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Herring (sild), killer whales (spekkhogger) and sonar

– the 3S-2006 cruise report with preliminary results

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Sammendrag

Denne rapporten oppsummerer resultatet fra et internasjonalt forskningstokt i Vestfjorden i november 2006. Bakgrunnen for undersøkelsen er påstander om at forsvarets bruk av sonarer skremmer bort sild og spekkhoggere fra området. Målsetningen for dette toktet var derfor å studere effekten av militære lavfrekvente (LFAS 1-2 kHz) og mellomfrekvente (MFAS 6-7 kHz) aktive sonarer på spekkhogger og sild. I tillegg testet man bruk av både passive og aktive sonarer til deteksjon av marine pattedyr, slik at man kan begrense eventuelt negative effekter av militære sonarer eller seismiske kilder som opereres i nærheten av pattedyr.

Toktet inkluderte følgende oppgaver: *1)* Merking av spekkhoggere med sensorpakker som registrerer atferd for deretter å eksponere dem for sonarsignaler. *2)* Eksponering av sildestimer som overvintrer i området for sonarssignaler mens sildas atferd ble monitorert med bunnmonterte ekkolodd. *3)* Monitorering av akustiske propagasjonsforhold i området ved å samle inn lydhastighetsprofiler og å anvende en akustisk modell (LYBIN). *4)* Undersøke bruk av tauet akustisk antenne (Delphinus) for å detektere vokaliserende spekkhoggere. *5)* Undersøke bruk av kommersielt tilgjengelige fiskerisonarer (Simrad SP90 og SH80) til aktiv deteksjon av spekkhoggere.

Følgende data ble samlet inn: *1)* Seks spekkhoggere ble merket med sensorpakke, 2 eksponeringer ble utført på til sammen 3 dyr, og 1 kontroll eksperiment ble gjennomført. *2)* Tilstedeværelsen av spekkhoggere i områder hvor enten vi eller Sjøforsvaret hadde brukt sonar dagen før ble undersøkt. *3)* Til sammen 12 eksponeringer ble gjennomført mot sildestim. *4)* Lydhastighetsprofiler fra 22 posisjoner i Vestfjorden ble samlet inn og analysert. *5)* Til sammen 294 timer med passiv akustisk monitorering, som inkluderte mer enn 4000 pattedyrdeteksjon ble registrert. *6)* Spekkhogger ble også detektert aktivt med både langtrekkende (SP90) og kortrekkende fiskerisonar (SH80).

Analysen av innsamlede data er ikke ferdig, men foreløpige resultater indikerer: *1)* Spekkhoggere reagerer sterkere på MFAS signaler enn LFAS signaler. Unnvikelse og endret dykkmønster ble registrert når mottatt lydnivå oversteg ca 150 dB (re 1µPa). Spekkhoggerne så ikke ut til å forlate områder hvor vi hadde brukt sonarer, men de forsvant tilsynelatende fra området i flere dager etter oppstart av militærøvelsen FLOTEX Silver 2006 som innebar bruk av MFAS sonarer. *2)* Sild ser ikke ut til å foreta verken horisontale eller vertikal unnvikelse når de blir eksponert for LFAS eller MFAS signaler. Derimot reagerte de på avspiling av lyder fra beitende spekkhoggere som dekker samme frekvensområdet. *3)* Bruk av fiskerisonarer til deteksjon av sjøpattedyr ser svært lovende ut på avstander opp til 1500 m avhengige av transmisjonsforhold. På korte avstander var SP90 og SH80 likeverdige, men på lengre avstander var SP90 overlegen.

Vi anbefaler at denne type studier følges opp slik at tilstrekkelig datagrunnlag oppnås til at vi kan gi vitenskapelig funderte anbefalinger om bruk av sonarer. Spesielt viktig er det at man gjennomfører flere eksponeringsforsøk på spekkhoggere og andre arter av hval, samt at man fortsetter å validere bruken av aktive akustiske metoder til deteksjon av pattedyr for å bergrense eventuelle negative effekter under operasjoner.

English summary

This report summarises the outcome of an international research cruise in Norwegian waters (Vestfjorden) in November 2006. The objectives of the trial were to study impacts of military low frequency - (LFAS 1-2 kHz) and mid frequency - (MFAS 6-7 kHz) active sonars on killer whales and herring. In addition the capability of active and passive sonar systems for detection of marine mammals, in order to mitigate possible effects of sonars or seismic sources, were tested.

In order to fulfil these objectives we had to achieve the following tasks: *1)* Tag free ranging killer whales with sensors recording behaviour, and thereafter execute controlled sonar exposure experiments on them. *2)* Expose herring over-wintering in the area to sonar signals while monitoring behavioural reactions of the herring using bottom mounted echosounders. *3)* Monitor the acoustic propagation conditions in the study areas by collecting sound speed profiles and use acoustic propagation models. *4)* Test the capability of the Delphinus passive acoustic array for killer whale detections. *5)* Test the capability of two commercially available fisheries sonars from SIMRAD (SP90 and SH80) for active detections of killer whales.

The achievements of the trial include: *1)* Deployment of six tags on killer whales and execution of 2 sonar exposure experiments on three animals, as well as one control experiment. *2)* Survey of occurrence of killer whales in the eastern Vestfjorden basin in relationship to military sonar activity. *3)* Execution of 12 sonar exposure experiments on herring. *4)* Collection of 22 sound speed profiles throughout the study area and period. *5)* Collection of data from 294 hours of passive acoustic survey with more than 4000 detections or marine mammals. *6)* Detections of killer whales on both a long range fisheries sonar (Simrad SP90, 20-30 kHz) and a short range sonar (Simrad SH80 110-120 kHz).

Data analysis is currently in progress. Preliminary results from these analyses indicate: *1)* Killer whales appear to be more sensitive to MFAS signals than LFAS signals. Avoidance reactions and changes in diving behaviour were observed when received level exceeded 150 dB (re 1μPa). Killer whale occurrence in eastern Vestfjorden did not appear to be affected by transmissions from our experimental sonar, but whale number did decline with no whales seen for several days following the start of a FLOTEX exercise which included use of sonar. *2)* Herring does not appear to react by neither horizontal nor vertical escape when exposed to LFAS or MFAS signals. However, they reacted to playback of killer whale feeding sounds covering the same frequency band. *3)* Active sonar detection of marine mammals using fisheries sonars looks very promising at ranges up to 1500 m depending on propagation conditions. At short ranges the SH80 and SP90 sonars had similar detection performances, but the SP90 was superior at long ranges.

We recommend that these studies are proceeded to obtain sufficient basis for scientific recommendations on the use of different sonar signals. Of particular importance are additional exposure experiments on killer whales and other species of cetaceans and further validation of active acoustic detection of marine mammals as a tool for marine mammal mitigation.

Contents

Preface

In November 2006, a highly dedicated group of scientist from 7 different countries representing 6 different research establishments was involved in the 3S-2006 field trial in the North of Norway. The common goal of all of us was to take one or two steps forward in understanding how marine organisms are affected by high power military sonars, and to contribute to the establishment of scientifically based procedures to mitigate negative effects on the marine environment and the people who base their income on marine resources. The research group was highly international, and the outcome of the trial was also expected to have an international impact. This report summarizes the achievements from the trial, and presents some preliminary results and interpretations. However, all the collected data are still being analysed, and thus the final recommendations that are expected to be the outcome of the trial, will be published in a suitable format at a later occasion. This report is a joint effort of all the authors, and the cruise leader Dr. Petter Kvadsheim has been the editor. On behalf of FFI he would like to express gratitude to our collaborating partners, participating scientists and sponsors.

1 Introduction

1.1 Project background

Modern anti submarine active sonars transmits very powerful acoustic signals at lower frequencies than traditional sonar in order to increase the propagation range of the signals. The Royal Norwegian Navy and the Royal Netherlands Navy are both in the process of acquiring or testing such active sonar systems in the frequency band 1-8 kHz. Such signals can be detected by many species of marine mammals and some species of fish, and can potentially be harmful to them. In order to establish guidelines for environmentally safe operations of these sonars, the impact of the transmitted sonar signals on marine life need to be investigated.

The occurrence of killer whales (*Orcinus orca)* in the coastal waters of northern Norway is related to the seasonal migration pattern of the Norwegian spring-spawning herring (*Clupea harengus*) (Simila *et al.* 1996). The herring over-winters in the Vestfjorden and Vesterålen area from October to January and during this time several hundred killer whales are normally present in the fjords. During the FLOTEX 2000 naval exercise claims were made from the local community and environmental groups that the use of naval sonars led to a decreased numbers of killer whales and herring in the area, and that this had a negative impact for the whale watching companies and for the herring fishing fleet.

Killer whales are common along the Norwegian coast and world wide. It is an average sized toothed whale and a top predator among cetaceans. Studies of the effect of sonar signals on the behavior of killer whales make a very relevant reference study for similar studies on other species of cetaceans, such as beaked whales.

The Norwegian spring spawning herring stock is very important both in an economical and ecological perspective (Føyn *et al.* 2002). The herring has a unique sense of herring among the fish species in Norwegian waters (Mitson *et al.* 1995). Being a clupeid fish it can hear signals in the frequency band up to about 5 kHz (Enger 1967), and consequently it may also react to such signals.

Studies of the effect of sonar signals on killer whales and herring in the Lofoten fjords in November, offers an opportunity to study two very relevant species at the same time. In addition, we could also study how the predator prey interaction may be effected by an anthropogenic influence like the sonar signal.

Operational protocols to mitigate possible effects of sonar signals on marine mammals will often require that you know that the mammal are in the vicinity of a naval vessel. Visual observations of marine mammals are very difficult and limited to daylight and good weather conditions. It is therefore also critical that alternative techniques to detect marine mammal are developed.

1.2 Project objectives

The scientific objectives of the projects involved in the trial was to investigate behavioural reactions of killer whales and herring to simulated Low Frequency Active Sonar (LFAS (1-2 kHz)) and Mid Frequency Active Sonar (MFAS (6-7 kHz)) signals, in order to establish safety limits for sonar operations in the vicinity of killer whales and in areas of high herring densities. In addition we wanted to test the capability of active and passive sonar systems for detection of killer whales in order to mitigate possible impacts of acoustic transmission during seismic or naval operations.

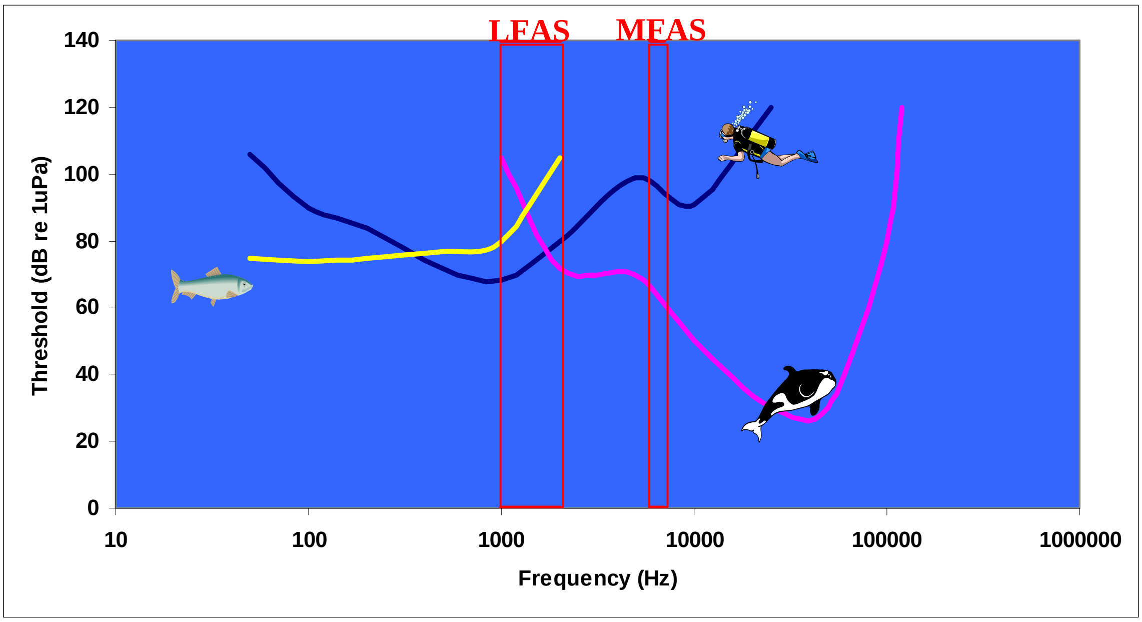

Figure 1.1. The hearing sensitivity of herring (Enger 1967), killer whales (Szymanski et al. 1999) and human divers (David 1999) at different frequencies. The frequencies of the LFAS and MFAS signals used in the study are also indicated.

1.3 Cruise tasks

1. Tag free ranging killer whales inside the Vestfjorden basin with sensors recording behaviour, and thereafter execute controlled exposure experiments (CEE) where the tagged animals are exposed to acoustic LFAS and MFAS signals.
2. Expose herring over-wintering in the area to LFAS and MFAS signals while monitoring behavioural reactions of the herring using bottom mounted echo sounders.
3. Monitor the acoustic propagation conditions in the study areas by collecting sound speed profiles and use the acoustic propagation model LYBIN.
4. Test the capability of the Delphinus passive acoustic array for killer whale detections.
5. Test the capability of two commercially available fisheries sonars from SIMRAD (SP90 and SH80) for active detections of killer whales.

2 Partners

2.1 Scientific Partners

The scientific partners in the projects were;

1. FFI – The Norwegian Defence Research Establishment, Maritime Systems Division, Horten, Norway. FFI is a governmental research institute giving scientific advice to the Ministry of Defence.
2. TNO, Defence Security and Safety, The Hague, The Netherlands. TNO is the Netherlands Organisation for Applied Scientific Research.
3. SMRU- Sea Mammal Research Unit, St. Andrews, Scotland. The SMRU is part of the University of St. Andrews.
4. IMR – Institute of Marine Research, Bergen, Norway. The IMR is a governmental research Institute giving advice to the Ministry of Fisheries.
5. WHOI – Woods Hole Oceanographic Institution, Woods Hole, MA, USA. WHOI is a private, non profit ocean research, engineering and education organisation.
6. SIMRAD AS, Horten, Norway. Simrad is a Kongsberg company and a commercial producer of acoustic fish finding equipment.
7. LKARTS, Horten, Norway. LKARTS is a private consultant company specializing in instrumentation of cetaceans.

2.2 Sponsors

The projects included in the 3S-2006 trial were financially supported by the Royal Norwegian Navy and the Norwegian Ministry of Defence, the Royal Netherlands Navy and the Ministry of Defence, The Netherlands. In addition the specific part of the trial which included a feasibility study to test active detection of marine mammals with SIMRAD sonars, was supported by the International Association of Oil and Gas Producers (OGP), E&P Sound and Marine Life Programme.

2.3 Cruise participants

Name	Institution	Embarked	Disembarked	Vessel
Frank Benders	TNO	10.11	17.11	Sverdrup
Kees Camphuijsen	TNO	03.11	10.11	Sverdrup
René Dekeling	RNLN	24.11	01.12	Sverdrup
Lise Doksæter	IMR/FFI	02.11	01.12	Sverdrup/Inger Hildur
Ari Friedlaender	SMRU	02.11	01.12	Sverdrup
Peter Fritz	TNO	24.11	01.12	Sverdrup
Ole Bernt Gammelseter	SIMRAD	24.11	30.11	Inger Hildur
Adrie Gerk	TNO	02.11	24.11	Sverdrup
Sander van Ijsselmuide	TNO	02.11	10.11	Sverdrup
Lars Kleivane	FFI	02.11	01.12	Sverdrup
Frank Knudsen	SIMRAD	24.11	30.11	Inger Hildur

Name	Institution	Embarked	Disembarked	Vessel
Joost Kromjongh	TNO	24.11	01.12	Sverdrup
Sanna Maarit Kuningas	SMRU	02.11	01.12	Nøkken/Sverdrup
Petter Kvadsheim	FFI	02.11	01.12	Sverdrup
Frans-Peter Lam	TNO	02.11	10.11	Sverdrup
Patrick Miller	SMRU	02.11	01.12	Sverdrup
Nina Nordlund	FFI	17.11	01.12	Sverdrup
Alice Elizabeth Moir Pope	SMRU	02.11	01.12	Nøkken/Sverdrup
Myriam Robert	TNO	10.11	24.11	Sverdrup
Filipa Samarra	SMRU	02.11	01.12	Nøkken/Sverdrup
Tommy Sivertsen	FFI	02.11	01.12	Sverdrup
Erik Sevaldsen	FFI	02.11	17.11	Sverdrup
Rune Sævik	FFI	17.11	21.11	Sverdrup
Hajime Yoshino	SMRU	02.11	01.12	Nøkken/Sverdrup
Timo van der Zwan	TNO	17.11	01.12	Sverdrup

Table 2.1. Alphabetical list of participants on the 3S-2006 cruise with institutional affiliation.

3 Logistics

3.1 Vessels

Three vessels were used during the trial. The FFI RV HU Sverdrup II was the leading ship, and most of the scientific crew was lodged on board the Sverdrup. Sverdrup was equipped with the SOCRATES sonar source, the Delphinus passive acoustic array, a VHF tracking system, two tag boats for tagging killer whales, fuel for the tag boats and CTD probes. The commercial purse seiner MS Inger Hildur was hired for a week. Inger Hildur was equipped with SIMRAD sonar SP90 and SH80, in addition to several echosounders. The FFI RV Nøkken was used as an observation platform for the killer whale studies. Nøkken was equipped with a towed hydrophone array, a visual tracking system and a VHF tracking system. Nøkken was land based and went back to harbour every night.

Figure 3.1. Vessels used during the trial. A; - FFI RV vessel HU Sverdrup II (180 feet), B; - MS Inger Hildur (162 feet), C; - FFI RV Nøkken (36 feet).

3.2 SOCRATES

During the controlled exposure experiments the multi purpose towed acoustic source, called Socrates I (Sonar CalibRAtion and TESting), is used. This source is a sophisticated versatile source that is developed by TNO for performing underwater acoustic research. It is designed as a high-tech, yet still low cost component that can be used for many applications. Socrates has two free flooded ring (FFR) transducers, one ring for the frequency band between 0.95 kHz and 2.35 kHz (max. power 209 dB re 1 μPa @ 1m), and the other between 3.5 kHz and 8.5 kHz (max. power 197 dB re 1 μPa @ 1m). It also contains one hydrophone, depth, pitch, roll, and temperature sensor. All these sensors can be recorded.

Figure 3.2. Scheme of the Socrates body (left), and Socrates I on board HU Sverdrup II (right)

Socrates can be remotely controlled by a COTS PC. The control software is a generalised WAV-player that allows for the transmission of any predefined or recorded acoustic signal. A graphical user interface controls the operational modes and monitors the systems' hardware and sensors. The different operation modes include; a locator mode with time triggering (GPS), a transponder mode with acoustic triggering of predefined signals, and an echo repeater mode, in which the recorded signals are retransmitted with simulated Doppler shift and target strength. Besides transmission of high power pulses (short signals), transmission of long duration signals (noise, signatures or communication signals) at modest power is also possible.

The system consists of a towed body with good hydrodynamic properties, a partly faired tow cable, a deck cable and a PC based operator interface, and a power amplifier rack containing amplifiers, power supply interfaces and transformers. The towed body contains two acoustic sources, a hydrophone, and a watertight inner pressure hull for the transformer and the non acoustic sensors. The deck unit of Socrates was placed in a container on deck of Sverdrup. Operation of Socrates was performed with terminals in the laboratory room of the ship.

The depth of Socrates depends on the speed (in water) and cable length (fig. 3.3). The Socrates source can be used with speeds between 3 and 12 knots. When the maximum source level needs to be transmitted, the source needs to be at more than 30 m depth. The maximum turn rate during towing is 15 deg per minute.

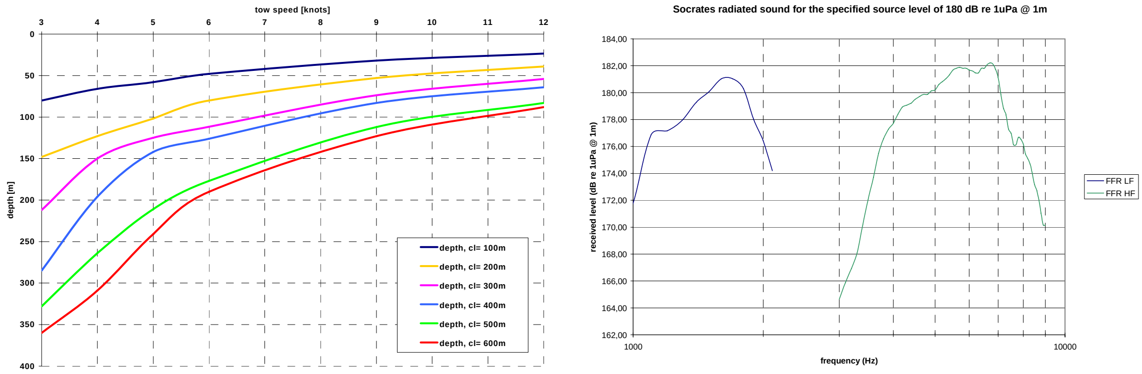

Figure 3.3. Left; depth of the Socrates body as function of tow speed and cable length. Right; Measured output spectrum of Socrates for a source level of 180 dB re 1 µPa @ 1m

The source level of the Socrates source depends slightly on the frequency (fig. 3.3). During the Controlled Exposure Experiments (CEE) the time triggered operation mode is used. The transmission were started (timed) and stopped via the control PC. During the CEEs, two types of signals were used:

1. LFAS HFM upsweep [1-2 kHz] 209 dB re 1µPa @ 1 m
2. MFAS HFM upsweep [6-7 kHz] 197 dB re 1µPa @ 1 m

Depending on the selected frequency band, the following ramp-up signals were used:

1. LFAS 150-209 dB re 1µPa @ 1 m,
2. MFAS 138-197 dB re 1µPa @ 1 m,

Where the pulse length was 1.0 second, pulse repetition time is 10 seconds, and the duration is 10 minutes. Immediately after the ramp up signals, the full power pulses were transmitted with a pulse repetition time of 20 seconds. During the experiments the acoustic and non-acoustic sensors data are recorded. During silent runs, the source is not transmitting, but the hydrophone and non acoustic sensors are recorded. In advance of the herring experiments, a shorter ramp-up scheme with a duration of three minutes was used.

3.3 Delphinus

During the trial, the TNO developed Delphinus array was used. It was deployed from the Sverdrup to acoustically search for marine mammals. Since the visual search could only be done during the short daylight hours, the array was widely used during the night.

Figure 3.4. Deployment of the Delphinus array from the HU Sverdrup II.

The Delphinus is a single line array (54 metres long) containing 18 hydrophones with a frequency range of 10 Hz to 40 kHz. The hydrophone section is 3.7 meters long and has an outer diameter of 65 mm and is neutrally buoyant. The sensitivity of the hydrophones including preamplifiers is 175 dB re 1 volt/µPa. The middle section contains 16 hydrophones that have a spacing of 6 cm, while the outer two hydrophones are spaced 60 cm from the rest. These two hydrophones are used for classification and localisation. All hydrophones are sampled up to 108 kHz. The array is also equipped with a depth sensor (also recorded). Figure 3.5. shows the frequency dependency of the hydrophone sensitivity.

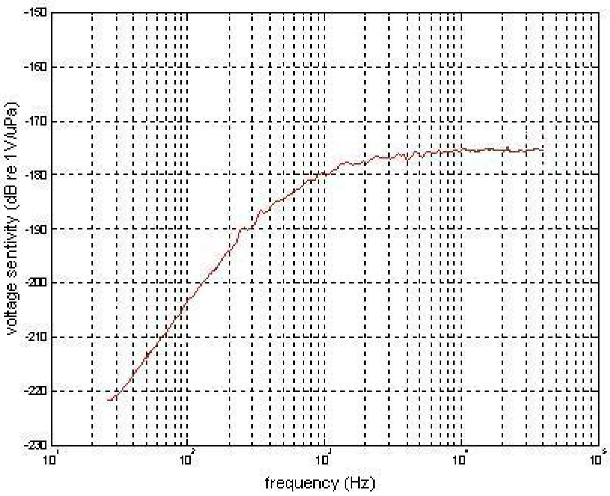

Figure 3.5. Frequency dependency of the Delphinus array. Frequencies are given from 10 Hz to 100 kHz on a logarithmic scale.

Besides the hydrophone section, two vibration isolation modules are used. The modules are standard modules developed at TNO. The purpose of these modules is to prevent cable and tail strumming vibrations on the hydrophones, and increase the distance between the tow cable and the Delphinus hydrophone section. The breaking strength of both sections is 18 kN. The tow cable of the array is 180 metres, which was wrapped on a Tabat winch during the trial.

The Delphinus array can be towed together with the Socrates source. When the Delphinus array is towed, the tow speed needs to be between 3 and 9 knots. The Delphinus functions best at a speed between 7 and 8 knots. The tow depth of Delphinus needs to be lower than the Socrates (depth separation). Delphinus need to always be deployed before Socrates, and Socrates will be recovered out of the water before Delphinus. Both systems were together in the water only during the calibration experiments. When a CTD sensor is used to measure the sound speed profile, Socrates and Delphinus need to be out of the water. The tow depth of Delphinus will depend on the tow speed and the cable length (table 3.1).

	Speed [kts]		
Cable length [m]	**3**	**6**	**9**
90	45	21	10
150	87	41	20

Table 3.1. Dynamic behaviour of the Delphinus array.

The processing of the data is done on one dual processor PC. One processor handles the data acquisition and the other one is dedicated to the processing of the data. For the data acquisition a dedicated data acquisition card from ICS type 610 equipped with Analogue Digital converters for 32 channels is used. These channels are equipped with anti-aliasing filters. The resolution of the ADC is 24 bits with a sample rate of 108 kHz per channel. During the trial all data was processed and stored on the rate system with a storage capacity of 6 TBytes.

The real-time processing chain of the Delphinus consists of an automatic transient detector and an audio and spectral analysis tool allowing manual classification. Offline, the detected transients can be fed to an automatic classifier which analyses the spectrogram features of the transients. These tools have been developed at TNO as part of a complete Detection Classification and Localisation (DCL) suite for transients analysis. The tools have been tested and validated at sea during three campaigns at sea in 2004, 2005, and 2006 (Royal Netherlands Navy, TNO). Two of these campaigns were dedicated to marine mammal research and focussed of the *Delphinus* real-time processing. The middle hydrophone section of the array is processed together up to 12 kHz to provide direction indication (beamforming), while the two classification hydrophones (processed up to 48 kHz) are processed separately over the whole frequency band. In the following subsections a short description of the three processing steps in the *Delphinus* processing chain is given.

3.3.1. Automatic detector

The TNO automatic transient detector was developed for both low frequency arrays and wide band arrays such as the *Delphinus*. It can be applied to any time-series, also received from single hydrophone receiving systems. For example it was used to analyse sonobuoy data from the

SIRENA 2003 campaign of the NATO Undersea Research Centre (NURC). Using the automated detector allows for a significant reduction (in real-time) of the huge amount of data that is recorded, such that only the interesting parts need to be analysed. It is based on the combination of a power-law integrator and a Page test for the passive detection of marine mammals. The power-law integrator is robust against varying signal bandwidth and the Page test detector (Abraham and Willett 2002) is an optimum detector for signals with an unknown duration. The processing can be separated into four basic steps:

1. Pre-processing
2. Beamformer
3. LOFAR (Short Time Fourier Transform)
4. Page-test/power law detector

The first step in the processing chain is equalisation of the hydrophone data. The second step in the detection processing is beamforming. This step is used to improve the signal to noise ratio by means of noise suppression from other directions than the looking direction. Furthermore, it gives an indication of the direction information of the detected transient. A special wideband beamformer is developed for this purpose. Standard beamforming algorithms can only be efficiently applied to bands of one octave or less. The problem is of computational nature and has its origin in the fact that the beamwidth depends on the frequency. For high frequencies many beams (twice the number of hydrophones) are required for omni-directional monitoring. The combination of many frequencies and many beams is unrealizable in current practice. Still, detection of transients over the whole operational band is essential for marine mammal detection. This was achieved by reducing the beamwidth by application of a constant (frequency independent) beamwidth beamformer. In the beamforming process, a fixed number of sectors (8, 16, 32 or 64) is constructed, which have a constant beamwidth in the full frequency band. This allows to monitor the underwater horizon in real-time on a COTS PC. With our current PC the number of beams is 32.

For monitoring, the results are displayed as a “multi-beam LOFAR” type of display. Therefore the LOFAR step is introduced. For the middle hydrophone section, only five beams are shown (front, beam 60º, broadside, beam 120º and aft). Even more beams can be made in the beamformer, but only five are necessary. Neighbouring beams are merged (by incoherent summation) for displaying only five beams. An example of the output is shown in figure 3.6. For each of the five beams, a time-frequency plot (*tf*-plot or gram) is shown with frequency on the horizontal axis and time on the vertical axis. The axes are rotated to make the display look like a more standard LOFAR gram (waterfall) as used in operational passive sonars. In the case of the classifying beams, no beamforming is performed and an omni-directional LOFAR is displayed.

The second step is automatic detection of the marine mammal transients. This is achieved by the combined use of a power-law and Page test algorithms (IJsselmuide & Beerens 2004), which acts on all the beams separately. The power-law integrator is robust against varying signal bandwidth while the Page test detector is an optimum detector for signals with an unknown duration. This combination of sector beamforming and power-law/Page test detector has proven to be very successful in detecting marine mammal vocalisations. After normalisation of the beamformed or omni-directional data, the power-law/Page test detector is applied for automated detection and extraction of the signals. The normalisation is an adaptive process in which the background is continuously measured and averaged, and then subtracted from the data. In this way, only fluctuations in the background are noticed. This step equalizes the stationary background noise. Thus, signals, i.e. fluctuations in the background, are clearly visible. The detector performs a summation in the horizontal direction over all frequency bins for each time step. Whenever this summation exceeds a certain threshold, a signal is detected. The thresholds specification depends on the background noise (including the tow ship noise). This level is usually set manually by the operator according to the acoustic conditions in the trial area, so that the detector is not sensitive for small noise bursts, but still detects the low amplitude transients. After the detection of a transient, the start and stop times of this transient are known and the transient can be stored. The stored transient files are displayed on the lower right part of the screen. This allows for further analysis; classification and localisation.

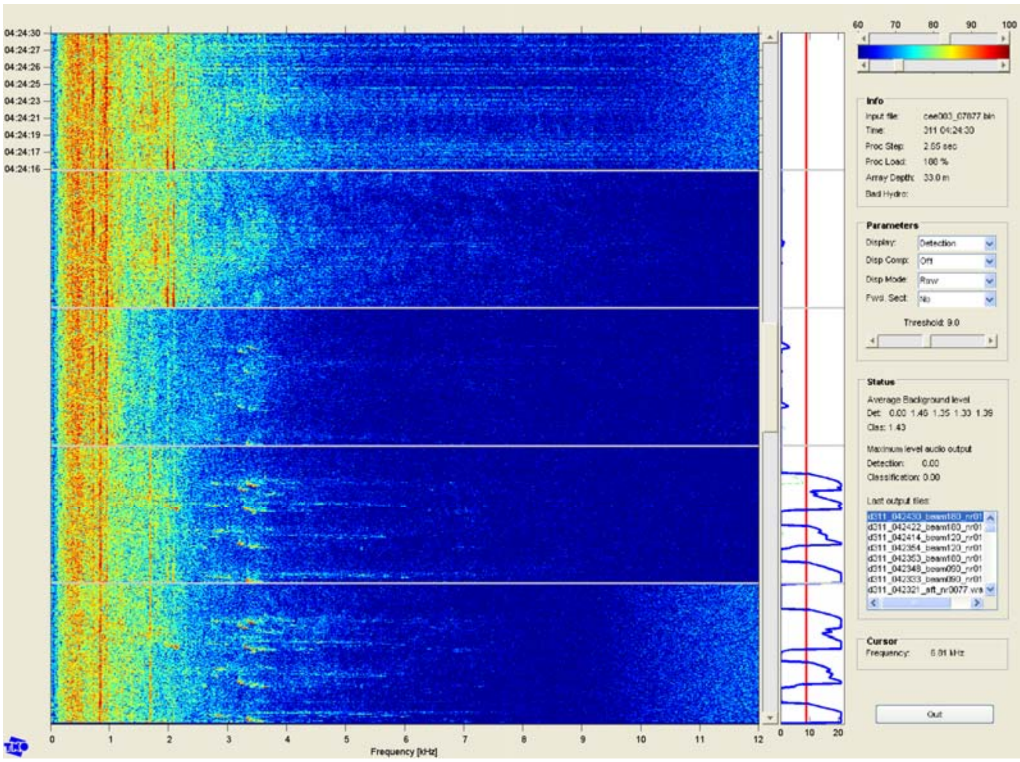

Figure 3.6. Example of multi beam LOFAR display on the low frequency processing of the Delphinus. To the right of the LOFAR display is an example of the output of the power-law/Page test detector. The blue lines shows the results on the middle section (16 hydrophones) while the green ones show the detection results on the classifying beams (outer hydrophones). The threshold is displayed in red. This allows the operator to monitor both sections simultaneously.

<u>*3.3.2 Audio and spectral analysis tool*</u>

In the current version of the software, the detected transients are passed on to an analysis tool one by one. This analysis tool is a Matlab®-based audio-player which shows the time series and a high-resolution gram of the transient and allows for filtering and audio analysis. Figure 3.7 depicts a screenshot of the analysis tool showing the time series and a high-resolution gram of a detected transient during the CEE experiments. On the top right corner of the screen, the operator can adjust the filtering of the signal and manually classify the transient as biological or mechanical. The classification can also be performed directly using the keyboard: pressing *‘B’* for Biological and *‘M’* for Mechanical. As a result, the transient is copied in the appropriate folder for further analysis.

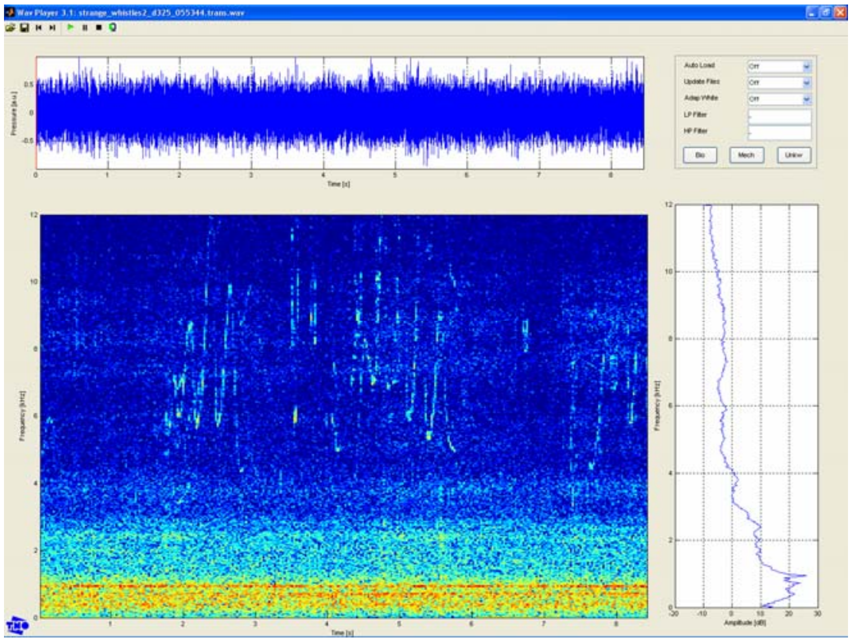

Figure 3.7. Screenshot of the Audio and spectral analysis tool

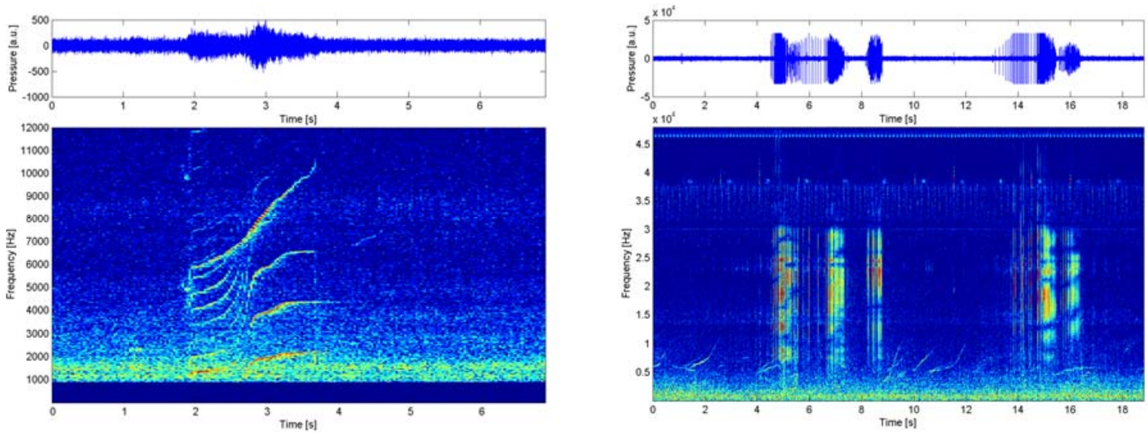

Figure 3.8. Example of a killer whale recording on the detection hydrophones (left) and on the high frequency classification hydrophone (right).

3.4 Ocean Hub

The Ocean Hub is owned and established by the Institute of Marine Research. It was used to monitor the behaviour of the herring layers during the exposure experiments on herring. The ocean hub consists of a system of two upward looking bottom mounted echosounders placed 300 m apart in the opening of Ofotfjorden. Both echosounders are of type Simrad EK 60, transmitting at 38 kHz. The northernmost echosounder (A) is placed at approximately 500 m depth, while the southernmost (B) is at ~ 400 m depth. These two echosounders together make up the ”sea-unit”, that is connected to an onshore site, the ”land unit”, through a hybrid cable with four copper wires and one fibre optic wire (Figure 3.9). The land unit is equipped with instruments and PC software to store and read the acoustic data recorded by the echosounders. Via satellite, the data is transferred to a database at IMR in Bergen, and is continuously put out as echograms on a web site, enabling real-time monitoring of echograms from both echosounders during experiments.

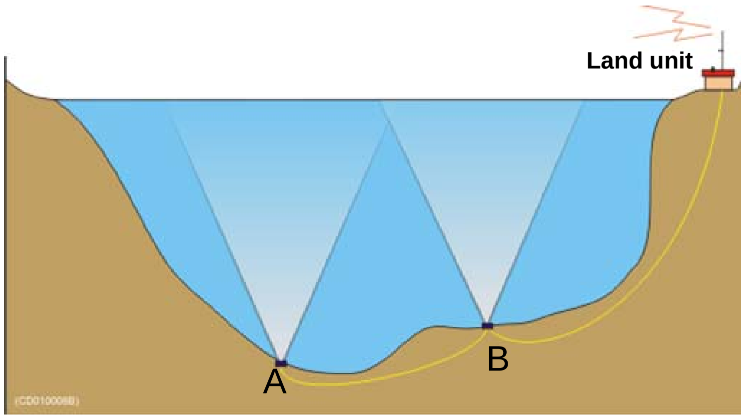

Figure 3.9. Schematic set up of the ocean hub: Two echosounders (A and B) connected to each other and a land unit though cables.

3.5 DTAG

The DTAG, a miniature sound and orientation recording tag developed at WHOI, was used to monitor the killer whale behaviour during the trial. The tag is attached to the whale using a hand held 8 m long carbon fibre pole with suction cups (fig. 4.2). At a pre-set time the vacuum is released from the suction cups and the tag floats to the surface. The tag contains a VHF transmitter used to track the tagged whale during deployment and to retrieve the tag after release. All sensor data are stored on board the tag and the tag therefore has to be retrieved in order to obtain the data.

DTAGs record sound at the whale as well as depth, 3-dimensional acceleration, and 3-dimensional magnetometer information. DTAG audio was sampled at 96 kHz and other sensors at 50 Hz, allowing a fine reconstruction of whale behaviour before, during, and after sonar transmissions. One of the tags collected stereo acoustic data, also sampling at 96 kHz. A 16-bit resolution sigma-delta analog to digital converter was used. The clipping level was set to 171

dB_{peak} *re* 1 μPa for the mono tags, and 171 and 186 dB_{peak} for the two hydrophones in the stereo tag, respectively. Data were stored digitally in up to 10 Gbyte of non-volatile memory (Johnson and Tyack, 2003). Soon after each deployment, tag data were downloaded and decoded into audio and sensor data. Audio data were in 16-bit .WAV file format. This audio format is a widely-used standard and freeware WAV players are available for Windows and Linux PCs. WAV files can also be read into MATLAB and similar analysis software packages for detailed examination and analyses. The audio sampling-rate is chosen according to the vocalisation frequency range of each target species. In order to represent the full spectrum of killer whale clicks, the sampling-rate was set to 192 kHz. The sensor data were distributed in MATLAB .MAT format files. MATLAB is a standard software package used for analysis and visualisation of time series and other data. MATLAB tools for processing the data sets are available on a WHOI website. Surface observations were combined using a spreadsheet program, such as Excel, or a geographical information system and distributed with the data set.

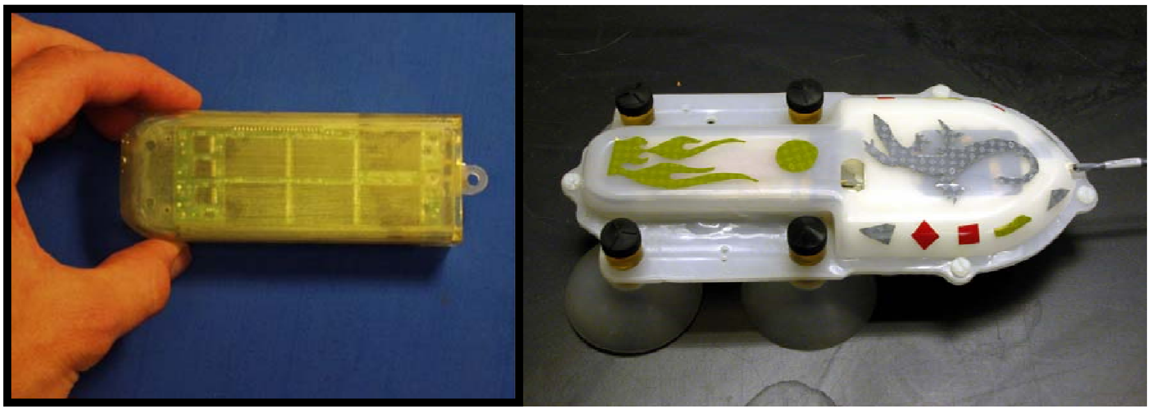

Figure 3.10. Left: Electronics package of the DTAG. Right: Complete attachment and housing for the DTAG.

The data analyses performed by the scientist for each tag deployment include the following tasks:

(i) Scoring the audio recordings. A listener reviewed the entire set of recordings to determine cue points for vocalisations, surfacing, noisy blows, boat/playback sounds, and any other interesting features. Individual vocalisations were extracted and combined in a vocalisation database.

(ii) Time aligning of surface observations and remote acoustic recordings with the DTAG data.

(iii) Identification of behavioural states during each focal follow. This is done by carefully considering the surface observations and DTAG measurements to estimate when the focal is sleeping, eating, diving, socializing, etc. Each behavioural state can then be parameterized in terms of fluke rate, depth, vocalisation rate, and presence of other animals.

(iv) Scoring the effect of any exposure to human-made sounds in terms of a change in the pre, during, and post-exposure behaviour of the focal. Responses were calibrated in terms of received sound level (RL), range to the sound source, initial behaviour, sex, and age.

Where a potential response to sound exposure was indicated, we analyzed how quickly they developed, how long they continued, and how they scaled to RL.

3.6 LKTAG and ARTS

The DTAG was the main tagging instrument used during the trial, but a LKTAG was developed as a back up system. While the DTAG is attached to the whale using a long pole, the LKTAG could be launched using the ARTS pneumatic tag launcher (Kleivane 1998). The tag is shaped like a 40 cm long rocket 40 mm in diameter containing a VHF transmitter, a time depth recorder and floatation material. Compared to the DTAG it contains a much simpler sensor package, but it may be launched at longer distances. In principal the tag is launched and anchored to the blubber of the whale, it releases through a galvanic time releaser and floats to the surface. Otherwise tracking techniques and pickup of the tag would be the same as for the DTAG. The advantages of this system (ARTS/RN-LKTAG) are launching flexibility, operational rapidity, and especially operational range as compared to other deployment systems. The LKTAG and the ARTS/RN is developed in cooperation with LKARTS-Norway in Horten. Both systems have previously been used extensively to tag many species of whales with different sensor packages.

Three attempts were made to tag killer whales with LKTAGs. The reactions of the killer whales to tagging attempts were similar to the reactions observed when they were tagged with DTAGs. This included a very short surprise reaction, turning towards the tag boat, before returning to normal swimming. On two occasions a killer whale were tagged with a LKTAG. On both occasions the VHF signal was lost instantly upon deployment, and the tag lost.

3.7 SIMRAD sonars SP90 and SH80

The capability of a low frequency and a high frequency SIMRAD sonar in detecting killer whales at different distances was tested. Simrad SP90 is a low frequency sonar operating between 20-30 kHz and the Simrad SH80 is a high frequency sonar operating between 110-120 kHz. The frequency characteristics of the two systems give SH80 a higher resolution and the SP90 a longer detection range, but both systems are optimized for detections of weak and scattered targets. Further more, both systems are omni directional with omni directional beam stabilisation, but they can also combine horizontal and vertical beams (fig 3.11). The pulse form used was 16-64 ms FM signals with 1 kHz bandwidth and a source level of 206 dB (re 1µPa @ 1m) for the SP90 and 13-26 ms FM signals with 5 kHz bandwidth and a source level of 211 dB (re 1µPa @ 1m) for the SH80. The signal duration varied with sonar range. The SP90 is within the most sensitive part of the killer whale hearing curve, while the SH80 is outside the expected hearing band (fig. 1.1).

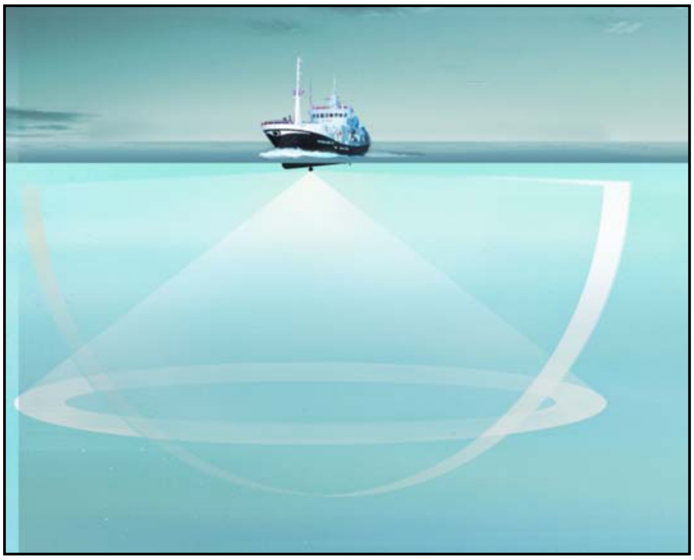

Figure 3.11. Illustration of horizontal and vertical sonar transmission from Simrad sonars.

4 Data Collection

4.1 Daily work plan

The cruise plan was shaped based on a pilot study on killer whales in the same area in 2005. This study was led by Ari Shapiro at WHOI and included tagging killer whales with DTAGs to study their un-disturbed (baseline) behaviour. However, the situation in the operation area during the trial had changed dramatically from the year before. The weather condition was significantly worse for tagging operations in 2006 compared to 2005. In addition the number of killer whales entering the inner part of Vestfjorden in 2006 was dramatically reduced compared to 2005, probably because less herring entered. This led to a difficult situation in three aspects:

1. The weather condition hardly ever allowed for tagging operations in the outer part of the Vestfjorden.
2. We had to move a lot around the entire Ofoten-Vestfjorden area to find whales, and since Nøkken was land based they often could not reach the operation area.
3. We had made plans to avoid the focal areas for whale tourism. This was expected to be the Tysfjord area based on previous experience. No animals entered the Tysfjord during the trial period and therefore the tourist operators repeatedly ended up in our operation area, which was a disturbance to us both.

As a consequence of these circumstances we decided to send Nøkken home midway through the trial and transfer the Nøkken team to Sverdrup.

Tagging of whales can only be done during daylight ours. The number of daylight ours varied between 8 hours at the beginning of the trial to only 6 hours at the end. It was therefore crucial to find the killer whales as efficiently as possible. Usually during the night, the Delphinus passive acoustic monitoring system was used to survey a large area for presence of killer whales. All mammal detections were processed and plotted on a map before dawn, and visual efforts could start in an area where killer whales were expected to reside at first light. During daylight hours a visual team consisting of at least two observers were stationed on the monkey platform of the Sverdrup. In addition a second observation team operating on board Nøkken, who sailed out of Korsnes every morning, was also searching for whales. Once killer whales were visually spotted and weather conditions allowed for it, the tag boats, two ≈20 feet outboard engine workboats, were launched from the Sverdrup. The tag boat teams consisted of a tag boat driver, a "tagger" and a third person taking photo ID pictures (fig. 4.2). The main tag used was the DTAG, which was deployed using an 8 m long carbon fibre pole. Tagging attempts were made until remaining daylight hours were to short to allow for exposure experiments to be conducted. If whales were tagged the Socrates was deployed and a control exposure experiment was conducted after a pre exposure period. On several occasions exposure experiments had to be cancelled because the tag fell off to early or because of disturbing tourism. Tagged whales were tracked using the VHF-beacon on the tag and a VHF tacking system which was installed onboard the Sverdrup. After release the tag was retrieved using the VHF tracking system. CTD profiles were taken opportunistically but always on occasions which included active sonar transmission. The herring experiments were usually conducted at night or when weather did not allow for whale tagging. Collection of data of active detection of killer whales using fisheries sonars was done independent of the Sverdrup and Nøkken using the third vessel Inger Hildur on the last week of the trial.

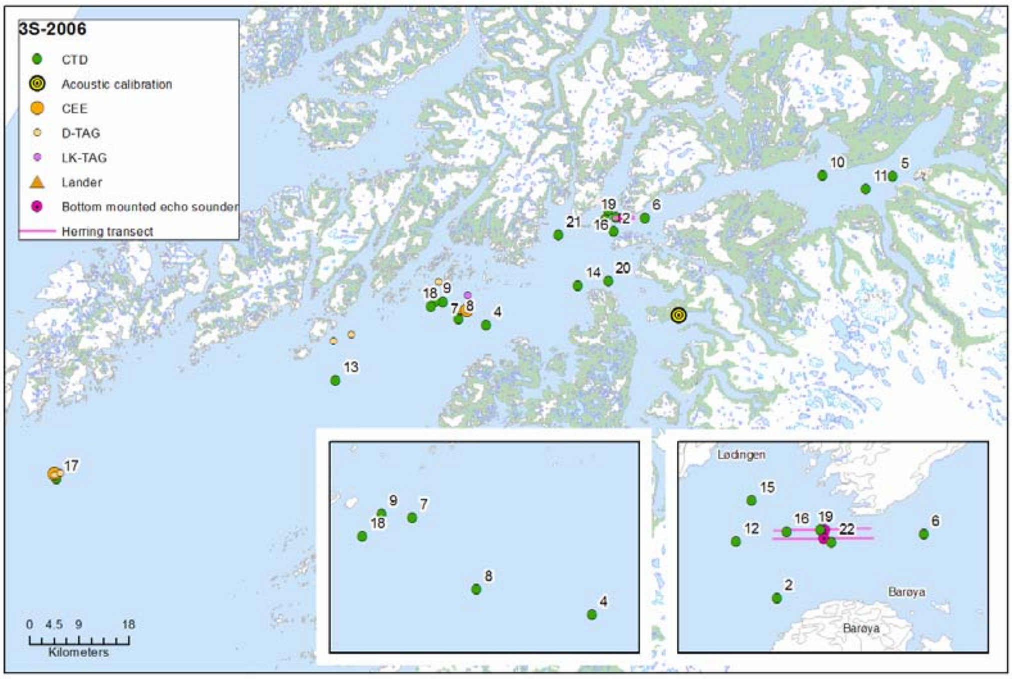

Fig 4.1. Chart showing operation area and the positions of different activities of the HU Sverdrup II.

4.2 Sonar exposure experiments on killer whales (CEE)

Our procedure was to 1) tag 1 or 2 whales, 2) allow a post-tagging observation period, 3) begin experimental sonar transmission with a ramp-up, 4) gradually approach the whales with the sonar transmitting, 5) collect post-exposure data using the tags, and 6) recover the tags for data analysis.

Killer whales were tagged with DTAGs from the tag boats (fig. 4.2) using an 8 m long carbon fibre pole. The tag is attached to the whale with four suctions cups and releases itself after a pre set time of 4-6 hours. Once a DTAG was attached to a whale, an initial start location for the Sverdrup was specified based upon the location and movement direction and speed of the whales. Sverdrup started to move towards this location and the Socrates source was deployed. The start location was approximately 3 nm away from the animal. We tested the reaction of the whales to two different sonar signals, LFAS and MFAS. The choice of which sonar signal to use was decided in advanced based on the behaviour of the tagged whale(s). The DTAG contains a VHF transmitter, which allows us to recover the tag, and to follow the tagged whale by an observation vessel. The observation vessel recorded the location of the tagged whale, and relayed this information back to the source vessel Sverdrup, for them to plan their movements during the sonar transmission phase. Observers on the observation vessel also made identification photographs of the tagged whale, and notes of behavior observed at the surface such as group size, presence of fish and sea birds, and group synchrony. During the exposure the Sverdrup moved at 8 knots on a course straight towards the latest known position of the tagged animals. If the animals changed position the source ship changed its course correspondingly. When the source ship was 1 nm away from the tagged animals, the course was no longer changed. This would allow the animals to avoid the signal, if they tried to. After about 20-25 min the Sverdrup passed the animals and continued on a straight course still transmitting for another 5 min. During transmissions, the visual observers on Sverdrup assured that a safety limit of 100 m from the source to any mammals was maintained. A shut down procedure was established and exercised, but was never executed.

Fig.4.2. Left; tagging of the killer whales with DTAGs were done from 20 feet open boats with 4-stroke engines using 8 m long poles. The tag boat team consisted of a tagger, a driver and a person taking photo id pictures of the whales. Right; a killer whale tagged wit a DTAG.

In addition to the controlled exposure experiments we also tracked the presence or absence of killer whales in the Eastern Vestfjorden area in relation to known transmissions of military sonar signals. These transmissions consisted of our own use of the experimental source Socrates, particularly used at night to study the effects on herring, as well as military sonars used predominantly during night time in the FLOTEX naval exercise. Each day, the positions of whales was recorded on the Sverdrup and some tour operators also provided sightings reports. We generally searched in areas where whales were found the day before to assess whether whales had moved simultaneous with the sonar transmissions. Search areas were widened when no whales were found. When whales were found, identification photographs were taken from the observation vessels. Through this approach, we were able to build a daily record of whale presence and absence in relation to military sonar use in the Vestfjorden basin.

4.3 Sonar exposure experiments on herring

The reactions of herring were measured in response to LFAS and MFAS signals. For both types of transmission, a ramp-up were conducted before transmitting at full power. The ramp up for LFAS transmission was 10 min, for MFAS 3 min. Full power transmission was 209 and 197 dB (re 1µPa @ 1m) for LFAS and MFAS transmission respectively.

Herring reactions were measured acoustically by two upward-looking bottom mounted echosounders (Ocean Hub), as the ship passed over one of them, transmitting sonar signals. The ship passed over the echosounder in a straight line, and transmission started 1 nm away from the position of the echosounder, and stopped 1 nm after passage of the sounder. The source ship kept a constant speed (~ 8 knots) during the run. The exact time for start and stop of transmission were noted, as well as the time when the middle of the ship passed the GPS position of the echosounder. Which of the two echosounders the experiments were conducted on were chosen based on which of them having the densest layer of herring in each experiment.

The experiment was conducted in a block design. Each block consisted of three runs (pass bys), one of LFAS transmission, one MFAS, and one without transmitting but still towing the Socrates. The silent pass by acted as control within each block. The order of the different transmission types was randomized. Three blocks were usually conducted during each experiment, with one hour break after each block before the start of the next. Experiments were conducted at different times of the day to look at day-night variations associated with diurnal vertical migrations (DVM) of herring.

During the experiment, the entire ship was dark, to prevent any light stimuli to affect herring behaviour. The ships echosounder were set in passive mode, to prevent interference with the hub-echosunder, as these were operating at the same frequency (38 kHz). Having the ship echosounder running in passive mode also helped us monitoring that the hub echosounder was actually passed, as the active transmission of this clearly showed up in the ships echogram. Immediately after each experiment, CTD measurements were made to create sound speed profiles and calculate transmission loss in the area. The depth of the towed sonar source (Socrates) was approximately 35-40 m in all experiments.

In addition to testing the effect of sonar signals, behavioural reactions to playback of killer whale sounds were also tested. This was done by lowering a pool loudspeaker into the herring layer from a small boat. Killer whale sounds were played while the source ship passed the echosounder as a control run, still towing the sonar source but without transmitting. The killer whale playback used was a mixture of feeding sounds. The recording used was made a few days earlier in Vestfjorden of killer whales feeding on herring.

4.4 Passive acoustic detection of killer whales

The Delphinus processing recorded ~4.5 TBytes of raw data in 270 hours of recording. In total more than 37082 sounds have been detected. At least 4038 sounds were biological (marine mammals). All bio-detections were plotted on a map to determine an estimation of the position of the marine mammals (fig 4.3). More information about the detections and the deployments of the systems can be found in Appendix A. During the trial, the Delphinus array was deployed (and recovered) 26 times. Beside marine mammals, Delphinus recorded many fishery sonars transmissions.

For the exposures of the killer whales and herring, the Socrates source was deployed (and recovered) 12 times (in total more than 45 hours in the water, while about 37 hours transmitting). During these exposures, the hydrophone in the Socrates is recorded. At least once (during one herring experiment) we also heard sounds from a killer whale on that hydrophone.

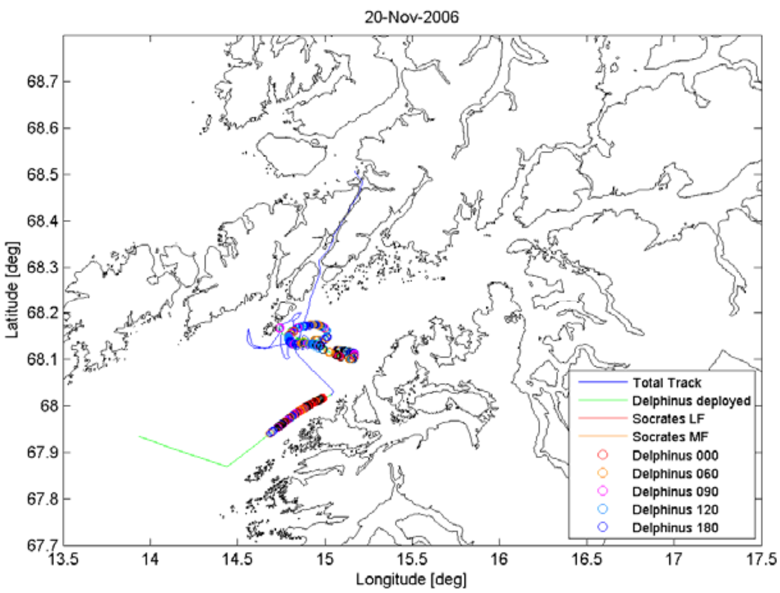

Figure 4.3. Example of acoustic detections of marine mammals on the Delphinus during one night. The colours of the circles indicate the direction in which the sound was detected. The colours of the tracks indicate where Delphinus and/or Socrates were towed.

4.5 Sound speed profiles and acoustic propagation modeling

Sound speed profiles (CTD) were collected in connection with every event which included sonar transmission. In addition CTD profiles were also taken intermittently between transmissions in order to monitor the acoustic propagation conditions in the operation area. The instrument used was SAIV CTD MODEL sd204 (SAIV A/S, Bergen, NORWAY). The probe was lowered at a max speed of 1 m/s to a depth of 150-200 m after which the sound speed was assumed to be stable. A total of 22 CTD profiles were collected during the trial (table 4.1). The sound speed profiles were continuously fed into the acoustic model LYBIN developed by the Norwegian Navy and FFI. This gave us a running overview of the acoustic propagation conditions in the area.

ST. NO	DATE	TIME UTC	NORTH		EAST		DEPTH	cast depth	COMMENT
			Deg	min	deg	min			
1	04.11.2006	17:00	67	58.60	15	41.00	250	Missing	Innermost Sagfjorden.
2	06.11.2006	8:45	68	21.54	16	3.30	250	Missing	NW of Barøy
3	09.11.2006	7:20	67	58.62	15	47.82	210	Missing	Økssundet
4	09.11.2006	19:20	68	12.50	15	29.30	215	Missing	Risvær-Hamarøy
5	11.11.2006	12:25	68	26.20	17	17.50	225	Missing	Near Narvik
6	12.11.2006	17:45	68	22.80	16	11.50	485	Missing	North of Barøy
7	13.11.2006	11:40	68	14.80	15	18.00	170	Missing	Risvær-Hamarøy
8	13.11.2006	16:05	68	13.11	15	22.04	480	Missing	Risvær-Hamarøy
9	15.11.2006	9:00	68	14.88	15	16.06	165	Missing	SW of Årstein
10	17.11.2006	8:50	68	26.50	16	58.80		150	
11	18.11.2006	9:40	68	25.07	17	10.29	240	150	before deploying Delphinus
12	18.11.2006	18:30	68	22.72	16	1.10	340	200	after recovering Socrates
13	20.11.2006	20:00	68	7.10	14	49.80	335	150	before deploying Delphinus
14	21.11.2006	14:21	68	16.29	15	53.56	590	200	after recovering Delphinus
15	22.11.2006	16:14	68	23.55	16	1.99	290	200	
16	22.11.2006	17:24	68	22.90	16	3.90	200	150	Before herring exp. with orca sounds
17	23.11.2006	22:21	67	57.15	13	37.38	125	100	
18	24.11.2006	11:12	68	14.37	15	14.86	265	200	
19	25.11.2006	21:10	68	22.93	16	5.77	340	200	After herring experiment
20	26.11.2006	12:57	68	16.68	16	1.53	185	150	
21	28.11.2006	18:17	68	21.27	15	48.61	113	100	
22	29.11.2006	15:36	68	22.66	16	6.38	500	200	Before herring experiment.

Table 4.1. Chronological overview of the CTD/Sound velocity profiles with positions, time, depth and cast depth. The positions are also shown on the chart in figure 4.1.

4.6 Acoustic calibration

At the start of the trial all acoustic equipment were tested. Reverberation conditions were tested to assure that the reverberation died out between each transmission when using the 20 s inter pulse interval. The sensitivities of the hydrophones in the DTAGs to the sonar signals transmitted by the Socrates source in this trial were also calibrated. Two different tags (ID 220 and ID 221) were lowered into the water next to a calibrated hydrophone from the Nøkken. Sverdrup was slowly approaching Nøkken, transmitting MFAS or LFAS signals from the Socrates. The calibrated hydrophone system, which includes an amplifier and an anti-alias filter (AAF), converted the acoustic waveform, $p(t)$ to a voltage waveform, $V(t)$. This process (hydrophone + amplifier + AAF) can be characterised by the amplifier sensitivity A:

$$A \equiv \left(\frac{V_{\mathrm{rms}}}{p_{\mathrm{rms}}} \right)^2 . \qquad (1)$$

The voltage waveform was then converted using Cool-Edit Pro to a digital waveform, $W(t)$, characterised by the digitiser sensitivity D:

$$D \equiv \left(\frac{W_{\mathrm{rms}}}{V_{\mathrm{rms}}} \right)^2 . \qquad (2)$$

The total processing chain is thus described by the equation

$$W_{\mathrm{rms}}{}^2 = p_{\mathrm{rms}}{}^2 \times A \times D , \qquad (3)$$

or in decibel form

$$\left(L_W\right)_{\mathrm{cal}} = L_p + S_A + S_D , \qquad (4)$$

where $\left(L_W\right)_{\mathrm{cal}}$ is the digitised level at the end of the calibration chain

$$\left(L_W\right)_{\mathrm{cal}} \equiv 20 \log_{10} W_{\mathrm{rms}} , \qquad (5)$$

L_p is the sound pressure level,

$$L_p \equiv 20 \log_{10} p_{\mathrm{rms}} \qquad (6)$$

and S_{amp} and S_{dig} are, respectively, the amplifier and digitiser sensitivities, in decibels

$$S_{\mathrm{amp}} \equiv 10 \log_{10} A \qquad (7)$$

and

$$S_{\mathrm{dig}} \equiv 10 \log_{10} D . \qquad (8)$$

The sound pressure level is calculated by rearranging Eq. (4) in the form

$$L_p = (L_W)_{\text{cal}} - S_{\text{amp}} - S_{\text{dig}}, \tag{9}$$

The digitised level L_W is calculated by Cool Edit as the "RMS intensity", always using a 1000 ms averaging window. The RMS intensity of the direct arrival from each ping was recorded on the calibrated hydrophone. The digitiser sensitivity S_{dig} was measured in the lab prior to the cruise. An input signal of 0 dB rms re 1 V was fed to the digitiser system, for which Cool Edit calculated an RMS intensity of -6 dB rms. This implies a sensitivity of

$$D = \frac{(1/2)^2}{1\,\text{V}^2} \tag{10}$$

and therefore, from Eq. (8)

$$S_{\text{dig}} = -6\ \text{dB re}\ 1\ \text{V}^{-1}. \tag{11}$$

The sensitivity of the total DTAG digital recording system, which includes a second AAF prior to digitisation, was then calculated on a ping-by-ping basis:

$$S_{\text{DTAG}} = (L_W)_{\text{DTAG}} - L_p, \tag{12}$$

where $(L_W)_{\text{DTAG}}$ is the RMS intensity (as calculated by Cool Edit) of the direct arrival from each ping recorded on the DTAG. Each ping was digitally downloaded from the DTAG and analyzed in this way using Cool Edit. The results for DTAG no. 220 are presented in Table 4.2 below.

	Left Channel		Right Channel		
Sonar Type:	S_{DTAG}	St. Dev.	S_{DTAG}	St. Dev.	# of pings
	dB re 1 μPa^{-1}	dB	dB re 1 μPa^{-1}	dB	
LFAS	-185.5	0.65	-174.3	0.74	17
MFAS	-191.4	1.06	-180.7	1.35	34

Table 4.2. Calibrated sensitivity of DTAG no. 220 hydrophones.

These results are consistent with the input gain settings applied to the left (0 dB) and right channels (12 dB) within the DTAG, and the presence of a shallow high-pass filter at frequencies below 2 kHz (put in place to reduce low-frequency flow noise).

4.7 Active acoustic detection of killer whales

The purse seiner "Inger Hildur" was hired by Simrad as the platform for a feasibility study to test the possibility of using fisheries sonars for marine mammal detection. The Inger Hildur participated on the last week of the trial. She is equipped with both Simrad SP90 and Simrad

SH80 sonars. Two experienced sonar operators from Simrad were operating the sonars. The two different sonars were not transmitting simultaneously. The Inger Hildur was searching for killer whales randomly or based on observations from the Sverdrup team. Sonar recording were only collected during daylight hours, when simultaneous visual observations of the whales were possible. When encountering whales, the vessel slowed down or stopped. Sonar recordings of the observed killer whales where done at different distances and depths. Data were collected throughout the observation periods either as screen dumps or as raw data recordings. Only recordings verified by visual observations of whales are used in the analysis.

5 Permits, Risk management and public outreach

5.1 Permits

The sonar exposure experiments on killer whales are considered an animal experiment according to Norwegian legislation. These experiments where carried out in accordance with permits from the Norwegian Authority for Animal Experimentation (permit no 2004/20607).

The LK-TAGs contained radio frequency transmitters in the 142 MHz band, and permits for the use of these were issued by the Norwegian Post and Telecommunications Authority (permits no 13673). The DTAGs contained radio frequency transmitters in the 148 MHz band, which is dedicated for military purposes. Permit for the use of these were given by the Norwegian National Joint Headquarter.

5.2 Risk management

Potential risks of operating a high power sonar source in the operation area were identified and a risk management plan was established (Appendix C). The risk inventory included risks of causing injury to human divers, risk of causing injury to marine mammals, risk of impact on whale safari activities, risk of impact on fisheries and risk to fish farms. Details of risk management procedures are given in Appendix C.

5.3 Incidents

During the trial a few undesired events took place. Most of them were already identified in the Risk Management Plan (Appendix C), and where handled accordingly.

Because of the unexpected situation with very few whales in the Vestfjorden, and none in the Tysfjord, during the trial, we unfortunately ended up working with the same group of killer whales utilized by some of the whale watching companies on several occasions. Some of the operators expressed concern and argued that we were interfering with their activity. If weather permitted we tried to avoid this situation and searched more outlying areas of the fjord. However, this was not always possible. The source ship (Sverdrup) was kept away from the most intense whale watching areas. However, the tag boats occasionally approached animals being utilized by whale watchers. However, the animals were approached carefully at slow speed, and the tag boats did not disturb the animal more than the whale watching boats. If a whale was tagged, no exposure experiments were conducted if the whale watchers were still utilizing the tagged group. On one occasion a control experiment was performed, which implied that the source ship was approaching the tagged animal but not transmitting, while the whale watchers were still in the area. On two occasions exposure experiments on tagged animals were cancelled because of intense whale watching activity, or because divers were in the water close to the tagged group.

We had some complaints from fishing vessels that we occasionally were towing the Delphinus or Socrates in areas with gill nets. We received daily up-dates from the Coastguard on the positions of gill nets and were particularly careful when sailing through such areas. We never experienced events where gill nets were caught by the tow.

On the 14. of November we picked up information from a local fisherman that a minke whale was found stranded in Ofotfjorden. This is rear in this area at this time of the year. According to the established procedure in the risk management plan (Appendix C) the appropriate authorities were notified. Terje Josefsen, an expert marine mammal pathologist from the National Veterinary Institute, was asked to perform an autopsy on the stranded animal as soon as possible. This was done at our cost and the pathologist was assisted by our research team. According to the autopsy report (Josefsen 2006) the pathological findings are indicative but not conclusive on a time of death preceding our first sonar experiment at the 9. of November. Further findings included a 70 cm long fish which was partly digested and stuck in the esophagus of the animals with the tail down. Also blood congestions in the lung and an anaemic liver were noted. These findings are indicative of suffocation and circulation failure caused by an increased pressure in the abdomen. This might have happened because of pressure building up in the rumen when the esophagus became obstructed by the fish. This is a well known phenomena called tympani in terrestrial ruminants. The animal was probably also dead when it stranded. Thus, any connection with sonar transmission in the area seems highly unlikely.

5.4 Public outreach

Given that part of the background for the trial was strong negative reactions in the local community to the use of military sonar in this area, we realized a strong need to inform the public about our activities. In advance of the trial information was sent to the local press about the planned activities. In addition a public information meeting was held at Tysfjord Tourist Center. The local press and local stakeholders such as environmental groups, fisheries organisations and the tourist companies involved in whale watching activities, was invited to this meeting. The Royal Norwegian Navy also participated with a high ranking officer, explaining why it is important for them to train on the use of their active sonars under varying geographical and oceanographical conditions. FFI was leading this meeting and informed about the plans for the trial. A second meeting was held between the research team and the tourist companies during the first week of the trial. This meeting was arranged upon request from the whale watching companies. During the trial the FFI information office had assigned a person to handle request from the media and the public. However, the research team had frequent direct communication with many of the tourist operators at sea. Most of these encounters were in a positive spirit. Several of the whale watching companies expressed support for the research, but not all. Some of the information which appeared in the local media was very misleading and was therefore contradicted by the research team and the FFI information office. After the trial several articles have been posted on the web about the achievements of the trial. Scientific reports, including this report, on the result from the trial, will be publicly available.

Date	**Media**	**Title**	**Web address**
17.10.06	Fiskaren	*Forsvaret eksperimenterer i Vestfjorden*	
11.11.06	Lofotposten	*Skyr spekkhoggere sonar?*	
14.11.06	Fiskeribladet	*Vært a skræmt no?*	
14.11.06	NRK Nordland	*Forsvaret skremmer spekkhoggerne*	www.nrk.no/nyheter/ distrikt/nordland/
16.11.06	Fremover	*Protester mot radiomerking*	www.fremover.no
17.11.06	Forsvarsnett	*Mer kunnskap-best for alle parter*	www.mil.no
17.11.06	Fremover	*Avviser kritikk mot radiomerking*	www.fremover.no
17.11.06	Fiskaren	*Kristisk til forsvaret i Vestfjorden*	
22.22.06	Fiskaren	*Forsvaret skremmer turister på kvalsafari*	www.fiskaren.no
23.11.06	Lofotposten	*Turistene skremt av forsvaret*	www.lofotposten.no
27.11.06	Lofotposten	*Skremmer ikke turister*	
08.12.06	Forsvarsnett	*Skremmer sonaren sild og hval?*	www.mil.no
07.03.07	Forsvarsnett	*Banebrytende forskningsprosjekt*	www.mil.no
March-07	TNO magazine	*Sea mammals and the impact of man-made sonar*	www.tno.nl

Table 5.1. Some of the articles written about the trial in newspapers or other written media.

6 Preliminary results

6.1 Sound speed profiles and acoustic propagation conditions

The mixed surface layer was of different depths in different areas within the operation area of the trial. Two profiles deviates from the rest, with a shallower surface layer. These are the two profiles obtained in Sagfjorden, a very long and narrow fjord. Comparing profiles obtained at approximately the same position, at different times, it seems to be a trend that the depth of maximum sound velocity is getting deeper over time. This can be explained be the cooling of the surface water, due to low air temperatures. This will also mean that the depth of the surface channel is increasing over time. But the horizontal changes in the survey area are more dominant than the changes over time.

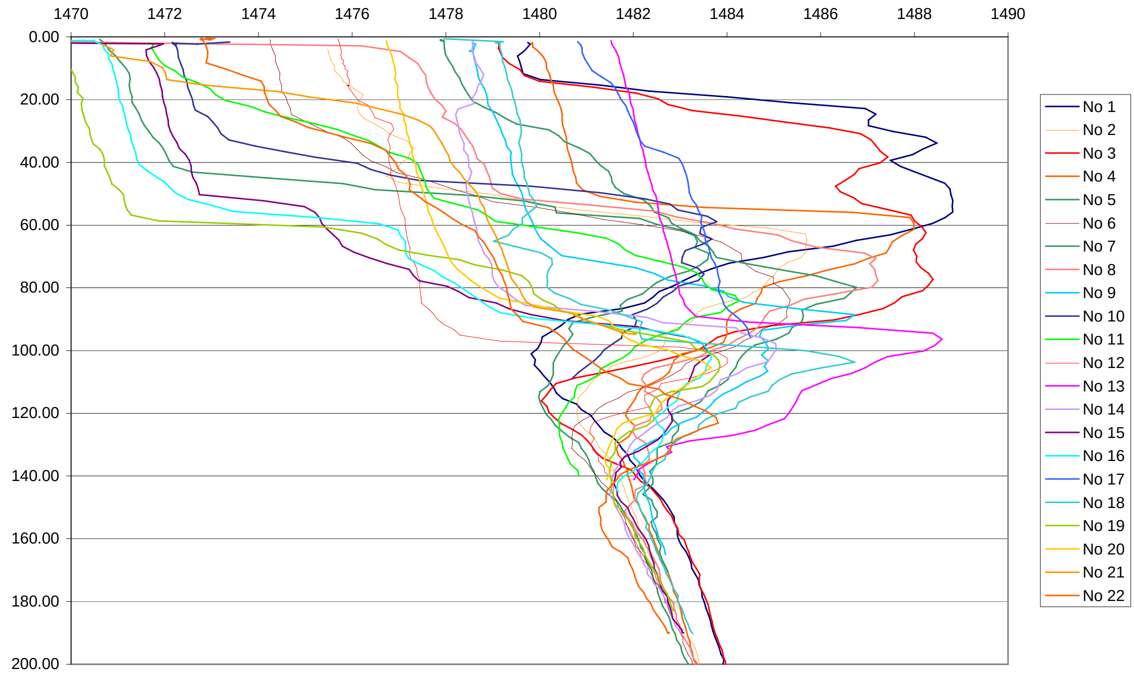

Figure 6.1. The figure shows all the sound velocity profiles obtained during the cruise. The profile number refers to the position given in table 4.1. and shown in fig. 4.1.

As an example, the sound speed profile collected after the herring experiments on November 12. is used to predict transmission conditions using the acoustic model LYBIN (fig. 6.2). The depth of the source was 35-40 m on this occasion.

The calculated transmission loss for the sound velocity profiles obtained in connection with the herring experiments, are not very different from each other up to a distance of about 1 km from the source. At longer distances from the source there is more variability on the estimated transmission loss, especially close to the surface.

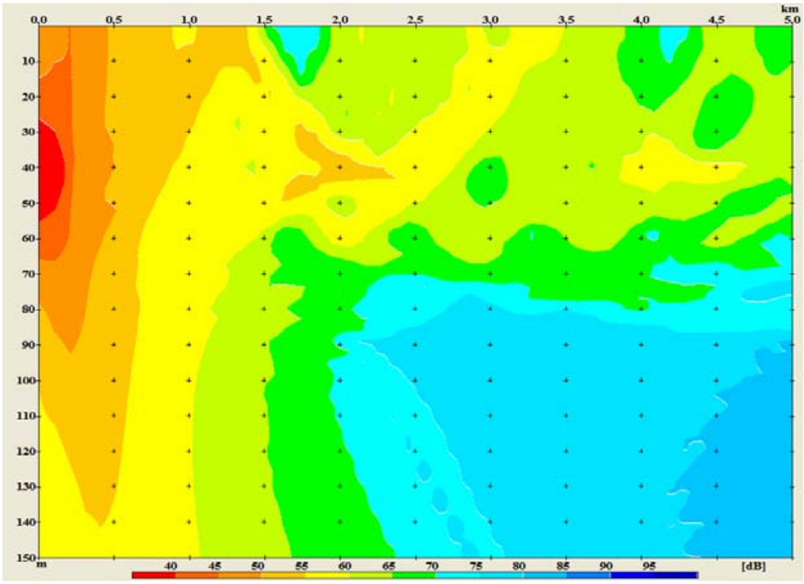

Figure 6.2. Calculated transmission loss using LYBIN and sound velocity profile no 6, obtained at Nov. 12. which is the position and time for a herring experiment. The assumed transmitted frequency is 6.5 kHz and source depth 40m. The distance across the area is 5 km, the depth is 150m.

Similarly, the sound velocity profiles taken in connection with the exposure experiments on killer whales are also used to calculate transmission conditions during these experiments using LYBIN (figure 6.3).

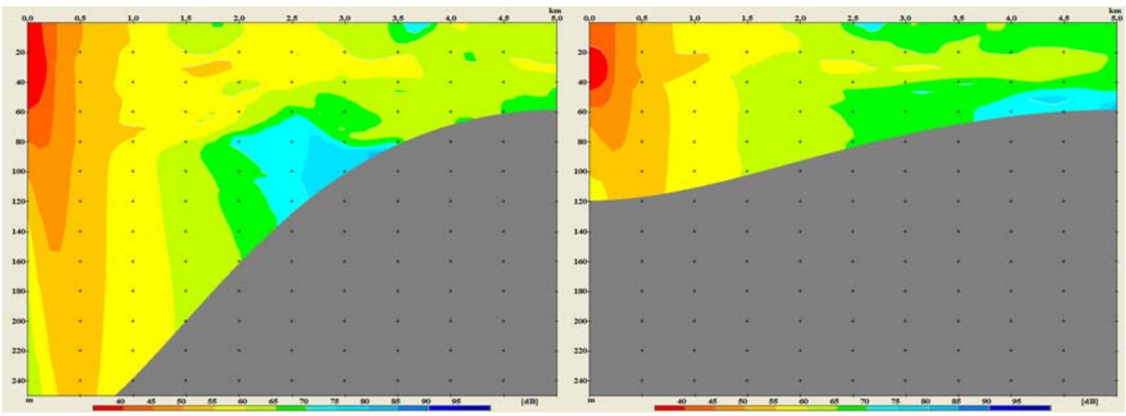

Figure 6.3. Calculated transmission loss using LYBIN and sound velocity profiles obtained in connection with controlled exposure experiments (CEE) on killer whales. Left: transmission loss based on CTD profile no 7, obtained in connection with the LFAS CEE. The transmitted frequency is assumed to be 1.5 kHz and source depth 30m. Right; transmission loss based on CTD profile no 17, obtained in connection with the MFAS CEE. The transmitted frequency is assumed to be 6.5 kHz and source depth 30m. The bottom profiles are extracted from bathymetric maps, but is somewhat simplified.

6.2 Sonar exposure experiments on killer whales

Though we faced many challenges, we were able to DTAG killer whales and conduct CEEs. The data obtained are of high quality, though we had hoped to collect more total data. The research staff and tools available were very suitable for the planned research, including vessel support, acoustic listening system Delphinus, visual search teams, DTAGs and tagging teams, behaviour observation teams, and the acoustic source Socrates. All of the research tools available contributed usefully as planned, except the Nøkken which was unable to move widely enough to support search and tracking efforts as planned.

Whale numbers were substantially lower during 3S-2006 than during the pilot-study period in 2005. On days when we did find whales, there were fewer groups available for research than during the pilot study in 2005, and the weather was worse because we were working further out in the Vestfjorden system. Nonetheless, we were able to tag 6 killer whales in 5 different groups with DTAGs. These tags collected a total of 17 hours and 46 min of data while deployed. The DTAG data have been inspected, both sensors and acoustics, and are of high quality. We conducted 1 sonar exposure experiment on 1 tagged animal using the LFAS-signal, 1 sonar exposure experiment on 2 animals using the MFAS-signal and 1 control experiment on 1 animal. This was less than our goal, though we made intensive efforts during the cruise to improve our methodology.

We assessed possible reactions of killer whales on two different scales. The broader scale linked the presence or absence of whales in eastern Vestfjorden depending on sonar activity. Such activity could have been generated either by the Socrates source under our control, or by the frigate KNM Narvik participating in the FLOTEX exercise, having a hull mounted sonar transmitting in the 5-8 kHz frequency band. The finer scale was reactions of tagged killer whales to an approaching sonar during controlled exposure experiments. While our analyses are still ongoing, some preliminary results are provided below.

6.2.1. Broad scale reaction to sonar signals

Relating to sonar use by ourselves, on 4 occasions, whales were found the following day near the location of a herring sonar exposure trial (for 2 trials whales were not seen the day before or after). On 1 occasion, whales were not found the day following a night time trial, but the whales observed the day before were moving away to the west, and bad weather made it impossible to search westwards. Thus, night time use of the Socrates source for herring experiments did not appear to strongly displace killer whales from the Eastern Vestfjorden area. In contrast, whale numbers apparently declined in Vestfjorden, with none seen for 3 days, following the start of the FLOTEX naval exercise, during which active sonars were used.

6.2.2. Fine scale reaction to sonar signals

During the LFAS CEE (1-2 kHz sweep), the tagged whale continued travelling in its group and did not appear to avoid the source (fig. 6.4). During the MFAS CEE (6-7 kHz sweep), two whales were tagged. The tagged whales along with other whales that had been carousel-feeding together, ceased feeding during the approach of the sonar and moved rapidly away to the South and West (fig. 6.5). The depth records from this experiment also indicate that the avoidance response seen is also associated with an intermittent change in diving behaviour (fig. 6.6).

The sonar arrivals were recorded by the DTAGs with high fidelity, and analysis of the received levels is clearly feasible. Though our analyses of the received sonar signals are still in progress, initial analyses indicate that during both CEEs, the tags recorded maximum single-ping received levels near 150 dB re 1μPa.

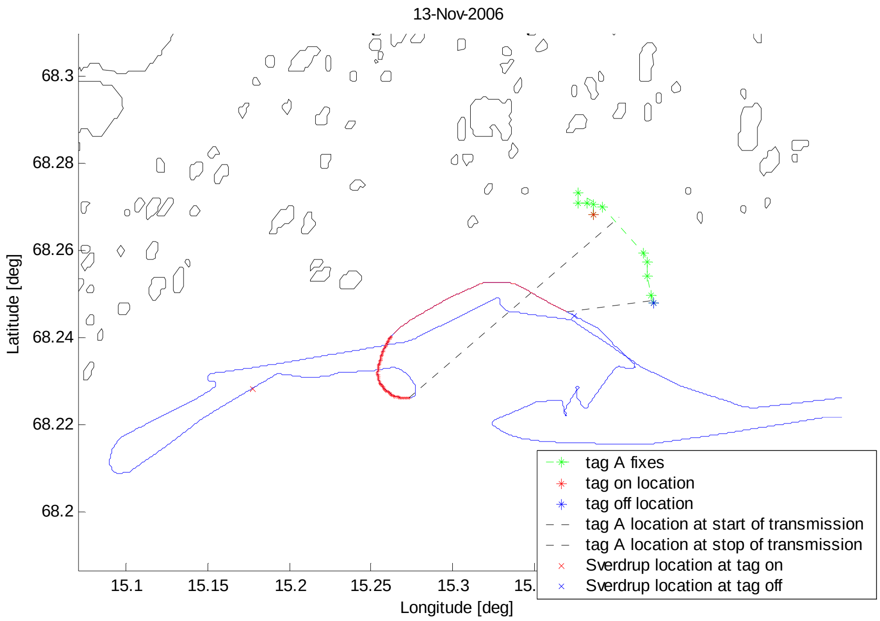

Figure 6.4. Track of the tagged whale and the Sverdrup during the LFAS CEE. Note that the whale turned south during active LFAS transmissions, more closely approaching the course of the source ship (Sverdrup). The Sverdrup track during transmission is shown in red.

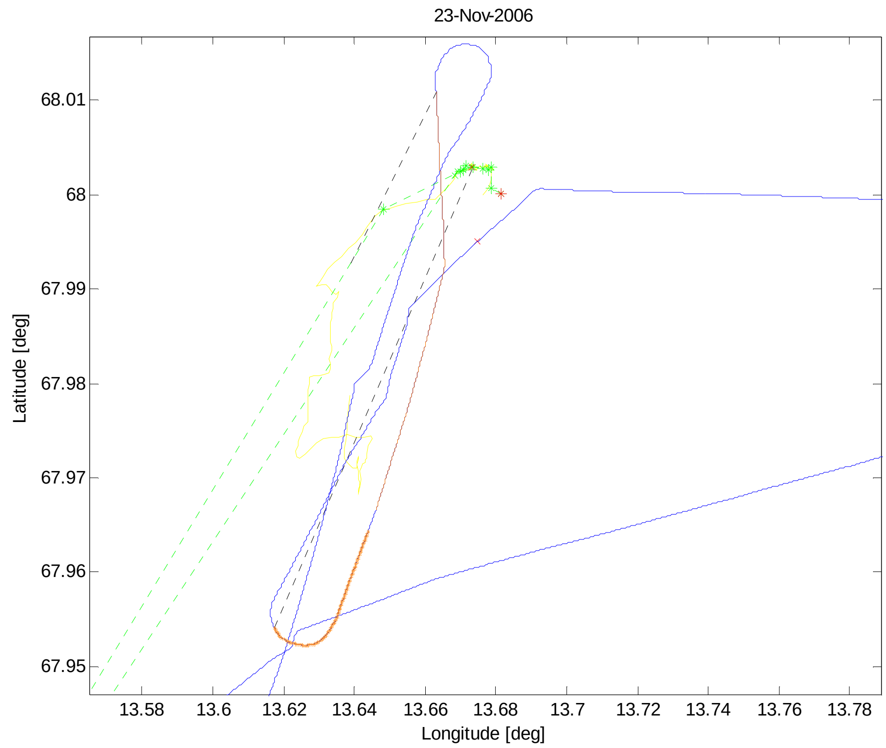

Figure 6.5. Track of the tagged whales (green), the observation boat (yellow) and Sverdrup (blue) during the MFAS CEE. The Sverdrup track during transmission is shown in red.

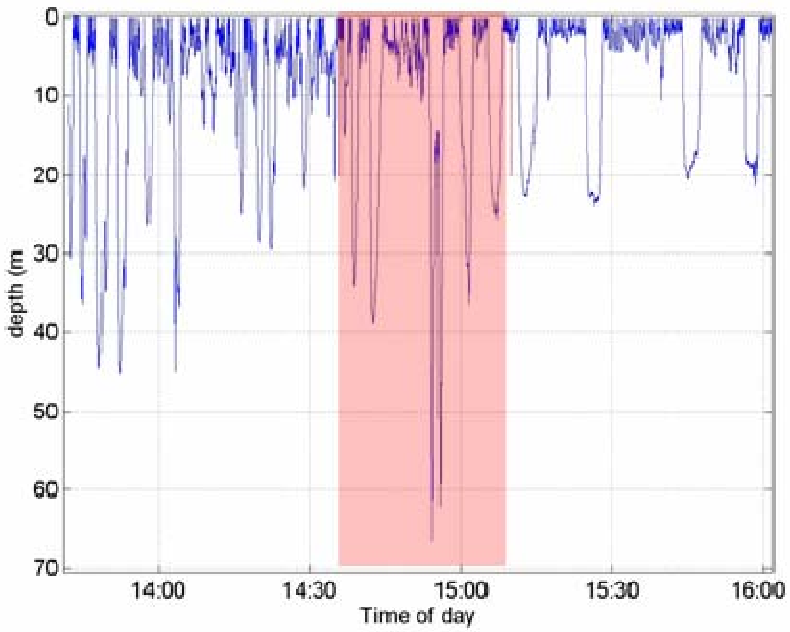

Figure 6.6. Diving record of one killer whale before, during (pink shaded area), and after transmission of the MFAS signal. During the exposure the animal performed an unusual long and deep dive. During the ascent the animal also reversed its ascent and started descending again. This unusual diving pattern was also seen on the second tagged animal synchronously, and was immediately followed by rapid movement by all of the whales in the area away from the source ship.

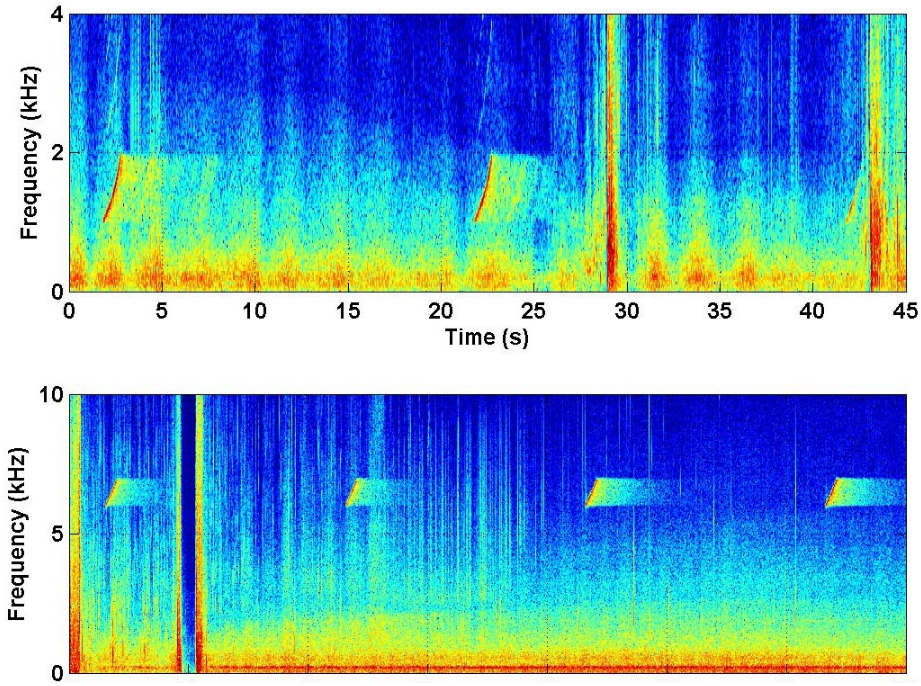

Figure.6.7. Sample spectrograms from the LFAS (top) and MFAS (bottom) DTAG recordings. Note the high signal to noise ratio of the received pings, except when the whales surfaced to breathe.

More data are required to describe how killer whales might behaviourally respond to sonar, but our preliminary results suggest that killer whales might be particularly sensitive to sonar signal in the MFAS frequency band. This preliminary conclusion is supported by the finding that whales were not found in the eastern Vestfjorden basin following the start of the FLOTEX exercise, and the apparently strong reaction to the MFAS CEE. In contrast, any reaction to the LFAS CEE appeared negligible.

6.2.3. Planned analysis and future data collection

1. Systematically measure received sound-exposure levels during CEEs.
2. Calibrate DTAG sensor data and link sensor data to acoustic time series.
3. Compare behaviour during CEEs to baseline data set.
4. Conduct additional CEEs with killer whales
5. Retrospective analysis of whale presence in relation to military exercises

6.3 Sonar exposure experiments on herring

Acoustic data were recorded with one ping per second. Herring density is given as acoustic volume backscattering values (Sv). For each ping, the median depth of the herring layer has been calculated. When testing for effects of sonar transmission, channels covering the main herring layer have been defined as the median depth of the layer ± 50 m, giving a 100 m channel. The Sv values in this channel are used in the analyses. These values were averaged over 30 sec intervals, and figures showing the 10 min before and 10 min after time of passage were created for the three transmission types, to determine whether there was any apparent difference between them, and detect possible differences in Sv values before and after time of passage. Also the median depth of the herring layer were averaged for each 30 second, and similar figures were made to detect if there was any change in depth of the herring layer before and after passage, and between the different transmissions.

Block number	Date	Time	Transmission
0	12.11.2006	19:38 - 20:02	Silent
1	12.11.2006	20:42 - 22:16	LFAS-MFAS-Silent
2	12-13.11.2006	22:59 - 00:45	MFAS-SIlent-LFAS
3	13.11.2006	01:24 - 03:07	Silent-LFAS-MFAS
4	16.11.2006	22.40 - 23:58	MFAS-LFAS-silent
5	17.11.2006	00:46 - 02:02	Silent-MFAS-LFAS
6	17.11.2006	02:42 - 03:53	LFAS-Silent-MFAS
7	18.11.2006	13:21 - 14:34	MFAS-LFAS-silent
8	18.11.2006	14.44 - 15:55	Silent-MFAS-LFAS
9	18.11.2006	16:44 - 17:50	LFAS-MFAS-Silent
10	22.11.2006	18:21 - 19:32	Silence-Orca-LFAS
11	25.11.2006	18:50 - 20:22	LFAS-Silent-Orca-Silent
12	29.11.2006	16.18 - 17:38	LFAS-Silent-MFAS
13	29.11.2006	18:28 - 18:46	MFAS-Silent-LFAS
14	29.11.2006	20:32 - 21.43	Silent-LFAS-MFAS
15	30.11.2006	14.10 - 14:40	Orca

Table 6.1. Overview of the blocks conducted in the herring exposure experiment. A total of 15 blocks were conducted, of these 12 were LFAS-Silent-MFAS runs and 3 of them killer whale playbacks.

<u>6.3.1. Sonar transmission experiment</u>

A first look at the data does not indicate any obvious avoidance reaction. The experiments done at herring layers located relatively shallow in the water column (25-50 m depth) tend to show a minor downwards reaction as the source ship and towed body passed over the echosounder (figure 6.8a). When herring layer were located deeper, or were less dense, this reaction was not detectable (Figure 6.8b). The observed reaction on dense, shallow layers was never apparent before the exact time the source ship passed the observing echosounder. Based on the expected transmission loss (fig. 6.2) and hearing curve for herring (fig. 1.1), the LFAS signals is expected to be clearly detectable to the herring from the point of full power transmission 1 nm away. The observed reaction to the passing ship and towed body by shallow herring layer was the same for all three types of transmissions (Figure 6.9). This might indicate that the reaction was a response to the source ship itself, and not to the sonar sound. Such reaction to a passing ship has previously been documented for many species of pelagic fish (Mitson *et al.* 1995), including herring in this area (Vabø *et al.* 2002, Ona *et al.* 2007).

For each block conducted figures showing Sv values in the 10 min before and after passage of the ship have been made, to compare the reaction of the herring to the different transmission types. No clear trends could be observed from this analysis. The same patterns were mostly observed on both echosounders, independent of which one the experiments were conducted on. Also, no differences could be detected between the time before and after passing of the source ship (Fig. 6.10).

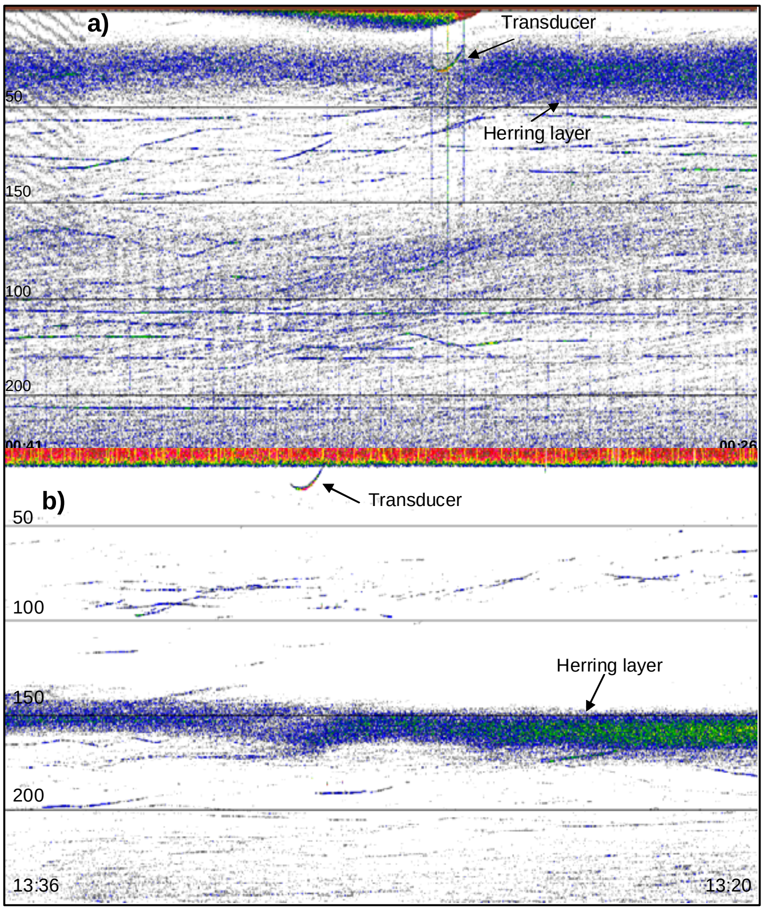

Figure 6.8. Echograms showing herring layers located a) shallow and b) deeper in the water column. When the herring layers are located at depths of 25-50 m depth (a), a minor downwards reaction can be seen as the source ship and tow-body passed by. When herring layers are located deeper (b), no reaction can be detected. Echogram in a) are from 12/11-06, and transmission type is LFAS, and echogram b) is from 18/11-06 with transmission type MFAS. The echo from the turbulence created by the passing source ship and the direct echo from the towed body transducer can clearly be seen on panel a). The timeline runs from right to left.

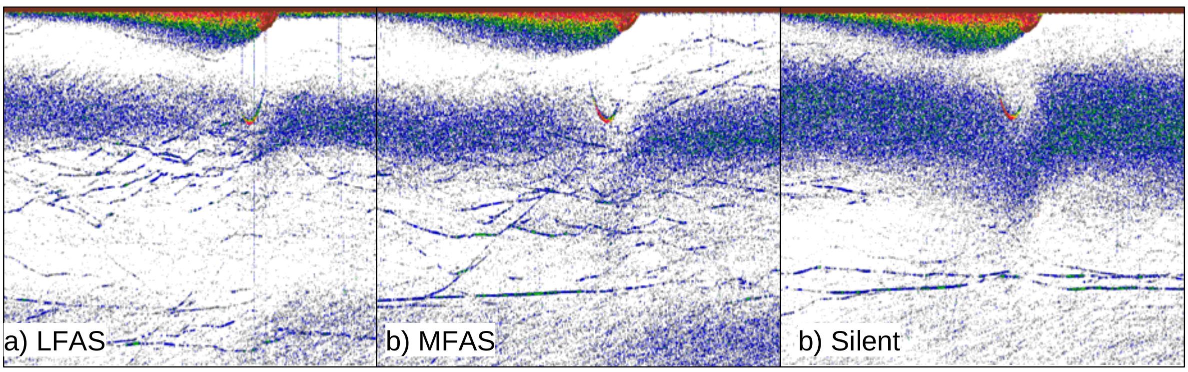

Figure 6.9. Echograms from the three different transmission types. From experiment 12/11-06. The timeline runs from right to left.

To detect possible vertical escape reactions of the herring layers in response to the transmission, similar figures as for backscattering, were made for median depth of the herring layers. No apparent differences in depth could be detected between neither the transmission types nor the two different echosounders (fig. 6.11).

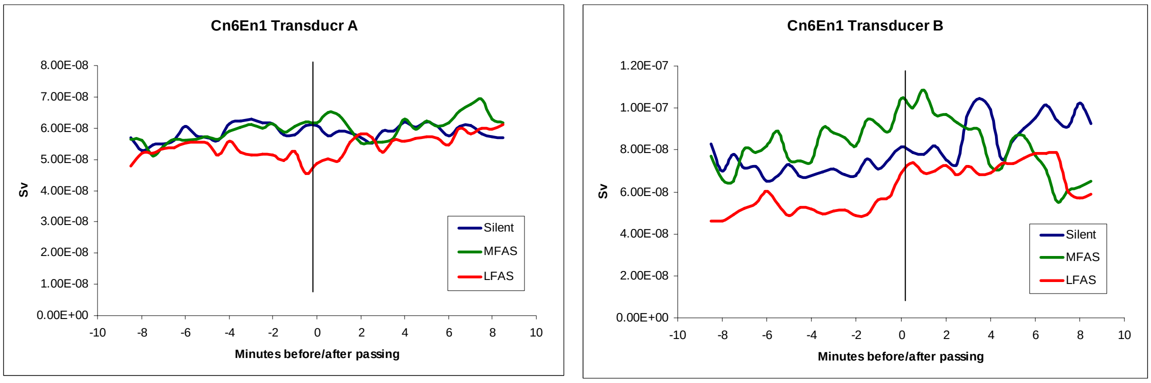

Figure 6.10. Sv values for the three transmission types in one block. The data in the figure is from the experiment at 29/11-06, and the experiment was conducted on echosounder B. The vertical line indicate the time of passage. No clear reactions can be seen on any transmission type, and the same pattern is seen on both echosounders. This result indicates that there is no detectable horizontal avoidance in response to the sonar signal exposure.

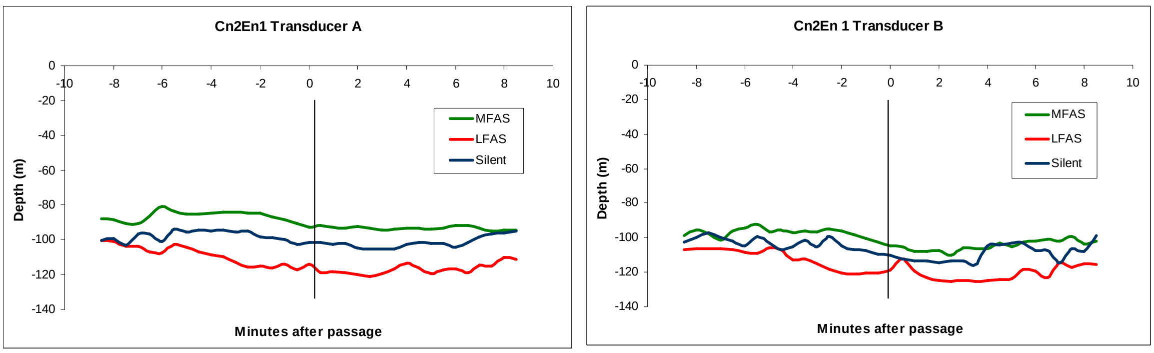

Figure 6.11. Median depth of the herring layers from 10 min before to 10 min after passing of the source ship. The data in the figure is from the experiment at the 18/11-06, and the experiment was conducted on echosounder B. No striking differences can be detected between the three transmission types, and similar patterns are seen on both echosounders. This result indicates that there is no detectable vertical avoidance in response to the sonar signal exposure.

6.3.2. Killer whale playback experiments

Three killer whale playback experiments were done. The first two were conducted as a block of silent-LFAS-orca runs with the ship passing by with the sonar source deployed, while the third experiment was only playback from one of the tag boats.

The first experiment (Fig. 6.12a) showed a decrease in Sv values during the playback period, and a subsequent return to the pre exposure level after the playback stopped. A similar drop in Sv values were also seen on the second echosounder (A), but this was much less pronounced and lasted much shorter. This indicates a horizontal movement of herring during playback. However, the second experiment (Fig. 6.12b) showed a small increase in Sv values during the playback period, and the pattern was almost identical on both echosounders. The last experiment (Fig 6.12c) showed again a decrease in Sv values during the playback period, but the Sv value continued to decrease after the playback stopped. This pattern was similar on both transducers.

Concerning median depth of the herring layers, all three experiments showed a downward movement of the herring layer on both transducers (Fig. 8.13).

The strongest herring reactions, both horizontally and vertically, were found in experiments 1. This experiment was conducted on herring layers distributed shallower in the water column than experiment 2 and 3. The received level of the playback sound might therefore have been higher in the first experiment. In all three experiments, similar reactions were detected on both echosounders, indicating that the sound is above reaction threshold also on echosounder A.

6.3.3. Summary and preliminary conclusions

No apparent differences could be detected between acoustic backscattering (Sv) values from the herring layer before and after passing of the ship, independent of transmission types, indicating that the herring does not avoid sonar signals by a horizontal avoidance reaction. Further more, no apparent differences could be detected in median depth of the herring layer before and after passage of the ship, independent of transmission type, indicating that herring did not show any vertical avoidance reaction to the sonar signals. However, shallow herring layers react by an intermittent minor downwards reaction as the source ship passed. Since this reaction seemed to be independent of transmission type, it appears to be a reaction to the passing source ship not a reaction to the sonar signals. No such reaction can be seen on deeper herring layers even though the sonar signals penetrate to this depth at a high level.

Reactions to killer whale playback seem to cause a stronger reaction on herring layers than sonar transmission, indicating that the herring may be able to distinguish between LFAS signals and killer whale calls and feeding sounds. However, only three experiments were done, each with somewhat different result. Hence, more experiments should be conducted to establish whether the reactions observed are due to the herring responding to killer whale feeding sounds or other stimuli.

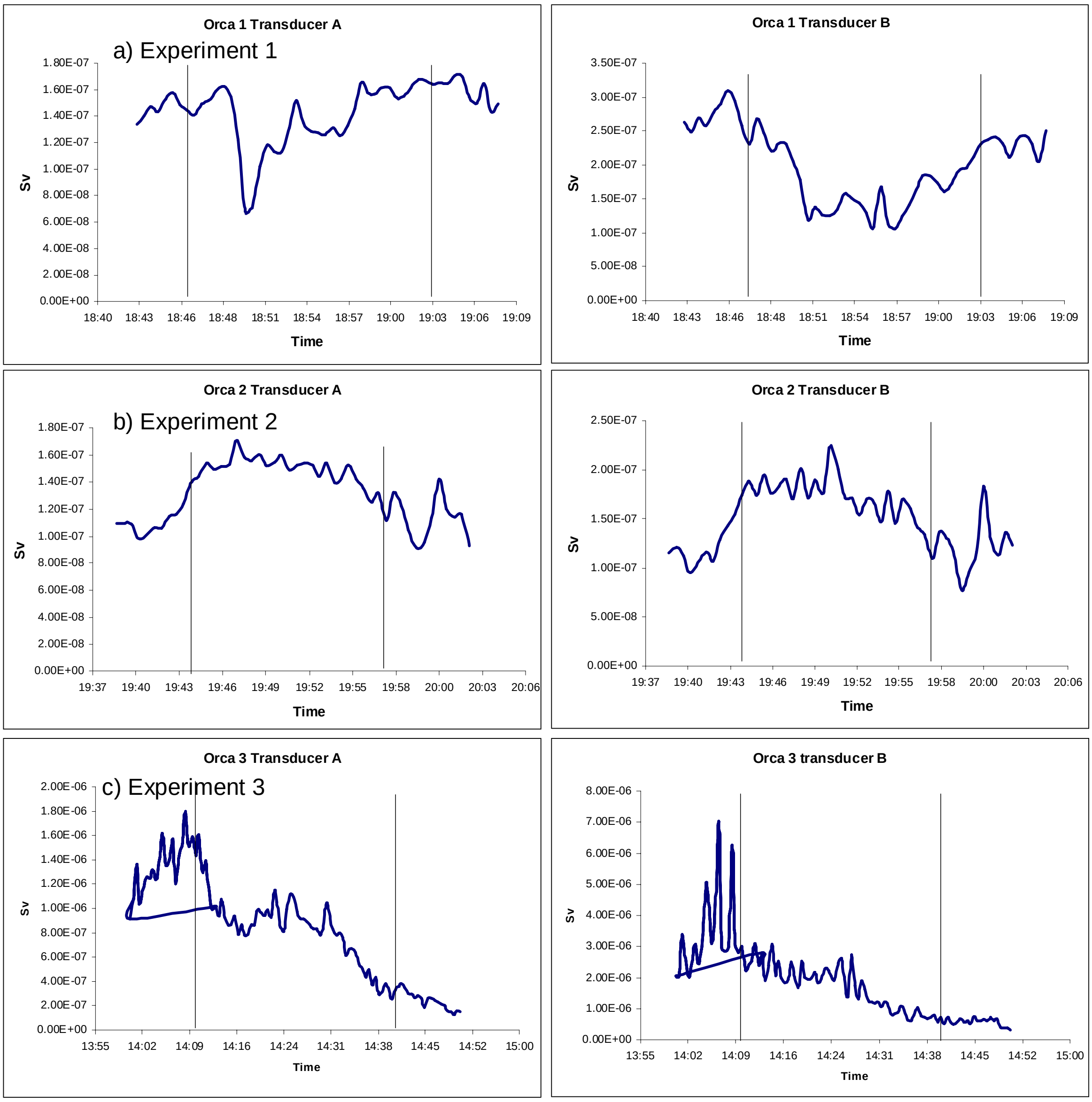

Figure 6.12. Acoustic volume backscattering values (Sv) for the killer whale playback experiments. The vertical lines indicate start and stop time of the playback. All experiments were conducted on echosounder B.

6.4 Passive acoustic detection of killer whales

The Delphinus was deployed 26 times during the 28 days at sea. It recorded for 294 hours, made 37082 detections and collected 4.5 Tbytes of data. About 4038 of these detections were classified as bio-detections. Most of these were killer whales but long finned pilot whales were also detected acoustically.

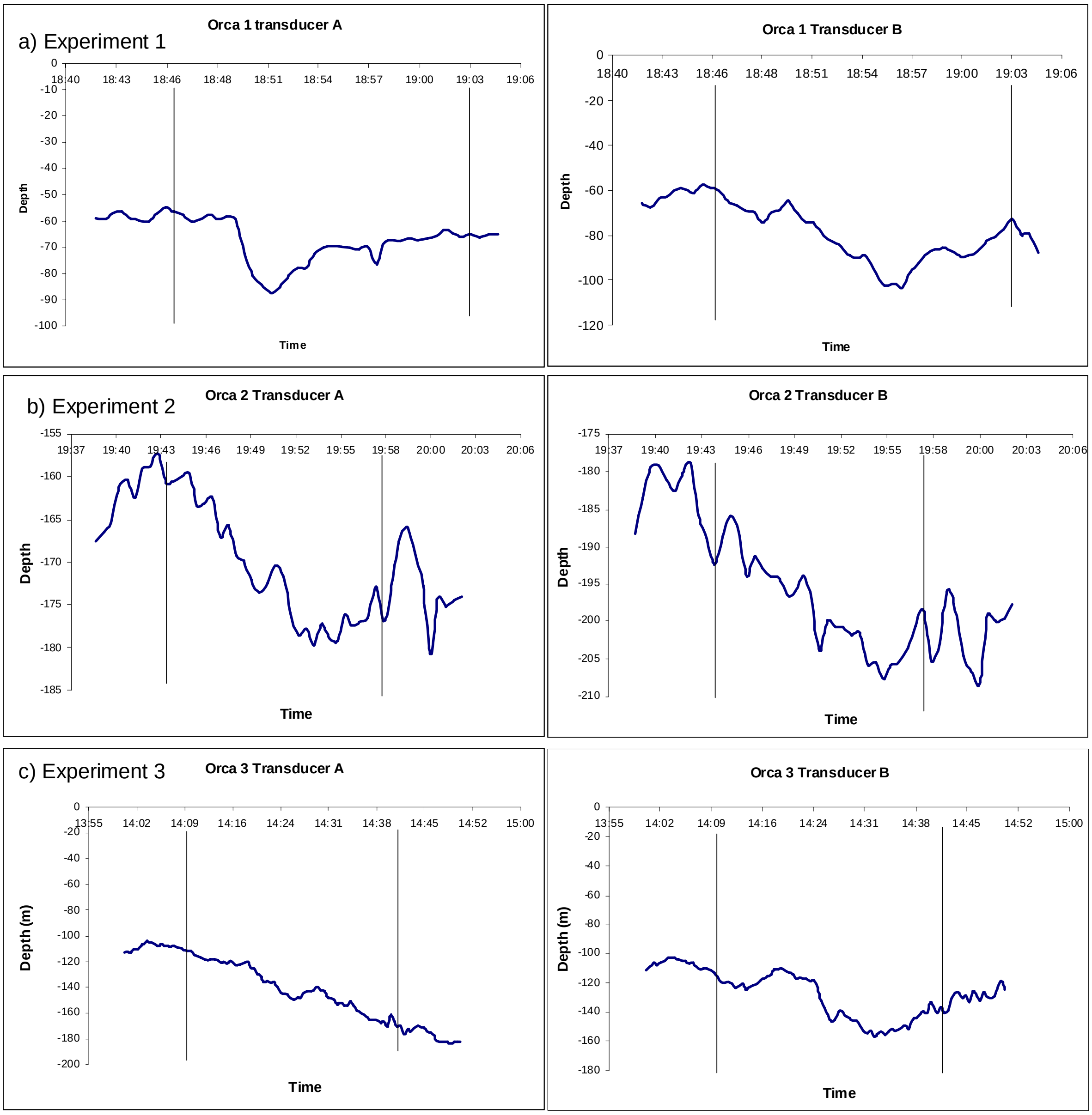

Figure 6.13. Median depth of herring layers during killer whale playback experiments. Vertical lines indicate start and stop time for the playback.

During the acoustic survey periods, the Delphinus processing chain allowed the TNO operators to monitor the area acoustically in real time during the day and to analyse night recordings in a relatively short amount of time in the morning (before daylight). This enabled a quick selection of the best area for tagging, such that the ship could be in a favourable area for the tag boats to be deployed at first light. It proved particularly efficient during the dark hours when visual monitoring was impossible, but it also has its value during day time, when the system was sometimes detecting mammals before they were at a visual detection range. Most of the times, acoustic detections could be correlated with visual observations during daylight hours.

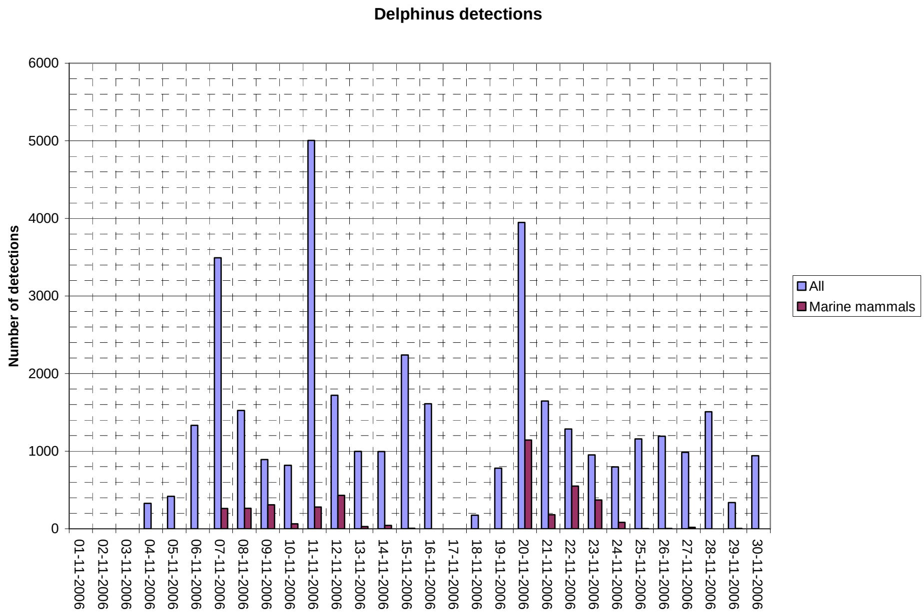

Figure 6.14. Number of detections and marine mammal detection with the Delphinus array throughout the trial.

6.5 Active acoustic detection of killer whales

Whale detections on the sonar screen were confirmed visually, however, fewer whales were typically seen visually on the surface than on the sonar screen. A direct comparison of the detection performance between the SP90 and SH80 sonar was difficult since they were not used simultaneously. However, the echo of the whales were clearly stronger at the SP90 sonar than on the SH80, but detection performance was similar at short ranges (<400m). At long ranges the SP90 was superior to the SH80. The main reason is the much higher sound absorption of the SH80 operating frequencies (37 dB/km) compared to the SP90 (5 dB/km). Maximum detection range of the SP90 was 1500 m, but this will vary with the transmission conditions (sound speed profile) and background noise. The SH80 did not give reliable detections beyond 400 m.

No apparent reaction to sonar transmission or the vessel was observed. However, the survey area is a fishing ground for many vessels using similar sonars to locate herring schools, and whales may therefore be well habituated to both sonar signals and vessels.

Positive whale detection can be difficult based on the echo from a target alone. In addition to the direct echo from the whale, weaker echoes were frequently picked up from the wake of the surfacing whale. This produced a characteristic pattern of echoes which could be used to classify the target. In addition whale vocalisation could be seen on the sonar screen and even heard on the sonar sound channel. The primary frequency band of the calls of killer whales are from 1-12 kHz, but extensive harmonics regularly range up to at least 48 kHz and could be registered by the SP90 system (Miller 2002). Killer whale echolocation clicks have peak energy at frequencies from 45-80 kHz, with 35-50 kHz bandwidth (Au et al. 2004), and therefore overlap with both the receiving frequency band of the SP90 and SH80. It is likely that the echo from a large swim bladder fish like cod and saithe can be confused with echoes from whales. Detections of vocalization and the wakes from the surfacing whale are therefore important criteria for classification of the detected target as a whale.

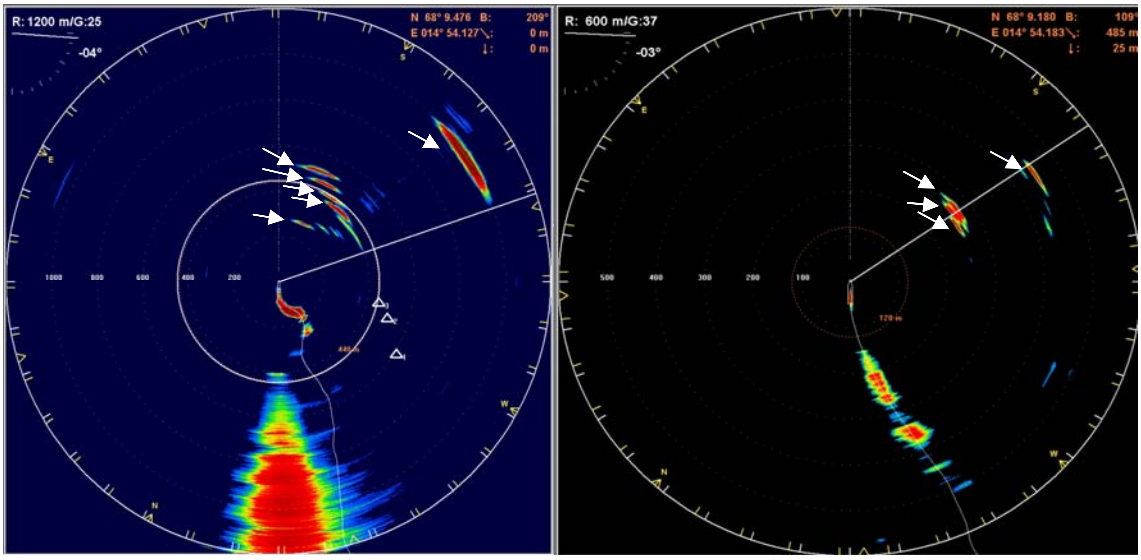

Figure 6.15. Typical sonar screens during killer whale detections. The position of the ship is in the centre. Behind the vessel echoes from the ships wakes are seen. Left: Sonar screens from the SP90 with echoes from at least five killer whales (white arrows) at ranges from 250 to 1000 m. Right: Sonar screen from SH80 with whale echoes from four killer whales (white arrows) at ranges from 250 to 450 m.

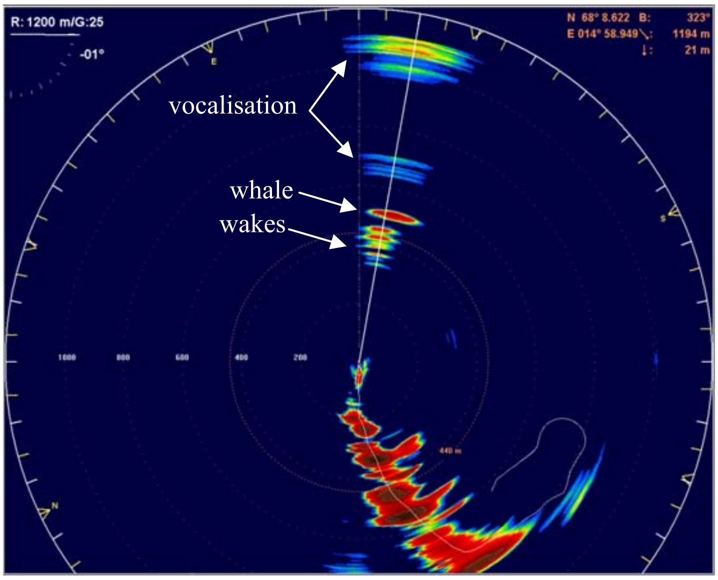

Figure 6.16. Sonar picture from SP90 showing the direct echo from a single whale at 500 m range, and the characteristic pattern of echoes from the wakes of the surfacing whale moving away from the ship. In addition apparent echoes caused by the vocalisation of the animal can be seen. These signals are mostly seen more distant than the whale because the sonar processes the received signal with a time dependent amplification.

7 Recommendations

7.1 Future studies on the effects of sonar on killer whales

The 3S-06 cruise was successful in demonstrating that we have the required personnel and research tools to conduct sonar exposure experiments. This is an important accomplishment, and the preliminary results appear to suggest that killer whales reacted much more strongly to mid-frequency (6-7 kHz) signals than to low-frequency (1-2 kHz) signals.

Though the results of the one 6-7 kHz experiment suggest a strong reaction to the sonar, we must consider - what was the probability that the observed behaviour (breaking off feeding and moving quickly away from the sonar) would have occurred by chance if the sonar actually didn't affect the behaviour of the whales? While some progress can be made by comparing the behaviour during the sonar exposure with normal behaviour, we need to conduct additional experiment to describe the potential variation in responsiveness to these signals. Therefore, additional data are likely to be necessary before we can make conclusions and provide clear recommendations about the use of different sonar signals.

Given the experience from the 3S-2006 trial and the current state of knowledge, we make the following recommendations for future work:

1. Getting the tag on the whale was a limiting factor during the trial. However, we consider that it is necessary to have a tag attached to a whale to conduct a valid controlled exposure experiment. This is to assure that the same whale is tracked throughout the experiment, and to obtain underwater behaviour records of the animal.
2. Tagging systems should be further developed to increase tagging range. This could be done either by developing a better launching system for the DTAG, or develop the LKTAG to include necessary sensors (acoustic sensor, depth sensor, swimming speed and horizontal movements (GPS)).
3. The annual migration pattern of herring is apparently changing, and this is likely to affect the presence of killer whales in the Vestfjorden in the October to January period where they have been numerous for the past 10-15 years. We therefore recommend that alternative field sites and periods are considered. Alternative areas/periods should have an expected high presence of whales, longer periods of daylight than during the 3S-2006 and less whale watching activities than in Vestfjorden in November.
4. If an alterative field site is chosen, a multi species approach is recommended to increase whale search efficiency, but the main focus should remain on killer whales. Relevant alternative species are pilot whales and minke whales.
5. The Delphinus towed passive acoustic monitoring systems was very useful to find whales in the darkness, and such a system should be mandatory on future trials. Passive acoustic monitoring could be further exploited using passive listening buoys to cover a larger area.
6. A critical factor during tagging is to be close to whales when they first come to the surface to breath following a long dive. Whales were successfully tracked using the SP90

Simrad sonar during the 3S-2006 and such a system could possibly be used to position the tag boat nearer to whales during tagging.

7. A retrospective analysis of the correlation between military sonar transmission and killer whale presence or absence in the Vestfjorden area the past 6 years is warranted.

7.2 Future studies on the effects of sonar on herring

A large data set was collected during the trial on the effect of MFAS and LFAS transmission on herring. The preliminary result indicate that herring does not respond with horizontal nor vertical escape, when exposed to such signals. Previous studies indicate that if the transmitted frequency is in the resonance band of the swim bladder, the herring becomes more sensitive (Kvadsheim and Sevaldsen 2005). The resonance frequency depends on the size of the herring and the depth (Løvik and Hovem 1979). Future analysis of the dataset will therefore also focus on the response of herring layers at different depths. Future studies should also include other fish species, particularly sprat which is also a clupeid fish like the herring, but much smaller. Final recommendations on the need for more data on herring and recommendations on operational use of military sonar in areas with high density of herring, will be pending the analysis of the current dataset.

7.3 Future studies on active detection of marine mammals

The feasibility study to investigate if the SP90 and SH80 SIMRAD sonars could be used to detect marine mammals is considered a great success. The SP90 sonar detected killer whales up to at least 1500 m, while the SH80 gave reliable detection at ranges up to 400 m. It is therefore strongly recommended that further research effort is made to evaluate active acoustic detection as a tool for marine mammal mitigation during seismic surveys. The most important uncovered matters are:

1. More data is needed on target strength of marine mammals, and knowledge of how target strength varies with water depth.
2. Simulations of how different sound propagation conditions will affect the sonar’s ability to detect whales should be executed.
3. The 3S-2006 was conducted in an area where the killer whales are well adapted to sonar transmissions. The lack of behavioural reactions might therefore not be the case under other conditions. Exposure experiments on a few species of whales using SP90 signals should therefore be executed.
4. This study has been limited to killer whales. Differences in vocalisation and swimming pattern (surface intervals) between whales species is expected and should be investigated to provide information for species identification.
5. A comparison of detection efficiency between existing methods for whale detection (visual surveys) and fisheries sonar’s is warranted.

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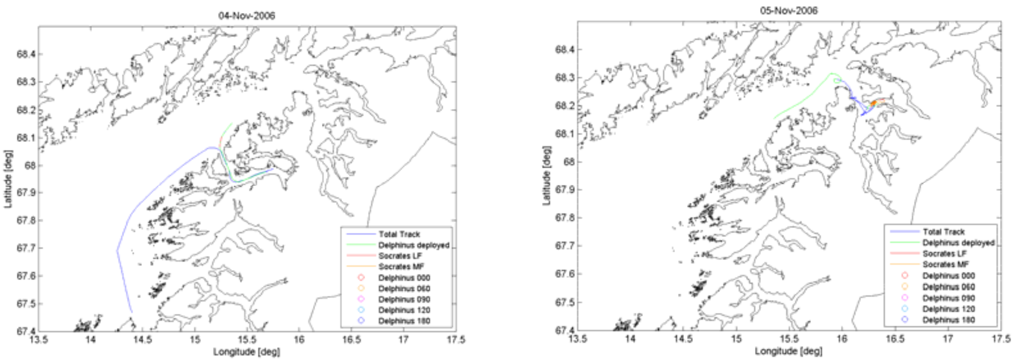
Appendix A Chronological summary of 3S-2006 cruise

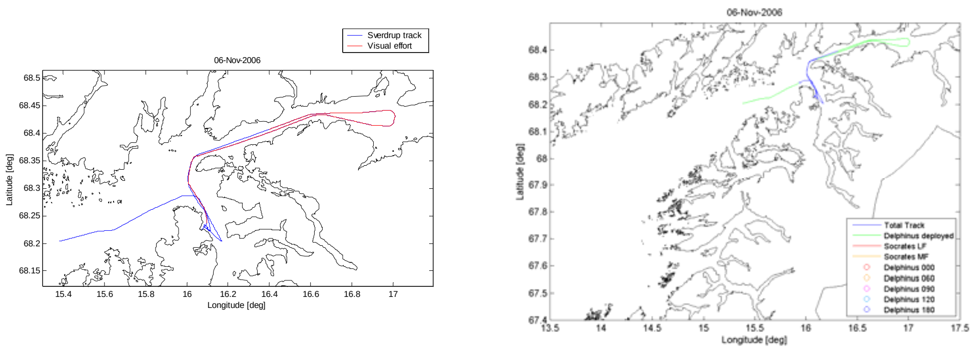
Date	Weather at noon	Main area	Main Activity
Oct. 31.		Tysfjord	Public outreach meeting at Tysfjord Tourist Center.
Nov. 1.		Korsnes-Bodø	Travel day. Nøkken delayed because of cold weather, SMRU team and Socrates delayed because of bad driving conditions.
Nov. 2.		Bodø	Sverdrup and Socrates arrived Bodø. Scientific team embarked and started installation of equipment.
Nov. 3.		Bodø	Shipped equipment delayed. Cruise leaders brief onboard Sverdrup. SMRU team arrived at Korsnes.
Nov. 4.	SSE6, G, SS2	Bodø-Økssundet	Sverdrup departed from Bodø at 1130. Continued installation of equipment on Nøkken. Engineer test on Socrates and Delphinus.
Nov. 5.	S4, B, SS1	Stefjord-Tysfjord	Calibration of acoustic equipment. Joint dinner on board Sverdrup.
Nov. 6.	E5, C, SS2	Ofotfjorden	Started searching for whales.
Nov. 7.	SW3, C, SS2	Stamsund-Henningsvær	Searched for whales. Difficult tagging conditions (swell). Unsuccessful attempts to deploy LK-tag.
Nov. 8.	SW3, C, SS3	Svolvær-Risvær	Searched for whales. Unsuccessful attempts to tag with DTAG. A big male was tagged with an LK-tag. Searched for lost tag.
Nov. 9.	N2, B, SS1	Økssundet-Skrova-Risvær	Searched for whales. Attempted to tag with DTAG. A DTAG deployed at 1337. Exposure experiment aborted because of tourist activity (divers). Control experiment executed. Tag off at 1553. Executed herring experiment off Risvær at night.
Nov. 10.	SW4, B, SS2	Risvær-Ofotfjorden	Attempted to tag with DTAG at first light. A DTAG deployed at 1155. Tourist boats and divers prevented exposure experiment. Tag off at 1403. Searched eastwards.
Nov. 11.	SW7, C, SS0	Narvik-Ofotfjorden-Skrova	Crew shift and provisioning in Narvik. Searched westwards.
Nov. 12.	ENE4, B, SS2	Ofotfjorden	Attempted to tag with DTAG at first light. Both tag boats worked all day without being able to tag. Nøkken had an engine breakdown and was docked for 4 days. Executed herring experiment at Ocean Hub at night.
Nov. 13.	S5, C, SS2	Barøya-Ofotfjorden	Killer whale survey in area of herring experiment last night. Attempted to tag with DTAG. A DTAG deployed at 1430. Executed LFAS exposure experiments on travelling animals at 1515. Tag off at 1545. Sverdrup picked up Nøkken team.
Nov. 14.	SE4, C, SS2	Ofotfjorden-Skrova	Received information of stranded minke whale in Ofotfjorden. Organised with autopsy. Searched for whales. Unsuccessful attempts to tag with LK-tag at the end of the day.
Nov. 15.	SE3, C, SS4	Risvær-Aarsteinen	Unsuccessful attempts to tag four male killer whales with DTAG all day. Negative reactions on tagging activity from whale safari boats. Nøkken team back in Korsnes.
Nov. 16.	SE3, B, SS2	Ofotfjord-Vestfjord	Searched for whales all night and day without any sightings or acoustic detections. Executed herring experiment at Ocean Hub.
Nov. 17.	SE8, C, SS3	Ofototen Narvik	Crew shift and provisioning in Narvik. Orca dance!
Nov. 18.	E6, C, SS2	Ofotfjorden	Searched for whales all day without any sightings or acoustic detections. Executed herring experiments at Ocean Hub. Sverdrup picked up Nøkken team again.
Nov. 19.	SE3, B, SS1	Vågsfjorden-Andfjorden.	Searched for whales all day without any sightings or acoustic detections. Participated in the FLOTEX free play (boarded by naval special forces). Transit back to Vestfjorden.
Nov. 20.	S4, B, SS3	Vestfjorden	Searched for whales. Attempted to tag with DTAG. A DTAG deployed at 1300. Divers in the water delay exposure experiment and the tag fell off at 1412.
Nov. 21.	SSE4, C, SS2	Vestfjorden-Ofotfjorden.	Searched for whales. Nøkken was sent home.
Nov. 22.	S3, C, SS1	Barøy-Tranøy	Unsuccessful tagging attempts with DTAG from first light until darkness. Executed killer whales playback experiment on herring at Ocean Hub.

Date	Weather at noon	Main area	Main Activity
Nov. 23.	S4, G, SS2	Skrova-Ballstad	Attempted to tag with DTAG at first light. Two DTAGs deployed within an hour (1330-1430). Executed MFAS exposure experiments on feeding animals at 1440. Continued to track animals until both tags were retrieved.
Nov. 24.	E6, C, SS2	Risvær	Searched for whales. Bad tagging conditions. Crew shift and provisioning in Narvik.
Nov. 25.	SE4, G, SS1	Ofotfjorden-Skrova	Searched for whales. Inger Hildur joins the trial. Unsuccessful tagging attempts with DTAG. Executed herring exposure experiments with killer whales playbacks at Ocean Hub.
Nov. 26.	SW7, C, SS3	Økssundet-Tysfjorden	Searched for whales visually and acoustically. Joins Inger Hildur in Tysfjord at night.
Nov. 27.	SW8, G, SS3	Skrova	Searched for whales without results.
Nov. 28.	SW4, G, SS2	Skrova-Kanstadfjord.	Searched for whales. Unsuccessful tagging attempts with DTAG.
Nov. 29.	ESE5, G, SS3	Kanstadfjord-Tranøy	Searched for whales around purse seiners at night. Deployed tag boats at 0700. Unsuccessful tagging attempts with DTAG. One LK-TAG was deployed but malfunctioned. Continued unsuccessful tagging attempts with DTAG. Executed herring experiments at Ocean Hub at night.
Nov. 30.	SW3, G, SS3	Tysfjord	Searched for whales without results. Executed a killer whale playback experiments on herring at Ocean Hub. Cruise leaders de-brief. Transit to Bodø.
Dec. 1.		Bodø	De-installation and shipment of equipment. Scientific crew disembarks.

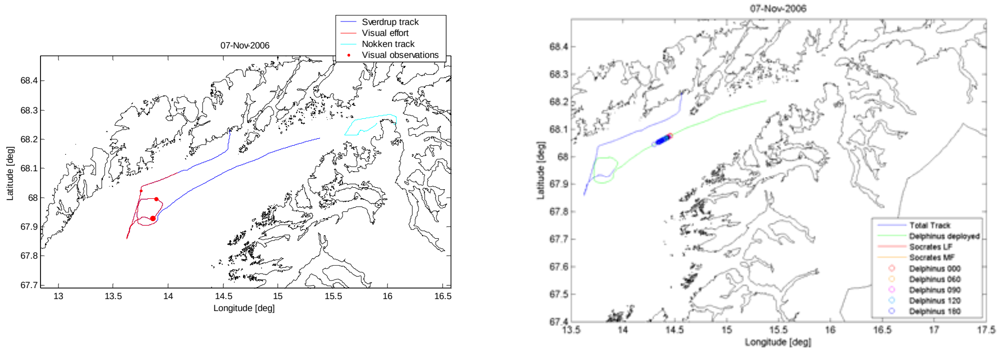
Table 1. Day by day activity during the trial. The weather at noon is given as wind direction and force on the Beaufort scale, weather code (A-J) and sea state (SS). The weather code is; A=clear sky, B=changing cloud cover, C=clouded, D=drifting snow, E=fog, F=drizzling rain, G=rain, H=snow, I=snow or rain shower, J=thunder.



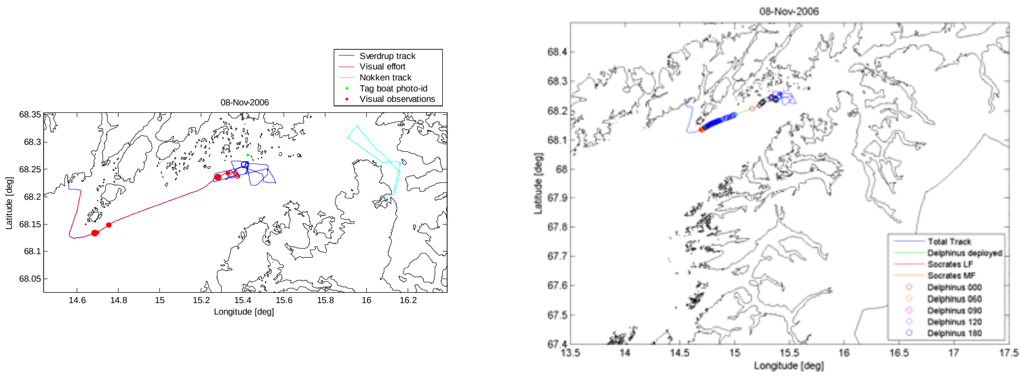
Nov 04. (left) and Nov 5. (right): Track of the Sverdrup with Socrates and Delphinus deployed.



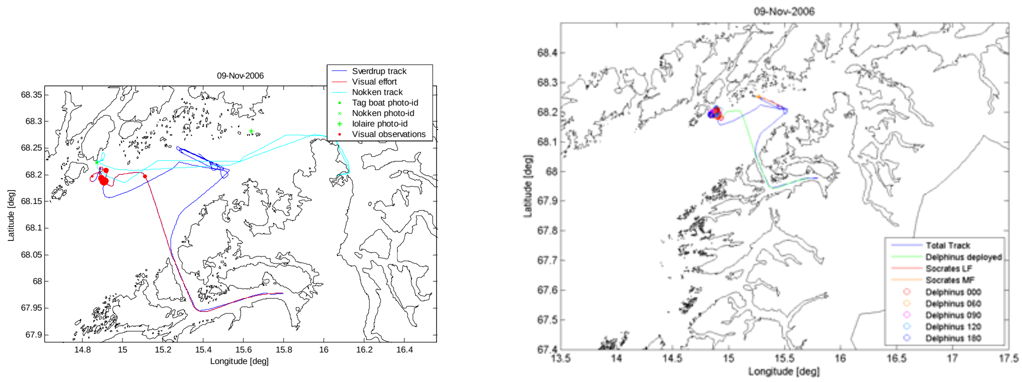
Nov 6: Track of the Sverdrup with visual (left) and acoustic (right) efforts to survey for killer whales.



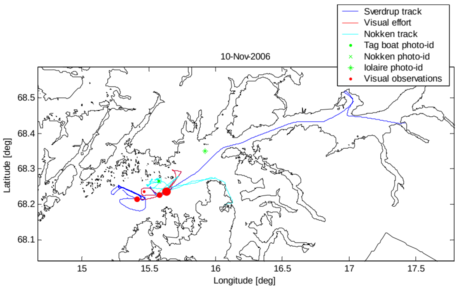
Nov 7: Track of the Sverdrup and Nøkken with visual (left) and acoustic (right) survey effort. The colors of the circles indicate directions in which the sound was detected.

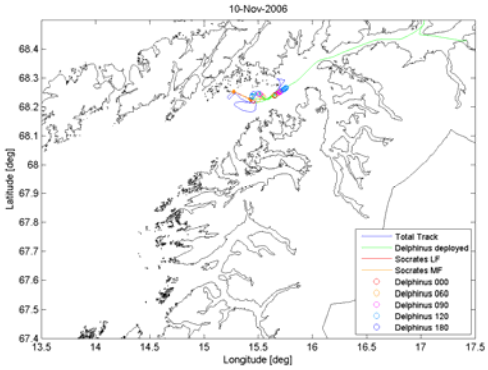


Nov 8: Track of the Sverdrup and Nøkken with visual (left) and acoustic (right) survey effort.

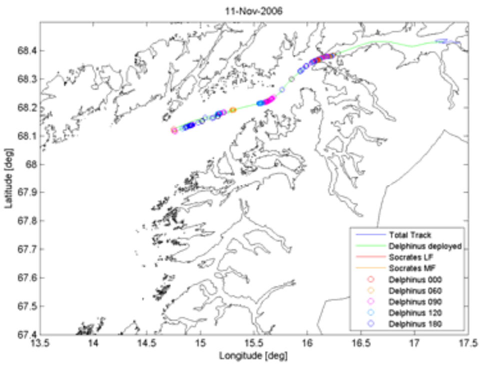


Nov 9: Track of the Sverdrup and Nøkken with visual (left) and acoustic (right) survey effort.

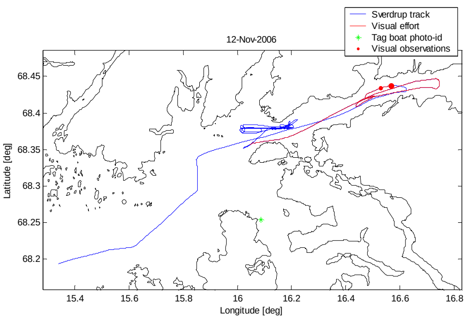


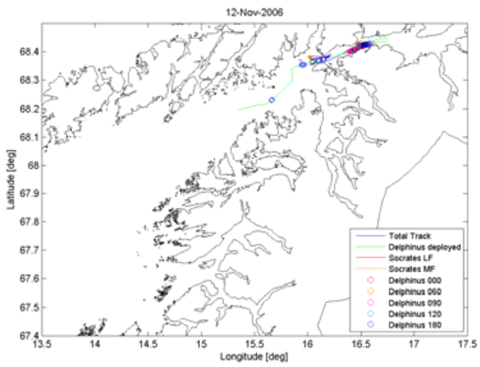


Nov 10: Track of the Sverdrup and Nøkken with visual (left) and acoustic (right) survey effort.

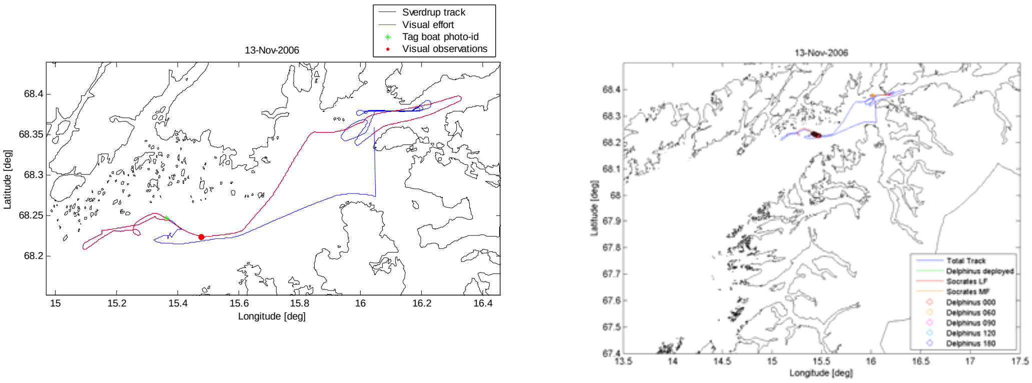


Nov 11: Track of the Sverdrup with acoustic survey effort. No visual effort was made.

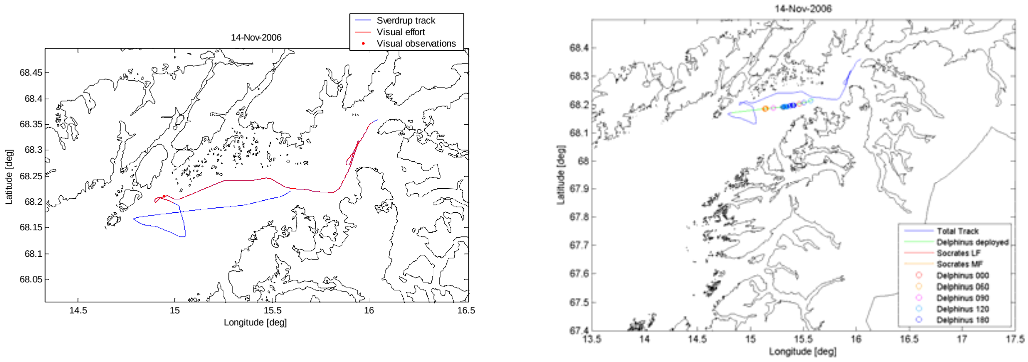




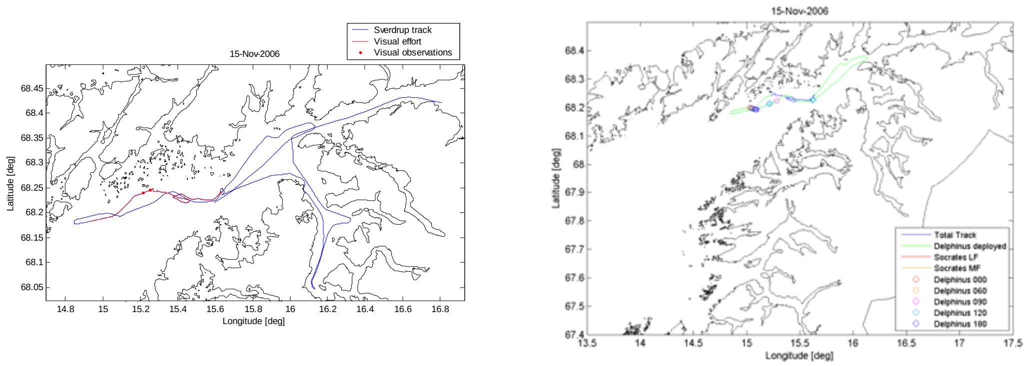
Nov 12: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



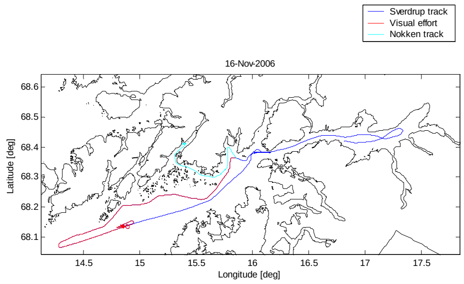
Nov 13: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.

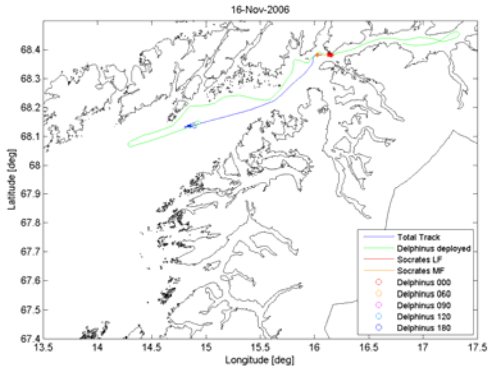


Nov 14: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.

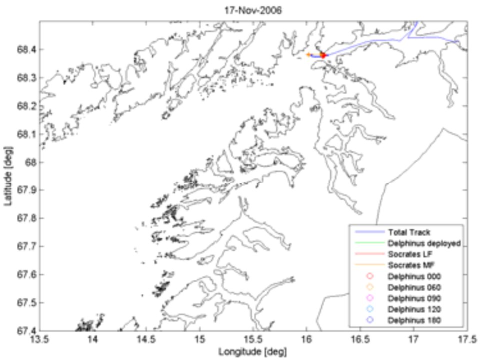


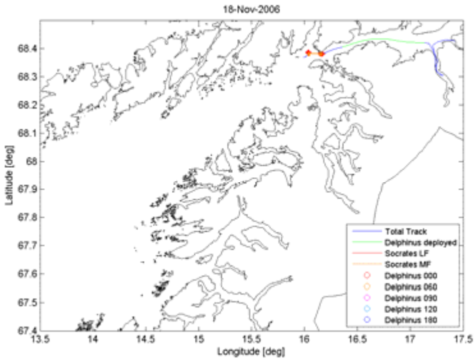
Nov 15: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



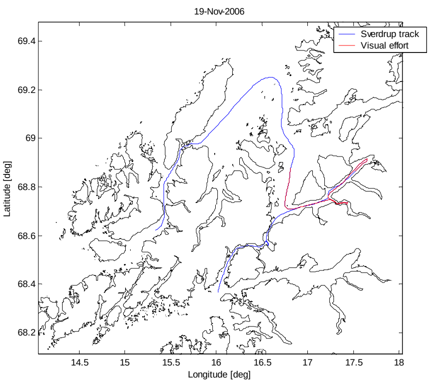


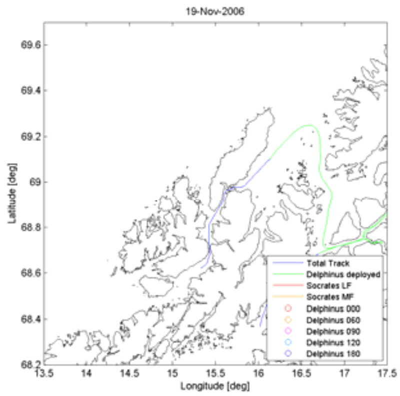
Nov 16: Track of the Sverdrup and Nøkken with visual (left) and acoustic (right) survey effort.



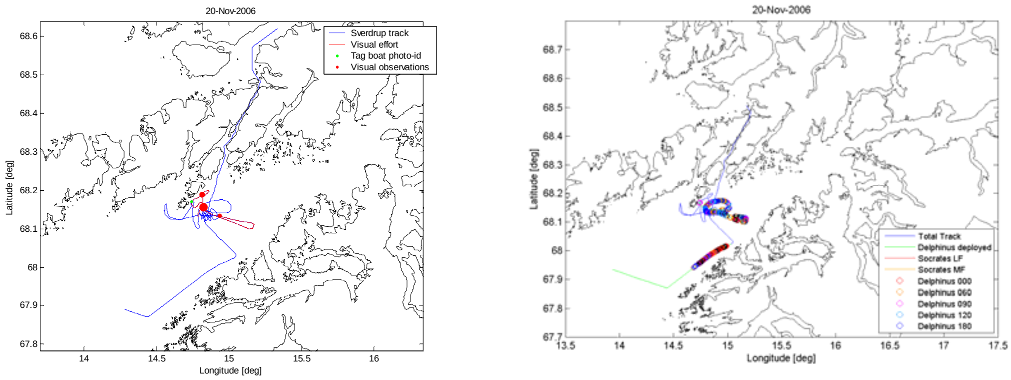


Nov 17.(left) and Nov 18. (right): Track of the Sverdrup with acoustic survey effort.

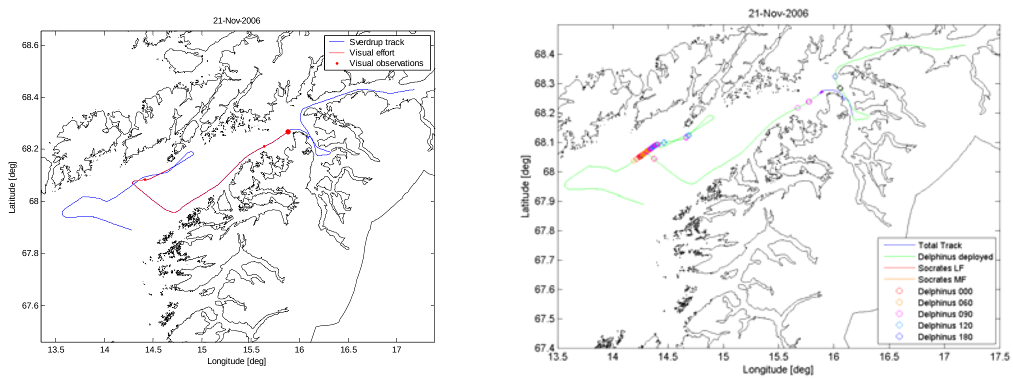




Nov 19: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



Nov 20: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



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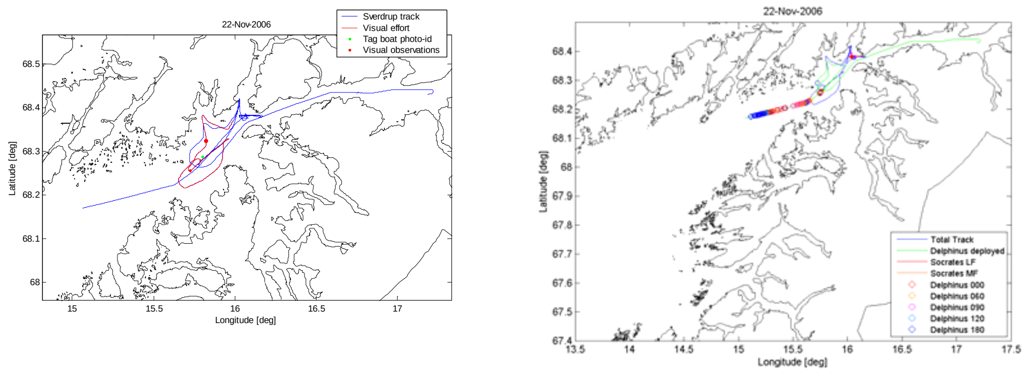
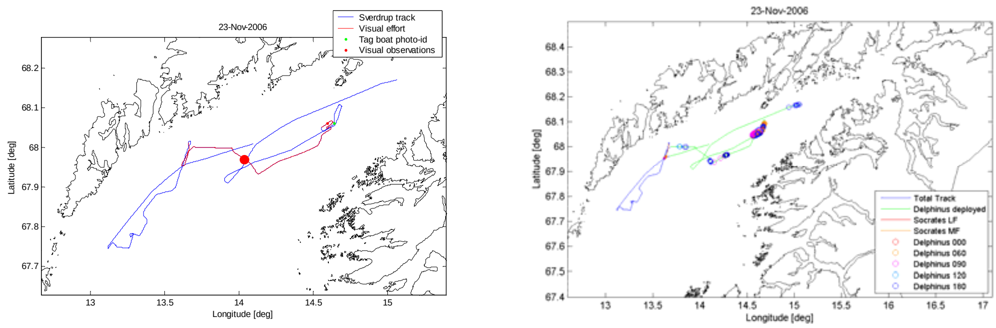
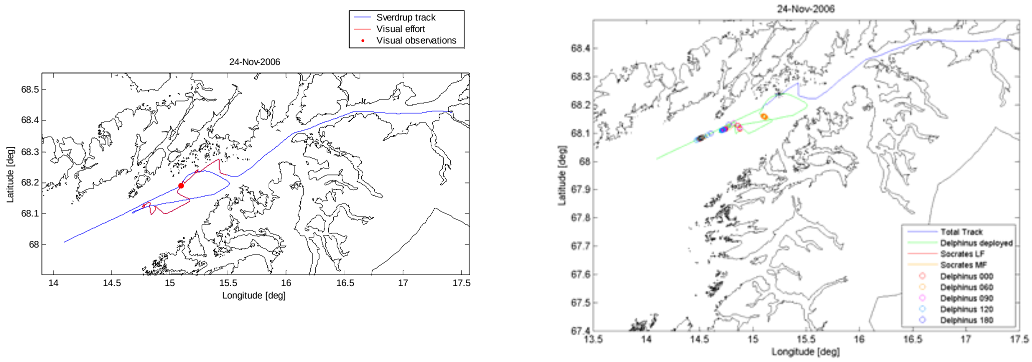


Nov 22: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



Nov 23: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



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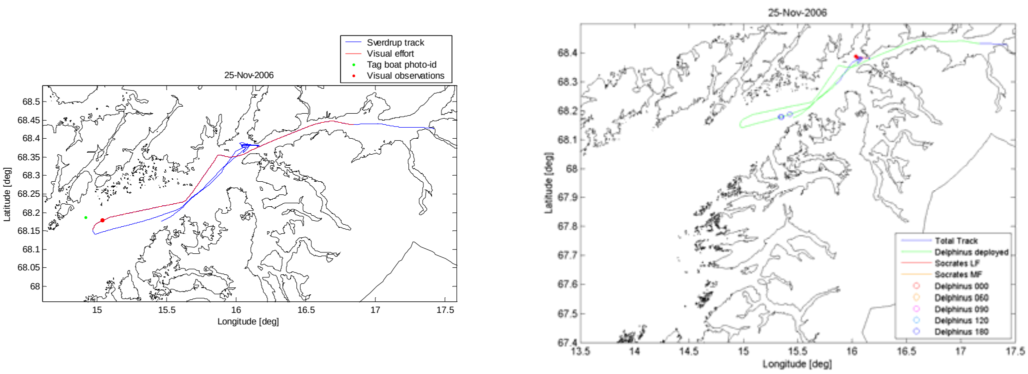
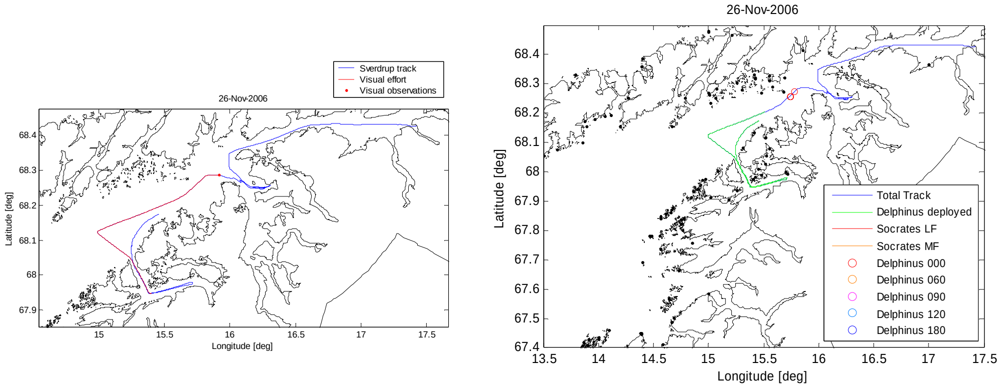
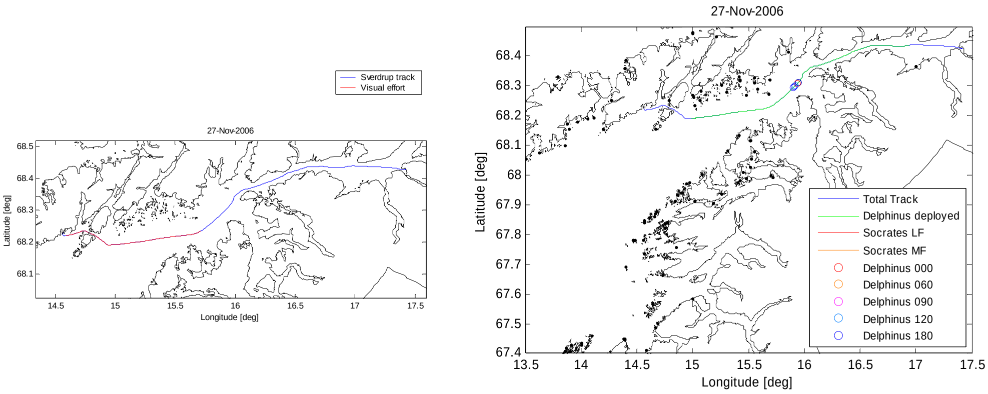


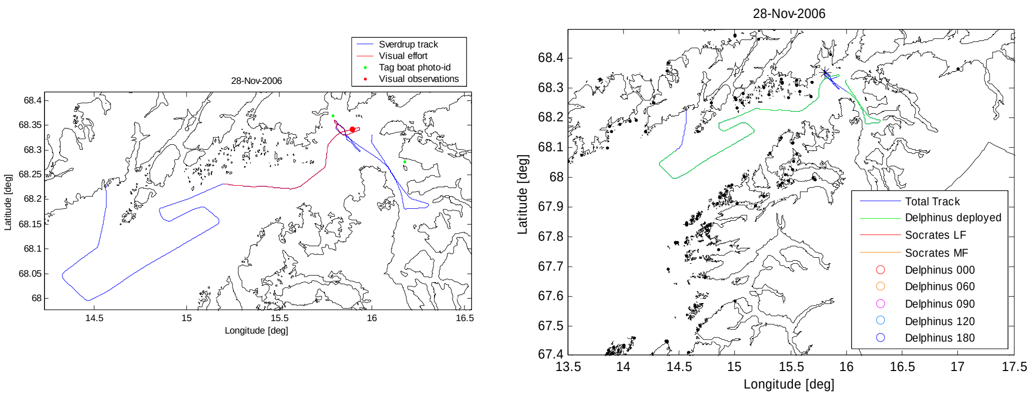
Nov 25: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



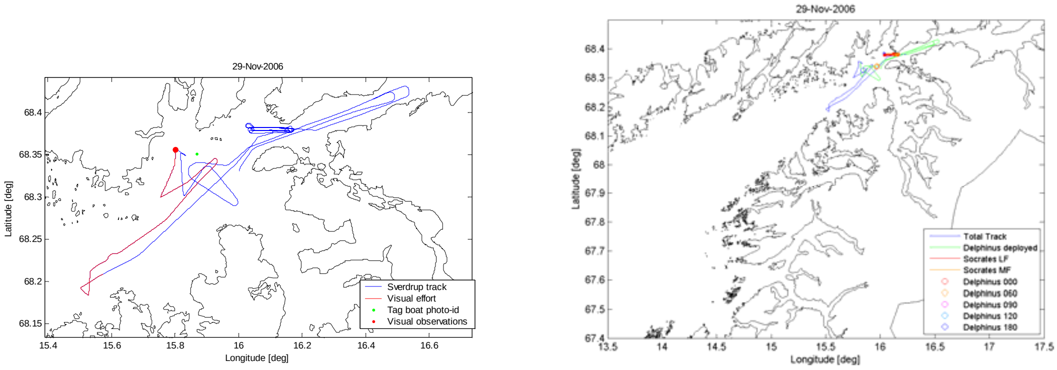
Nov 26: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



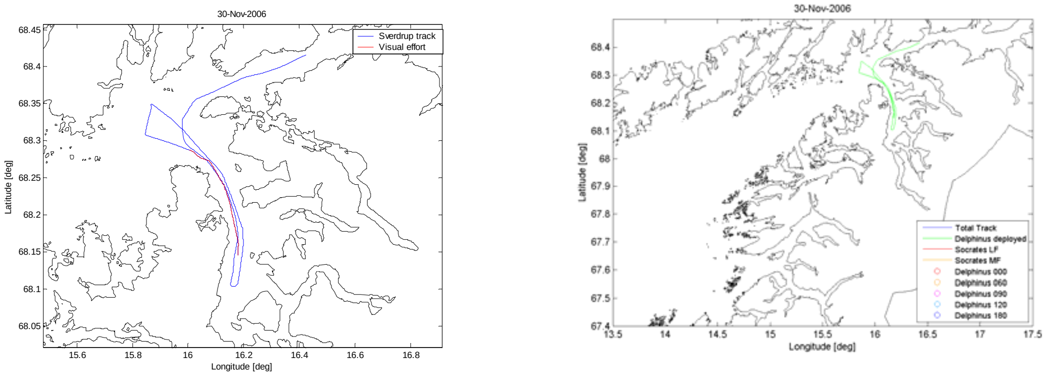
Nov 27: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



Nov 28: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



Nov 29: Track of the Sverdrup with visual (left) and acoustic (right) survey effort.



Nov 30: Track of the Sverdrup with visual (left) and acoustic (right) survey effort

Appendix B 3S-2006 Cruise plan

Project objective:
Investigate behavioral reactions of killer whales and herring to transmitted Low Frequency Active Sonar (LFAS) and Mid Frequency Active Sonar (MFAS) signals, in order to establish safety limits for sonar operations in the vicinity of killer whales.

Cruise tasks:
Primary tasks:
1. Tag free ranging killer whales inside the Vestfjorden basin with sensors recording behavior, and thereafter execute controlled exposure experiments (CEE) where the tagged animals are exposed to acoustic signals simulating LFAS and MFAS signals.
2. Expose herring overwintering in the area to LFAS and MFAS signals while monitoring behavioral reactions of the herring using sub-surface acoustic buoys.
3. Do CTD and transmission loss measurements in the study area.

Secondary tasks:
4. Playbacks to tagged killer whales, using natural killer whale sounds (natural controls).
5. Do behavioral observations of whales and herring being exposed to sonar signals during feeding events using SH80 SIMRAD sonar (110-122 kHz).
6. Evaluate the use of SIMRAD fisheries sonars (SH80 and SP90 (20-30 kHz)) for detection of whales.

Sponsors:
The research project is sponsored by;
· The Royal Norwegian Navy and the Norwegian Ministry of Defense
· The Royal Netherlands Navy and the Dutch Ministry of Defense
· OGR JIP on E&P sounds on marine life.

Collaborating organizations:
The trial is a joint effort between:
· The Norwegian Defense Research Establishment (FFI), Norway
· The Royal Netherlands Navy (RNLN)/Defence Materiel Organisation, The Netherlands (NL MOD).
· Sea Mammal Research Unit (SMRU), Scotland
· Woods Hole Oceanographic Institution (WHOI), USA
· Institute of Marine Research (IMR), Norway
· SIMRAD, Norway
· LKARTS and Wild Idea, Norway.

The Netherlands Organisation for Applied Scientific Research TNO is through the NL MOD an indirect participating organization to this experiment. The performance of the tasks of NL MOD to this experiment will be carried out by TNO, as a contractor of NL MOD under the terms and conditions of the agreement with reference number UTP 016.06.5105.01 (Internationale samenwerking Marine Mammal Protection Fase 1) between TNO and NL MOD.

Schedule/Sailing plan:

October 31. Public outreach presentation at Tourist Centre, Tysfjord.

November
1. Sverdrup transit Tromsø-Bodø. Nøkken arrives cargo harbor in Narvik.
2. Sverdrup arrives at initiation port in Bodø at 08.00. Scientific crew embarks Sverdrup during day. Installation of equipment. Nøkken arrives Korsnes at 10.00. Installation of equipment.
3. Planning meeting and continued installation on Sverdrup in Bodø and Nøkken in Korsnes. Sverdrup starts transit to operation area during night.
4. Engineer tests of Socrates including reverberation tests. Joint meeting with entire Nøkken and Sverdrup crew at Korsnes.
5. Start of scientific experiments.
10. Option for crew shift in Lødingen
11. Sverdrup transit to Andenes for herring trials. Nøkken stays in Vestfjorden with 1 tag boat and Miller.
13. Sverdrup transit from Andenes back to Vestfjorden
17. Option for crew shift in Lødingen.
24. Option for crew shift in Lødingen.
27. Inger Hildur joins the trial (departure port Bodø)
30. Last day of scientific experiments. Sverdrup transit to Bodø at night. Nøkken returns to Korsnes.

December
1. Sverdrup arrives at Bodø. Deinstallation of equipment on Sverdrup in Bodø and Nøkken in Korsnes. Shipment of equipement. Scientific crews disembark. Nøkken transits to Narvik for shipment to Horten.

Vessels:

<u>R/V H.U. Sverdrup II</u>

Captain: Jonny Remøy
Length: 180 feet
Max speed 13 knots
Crew: 7
Scientific crew: 12-15

Sverdrup will be outfitted with the Socrates source and operating software, Sakamata decision aid software, Delphinus towed array system, a VHF tracking system, and a cradle for loading/off-loading the tag-boats. Fuel will be carried for the tag-boats. In addition Sverdrup will also carry and redeploy the echo sounder/ADCP buoys for herring studies and carry CTD equipment.

Scientific crew on Sverdrup

Cruise leader:	Petter Kvadsheim (FFI)
PI CEE orcas/tagger:	Patrick Miller (SMRU)
PI CEE herring:	Olav Rune Godø (IMR)
PR:	Rune Sævik (FFI)
Visual observations:	Lise Doksæter(IMR/FFI)/Kees Camphuijsen(TNO/KNIOZ)
VHF-tracking/CTD/TL:	Erik Sevaldsen / Nina Nordlund (FFI)
Hardware eng Socrates/Delphinus:	Adri Gerk / Joost Kromjongh / Peter Fritz (TNO)
Software eng Socrates/Delphinus:	Sander van Ijsselmuide/Timo van der Zwan (TNO)
Chief scientist TNO:	Frans-Peter Lam/Frank Benders (TNO)
Naval Observer:	René Dekeling (RNLN)
SAKAMATA/Delphinus operator:	Myriam Robert (TNO).
Dtag Technician:	Ari Friedlaender (SMRU)
Buoy technician:	Ronald Pedersen (IMR)
Driver tagboat I/tagger	Lars Kleivane (FFI)
Driver tagboat II	Tommy Sivertsen (FFI).

R/V Nøkken:

Captain: Ulf Johansen/Otto Book (FFI)
Length: 36 feet
Max speed: 14 knots
Crew: 1
Scientific crew: 5-6

The Nøkken will be based in Korsnes, with housing on-shore for the crew. There is a second tagging team from WHOI studying natural undisturbed behavior that will also be based in Korsnes. This team is led by Ari Shapiro of WHOI and Tiu Similä of NORCA. Nøkken will have a towed hydrophone array, a visual tracking system including photo-id and laser distance meter, a VHF tracking system and CTD-probes.

Scientific crew on Nøkken

Chief scientist and:	Patrick Miller (SMRU), will transfer from tagging boat after tagging
Co-Chief Sci/photo-id:	Sanna Kuningas (SMRU)
Acoustics:	Filipa Samarra (SMRU)
Visual tracking:	Alice Elizabeth Moir Pope (SMRU)
Visual tracking:	Hajime Yoshino (SMRU)
VHF tracking:	Someone will transfer from Sverdrup

Tagging boats (Sverdrup workboat and SMRU workboat):
The tagboats will be launched from, and recovered to, the Sverdrup daily. They will carry tagging gear, and a calibrated hydrophone to record during CEE transmissions. In addition CTD profiles and transmission loss (TL) measurements will take place from the tagboats. The tagboats will have a regular crew of 2. One driver and one tagger.

Inger Hildur:
The purse seiner Inger Hildur will join the trial at November 27. They will try to do sonar observations of whales and herring. Inger Hildur is installed with SIMRAD sonars SP90 (20-30kHz) and SH80 (110-120 kHz). The main objective of Inger Hildur will be to test the use of these sonars for marine mammal detection. We will also attempt to use SH80 to monitor killer whales and herring involved in feeding events

during CEE's. Since the killer whales are able to detect the SP90 signals, Sverdrup and Inger Hildur have to coordinate to avoid interference with the CEE trial when using this sonar. Inger Hildur will have a scientific crew of 2-3. Two sonar operators from SIMRAD and a scientist from IMR (Lise Doksæter transferred from Sverdrup).

Communication:
This trial involves 3 to 5 different boats, and coordination and communication are crucial. To ensure good communications all teams must bring a VHF radio and a cell phone. A main VHF working channel and an alternative channel will be specified. The VHF call signals for the different units will be:

"Sverdrup"	Sverdrup bridge
"Nøkken"	Nøkken
"Tag boat I"	Sverdrup work boat
"Tag boat II"	SMRU work boat
"Cruise leader"	Kvadsheim
"Socrates"	Sonar operator

Responsibilities:

FFI

Personnel: Cruise leadership and permits, VHF-tracking, visual observations from Sverdrup, CTD/TL-measurements, tag-boat drivers, back up tagging (LK-tags).

Equipment: 2 Research vessels with crew, 2 tag boats, gas for tag boats on board Sverdrup, CTD's (a stationary one on Sverdrup and a mobile one for Nøkken), ATS-VHF-tracking system for Nøkken, Taiyo VHF-tracking system on Sverdrup, 1 hand-held Televilt VHF tracking system, laser distance meter for Sverdrup, GPS-tracker for Sverdrup, digital video camera, LK-tags, calibrated hydrophone with digital recorder, and VHF-communication equipment.

SMRU

Personnel: PI orca CEE, exposure coordinator, dtag-technician, dtag taggers, acoustic observer, visual observers, photo id.

Equipment: Dtags, dtag poles, hydrophone array for Nøkken, laser distance-meter for Nøkken, equipment for visual observations from Nøkken, digital cameras, 2 hand-held VHF-tracking systems.

TNO

Personnel: Chief scientist TNO, SAKAMATA operator, software and hardware technicians for Socrates and Delphinus array, visual observations from Sverdrup

Equipment: SAKAMATA, Socrates, Delphinus, XBT.

IMR

Personnel: PI CEE herring, herring buoy technician, sonar observations.

Equipment: 2 Sub-surface acoustic buoys with acoustic release, acoustic release unit, stationary acoustic observation platform.

LKARTS

Equipment: LK-tag and ARTS/RN

Daily work plan:
Before the end of each day, the cruise leader will convene the chief scientists of SMRU, TNO, IMR and FFI to discuss the plan for the following day. Weather forecasts, expected tourist activity, fishing activity, killer whale and herring availability, staff situation and scientific priorities are all factors that will have to be considered.

Whale tagging and controlled exposure experiments on killer whales will have to be carried out during daylight hours. However, occasionally we may decide to keep a tag deployed through the night, and therefore have to track the tagged animals from Sverdrup. Tagging boats and Nøkken will only operate during daylight ours, and then return to Korsnes/Sverdrup before nightfall. Herring experiments may be carried out after nightfall, but some experiments should be executed during daylight for scientific reasons. Sound velocity profiles may be obtained from Sverdrup, Nøkken or tagging boats at needs and opportunities during days and nights.

Controlled exposure experiments on killer whales:
Before dawn each day, the Nøkken and Sverdrup will search for whales in the specified locations using towed array acoustics and visual observations from both vessels. As soon as whales are located, the tag boat(s) will be launched from the Sverdrup, and the Nøkken will take identification photographs.

Tagging
If possible, we will try to tag more than one whale within a group for testing. This increases the total number of whales tested (and helps assure that a tag will remain attached for the full experiment duration), but has the cost of taking time attempting to tag. A 2-experiment cycle (2 exposure runs) takes 3.5 hours to complete, and should be completed by apparent sunset. If the first tag is attached more than 4 hours before apparent sunset, second-whale tagging attempts will continue up to 4 hours before apparent sunset for a 2-experiment test. If the first tag is attached with less than 4 hours remains before apparent sunset, second-whale tagging attempts will continue up to 2 hours before apparent sunset, enabling a 1-experiment test.

Local time of:	Start (2 Nov)	End (29 Nov)
Apparent sunrise	08:13	10:35
Apparent sunset	15:02	12:50

Once tagging efforts cease, Miller will transfer from the tag boat to the Nøkken which will photo-id, visually monitor, and VHF-track the tagged whale(s). Kvadsheim will transfer back to Sverdrup, and Sverdrup will move into position to start the CEE. Real-time estimates of the received levels close to the tagged whale will be made using the towed array on the Nøkken, which will be recalibrated at the start and end of the trial. To better characterize the acoustic propagation more widely, a tag boat will station itself further away to make additional acoustic recordings of received levels using a calibrated hydrophone system.

CEE
Once a tag is attached to a whale, an initial CEE start location for the Sverdrup will be specified based upon the location and movement direction and speed of the whales. The primary goals of the start location are: **1)** far enough from the whales to have a low (140 dB re 1μPa) received sound pressure level at the start of CEE; **2)** an up-Fjord location to minimize broader acoustic exposure into the Vestfjord and Tysfjord killer whale habitat; **3**) a position to the side or in front of the whales direction of movement; **4)** sufficient water depth and absence of obstacles for vessel movement. The CEE start location may need to be updated if the whales' movements change. For this purpose, good communications between Nøkken and Sverdrup are critical, and the Sverdrup may need to move at high speeds to arrive at a CEE start location. These whales can travel at 8 knots for extended periods! Source transmissions will start one hour after tagging, once the Sverdrup is in an appropriate location to start the exposure. The chief scientist of TNO makes the final decision to deploy or not to deploy the Socrates, based on sea state, navigation conditions and technical readiness of the source. The final decision to start sonar transmission is made by Kvadsheim after consultation with Miller and the Socrates operator. During the 30-minute transmission cycle, the Sverdrup will approach the whales at a speed sufficient to move to ~100m range by the end of the 30 min period.

As a rule of thumb the starting point should be 3nm away from the animals. That will give a transmission loss of roughly 60-70 dB re 1m (using the estimated loss with 16-19log R). Transmission will start with a short ramp-up as specified by SAKAMATA for an area containing killer whales (source levels of 170-209 dB re 1μPa @ 1m within 3 min). This will decrease the risk to other animals in the area, and the initial received level at the tagged animal will be below any expected reaction threshold. Towing speed should be constant at 7 knots, and initially course set directly towards the tagged animals. If the animals changes position the source ship will change the course correspondingly, but turning angle should not exceed 15 deg per min. After 10 min the course will be maintained constant. This will allow the animal to avoid the signal, if it tries to. This will imply that we will pass the animals after 20-30 min. The Sverdrup will maneuver to pass no closer than 100m from the closest killer whale. We will continue on a straight line course for another 5 min, while transmitting at max SL. Towing depth should be at least 30 m to achieve the max source level. After 30 min, transmission will stop, and Sverdrup will reposition for a second exposure run. A second exposure will only be attempted if the first experiment ends 2 hours or more before apparent sunset for that day. The second exposure experiment will start one hour following the end of the first experiment, once the source vessel is in a new acceptable location. All protocols will be identical for first and second experiment.

During transmissions, the visual observers on Sverdrup will assure that a safety limit of 100 m from the source to any mammals is maintained. The permit and safety plan for the experiment defines unexpected situations were sonar transmission will be stopped. The decision to stop transmission outside the protocol is made by Kvadsheim or by the exposure coordinator observing the whales from the Nøkken. The Nøkken will visually monitor and track the tagged whale(s) continuously before, during, and after transmissions and make recordings using towed hydrophone array. The Nøkken will inform the Sverdrup of the whales' location every 5 minutes.

After all transmissions are completed, the Nøkken will continue to track the tagged whales until dark, at which point it will return to Korsnes. Miller will transfer back to the Sverdrup on the tag boat before dark. After dark, the Sverdrup will track any tagged whales, and recover the tags when they detach from the whales. Tags will be programmed to release roughly one hour after apparent sunset, unless it is determined to be useful to attempt early morning experiments on a whale tagged late the previous day. Data will be downloaded from the tags, and the tags will be prepped for the following day.

Exposure protocol:
The main protocol involves transmission of one of two different sonar signals. In addition, we will try to do some pilot playbacks of natural sounds (killer whale sounds during carousel feeding). The availability of the sonar source this year makes sonar signal exposure the highest priority. The waveforms will be specified and prepared in advance of the trial. To maximize the relevance of the research, the sonar signals should correspond to signals used on operational sonars. However, pulse length may have to be a compromise between operational relevance and the experimental need to keep everything but the frequency constant, in order to study the effect of different frequencies. The transmitted sonar signals will be:
1. A 1000 ms 1-2 kHz hyperbolic up-sweep (LFAS).
2. A 1000 ms 6-7 kHz hyperbolic up-sweep (MFAS).
The repetition time will be 20 s if reverberation dies down within this time. Otherwise the repetition time should be modified. Reverberations conditions will be tested during the sonar engineer tests, prior to the start up date of the experiments.

The schedule for transmission will have to be alternated between the different sonar signals and the behavioral context of the animal according to this table:

		Behavioral Context	
	Transmission	**Travel**	**Feeding**
DOUBLE EXPOSURE	LFAS-MFAS		
	MFAS-LFAS		
	LFAS-MFAS		
	MFAS-LFAS		
SINGLE EXPOSURE	LFAS		
	MFAS		
	LFAS		
	MFAS		

Of course, we will strive to achieve as many CEEs as possible during the field effort, up to the permitted limit of 20 total tagged animals tested. It should be kept in mind that daylight decreases radically during November, so 2nd experiments will be more difficult later in the effort. The signals to be used in an experiment will not be specified before we know the behavioral context of the tagged animal during the exposure.

Back-up tags (LK-tags):
LK-Konsult (Lars Kleivane) in collaboration with FFI has developed a whale tag containing a depth sensor and a VHF-transmitter. This tag is launched from an ARTS (Aerial Rocket Transmitter System) system and attached to the animal by a small anchor (ca 40 mm long) which is shot into the blubber of the animal. It releases itself from the animal using a galvanic time releaser. The advantage of this system is that deployment of LK-tags could be done at longer distances from the whales and is not as weather dependent as deployment of dtags. However, LK-tags collect much less information, and dtags are therefore the main instrument during the trial. LK-tags may be used supplementary to dtags (simultaneous taging of another individual in the same group), or as an alternative, if conditions does not allow for the use of dtags.

Controlled exposure experiments on herring:
The IMR research vessel G.O. Sars are operating in the area west and northwest of the Vestfjorden basin in the first part of our trial, doing herring surveys. G.O. Sars will deploy sub-surface acoustic buoys in the area west of Andenes. These buoys contain an echo sounder and ADCP which collects and stores information about density, depth and swimming speed of herring schools. The plan is for Sverdrup to transit up to this area at November 11. The exact date for this experiment may be shifted a day or two in both directions depending on weather and conditions for whale tagging. Once Sverdrup arrives we will make several run-bys across the observations buoys with Socrates deployed but not transmitting or while transmitting LFAS-signals or while transmitting MFAS-signals. We will use the same signals and exposure protocols as for the killer whale trials (LFAS and MFAS). The entire experiment with run-bys with and without acoustic transmission should be repeated twice, once during daytime and once during night to look at day-night variations. In connections with the exposure runs it is important to collect sound speed profiles. This may be achieved using a light boat and a mobile CTD-probe. After the experiments, Sverdrup will release and pick up the boys and transit back to Vestfjorden. If opportunity permits the experiment may be repeated inside the Vestfjorden.

IMR also has an acoustic observatory placed in the mouth of Ofotfjord. This platform is permanently mounted on the bottom and contains echo-sounders, ADCP and a horizontal sonar. If opportunity permits, with favourable occurrences of herring at this location, we will also try to exploit this opportunity to conduct herring experiments. The protocol will essentially be the same.

When choosing an area for herring experiments inside the Vestfjorden the availability of herring (density, schooling behavior and depth) has to be appropriate. It is also very important to consider conditions for Socrates operations. Finally an area has to be chosen so that sonar transmission in that area interferes as little as possible with the killer whale experiment. We should strive to expose as few killer whales as possible to as low sonar signal levels as possible during the herring trials.

Sonar observations from Inger Hildur
The main objective of the SIMRAD cruise is to conduct a feasibility study to evaluate the use of their sonars as marine mammal detectors for mitigation purposes during seismic or military operations. Inger Hildur will join us for a few days at the end of our trial. Frank Knutsen at SAIMRAD will be leading the Inger Hildur cruise. He will coordinate with Kvadsheim to avoid using SP90 in areas were we are engaged in tagging and CEE trials. If opportunity permits for both parts, we will try to use the SH80 sonar on Inger Hildur to do sonar observations of killer whales and herring involved in feeding events during a CEE. Lise Doksæter will transfer to Inger Hildur during their participation.

Socrates operation:
Socrates can transmit one list of sounds (defined by wav-files) that can be repeated. For each wav-file the source level is specified. The first transmission can start exactly on the minute (using the GPS time).

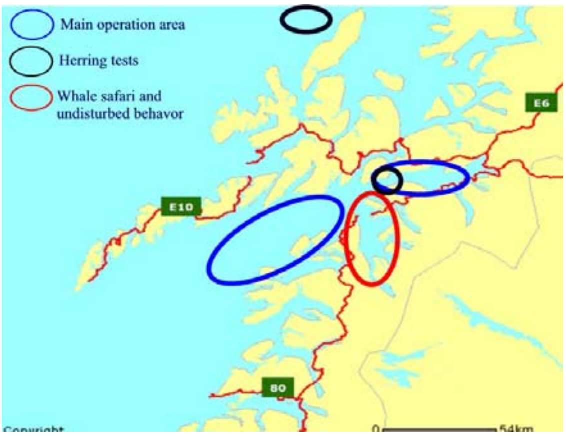
Changing the transmission scheme can be done (by hand) every minute. During the transmissions, the tow cable length of the Socrates can not be modified (only the depth can change when the speed is modified). During the towing of Socrates the ship has to sail between 3 and 12 knots. The Socrates has to be towed below 30 meters of depth, or maximum source level is limited. During towing of Socrates the ship can turn once at a rate of 15 deg per min. Delphinus can be towed together with Socrates. When the Delphinus array is towed, the tow speed needs to be between 3 and 9 knots. The Delphinus functions best at a speed between 7 and 8 knots. The tow depth of Delphinus needs to be lower than the Socrates (depth separation). Delphinus needs always be deployed before Socrates and Socrates will be recovered out of the water before Delphinus. When a CTD sensor is used to measure the sound speed profile, Socrates and Delphinus need to be out of the water. XBTs can be used during the deployment of Socrates and Delphinus.

SAKAMATA

The current SAKAMATA tool is able to compute the exposure level depending on the range and depth of the marine mammals. For this calculation the actual sound speed profile and water depth need to be known. SAKAMATA can also compute a ramp-up scheme when starting an operational sonar. It is not able to give a transmission scheme for the CEE (e.g. to get a constant received level at the position of the whales). For inclusion in the SAKAMATA or other transmission loss models (LYBIN), sound speed profiles should be taken as often as possible. Especially in the first part of the trial to map geographical and temporal variations. CTD’s may be deployed from Sverdrup when Socrates in on deck. CTD-profiles should also be collected using the mobile system on Nøkken or from the tag boats.

Location:

The orca trials will primarily be executed in the Vestfjord and Ofotfjorden area (see map below). We should strive to avoid operating in the primary whale-watching areas, particularly for early tests. We also have to coordinate with the WHOI team of Shapiro and Similä to avoid interference with their studies of undisturbed behavior. Miller is in charge of this coordination, and will call the Shapiro/Simila team before each transmission to inquire about their location and status (tagged whale, following whales etc) and to notify them. Ideally, we will find whales within fjords that we can study without exposing the wider area to noise from the sonar. The initial herring tests will be executed west and north of Andenes. We will also try to execute some herring experiments at the IMR acoustic station East of Barøy. The irregular herring distribution pattern this year may force us to move into other areas. If possible, we will take the Nøkken team with us on Sverdrup, or find alternative accommodation for them.



Accommodation:

All personnel stationed on Sverdrup will sleep and eat on board. This includes the tag boat teams. The Nøkken team will be housed in cottages in Korsnes. The captain of Nøkken will sleep at the Tysfjord Tourist Center. If the decision is made to change operation area, the Nøkken team will be housed on board Sverdrup, or alternative on-shore accommodation will be organized.

Weather and Light:

In November the air temperature will be mild: -3 to 10 ºC. Winds vary widely by location, often with a down-Fjord weather effect. Note that day lengths are quite short, particularly near the end of the trial. Depending on lighting, whales can be visually observed ~30 minutes before and after apparent sunrise and sunset, respectively.

Travel:
Bodø: Fly to Bodø airport and take a taxi to Bodø port.
Lødingen: Fly to Harstad/Narvik airport and take the airport buss to Lødingen.
Korsnes: Travel to Lødingen, and take the ferry to Bognes. Take a taxi to Korsnes or get someone from the Korsnes team to pick you up in Bognes.

According to the cruise schedule, there is an option for crew shift every Friday. All exchange of personnel should as much as possible be limited to this day. Disembarking crew will be transported to Lødingen harbour Friday evening (after 1800), and embarking crew will be picked up at the same time. There is a hotel in Lødingen if needed (Brygga Hotell +47 76931805).

Shipping:
Heavy equipment for Sverdrup should be shipped to Bodø port and loaded on-board there (Bodø harbor office phone no +47 75 55 10 80). Heavy equipment for Nøkken should be shipped to Lødingen port and loaded on-board there (Lødingen harbor office +47 76 98 66 18). Coordinate with captains or FFI.

Risk Management and Permits:
We will operate under a Norwegian Animal Research Authority permit (permit no 2004/20607-4) acquired by Petter Kvadsheim. In addition to Kvadsheim, Patrick Miller is a field operator and will be responsible for permit compliance in the field. FFI has also obtained necessary permits for VHF transmission for the whale tags from the Norwegian Post and Telecommunication Authority.
A “Humans diver and environmental risk management plan” is specified for this trial. The cruise leader is primarily responsible for these risk issues, but other key personnel should also be aware of the risks management plan. A separate risk management plan has also been specified for the handling operation of Socrates and Delphinus. All personnel involved in handling this equipment, including navigators, must be aware of the content of this plan. Risk involved in the handling and operation of this equipment is the primary responsibility of the TNO chief scientist.

Public outreach and media:
To ensure good relations and interactions with whale-watching companies, fishing vessels and environmental stake-holder groups, we will hold a public outreach event prior to the cruise at the Tourist Centre, Tysfjord. Outreach efforts are also made prior to this time, and following the cruise at some appropriate time.
During the cruise, all media contact should be referred to the cruise leader who will coordinate with the research PI’s and FFI’s information office. The on-shore PR-contact at FFI is Rune Sævik.

Crew plan:

Name	Institution	Embarks	Disembarks	Vessel
Lars Kleivane	FFI	2.11	1.12	Sverdrup
Tommy Siversten	FFI	2.11	1.12	Sverdrup
Erik Sevaldsen	FFI	2.11	17.11	Sverdrup
Nina Nordlund	FFI	17.11	1.12	Sverdrup
Otto Book	FFI	16.11	2.12	Nøkken
Petter Kvadsheim	FFI	2.11	1.12	Sverdrup
Rune Sævik	FFI	17.11	21.12	Sverdrup
Ulf Johansen	FFI	1.11	15.11	Nøkken
Olav Rune Godø	HI	10.11	15.11	Sverdrup
Ronald Pedersen	HI	10.11	1.12	Sverdrup
Lise Doksæter	HI/FFI	2.11	1.12	Sverdrup
René Dekeling	RNLN	24.11	1.12	Sverdrup
Hajime Yoshino	SMRU	2.11	1.12	Nøkken
Alice Elizabeth Moir Pope	SMRU	2.11	1.12	Nøkken
Ari Friedlaender	SMRU	2.11	1.12	Sverdrup
Sanna Maarit Kuningas	SMRU	2.11	1.12	Nøkken
Filipa Samarra	SMRU	2.11	1.12	Nøkken
Patrick James Miller	SMRU	2.11	1.12	Sverdrup/Nøkken
Kees Camphuijsen	TNO/KNIOZ	3.11	10.11	Sverdrup
Adri Gerk	TNO	2.11	24.11	Sverdrup
Frank Benders	TNO	10.11	17.11	Sverdrup
Frans-Peter Lam	TNO	2.11	10.11	Sverdrup
Joost Kromjongh	TNO	24.11	1.12	Sverdrup
Myriam Robert	TNO	10.11	24.11	Sverdrup
Peter Fritz	TNO	24.11	1.12	Sverdrup
Sander van Ijsselmuide	TNO	2.11	10.11	Sverdrup
Timo van der Zwan	TNO	17.11	1.12	Sverdrup

Appendix C Human diver and environmental Risk Management plan

Introduction

In November 2006 a multi-national experiment is scheduled in Vestfjorden, Norway. The main objective of this experiment will be to tag free ranging killer whales inside the Vestfjorden basin with sensors recording behaviour and acoustic signals, and thereafter expose the tagged animals to naval Low and Mid Frequency Active Sonar (LFAS and MFAS) signals, in order to study behavioral reactions of the animals to such signals.

Other experiments will also be executed, including the exposure of herring overwintering in the area to LFAS and MFAS signals while monitoring behavioral reactions of the herring using subsurface acoustic buoys.

We have designed this scientific experiment to generate important data for the naval partners to consider in their specification of “safe” sonar operations. The objective of this experiment is thus, to enable navies to use sonars while minimizing the impact of their sonar transmissions on the marine environment and on commercial interests like fisheries and whale watching tourism. The nature of the experiment makes it necessary to use a high-power sonar source in an ecologically important area. Therefore careful risk mitigation measures during the operation of the sonar source are essential. We do not want to end up with exactly the opposite of our main goal, that the experiment itself leads to unnecessary environmental damage. This risk management plan specifies the risk involved and the steps we will take to minimize the risk of unintended harm to the environment and to human divers.

Participating organizations:

The trial is a joint effort between:

· The Norwegian Defense Research Establishment (FFI), Norway
· The Royal Netherlands Navy (RNLN)/Defence Materiel Organisation, The Netherlands (NL MOD).
· The Royal Norwegian Navy (RNoN) and the Norwegian Ministry of Defense (MOD)
· The Royal Netherlands Navy (RNlN)/Defence Materiel Organisation, The Netherlands
· Sea Mammal Research Unit (SMRU), Scotland
· Woods Hole Oceanographic Institution (WHOI), USA
· Institute of Marine Research (IMR), Norway
· SIMRAD, Norway
· LK-Konsult and Wild Idea, Norway

The Netherlands Organisation for Applied Scientific Research TNO is through the NL MOD an indirect participating organization to this experiment. The performance of the tasks of NL MOD to this experiment will be carried out by TNO, as a contractor of NL MOD under the terms and conditions of the agreement with referencenumber UTP 016.06.5105.01 (Internationale samenwerking Marine Mammal Protection Fase 1) between TNO and NL MOD.

Risk inventory

The operation area (Fig. 1) includes Vestfjorden, Ofotfjorden and the area West of Andøya. The trial starts at November 3. and ends at December 1. During this time it is expected that large amounts of herring will enter the fjord system to overwinter. Usually, numerous groups of killer whales also enter the fjord to feed on the herring. The high presence of herring also implies a high fishing activity for herring from the purse seine fishing fleet. Generally, there are also a fairly intense cod fishery in the area, using seine, nets and jigs. The high presence of killer whales in the area also leads to a high number of whale safari companies operating, and some of these also arrange diving excursions. The area is also densely populated with fish farms, primarily mussels, cod and salmon. During the experiment a high-intensity sound source is going to be used. This sound source is a horizontally omni-directional towed transducer, which will be towed from the FFI research vessel HU Sverdrup (Fig. 1) at approximately 30 m depth. The transmitted signals will be in the 1-2 kHz and 6-7 kHz band. The corresponding transmitted source levels will be 209 dB (re 1μPa @ 1m) and 200 dB (re 1μPa @ 1m), respectively. Hearing curves indicate that both the herring, human divers and marine mammals in the area will hear the transmitted signals at considerable distances (Fig. 2).

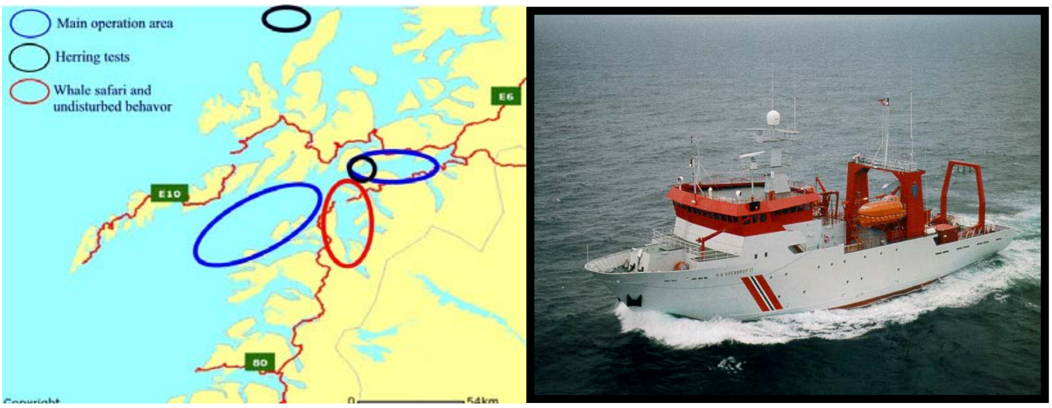


Fig.1. *Expected operation area of HU Sverdrup during the trial*

The risk inventory includes:

1. Risk of causing injury to human divers.
2. Risk of causing injury to marine mammals
3. Risk of impact on whale safari activity.
4. Risk of impact on the fishery
5. Risk to fish farms.

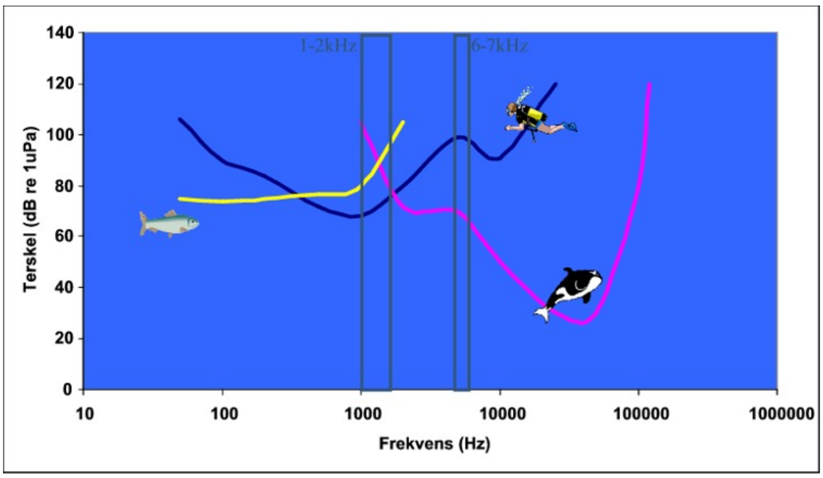


Fig. 2. *Hearing curve of herring, killer whales and divers. The frequency band of the transmitted frequencies are also indicated.*

Risk mitigation

1. Mitigation of risk to human divers

Diving areas

It will be determined in advance of the experiment if diving activity, or possible diving areas, have been identified in the planned operations area. Local diving clubs have reported the most commonly used diving sites within the operation area (Fig. 3). However, at this time of the year most of the diving in these waters is in relation to whale-watching activities. Therefore, good communication with the diving whale-watch operations would be helpful to assure that we are not in the same areas. Also, we will try to avoid working in areas heavily used by whale-watch safari companies, particularly those with diving.

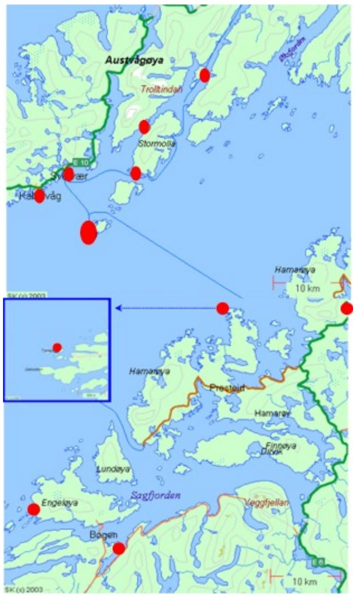


Fig.3. *Recreational diving sites based on reports from local diving clubs*.

Maximum received sound pressure levels

The main concern with exposure of divers is that divers might experience a high stress level during the exposure because they are unacquainted with the sound. NATO guidelines therefore differentiate between risk to naval divers and commercial and recreational divers. The guidelines are based on psychological aversion testing, and for commercial and recreational divers a maximum received sound pressure level of 154 dB re 1μPa is established for the relevant frequency band. Based on the source level of 209 dB re 1μPa @ 1m and the maximum received sound pressure level of 154 dB re 1μPa and expected propagation conditions during the trial, the stand off range will be 1000 m.

Mitigation measures

1. We will stay away from known diving sites.
2. We will communicate with whale watching diving operations to avoid transmitting in their vicinity.
3. During transmission there will be visual observers on the source boat and on a secondary observation vessel placed on the course line of the source boat. Any observed diving activity should be reported to the cruise leader instantly.
4. If any diver comes within the 1000 m stand off range, transmission will be stopped.

2. Mitigation of risk to marine mammals

<u>Species:</u>
The species of marine mammals likely to be encountered in the operation area (fig. 1) are:

1. Gray seals
2. Harbor seals
3. Harbor porpoise
4. Killer whales
5. White-beaked dolphins
6. Sperm whales
7. Minke whale
8. Fin whale

The study animal, the killer whales, are the most common. Seals and porpoises tend to stay away from areas with many killer whales. We will not work in shallow areas with water depths less than 100m. This will reduce the risk that shallow water species like harbor porpoises and seals may be exposed unintentionally to high sound pressure levels. Seal colonies are mostly outside the main operation area. Grey seals are within their pupping season, and grey seals colonies should therefore be avoided (Fig. 4).

<u>Area</u>
The operation area is specified in fig. 1. We will avoid working in areas where 'embayment' is possible, such as very close to the head of fjords. However, the subject species, killer whale, are often found within these fjords, and it is likely that we will work inside the fjords in some cases. When we do work within fjords, the source ship will start transmission inside the fjord and move towards the outlet of the fjord, never towards the head of the fjord. Before commencing transmission visual observers on the source ship should search for marine mammals further up the Fjord to reduce the risk of animals being trapped within fjords.

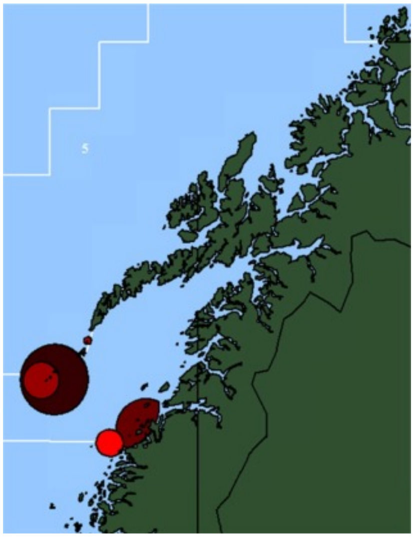


Fig. 4. *Harbour seal (dark red) and grey seal (bright red) colonies.*

<u>Maximum received sound pressure levels</u>
Maximum exposure levels are determined to avoid physical injury (e.g. hearing injury) to marine mammals. Such injuries are not expected to occur unless an animal comes very close to the transmitting source. According to the permit issued for this trial by The Norwegian Authority for Animal Research, the maximum exposure limit are 200 dB (RMS re 1 µPa). We will operate using a safe stand off range of 100 m, which according to the maximum source level and estimated

transmission loss keeps the maximum exposure level way below this. During transmissions, visual observers on Sverdrup will assure that no marine mammal comes within this safety zone. The objectives of the experiment are to study behavioral reactions of killer whales to sonar signals. Therefore transmission will not stop based on behavioral reactions of the study subjects unless the reaction puts the animals in direct danger of getting hurt (e.g. stranded). However, transmission will be ceased immediately if any animal shows any signs of pathological effects, disorientation (unusual non-directional swimming), severe behavioural reactions (succession of forceful actions such as breaches, behaviour outside species-typical behaviour) or if any animals swim too close to the shore or enter confined areas that might limit escape routes. The decision to stop transmission outside the protocol is made by the cruise leader stationed on the source vessel, based on advice from the visual and acoustic monitoring team on Sverdrup and on a separate observation vessel (Nøkken), which will stay close to the tagged animals. The Nøkken will inform the Sverdrup of the whales' location every 5 minutes.

Exposure protocol

The starting point of the source vessel Sverdrup should be 3 nm away from the tagged subject animals. That will give a transmission loss of roughly 60-70 dB (using 16-19logR). We will start with a short ramp-up allowing other marine mammals in the area to escape the proximity of the source. The initial source level will be 170 dB re 1μPa @ 1m, and this will be increased to the maximum source level of 209 dB re 1μPa @ 1m within 3 min. Towing speed should be constant at 7 knots, and initially course set directly towards the animals. If the animals changes position the source ship will change the course correspondingly, but after 10 min the course will be maintained constant. This will allow the animals to avoid the signal, if they try to. We will pass the animals after 25-30 minutes. The Sverdrup will maneuver to pass no closer than 100 m from the closest killer whale. At 100 m range, the received sound pressure level should be roughly 170 dB re 1μPa. Transmission will continue for another 4-5 min after passing the animals. The received level of the sonar near the whales will be monitored in real time using a towed array from the observation vessel. This information will be passed to the source vessel to assure that the source is operating correctly within the planned acoustic exposure range. The behaviour of the tagged killer whales will be monitored closely from the observation vessel by a team of experienced marine mammal observers. This team will be led by Dr. Patrick Miller who is a highly experienced marine mammal behavioral biologist, whose expertise is killer whale behavior.

Mitigation measures

1. Stay away from shallow areas and sensitive areas like gray seals colonies.
2. Avoid working in areas where 'embayment' is possible, such as very close to the head of fjords.
3. If transmitting inside a fjord the source ship will move way from the fjord head towards the outlet.
4. During transmission there will be visual observers on the source boat, and on a secondary observation vessel placed closed to the tagged animals.
5. A safe stand off range of 100 m will be established. If any marine mammal comes within this zone, transmission will be ceased.
6. Transmission will always commence using a ramp-up.
7. A protocol for termination of exposure experiments if animals are in danger of getting injured is established.

3. Prevention of conflict with whale-watching activities

The main objective of the trial is to obtain information about the behavioral reactions of killer whales when exposed to sonar signals. This will give us a basis to assess how future naval exercises will affect whale watching activities. Our planned operating area (fig.1) overlaps with the whale watching area as reported to FFI by the whale watching companies (fig. 5). However, the area with the highest whale watching activity is Tysfjord. To reduce potential conflict with whale-watching activities, we will focus our research in outlying areas of killer whale habitats, preferring other fjords. We will strive to avoid operating in the primary whale-watching areas, particularly for early tests. When we have gained some experience with how the killer whale reacts to the signal, we will consider if it is possible to operate closer to the whale watching activities without causing conflicts. Risk to divers should then be considered thoroughly. The most important mean to prevent conflicts with the whale watching activity will be to establish good collaboration with the whale watching companies. We will try to establish good communication and have continuous dialog with them during the trial. In good time before commencing the experiments written information about the trial will be sent to the whale watching companies. In addition a public meeting will be held in the area to inform about the execution of the trial and the risks involved. The whale watching companies will be invited to this meeting, and further mitigation measures will be discussed there.

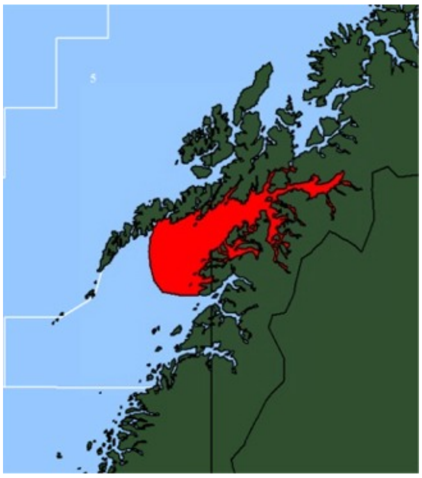


Fig. 5. *Whale watching area as reported by the local whale watching companies*.

4. Prevention of conflict with the fishing industry

A main objective of the trial is to obtain information about the behavioral reactions of herring when exposed to sonar signals. This will give us a basis to assess how future naval exercises will affect the herring fishery. Based on historical catch data from the Directorate of Fisheries it is expected that there will be a high fishing activity in the operation area. The primary target species are herring and cod fish. The primary fishing gears are purse seine, nets and jigs.

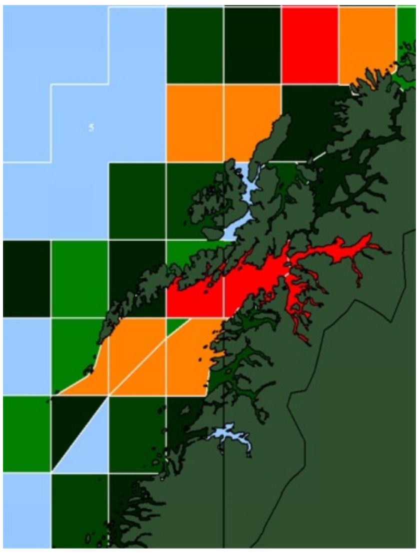


Fig 6. *Expected fishery activity in the area based on historical catch data. Red areas have a high activity, orange a moderate activity, and green areas moderate to low activity depending on darkness of the green color.*

To reduce conflicts with the fishery industry we will strive to avoid operating in the most intense fishing areas, particularly for early tests. When we have gained some experience with how the herring reacts to the signal, we will consider if it is possible to operate closer to the fishing fleet. We will have a local fishery adviser on board, and his main task will be to communicate with the fishing vessels, and keep track of the most intense fishing areas. Based on knowledge of hearing curves and previous studies of acoustic sensitivity of different species it is expected that cod fish will not be affected by the signals transmitted during the trial. The herring fishery is the biggest concern. Preliminary studies of stress reactions in adult herring exposed to sonar signals indicate a reaction threshold of 160 dB re 1μPa at the lowest transmitted frequencies (1-2 kHz). Thus, a stand off range of 300 m from purse seine vessels actively fishing will be maintained during transmission. Occasionally, live herring catch are temporarily put into net cages. The 300 m safety distance also applies to these net cages. When transmitting in the high frequency band (6-7 kHz) a standard safety distance of 100 m is sufficient.

5. Prevention of conflict with fish farms

There are numerous fish farms in this area (fig. 7). These are placed in shallow sheltered areas such as narrow straits and bays. This implies that we are unlikely to enter the proximity of any fish farms during transmission. The main concern with farmed fish is physiological stress, which might lead to reduced survival, growth or meat quality. According to the register of the Directorate of Fisheries the fish farms in the area contains cod, salmon and mussels. These species are not considered to be sensitive to acoustic signals in the relevant frequency band. They are not likely to detect the signals unless the source is in the immediate proximity of the farm. A standard 100 m stand off range from any fish farms is considered sufficient.

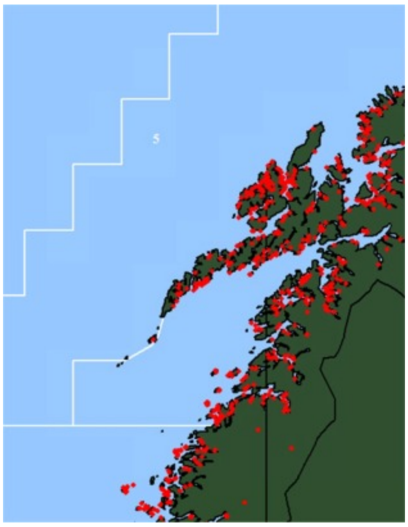


Fig. 7. *Fish farm concessions based on data from the Directorate of Fisheries.*

Incidents

Although we will use extensive safety measures, it is still possible that undesired events will take place. The trial is an animal experiment and as such it has been approved by the Norwegian Authorities for Animal Experimentation. The legal aspects is regulated through the Animal Welfare Act (Dyrevernloven) and the Regulation on Animal Experimentation (Forskrift om Forsøk med Dyr). Should stranded or injured animals be discovered in the operation area, we should seek to react as quickly as possible to identify the location of the animal, to assess whether any link with our sonar transmission is possible.

Marine mammal strandings:
Strandings of dead seals and porpoise are not uncommon in the operation area, while strandings of larger species are uncommon. All strandings should be treated as suspicious. Norway does not have an official stranding network, but if any link with our sonar transmission can not be excluded we should be prepared to assist with the stranding operation, and in the case that animals die, we should assist to get the animal quickly to a facility where good necropsy procedures can be carried out. The appropriate authority to contact is the local animal welfare authority (Mattilsynet/Viltnemd) and the local veterinary authorities (Distriktsveterinær). We have a pre-established contact with expert marine mammal pathologists at the Norwegian College of Veterinary Science in Tromsø. They will advise us on how to prepare the necropsy, and assist us as soon as possible. All possible mans will be applied to try to establish the cause of death

Injured marine mammals:
If any marine mammals are found injured during the trial, we will respond quickly to establish if our sonar transmission could be the cause of the injury. If any causal link between the injured animal and our activity can be irrefutable excluded, the local animal welfare authority (Viltnemd) will be notified, and they will take over responsibility. The responsibility of handling injured animals which are injured or could have been injured as apart of the exposure experiment lies with the permit holder. We have pre-established contact with veterinarians at the Norwegian College of Veterinary Science in Tromsø, and in such an event they will be consulted. The local animal welfare authority will also be notified. In the highly unlikely event that an animal has to be terminated (put to death) in accordance with the Animal Welfare Act and the Regulation on Animal Experimentation, the decision to do so lies within the permit holder. He will also decide if the destruction can be done by ourselves, using a large-bore rifle, or if other means (e.g. harpoon canon) are needed. In a situation like this all possible means will be applied to try to establish the cause of the injury.

Responsibilities

Damage to third party
FFI will be fully liable for any damage arising out of and/or resulting from the performance of the experiment suffered by any third party.

Permit issues
Petter Kvadsheim (FFI) is the formal permit holder, and he is responsible for any issues related to the welfare of the experimental animal during the execution of the animal experiment. In addition to Kvadsheim, Patrick Miller (SMRU) is a field operator and will also be responsible for permit compliance in the field.

Marine mammal and diver safety
The cruise leader (Petter Kvadsheim, FFI) is responsible for human diver and marine mammal safety issues.

Communication
The cruise leader (Petter Kvadsheim) has a superior responsibility for communication with third parties, including relevant authorities, and between the different groups within the trial team. The chief scientists of the participating organisations are responsible for communication with their team members on relevant safety issues.

PR issues:
During the trial the field scientist cannot be expected to handle all public enquires and media contacts at all times. FFI has appointed on-shore point of contacts that will assist in handling these enquiries. Rune Sævik (FFI) is particularly responsible for handling enquiries from the media.

Other relevant documents

For more information on the execution of the experiments please refer to Petter Kvadsheim (FFI) and the “3S-2006 Cruise Plan” (available at phk@ffi.no)

For more information on the objectives of the study please refer to Patrick Miller (SMRU) and the white paper proposal “Killer whale and naval sonar – does avoidance indicate disturbance or protection from exposure” (available at pm29@st-andrews.ac.uk)

For more information on permits issues please refer to FFI for the permit documents (permit no **2004/20607-4**) from the Norwegian Authority for Animal Research (Forsøksdyrutvalget) (available at phk@ffi.no).

For more information on legal issues please refer to the Animal Welfare Act (Dyrevernloven) and the Regulation on Animal Experimentation (Forskrift om Forsøk med Dyr) (available at http://www.mattilsynet.no/fdu/regelverk).

For more information on NATO guidelines for sonar operations in the proximity of divers, please refer to NATO-URC “staff instruction 77” (available at http://192.106.197.208/solmar/PDF/77-04%20Marine%20Mammal.PDF).

For more information on the Royal Norwegian Navy’s “Regulations for use of active sonar in Norwegian waters”, please refer to Capt. Bjørn Egenberg, chief of the frigate service (available at Bjegenberg@mil.no).