm whale *Physeter catodon*. In S.R. Galler, K. Schmidt Koenig, G.J. Jacobs & R. Belleville (eds.). *Animal Orientation and Navigation*. NASA Spec. Pub. 262: 397-417.
- Norris, T.F. (1994). The effects of boat noise on the acoustic behaviour of humpback whales. *Proc. Acous. Soc. Amer 128th annual conference*. **96**(5): 3251.
- Notarbartolo di Sciara, G. & Gordon, J. (1997). Bioacoustics: a tool for conservation of cetaceans in the Mediterranean Sea. *Mar. Fresh. Behav. Physiol.* **30**: 125-146.
- Potter, J.R., Mellinger, D.K. & Clark, C.W. (1994). Marine mammal call discrimination using artificial neural networks. *J. Acous. Soc. Amer.* **96**: 1255-1282.

- Rasmussen, M.H., Miller, L.A. & Au, W.W.L. (1999). The sounds and calculated source levels from the white-beaked dolphin recorded in Icelandic waters. In P.G.H. Evans, J. Cruz & J.A. Raga (eds.). *European Research on Cetaceans 13: Proceedings of the 13th Annual Conference of the European Cetacean Society*: 43-45.
- Rendell, L.E., Matthews, J.N., Gill, A., Gordon, J.C.D. & MacDonald, D.W. (1999). Quantitative analysis of tonal calls from five odontocete species, examining interspecific and intraspecific variation. *J. Zool. Lond.* **249**: 403-410.
- Rendell, L.E. & Gordon, J.C.D. (1999). Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. *Mar. Mamm. Sci.* **15** (1): 198-204.
- Richardson, W.J., Greene, C.R., Malme, C.I. & Thomson, D.H. (1995). *Marine Mammals and Noise*. Academic Press, London. 576 pp.
- Rogan, E. & Berrow, S.D. (1995). The management of Irish waters as a whale and dolphin sanctuary. In A.S. Blix, L. Walløe & Ø. Ulltang, (eds.) *Whales, seals, fish and man*. Amsterdam, Elsevier Science. p 671-681.
- Roden, C.L. & Mullin, K.D. (2000). Application of sperm whale research techniques in the northern Gulf of Mexico -A pilot study. Unpublished report of the NOAA ship *Gordon Hunter* cruise 009. U.S. Dept. of the Interior.
- Scarpaci, C., Bigger, S.W., Corkeron, P.J. & Nugegoda, D. (2000). Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence of "swim-with-dolphin" tour operations. *J. Cet. Res. Manage.* **2**(3): 183-185.
- Simmonds, M. & Lopez Jurado, L.F. (1991). Whales and the military. *Nature* **351**: 448.
- Skalski, J.R., Pearson, W.H. & Malme, C.I. (1992). Effects of sounds from a geophysical survey device on catch-per-unit effort in a hook-and-line fishery for Rockfish (*Sebastodes*). *Can. J. Fish. Aquat. Sci.* **49**: 1357-1365.
- Sparks, T.D., Norris, J.C. & Evans, W.E. (1993). Acoustically determined distributions of sperm whales in the northwestern Gulf of Mexico. *Proceedings of the 10th Biennial Society of Marine Mammalogy Conference on the Biology of Marine Mammals*. Galveston, Texas.
- Tasker, M. (1998). Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys. JNCC unpublished report. Joint Nature Conservation Committee, Peterborough. UK.
- Thurman, H.V. & Burton, E.A. (2000). *Introductory oceanography*. Prentice Hall, New Jersey.
- Todd, S., Stevick, P., Lien, J., Marques, F. & Ketten, D. (1996). Behavioural effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). *Can. J. Zool.* **74**: 1661-1672.
- Turnpenny, A.W.H. & Nedwell, J.R. (1994). *The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys*. Fawley Aquatic Research Laboratories Ltd., FCR **089/94**: 1-40.
- Ward, P.D., Donnelly, M.K, Heathershaw, A.D., Marks, S.G. & Jones, S.A.S. (1998). Assessing the impact of underwater sound on marine mammals. In M. Tasker & C. Weir (eds.). *Proceedings of the Seismic and Marine Mammals Workshop*. UKOOA. London.
- Wardle, C.S. & Carter, T.J. (1998). Effects of a Triple 'G' Airgun on Fish Behaviour. In M. Tasker & C. Weir (eds.). *Proceedings of the Seismic and Marine Mammals Workshop*. UKOOA. London.
- Watkins, W.A. (1986). Whale reactions to human activities in Cape Cod waters. *Mar. Mamm. Sci.* **2**(4): 251-262.
- Wenz, G.M. (1964). Curious noises and the sonic environment in the ocean. In W.N. Tavolga (ed.). *Marine bioacoustics*. Pergamon Press. New York.
- Wheeler, A.J., Degryse, C., Limonov, A. & Kenyon, N. (1998). OREtech sidescan sonar data: the eastern Porcupine Seabight. In N.H. Kenyon, M.K. Ivanov, A.M. Akhmetjanov (eds.). *Cold Water Carbonate Mounds and Sediment Transport on the NE Atlantic Margin: Preliminary Results of Geological and Geophysical Investigations during the TTR-7 Cruise of the RV Professor Logachev Co-operation with CCORSAIRES and ENAMII programs*. IOC Technical Report **52**: 49-54.
- Whitehead, H. (2001). *Comments on U.S. Navy use of SURTASS LFA sonar*. Testimony to U.S. House of Representatives, Subcommittee on Fisheries Conservation, Wildlife and Oceans. Published on the International Society for Marine Mammalogy Marmam web-discussion list. 20/11/01.
- Winn, H.E. (1964). The biological significance of fish sounds. In W.N. Tavolga (ed.). *Marine bioacoustics*. Pergamon Press. New York.