Using acoustic data from pelagic fishing vessels to monitor fish stocks

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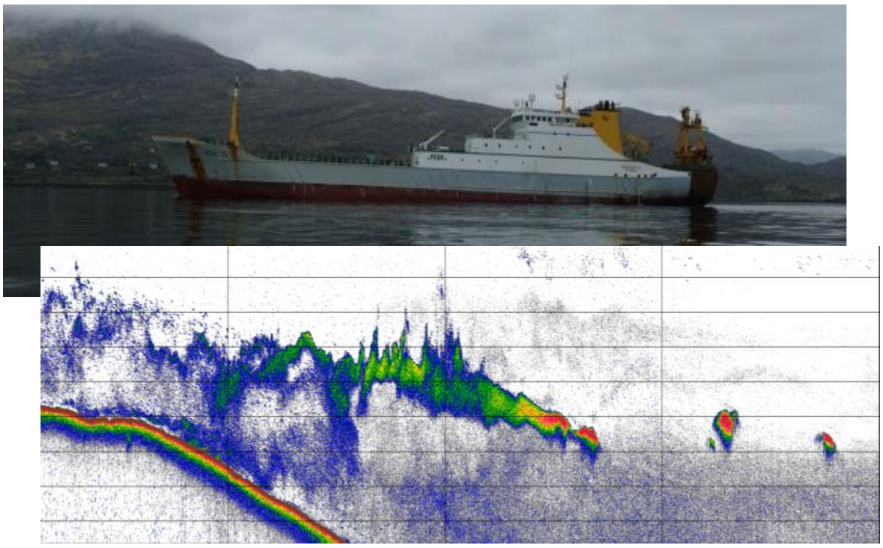

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Summary

Pelagic trawlers make intensive use of echosounders and therefore could potentially be used as acoustic data collection platforms. The present project has investigated the possibility of collecting acoustic data during normal fishing trips and the potential of this data to estimate fish stock biomass.

Within this project, two real-scale data collection trials were realised, one in spring 2012 during the blue whiting fishing season, and one in summer 2012 during the North Sea herring and sprat fishing season. For a selected number of fishing trips, the echosounder data was logged on external hard drives. Within this project, the echosounders of the Dutch pelagic trawlers were calibrated for the first time. This allowed to use the collected and post-processed data to compute absolute abundance estimates along the path covered by the vessels.

The usefulness of the data collected for calculating stock abundance indices was investigated using a fisheries simulator – a tool modelling the behaviour of a commercial fleet fishing on a spatially distributed resource. Simulations results suggest that the accuracy of such indices appear insufficient for very densely aggregated species such as blue whiting but show more potential for more evenly distributed species such as herring. Further methodological developments are still needed to better take account of irregular spatial and temporal distribution of the data collected during fishing trips.

The project highlighted the possibilities of a national science-industry collaboration to collect data for scientific purposes, such as fish stock monitoring. Further projects should focus on self-calibration of the echosounders, to increase the amount of data collected and on the implementation of this approach at an international level.

Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

1. Introduction

1.1 Background

An essential source of information to monitor pelagic fish stocks comes from scientific acoustic surveys. These make use of echosounders, which send out sound pulses and quantify the sound intensity that is reflected by objects in the water column. The research vessels measure fish backscatter which is converted into density values per area along predefined transects. A survey biomass index for the targeted stock within the area covered can then be derived from the acoustic data. However, scientific surveys are limited by practical and financial constraints and are therefore restricted to a short period of time, and therefore only provide a snapshot view of the stock abundance. Furthermore, many commercial stocks are not assessed by a directed acoustic survey.

Echosounders are also an essential tool for fishermen. From the echosounder display, an experienced skipper is able to locate fish schools, identify the species and get a rough estimate of the biomass present. Such information is used to make a decision on where and when to shoot the nets.

The most advanced acoustic equipment used by fishermen is nowadays of comparable design and performance as those used on scientific research vessels. Providing that a list of protocols are defined to insure that required quality standards are met, pelagic fishing vessels can be used as acoustic data collection platforms and provide a useful source of information to complement or in some instances compensate for the lack of scientific data. On many occasions, fishing vessels have been chartered to carry out acoustic surveys with scientists on board (Honkalehto et al. 2011; Hordyk et al. 2011; ICES 2007; Ressler et al. 2009). In Eastern Canada, near real-time management decision about the herring fishery are taken on the basis of such industry based surveys (Melvin et al. 2001).

However, the availability of fishing vessels for performing surveys is limited and the related costs and loss of income have to be supported either by the industry or by public funding. Some attempts have been made to combine data collection and fishing activity, for instance by using spare time during regular fishing trips to perform mini-surveys (O'Driscoll and Macaulay 2005). But this is only applicable when spare time (e.g. time needed to process the catch on factory vessels) is available and for a resource distributed over a restricted area (e.g. deep sea fish on sea mounts).

The pelagic fleet is present on the fishing ground for a longer period of time than scientific vessels. Even if fishing behaviour does not follow pre-established design, a considerable amount of information can potentially be made available by recording acoustic data from commercial echosounders during regular fishing trips at negligible costs. It is therefore worthwhile investigating how such data can be collected and how to ensure that quality standards are met so that scientific use of these data is possible. The usefulness of such "unconventional" data for monitoring fish stocks should also be considered.

Based on this idea, Canadian scientists have developed an automatic acoustic logging system and collected data on Atlantic herring during fishing operations in early 2000 (Melvin et al. 2002). This data was used to monitor the aggregation of herring and decide on the timing of the scientific survey (performed on the same fishing vessels).

More recently, ICES held a study group (see ICES (2007)) dealing with the technical aspects and the definition of protocols for acoustic data collection on board fishing vessels. The conclusions of this group provided a useful basis to start pilot studies in collaboration between the Dutch pelagic fishing companies and IMARES (Ybema et al. 2008, Brunel et al. 2010 and IMARES 2010).

These studies concluded that most of the vessels of the Dutch pelagic fleet have suitable acoustic and computer equipment to be used as data collection platforms. A small data collection experiment has been conducted, revealing that logging acoustic data onto an external hard drive was relatively easy and did not require any further technical development. However, these studies pointed out that clear guidelines should be established to ensure the standardised data collection required for scientific purposes. Further, they raised the question of how the standard analytical procedure used during regular scientific surveys to calculate abundance indices should be adapted for commercial acoustic data.

The pelagic sector is willing to take an active role in the process towards a sustainable exploitation of fish stocks. Providing acoustic data collected during their regular fishing trips would be a good opportunity to do so. Therefore, the pelagic fishing industry financed a new project in collaboration with scientists from IMARES (Institute for Marine Resources and Ecosystem Studies) to further develop this new approach for monitoring fish stocks.

1.2 Aims of this project

This project aimed at going one step further in the process of designing a framework, methods and tools necessary for an operational collection, analysis and use of commercial acoustic data produced during regular fishing trips to derive stock abundance estimates.

Calibration of echosounders is a requirement if one wants to make a quantitative use of the data collected. This operation is routinely performed at the start and at the end of research surveys, but has never been carried out on a Dutch pelagic freezer trawler. One of the main aims of the project was hence to successfully calibrate the echosounders on pelagic trawlers. The project should identify the specifics of this type of fishing vessels with regards to performing a calibration, and consider how the standard protocols used on research vessels can be applied to commercial vessels. To facilitate this operation, specific equipment or software may have to be developed. During this project the development needs should be identified and if possible achieved. The project aimed at gaining experience in calibrating these vessels. Such experience will be crucial in the future in order to provide the crew of these trawlers with guidelines and training on how to calibrate the echosounders.

The project also aimed at conducting large scale data collection experiments, taking the North Sea herring, sprat and the blue whiting fisheries as case studies. These experiments involve data recording for a number of fishing trips, retrieving the raw data, processing it, and to compute a range of candidate metrics to make quantitative estimates of the targeted stocks (abundance and distribution). The goal of these experiments is to test the entire process, assess the amount of time required for the different tasks and identify potential difficulties. In addition, the aim is to start collecting data to build an abundance index time series (pending on the success of these experiments).

Unlike scientific surveys which follow a predetermined sampling scheme (usually along parallel transects) to cover the area systematically, the fishermen concentrate their effort on areas with high densities of the resource and do not cover areas with low density that are less profitable for them. To compute an abundance or biomass index that is representative of the whole stock from the data collected on pelagic trawlers is hence not straightforward. In this project, a fishing simulator will be used to test different analytical approaches to compute abundance estimates from acoustic data collected on commercial vessel and to assess their accuracy and biases. This simulator aims to reproduce the behaviour of a fleet of vessels fishing on a spatially distributed resource and producing acoustic data. To be as realistic as possible, many features of the behaviour of pelagic trawlers and of the fish schools distribution will be incorporated in this simulator. The "simulated" acoustic data (in reality, the biomass of fish recorded along the track of the vessel) can be used to assess the accuracy and precision of different methods to derive abundance estimations by comparing it to the known "true" stock biomass.

Finally, the project also aimed at developing contacts with scientists from other countries to promote this new approach and try to set up new international projects to further develop this approach. The results of this project will be presented to stock assessment experts in order to discuss their use in the stock assessment models.

1.3 Summary of the project development

The development of the project is summarised in Figure 1.

The project started on the 30th of November 2011 with a kick-off meeting at IMARES with the pelagic industry. A detailed plan for the content of the project and a time schedule were presented and agreed upon.

Shortly after, a meeting was held on a trawler in Ijmuiden to discuss the question of calibration. After this meeting it became clear that echosounder self-calibration (by the fishermen) was not yet achievable. It was decided that calibration on the trawlers should first be tested by scientists, and experience should be gained to prepare for self-calibration (i.e. to identify the needs for new equipment/software and for relevant training of the members of the crew).

Early 2012 was dedicated to the preparation of the first calibration experiments planned for spring. The preparation involved developing and building special equipment to facilitate calibration on commercial vessels (see section on echosounder calibration) and getting the necessary information about the vessels (drawings with location of the transducers and inspecting vessels in dry-dock).

In spring 2012, acoustic data were recorded during 3 fishing trips on blue whiting in the West of Ireland. Calibration of the echosounders of two vessels was performed. The lessons learned from these calibration exercises were that good logistics and time flexibility are essential to organise calibrations by IMARES scientists on board of commercial vessels. It also appeared that calibration by scientists was costly (travel + time), and that, unless self-calibration can be achieved, this would be a limiting factor for the amount of data that can be collected from calibrated echosounders.

During late spring, the raw acoustic data was processed (scrutinising, see corresponding report section). The data did not prove to be much more difficult to process than "normal" scientifically collected acoustic data, but the procedure was time consuming nonetheless: 3 full working days were needed to process data from a 3 week blue whiting fishing trip. The amount of data collected during the three fishing trips was good and comparison with survey measurements showed that the range of values were similar and no major aggregations were missed out by the survey.

In August, data was recorded for another 3 fishing trips in the North Sea during the herring and sprat season.

During autumn 2012, a desk study was carried out on how to use the acoustic data to estimate stock size, based on real data collected during the project, and data from the 2012 international blue whiting survey (see the corresponding report section for details).

During the course of 2013, the project and its results will be presented at ICES stock assessment working groups (HAWG and WGWIDE).

During the whole project, the collaboration with members of the fishing companies involved in the project was excellent. The availability of the fleet managers, with whom we had to arrange the logistics of data collection, was greatly appreciated. Enthusiasm and help from the crew for echosounder calibration and in providing detailed information on their catches was very good.

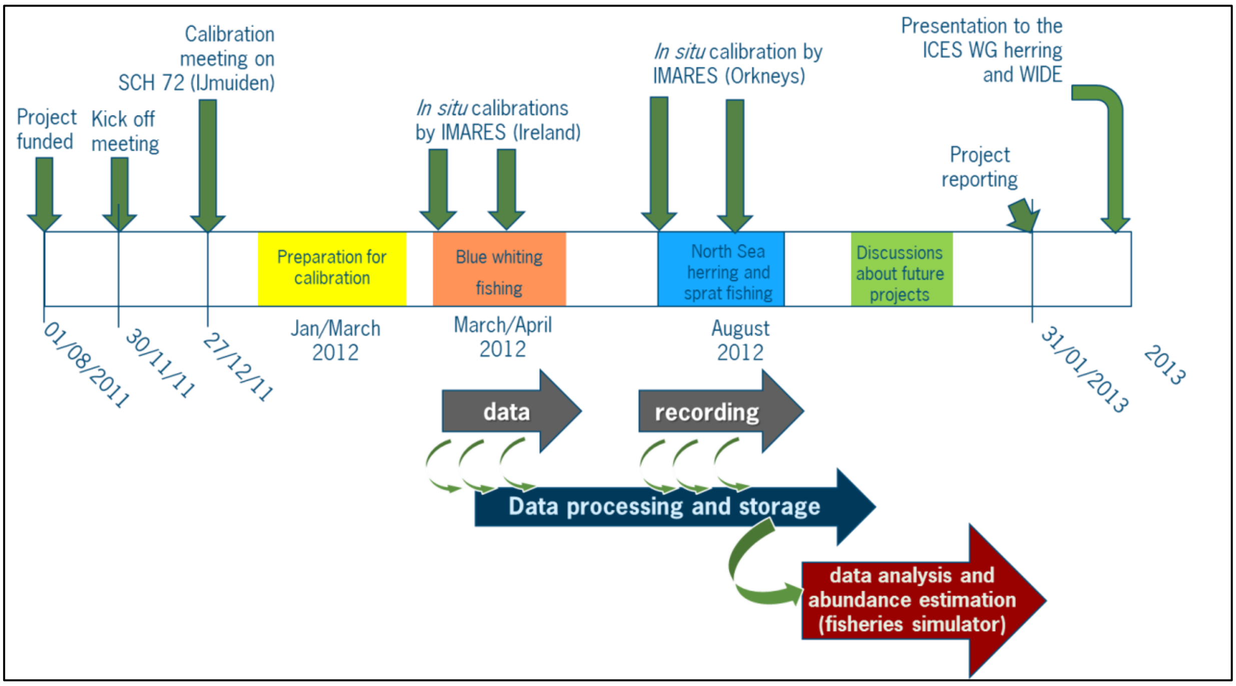


Figure 1 : summary of the development of the project.

2. Echosounder calibration

2.1 Rational

Calibration of transducers is important in order to check the correct functioning of the equipment, increase the accuracy of the data and to eliminate as many uncertainties as possible. It has to be recognized that minor differences in the calibration settings can result in a significant bias of the resulting biomass indices or estimates and make an inter-vessel or –annual comparison, as well as multi-frequency analysis, impossible.

The calibration of transducers must be conducted at least once during a survey or a fishing season (as long as the vessel stays in the same area) using the same settings (importantly: pulse duration (length), input power and transceiver gain) as during the data collection process. If possible, the transducer should be calibrated both at the beginning and the end of the trip.

Ideally, calibration should be carried out with the vessel laying still in calm conditions in deep water (>30 m under the ship's hull!). Areas with large differences in tidal height or near river mouths should be avoided. Two-point anchoring is preferable, e.g., by dropping a trawl door to serve as the stern anchor. The location of the vessel's transducer(s) should be known before the start of the calibration process to spare the time needed looking for them. Calibration normally takes 4-6 hours (plus steaming time to the calibration site if any). Sheltered bays such as 'Bantry Bay' or 'Dunmanus Bay' in Ireland, 'Penzanze Bay' in England as well as 'Douarnenez Bay' in France are known suitable locations.

2.2 How to calibrate and what is special on a fisheries vessel?

2.2.1 Standard procedure

Calibration is a standard procedure during any scientific acoustic survey. As fishermen do not require quantitative information at the same accuracy level as scientists during normal fishing operations and because calibrating remains a time consuming operation, their acoustic equipment is generally not calibrated. The standard procedures on how to conduct a calibration on a scientific vessel can be found in the SIMRAD ER60 manual[1]. In more general terms, a metal reference sphere (e.g. made of tungsten-carbide) with known acoustic properties is attached to three rods which are placed in a triangular shape on deck. The sphere has to be lowered into the sound beam and moved around to cover the entire beam. Effective scattering properties are then compared to the measured values. If the scientific echosounder version is used, the echo sounder settings can be directly updated with the calibration values via the SIMRAD ER60 software.

2.2.2 Differences in the setup

One major difference between commercial and scientific vessels is the placement of the echosounders. While on most fishing vessels the echosounders are hull mounted on scientific vessels they should generally be placed on a drop-keel. The main advantage of having a drop-keel is bubble avoidance and hence the possibility to collect data with best possible quality even in rather rough conditions, while rather noisy echograms are expected from a hull mounted sounder.

[1] Available on internet at http://www.simrad.com/www/01/NOKBG0397.nsf/AllWeb/F2AB311B3F6E6B15C1257106003E0806/$file/164692ad_ek60_reference_manual_english_lores.pdf?OpenElement

Such a difference requires a slightly different setup of the calibration rods, but the exact same principle as described above and shown in Figure 2 does apply. In order to be able to place the rods at the right spot, exact ship drawings including the placement of the acoustic equipment or alternatively a visit to a vessel in dry-dock (given the opportunity) are required.

Further the Dutch pelagic freezer trawlers that were used in the present study are of a different size class (~100m length), when compared with the average scientific vessel and therefore specific adjustments to the calibration equipment had to be made.

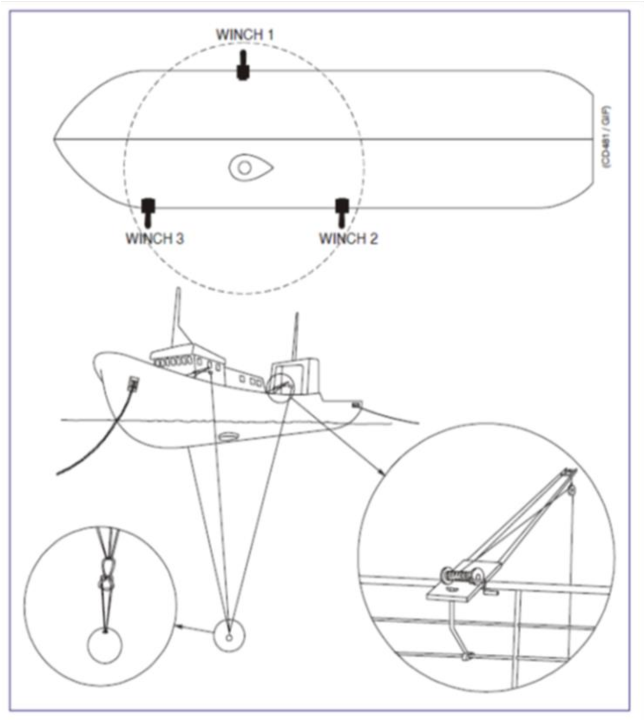


Figure 2 : Calibration setup (Simrad EK60 Reference manual)

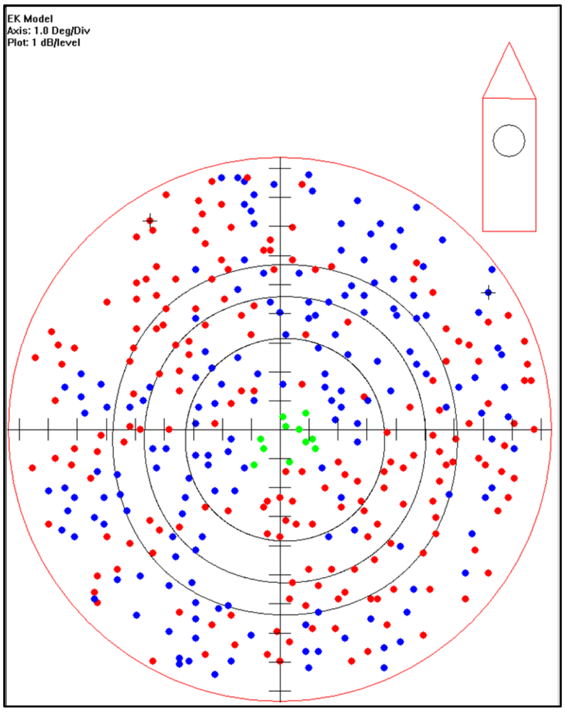


Figure 3 : Collected data points during the calibration, as visualised in the EK60 calibration module

2.2.3 Software

Commercial fishing vessels normally use the cheaper ES70 echosounder, which is specifically designed for fish finding applications. In terms of hardware requirements, it is virtually the same as the scientific version (EK60). It should deliver comparable data which however contain an error offset added by the factory that has to be corrected prior to analysis. Further, the software delivered with the two different echosounders is not interchangeable. And importantly, the commercial version lacks a calibration module. In practice this means that data has to be recorded in the commercial ES70 software before being replayed in the calibration module of the ER60 software in order to check if the beam was covered adequately during calibration. If the latter is not the case the sphere has to be directed to missing spots, until at least 25 points per quadrant (100 are recommended) are collected (Figure 3).

2.3 Innovative material development

In order to be able to execute a calibration on the participating vessels, new calibration material had to be developed.

During the project a remote controlled calibration system was developed, allowing remote steering of the calibration sphere from the bridge. The system consists of 3 major components. The first part of the system consists of three metal rods with stepper motors, which are controlling the movement of the sphere (Figure 4, left), the second part is a control box which can be placed anywhere on deck. It contains three joysticks (one for each rod) and a speed control (Figure 4, centre). Additionally, for each rod, a counter displays the amount of steps executed, in order to give an idea about how much line has been fed for each of the rods. The third component is the remote control (Figure 4, right), having the same function as the box on deck but making it possible to look at the echogram, to gain information about the current position of the sphere and move it in real time. The steering box on deck can be seen as a backup if the remote control fails. In this case the position of the sphere and future movement directions have to be communicated via radio.

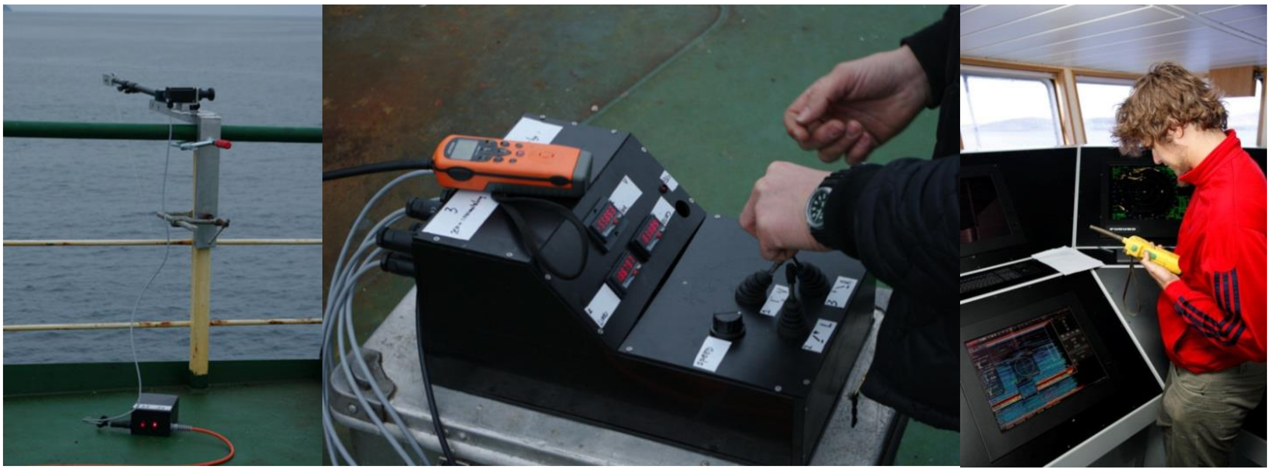


Figure 4 : material developed for the calibration. Left : Metal rod with stepper motor installed on deck; Centre : Steering box on deck, Right : remote steering of the sphere from the bridge

2.4 Calibrations performed

A total of 4 calibrations on 3 different vessels (Alida, Frank Bonefaas, Carolien) were executed successfully. The dates and locations of the calibrations are given in Table 1.

The first calibration was executed onboard ALIDA on the 10th of March 2012. For all calibrations the rods were placed, as suggested by the manual in a triangular form, allowing best possible coverage of the beam. The location of the echosounders was known precisely as drawings were available, or the vessel was visited in dry dock beforehand.

For each calibration (with the exception of the first one, where an ordinary weight was used instead of the second sphere), two spheres were attached to the ropes allowing two measurements at once, enabling verification of the measurements as well as adding weight, and hence stability to the sphere.

During the first 2 calibrations complications with the remote steering of the sphere occurred and hence the rods were operated directly from deck while the position was observed from the bridge and future movements had to be communicated via radio. At the time it was believed that enough points were collected, the sphere was brought back to the centre of the beam and the up to then recorded raw data was replayed in the scientific ER60 software (Figure 3), while raw data was continuously recorded. Some missing spots in the coverage of the beam were identified and covered subsequently.

All calibrations were done without anchoring. Generally it proved to be wiser to try a drifting calibration, as the sphere might otherwise get out of range easily when exposed to currents. It is advised to switch off the main engine in order to avoid strong noise exposure, although on Alida the main engine was not switched off during the calibration as we would otherwise have taken the risk of drifting to close to shore without the possibility of a quick reaction. On Frank Bonefaas, anchoring was shown to be not applicable as the anchor is located very close to the echosounder transducers, which makes the manoeuvring of the sphere into the beam a rather difficult task.

The first 2 calibrations were executed in the Bantry Bay (Ireland) while the 3rd and 4th where located in Scapa Flow on the Orkneys (Figure 5).

Table 1 : dates and locations of the four calibrations performed during the project

Vessel	Date	Location
ALIDA	10/03/2012	Bantry Bay (Ireland)
Frank Bonefaas	11/03/2012	Bantry Bay (Ireland)
ALIDA	02/08/2012	Scapa Flow (Orkneys, Scotland)
Carolien	23/08/2012	Scapa Flow (Orkneys, Scotland)

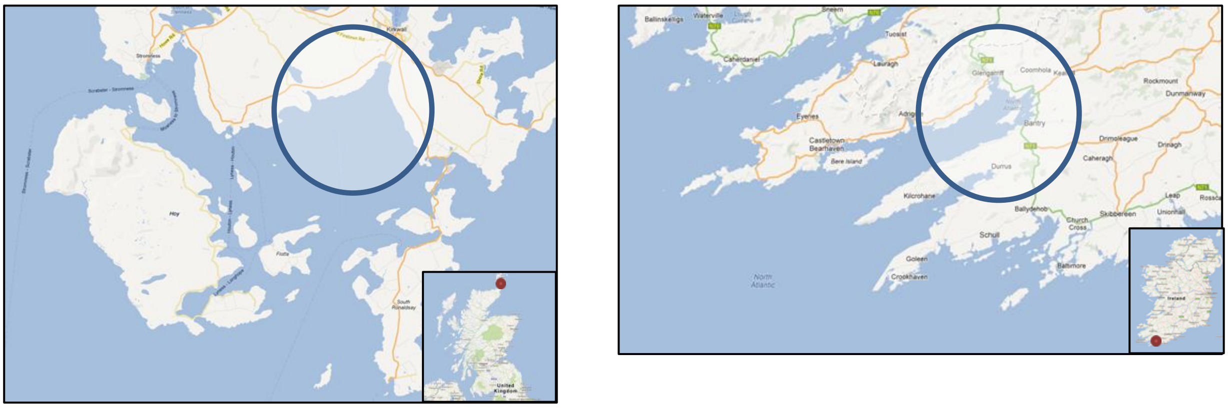


Figure 5 : Calibration sites. Right : Scapa Flow on the Orkneys (Scotland); Left : Bantry Bay (Ireland)

2.5 What have we learned, how to go further

In general the calibration part of the project was very successful; we managed to calibrate 4 vessels. During the calibration exercises it was shown that attaching two calibration spheres above each other, with a long enough distance in between to avoid shadowing, is very useful. First, to stabilise the upper sphere, and second, the lower sphere will follow the first sphere with a slight delay but generally cover the beam in a similar way, hence one calibration run can be counted as two.

It is intended that skippers and crew should get trained in executing calibrations themselves, without the assistance of scientists. For this purpose, each participating vessel should get a dedicated training session and during the first calibrations IMARES scientists will stay in constant contact with the crew. It has to be recognised though that during calibrations unforeseen problems occur frequently and solving those can be a time consuming job, especially if it has to be done remotely. Further it is crucial that the results of the calibration are being revised by experienced staff before the vessel leaves the calibration location.

As the commercial SIMRAD software does not contain a calibration module, separate calibration software should be developed, allowing a more intuitive execution of the calibration, at least from the software side. It is estimated that such a development is also crucial if the calibration should be executed by fishermen alone.

One calibration kit for each participating vessel should be produced in order to make the timing of calibrations more flexible. There is potential to further develop the calibration kit. It could for example be upgraded in a way that the movement of the sphere around the beam is executed automatically.

In a further step multiple frequencies, if available, should be calibrated in order to allow multi-frequency analysis of the data.

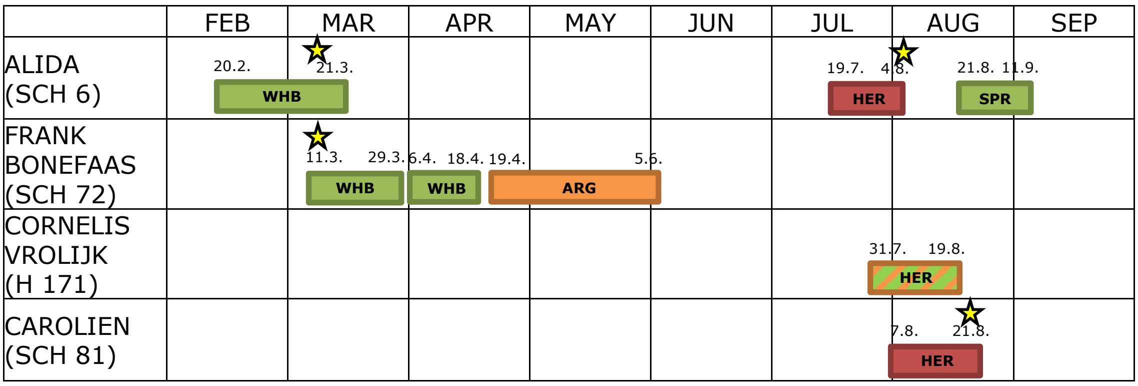
Both the crews and skippers were very helpful and enthusiastic about the procedure and it is recommended to further continue calibrating fishing vessels, to be able to use the data recorded during fishing trips for scientific purposes.

3. Data collection

3.1 Data collection and post-processing

Acoustic data were collected by selected trawlers during several fishing trips between February and September 2012 (see Table 2). The trawlers were operating Simrad ES60/70 commercial echosounder systems at 38 kHz and the data were recorded and stored as ".raw" files on external hard disks. On Alida (SCH 6), a SIMRAD EK60 scientific echosounder was installed in May and used for data collection thereafter. Hard disks were connected to the computers operating the echosounders shortly before individual fishing trips started and collected again after the trawlers returned to port. For operational reasons, echosounders were set to record data from the very beginning when leaving the home port until they returned back. This was to prevent accidental data loss and to monitor the proper functioning of the echosounder during the whole recording period. During data collection, echosounder settings (importantly: pulse duration, input power and transceiver gain) were not changed and were kept the same. When the systems were calibrated, these same settings were used to update the transceiver gains and acoustic beam patterns on Alida, where EK60 equipment was available. For other vessels that used the ES70 version the calibration values had to be applied afterwards during post-processing.

Table 2. Timing of fishing trips by participating vessel in 2012. Individual begin and end dates are given and yellow stars represent calibrations. Acronyms indicate target species (WHB: blue whiting; ARG: silver smelt; HER: herring; SPR: sprat). Colours correspond to data quality: green = calibrated & scrutinised; orange = calibrated & not scrutinised; orange/green = not calibrated & scrutinised; red = not usable, no GPS information available.



Data collected by commercial Simrad ES60/70 contain an embedded systematic error component. The systematic error has an overarching shape of a triangle wave of approximately 1dB peak-to-peak amplitude with a period of exactly 2721 data points (Figure 6). Close-up inspection of the triangle wave reveals that data points remain at the same value for 16 pings, after which there is a step to the next level where the next group of 16 data points will reside. The quantising value is equal to the amplitude resolution of the ES60/70, which is given as $10\log_{10}(2)/256$ or $1.176e^{-2}$ dB. The direction of the step (either up or down) depends on the location of the group of 16 data points in relation to the overall triangle wave shape sequence. The error triangular wave structure can be established from the transmit pulse section of the echogram data. The error wave structure embedded in the transmit pulse can be used as a basis for correcting the entire echogram. A java utility written by scientists from the Australian institute CSIRO (pers. comm. Tim Ryan, CSIRO, Hobart, Australia) inspects the transmit pulse section of the data to establish the triangle wave sequence. The utility was used to produce new corrected ".raw" data files with the error sequence filtered out.

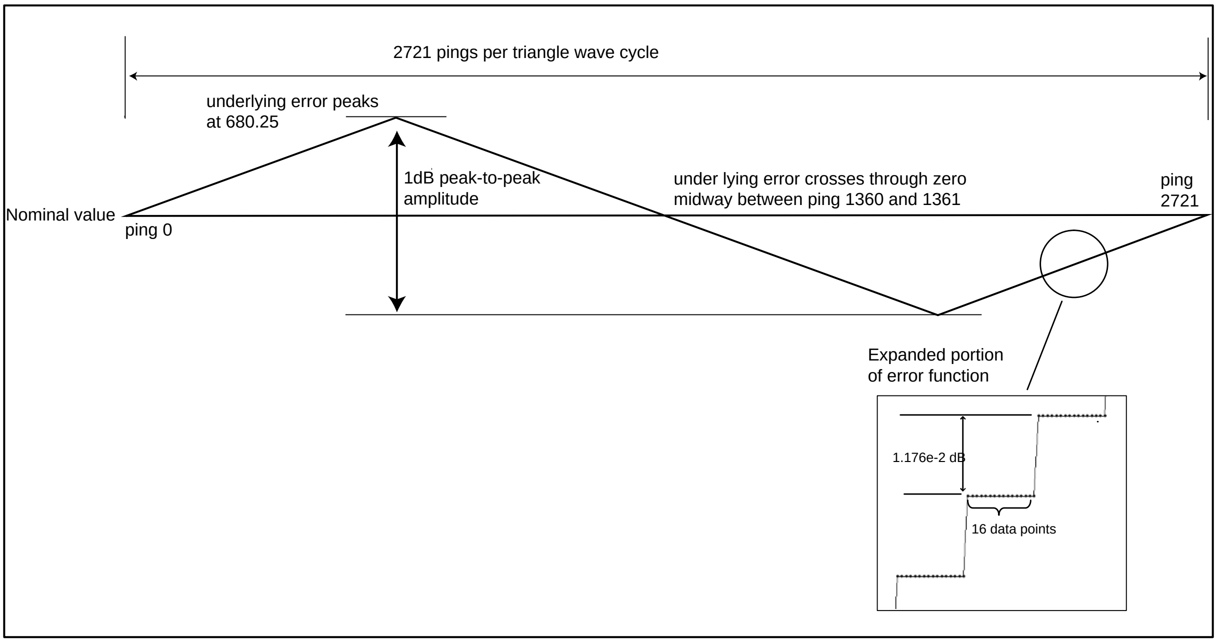


Figure 6. Schematic description of the error component in the ES60/70 data.

The collected acoustic data, corrected for the triangle wave error (if necessary) was analysed using the post-processing software LSSS (Large Scale Survey System, marec, NO, www.marec.no). Implementation of the calibration results were done within the KORONA processing application of LSSS, resulting in a new data set of corrected, calibrated ".raw" files. LSSS was then used to allocate echo energy values of the fish schools to species (scrutinising). This process was based on experience and the information available from trawl lists submitted by the respective fleet managers. Scrutinising was done for collected data, where position and time information (GPS data) was available, resulting in 4 analysed fishing trips of 73 days in total. In one case however, the trawler could not be calibrated due to shortages in IMARES staff availabilities (herring trip of Cornelis Vrolijk (H 171); see Table 2). These data were nonetheless scrutinised but could only be used to give information on species distribution and relative abundance. On the vessel Frank Bonefaas (SCH 72), data were also collected during a fishing trip targeted on greater argentine or silver smelt (*Argentina silus*), however these were not scrutinised as this project primarily focused on blue whiting and clupeids (herring and sprat). After the scrutinising process, LSSS was used to produce output reports containing acoustic density values per 1-nmi (nautical mile) intervals along the track covered by the trawlers. These reports contained information on date, time, position and acoustic density of the respective target species for each trip. With knowledge on the acoustic scatter intensity (= 'target strength') and length of the target species encountered on the fishing grounds, (relative) acoustic densities can be converted into (absolute) fish abundances.

3.2 Data quality issues

Problems experienced with the quality of the collected data are typically associated with hull-mounted transducers and non-dedicated survey vessels. These involve: (1) reduced/masked acoustic signal caused by increased amounts of air bubbles in the surface layers of the water in bad sea state, (2) increased electrical and/or ship noise, and (3) interference from other instruments.

All of these problems affect the accuracy of the measured acoustic echo energy which is eventually used for the conversion of acoustic data into fish abundance. Therefore, if these problems are too severe, a reliable estimation of fish abundance and biomass from the data collected on fishing vessels is not possible.

When weather conditions are poor, hull-mounted echosounder transducers are affected by aeration and noise caused by wind-generated air bubbles and bubbles trapped beneath the hull, masking the returned sound signal and therefore underestimating the resulting acoustic fish density. Although electric noise at echosounder frequencies is mainly caused by propeller cavitation and varies with vessel speed, internal hydraulic pumps in operation on fishing vessels can also be significant sources. If this is too bad, it may result in a reduced fish-detection capability, which could contaminate the data. This destructive interference can be difficult to track down, although it can often be resolved by proper grounding of the electrical instruments. Proper installation and screening of acoustic and other electrical equipment is extremely important. One of the most common problems encountered when collecting acoustic data from fishing vessels is the acoustic interference from other installed echosounders and sonars. This interference may range from being insignificant to unacceptable, thereby severely contaminating the collected echosounder data. The only solution would be to temporarily switch additional systems off during data collection, however, this would interfere with the normal fishing operations and is therefore not usually possible. Examples of the aforementioned problems, characteristic for data collected on various fishing trips, during this project are illustrated in Figure 7.

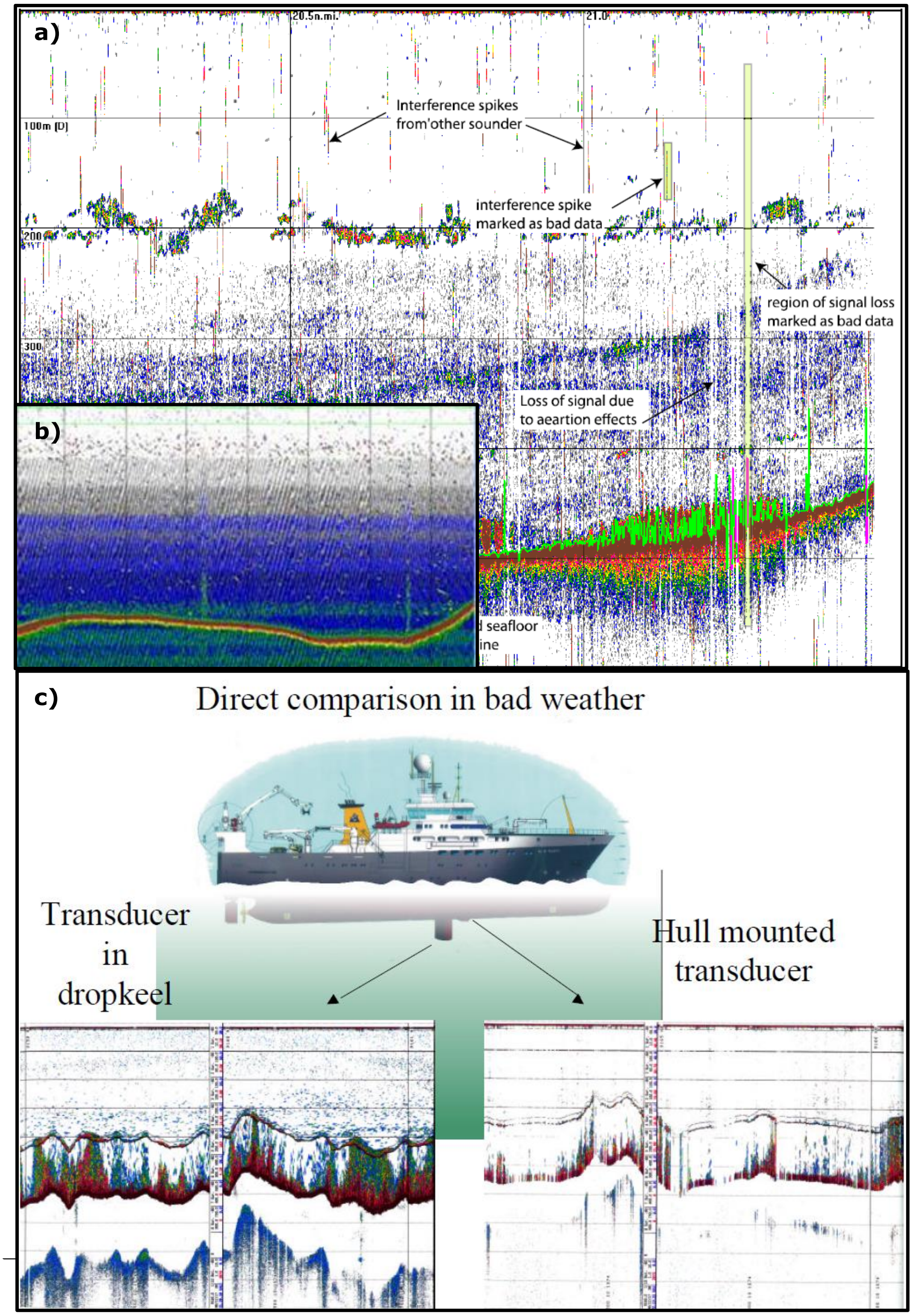


Figure 7. Echogram examples of poor data quality: (a) Noise spikes from another sounder and signal loss caused by aeration, (b) prolonged noise bands caused by the ship or electrical interference from other equipment on board, (c) data collected simultaneously with hull mounted and drop keel mounted transducers indicates the signal loss caused by increased amounts of air bubbles in surface waters, masking the measured acoustic intensity.

3.3 Results from the data collected

Data collected on blue whiting trips performed by Alida (SCH6) and Frank Bonefaas (SCH72) covered areas along the continental shelf slope west of the British Isles (see Figure 8). Acoustic data were also recorded on Frank Bonefaas after the blue whiting fishery, when the vessel was targeting silver smelt northwest of Scotland, west of Ireland on the Porcupine Bank and further south. The blue whiting density estimates measured during the fishing trips (figure 9) were mostly around 15t/nmi² (modal value), and usually lower than 500t/nmi², except for a few outliers for which the density could reach values as high as 11 000t/nmi². This area is also annually surveyed by research vessels during the ICES-coordinated blue whiting spawning stock survey (IBWSS). Data concurrently collected during a systematic survey will greatly improve precision estimation of abundances from fishing trip data and help to evaluate their use in the whole assessment process. However, there was no overlap in the spatio-temporal coverage of the survey and the fishing trips, which makes any direct comparison impossible.

During herring fishing trips, data were collected on three different trawlers, however, in two cases there was no location information (GPS data) available and for one vessel no suitable calibration could be arranged. These vessels generally covered the northern North Sea around the Orkney and Shetland Islands. On Alida, data could be collected on another clupeid species (sprat) in the southern North Sea in August and September after fishing on herring had ended (see Figure 8). Sprat density estimates were mostly lower than 200t/nmi² (although outliers with density up to 6500t/nmi² were observed), and the modal value was around 20t/nmi² (figure 10).

Overall, different fishing patterns could be observed between the two target fisheries covered in this project. Vessels involved in the blue whiting fishery were strongly confined to geographical features (shelf slope), as the resource is typically aggregating there in high densities. As a result, more constant acoustic detections could be observed when blue whiting was targeted, with less time spent for searching once the fishing grounds were reached. The same could be observed from the collected fishing tracks for silver smelt. Clupeids (herring and sprat), on the other hand, are more characterised by localised schooling behaviour with larger shoals or schools and aggregations occurring more sporadically, hence increasing the relative time spent searching for the trawlers.

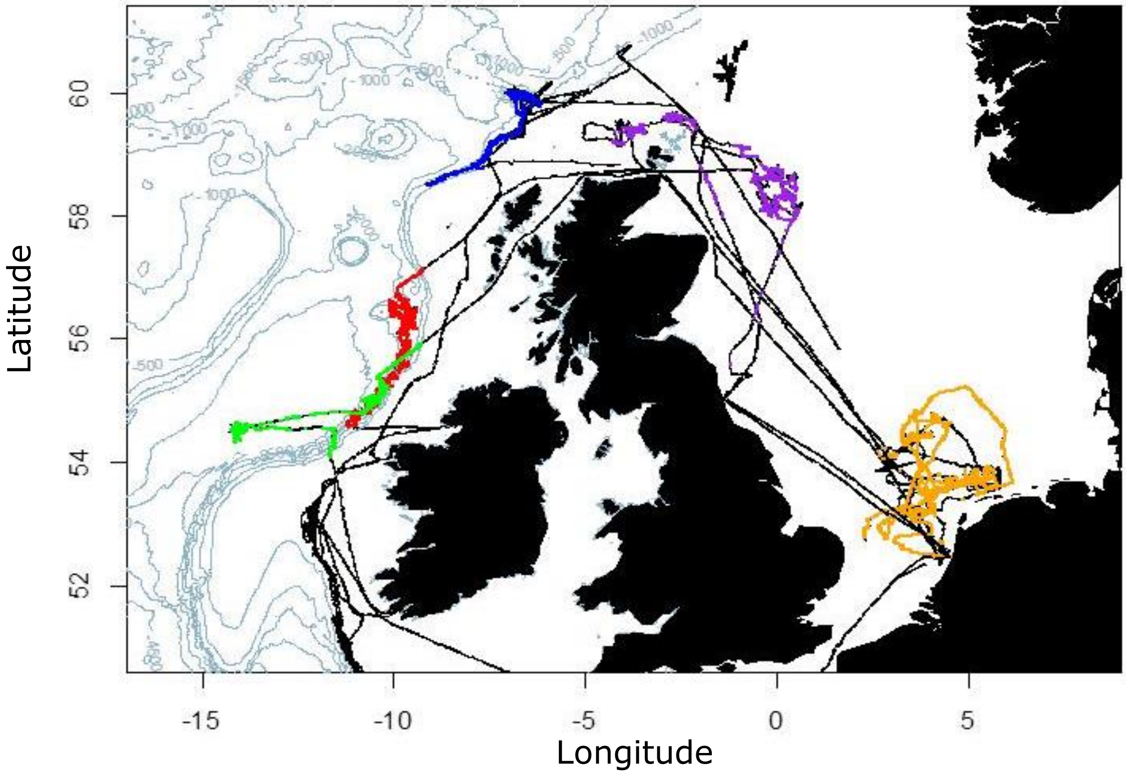


Figure 8. Tracks of fishing trips on which acoustic data was collected and recorded. Coloured sections correspond to locations where acoustic density values of fish species were recorded: blue whiting (green, red and blue), herring (purple) and sprat (orange).

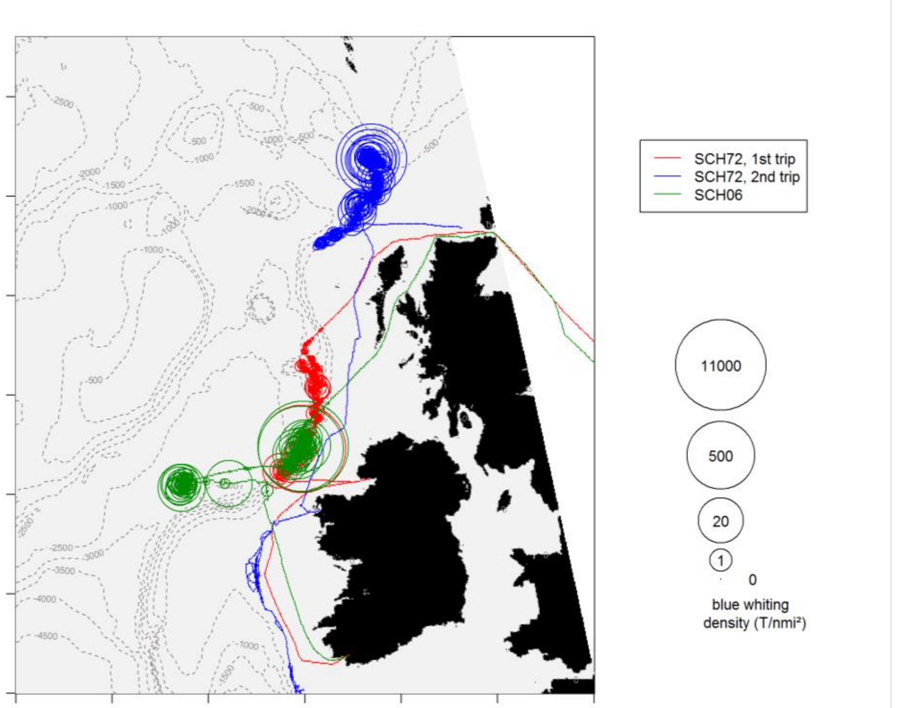


Figure 9 : acoustic estimates of blue whiting density (circles size proportional to the log density, colour represents individual fishing trip).

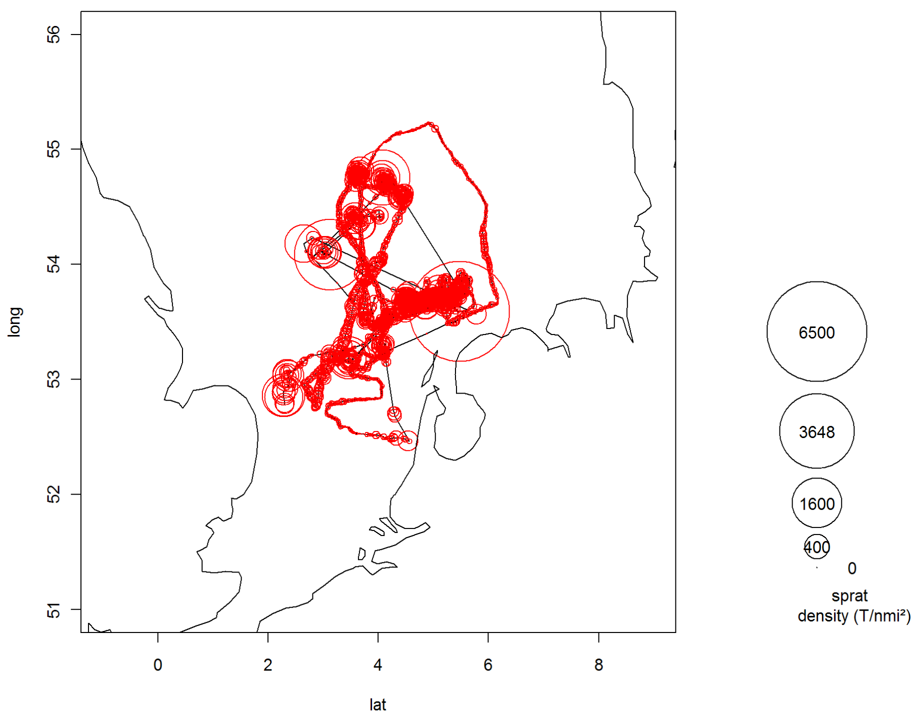


Figure 10 : acoustic estimates of sprat density in the Southern North Sea from the Alida (circles size proportional to the log density).

3.4 Achievements and future work

The close vicinity of Imares in Ijmuiden to the departing/returning harbour of the vessels used in this project greatly facilitated timely connection of hard disks and subsequent data retrieval at the end of the fishing trips. Quick communication between vessel managers and the scientists about times of departure/arrival of vessels (and possible calibration operations) could generally be achieved by phone or e-mail. The project also helped to design structured and smooth procedures for data collection, recording and subsequent storage. All recorded data collected during the project (total size: 1.29 TB) are stored and back-upped on a network drive at Imares. Through use of the LSSS software, data could be scrutinised by an experienced scientist in a relatively short amount of time, with a typical 3 week fishing trip requiring about 20-30 hours' work.

Data quality can be improved by making changes to the electric equipment, improved transducer mounting (in conjunction with the manufacturer) and switching-off of other electronic and sonar equipment used on board. While the fishing industry may accept to realise some of these changes, others would fundamentally interfere with the fishing operations and would therefore not be workable. Additionally, with more time spent during post-processing of the data, the observed noise signatures could be to some extent filtered out with help of more complex filter algorithms. However, in the specific cases where no GPS data was recorded or stopped to be recorded together with the acoustic data for unexplained reasons, a control mechanism could have helped to reduce loss of valid data. This could mean for example a daily check of the system where the skipper sends a print screen back to the scientists for quality check. Actually, any form of real-time control of the vessels' systems from a land-based computer will help to monitor collection, recording and storing of acoustic data and therefore provide a safety check to counter data loss or storage of invalid data (e.g. by use of the free software TeamViewer available at www.teamviewer.com). Eventually, proper storage of both raw and processed data will be vital to provide good quality and accessible data in the future. Setting up of a special database system to store acoustic data is currently underway at Imares.

4. Abundance estimation

4.1 Most common indices of fish stock abundance

There are many types of abundance indices for fish stocks, based either on fisheries dependent information (effort and catches of the commercial fishing vessels) or on fisheries independent information (surveys, tagging-recapture). The two types of indices most frequently used are catch per unit effort ratios and scientific survey estimates.

The idea of using CPUE, mainly applied to demersal species, is that for a single fishing action (e.g. trawl haul) the catch divided by the effort is proportional to the local density of the population (Gulland 1969), with a coefficient of proportionality equal to the catchability, q, of the species for a specific gear[2]. Therefore, assuming that q is constant the CPUE of a fishing fleet is proportional to the size of the stock, and interannual variations of stock size can be represented by a CPUE time series.

There are however potential sources of bias on the CPUE indices. For instance, the assumption of a constant catchability is not always realistic. Fishing technics improving over the years, the catchability of a fleet for a given species is likely to increase over years. If the changes in the fishing efficiency of a fleet are known, there are methods available to correct for the increasing trend in q when computing the CPUE time series. Another source of bias comes from the fact that fishing effort is not randomly distributed, but on the contrary concentrated on the areas of higher fish densities. If variations of local density are not representative of the variations in stock size, the CPUE indices may not reflect the variations in stock size. This bias will be particularly significant for species for which a decrease in abundance results in a contraction of the spatial distribution. In this case, despite a general decrease in abundance, the fishery will concentrate on high density areas and the CPUEs will remain high.

There are also problems specific to the case of pelagic fish stocks. First, the proportion of the water column actually sampled by a pelagic fishing gear (mid-water trawl, long-line, and seine) may represent a variable fraction of the vertical distribution of the fish. Hence the catchability of the gear may not be constant, but change according to the characteristics of the vertical distribution of the fish. Pelagic fisheries also mainly operate when the fish is aggregated in schools. Finally, defining and calculating the effecting fishing effort of a pelagic fishery is a more difficult task as for demersal fisheries. The effort is typically measured for demersal trawlers in days at sea (possibly multiplied by the power of the vessel). For pelagic fisheries, different types of activities are carried out during a fishing trip: steaming, searching for fish, fishing, and for factory vessels such as freezer trawlers, processing the catch. Detailed information on the time spent for these different activities during a fishing trip is seldom available and it has proven difficult to estimate it from external sources of information (e.g. VMS positioning). It is also not straightforward which of these activities should be considered as part of the fishing effort.

Another type of abundance index frequently used is scientific survey estimates. Most of the surveys targeting pelagic fish are based on acoustic measurement of fish density (although some important stocks such as mackerel are estimated by egg surveys). Acoustic surveys measure continuously fish density along pre-established transects in an area covering the distribution of the stocks of interest. Local density estimates are then raised to come up with a biomass estimate, typically by computing the average density per ICES rectangle, multiplying by the surface of each rectangle to get a biomass per rectangle, and summing up over the whole survey area. The precision of the

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[2] Catchability : probability for 1 individual fish of the stock of being caught by 1 unit of fishing effort.

abundance estimate from a survey is proportional to the amount of information collected. However, this amount is limited by time constraints, related partly to the cost of survey time, but also to the necessity to quickly cover the entire distribution area of the stock, in order to avoid the risk of double-counting fish. The success of a survey, and hence the accuracy of the abundance estimate can be hampered by technical problems or bad weather.

Acoustic surveys provide an absolute biomass (or abundance) estimate, which means that they give information both on the absolute size of the stocks and about their temporal variations. On the contrary, CPUE indices are only relative estimates, since they only show the temporal variations in stock abundance. In practice, survey indices are most of the time treated as relative indices, and are used in the same way as CPUE indices, to tune the stock assessment models.

4.2 Particularity of the acoustic data collected from pelagic trawlers compared to conventional acoustic survey or CPUE data

As they are collected during normal fishing activity of pelagic trawlers, some of the sources of errors of the CPUE data also apply for the acoustic data. A major challenge is that the data will be mostly representative of high abundance areas where the vessel is fishing. However, since the echosounder also collects data when the vessel is searching, some information on lower abundance areas will also be available. In addition, unlike CPUE, there is no bias linked to variability of catchability in the case of acoustic data. Indeed, if properly calibrated, the echosounder delivers absolute density estimates all along the vessel’s track (which is equivalent to a constant catchability). Finally, while fishing effort for CPUE may be difficult to estimate, measuring the “effort” corresponding to acoustic detections is rather straightforward. The distance covered by the vessel can for instance be used.

Unlike acoustic surveys, where survey tracks are planned in advance to have a synoptic coverage of the area occupied by a fish stock, the track of a fishing vessel in not established in advance, and depends on the activity of the vessel (succession of searching, fishing, and processing actions). This has the following implications for the data collected:

- The commercial acoustic data will not cover the entire distribution area of the targeted stocks, which implies i) that absolute abundance estimates will underestimate the abundance of the whole stock, and ii) that relative estimates may be biased if the proportion of the stock not covered by the fishing vessel(s) varies from year to year.
- The resolution of the data (and hence the precision of the abundance estimates) will be high for the fishing grounds, but lower (or even null) for the areas of lower abundance.
- In addition, for migrating species (e.g. blue whiting) scientific surveys adopt a specific design to avoid double counting of migrating fish. The fishery will probably follow the migration of the bulk of the stock, and hence the data collected may be only representative of the same migrating proportion of the stock.

4.3 Potential types of abundance indices

Three types of abundance indices were considered.

Biomass estimate (absolute)

First, the data collected by the fishing vessels may be treated as if it was survey data, and the same method can be used to compute absolute estimates of fish biomass. The acoustic density is averaged per ICES rectangle and converted into fish density (t/nmi²) using information on the size composition of the species in the corresponding rectangle. For the sake of simplicity, the average fish length from the measurements taken during the herring and blue whiting surveys were used to calculate absolute abundances.

Average density (relative)

Similar to a CPUE index, one can define an "acoustic detection per unit effort" index. This could be calculated by summing all the local estimates of fish density, and dividing by the total length of the track which comes down to computing the average fish density detected during the fishing trip.

Spatial occupation (relative, semi-quantitative)

It was also interesting to consider which type of abundance indices could be computed in a situation where echosounders could not be calibrated. In this case, the data cannot be used quantitatively, and data collected from different vessel are not comparable. Hence acoustic data from non-calibration echosounders only give presence-absence information. Two spatial indices were considered:

The *area* covered by the stock, represented by the total number of ICES rectangles where the fish were present.

The *surface occupation index*, computed as the proportion of the track (in nmi) covered by the vessels where fish was present. This index has been shown to be proportional to the abundance for the case of sardines in Chile (Castillo and Robotham 2004).

4.4 Values for the data collected on blue whiting and North Sea herring and sprat in 2012

The values for the 4 indices were computed from the data recorded during the blue whiting and North Sea herring/sprat fishing trips (table 3). In order to compute those values, the part of the track corresponding to steaming to and from the fishing ground (where the targeted species where absent) was removed. For one of the two fishing trips in the North Sea, the echosounder could not be calibrated. The data collected during this trip could not be used quantitatively (to give information on abundance and biomass) and was used only to describe the presence/absence of herring.

The values presented in Table 3, especially the biomass estimates, should be treated with caution, since the accuracy of the estimates has not properly been investigated. The simulation work presented below gives some insight on the robustness of these indices and their usefulness to represent stock abundance. However, to better assess the accuracy of the abundance estimates derived from commercial acoustic data, it will be necessary to build a time series and to compare the temporal variations of these indices with other abundance indices.

Absolute biomass estimate for the blue whiting is much larger than the survey estimate (of 2 219 thousand tonnes), despite the fact that it is based on data covering only partially the distribution area. This might be due to the fact that fishing trips cover a period of almost 3 months, during which the stock is moving. During this time the vessels move with the stock and therefore sit constantly on top of high density areas. Consequently, the abundance measured at the end (second trip of SCH72) in the northern area of the blue whiting fishing grounds may have already been partly measured earlier in the season further south. This would correspond to what is commonly called double-counting.

There is no absolute abundance index available for sprat from the assessment. The only indicator of the order of magnitude of the stock is the catch, which in the recent period, has fluctuated around 140 000t.

Table 3 : abundance indices calculated for blue whiting, North Sea herring and sprat from the acoustic data collected during several fishing trips in March-April 2012 and in August 2012 (bootspraped confidence intervals are show between brackets).

	Blue whiting	**North Sea herring**	**North Sea sprat**	**(units)**
Biomass estimate	3 218 [2.940;3.543]	- [1]	682 [2] [606;771]	10^3 t
Average density	205 [190;222]	- [1]	33.3 [2] [29.7;38.0]	t/nmi²
Area	22 [21;22]	24 [23;24]	24 [24;24]	ICES rectangles
Surface occupation index	0.86 [0.85;0.87]	0.38 [0.36;0.39]	0.57 [0.57;0.57]	
Total distance covered (excl. steaming)	3297	2389	3351	nmi
Number of trips	3	1	2	

[1]: no quantitative estimate could be calculated for this trip because the echosounder was not calibrated
[2]: data collected from the uncalibrated echosounder were not used to compute this number

4.5 Assessing the accuracy of different types of abundance indices calculated from acoustic data from pelagic trawlers based on simulated data

Whether or not the four indices described above give an accurate perception of the abundance of a stock can only be assessed by comparing the interannual variations of these indices and of other sources of information on abundance (e.g. survey estimates, assessment output), which requires that a long enough time series has been built. Nevertheless, using simulation to generate artificial time series of these indices can provide a priori information on the accuracy of these indices, and can help to understand how their accuracy may vary depending on the characteristics of the spatial distribution of the resource (depending on species) or on the sampling effort.

4.5.1 The “fisheries simulator”

A fisheries simulator was developed to generate fake acoustic data collected by vessels fishing on the resource of which the true abundance is known. The simulator was parameterised in two different ways to match with the two fisheries on which the present project is focussing: blue whiting and North Sea herring.

In order to be able to draw any conclusion from this simulation study, the simulated data must have similar properties as the data collected during fishing trips. In reality, this implies that the simulator reproduces the main features of the spatial distribution of the resource and the characteristics and behaviour of the fishing vessels and that time and space units in the simulator are realistic.

For the two species considered here, the spatial distribution was based on acoustic survey data. For both species, the surveys are carried out approximately at the same time as the fishing season. The survey data (abundance per nmi on horizontal transects) was extrapolated to a grid (cells of 1 nmi), using a method reproducing the characteristics of the distribution observed by the survey[3]. For North Sea herring, data was available only for the Dutch part of the survey, and hence the simulator is representing only the area covered by this part of the survey. For blue whiting, data was available for all survey participants. Figure 11 shows an example of the survey data and extrapolated biomass distribution.

For blue whiting, four different years (2005, 2006, 2011, and 2012) were chosen to generate four fish distribution maps with a different total abundance (survey estimate of stock biomass varying between 1.58 and 3.36mt). For North Sea herring, only data from the 2011 survey was available. Different maps corresponding to different stock abundances were generated by removing an increasing proportion of the fish aggregations from the original map, extrapolated from the 2011 survey data.

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[3] The abundance in a given cell was chosen by sampling one value among all the abundance observations on the survey transect, using the inverse of the distance between the cell and each observation as a probability for each observation of being sampled. In addition, for blue whiting, the relationship between survey abundance and bottom depth was modelled using a GAM. The extrapolated abundance was multiplied by a "depth effect" (prediction from the GAM model), in order to have a realistic depth distribution of the resource.

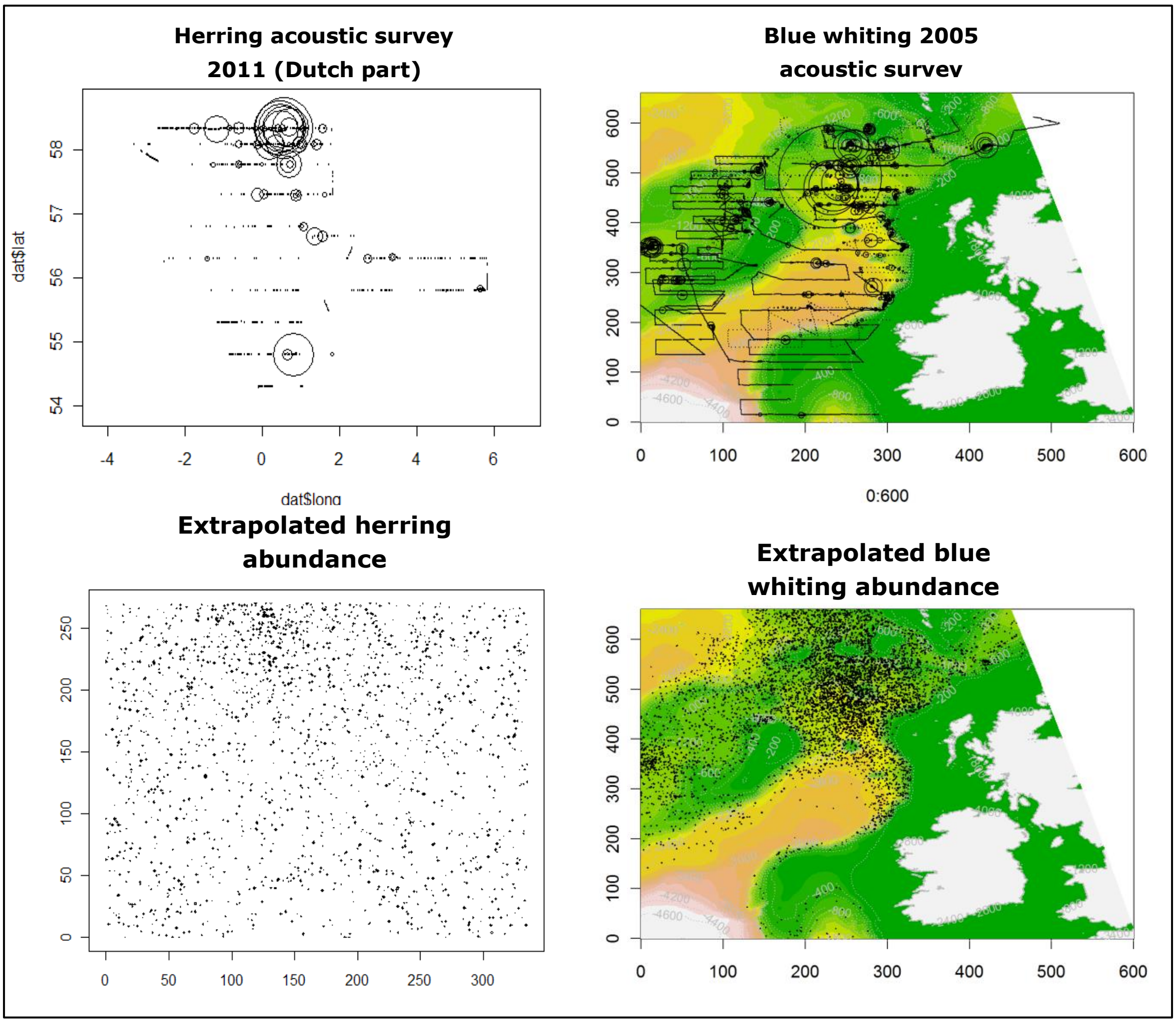

Figure 11 : examples of resource distribution used in the simulator (left :herring ; right : blue whiting). The top panel shows the actual survey data (circles proportional to the fish biomass per nmi²). The bottom panel shows the extrapolated fish distribution (black points indicate the cells where fish is present, not the abundance of fish in the cell).

<u>Principle of the simulator</u>

The simulator was designed to represent the searching and fishing activity of pelagic trawlers. The vessels in the model behave according to a few simple rules.

Searching

A vessel scans permanently a half disc area of the ocean with a sonar. As long as no fish aggregation is found, the vessel continues his route straight ahead. When a fish aggregation is detected in the scanned area, the vessel changes direction to go to this aggregation and fishes on it. At the next time step, if there is no aggregation in the scanned area, the vessel continues straight ahead on its new heading. If there is another aggregation, it changes its heading again toward this aggregation and goes to fish on it.

If during searching the vessel sees too few fish, it contacts the other vessels, and if one is in a favourable area, it steers towards this vessel. This communication between vessels avoids vessels to search for too long in areas which are not favourable fishing grounds.

In the case of blue whiting, the searching activity avoids going in too deep or too shallow areas. Based on the data recorded during true fishing trips, searching is restricted to areas between -2500m and -250m depth, except when a vessel is steaming towards another area where other vessels reported higher fish abundance.

Fishing

While fishing, a vessel sails on a straight line over 15 cells (15 nmi). The vessel may stop fishing before 15 cells if the catch has reached the maximum possible catch value (140t for blue whiting, not implemented for herring). The amount of fish caught in each cell is a proportion of the biomass in the cell (0.07, calculated by comparing the catch of individual trawl hauls from a real fishing trip on blue whiting with the acoustic estimates of biomass recorded during the same haul).

Processing

After a trawl haul, the vessel is processing the catch. It goes in the same direction during 10 time steps. The direction taken is the same as during the previous fishing haul, except if the catch was high, in which case the vessels turn around in the direction of the previous haul before starting processing. While the catch is processed, the vessel starts searching again.

In the case of blue whiting, the simulator was calibrated using information from one of the real fishing trips from which data was collected. Parameters such as the maximum catch per haul, the max duration of a haul, the processing time, the minimum abundance needed to decide to fish, the depth range at which fishing occurs, the catchability of the vessel were derived from the acoustic information collected, coupled with detail trawl haul information.

4.5.2 Simulations setup

For both species the simulator was run on the different abundance maps to generate acoustic data. The abundance indices computed based on this simulated data were then compared to the "true" abundance (i.e. the total biomass at the start of the simulation).

The fishing trips covered 2000 cells/time steps for blue whiting, and 1600 for North Sea herring. This corresponds roughly to the distance covered by the real fishing trips, as observed in the data collected for this project.

For blue whiting, additional simulations were run. First, 10 simulations were run for each abundance map, in order to assess the variability of the abundance estimates. Then, to investigate the sensitivity of the indices and of their precision to the amount of data collected, three trials of simulations were run, with increasing number of fishing trips for which data was recorded (2, 5 and 10 trips). For North Sea herring simulations were run with 4 fishing trips.

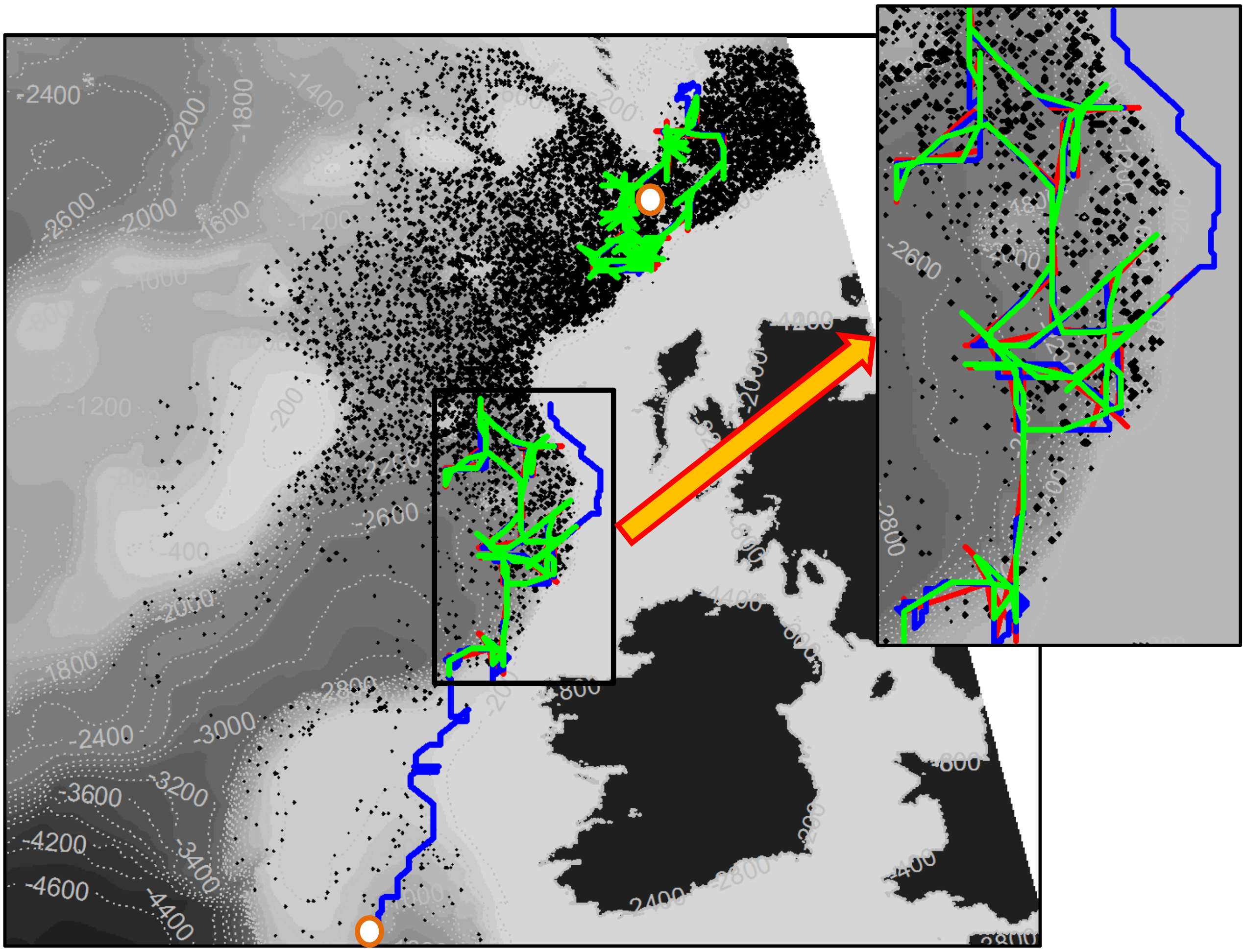

Figure 12: example of two simulated fishing trip on blue whiting, based on the 2011 abundance. The white dots show the starting point of the vessels. The colour of the track represents the activity of the vessel (blue : searching, green : fishing, red : processing). Black spots represent the extrapolated fish distribution.

4.5.3 Results

Figure 12 shows an example of a simulation run. The vessel on the top started directly in high abundance areas, and was mainly busy fishing and processing. The second vessel, in the south, started in a low abundance area and managed to find a suitable fishing ground, after communication with the other vessel, combined with its searching activity.

For North Sea herring, the absolute biomass estimate and the average density were strongly correlated with the true abundance of the stock (figure 13). The correlation between the surface occupation index and the true biomass was also high, but the relationship was not well represented by a linear model (a power function would seem more appropriate). The area occupied by the stock was weakly correlated to the true abundance.

For blue whiting, the correlations between the true abundance and both average density and estimated biomass were high but not significant (figure 14). It should be noted, however, that the amplitude of variation of the true biomass was much larger for the set of simulations for North Sea herring than for blue whiting. The area index and surface occupation index were poorly correlated to the stock abundance.

For blue whiting, neither the accuracy of the indices (correlation of the indices with the true abundance) or their precision (inverse of the variability between the replicates) were clearly affected by the amount of acoustic data collected. The only exception was the average density, for which the correlation was substantially lower and the uncertainty was larger when only 2 fishing trips were used. Finally, the value of some indices was clearly proportional to the amount of data collected. This was especially the case for the absolute biomass estimate and the number of rectangle where fish was present which increased with the number of trips used.

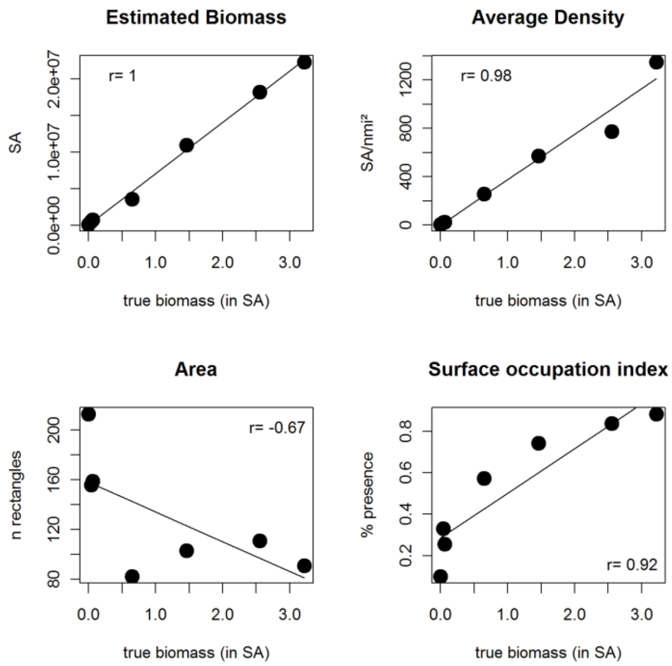

Figure 13: results of the simulations on North Sea herring. Relationships between the four abundance indices calculated on the data collected during for 4 simulated fishing trips and the true biomass (expressed in acoustic detection units). Regression line and correlation coefficient show the strength of the relationship.

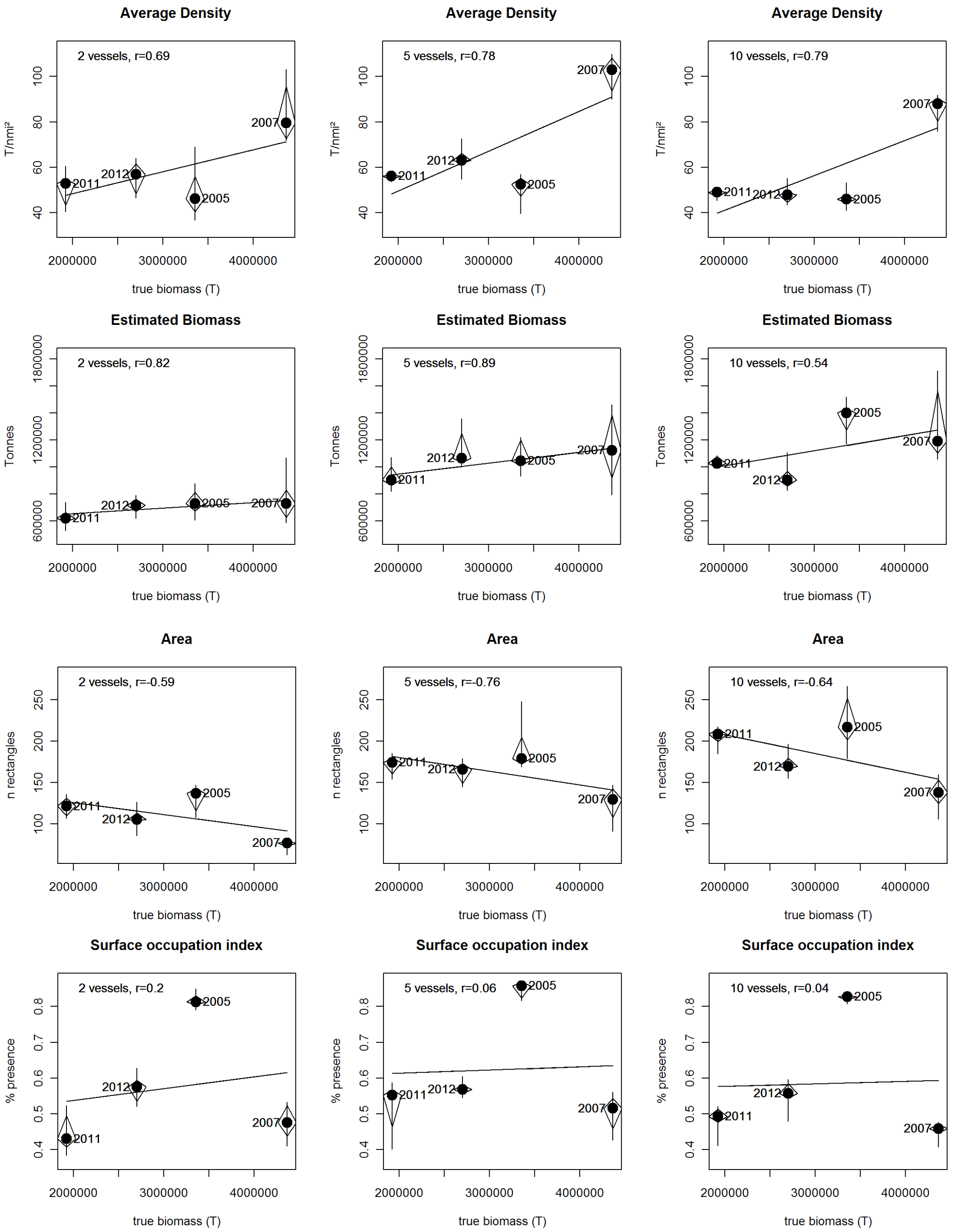

Figure 14: results of the simulations for blue whiting. Relationships between the abundance indices derived from the simulated acoustic data collected by the vessels, and the true biomass. Three different sets of simulations were run with increasing amount of data collected (1^{st} column : 2 vessels, 2^{nd} column : 5 vessels, 3^{rd} column 10 vessels). Each simulation was run 10 times to estimate the uncertainty in the abundance estimates (vertical bar represent the 90% confidence intervals, and the diamond represent the interval between the 1^{st} and 3^{rd} quartiles). In each panel the relationship between abundance estimate and true abundance is shown by the regression line and the correlation coefficient r.

4.5.4 Discussion – conclusion

Realism of the simulator

The simulator has been significantly improved compared to the earlier version used in previous pilot projects (Brunel et al. 2010). These improvements were made by using real data to get a better representation of the resource and of the pelagic fleet. The shape of tracks of the simulated vessels (Figure 12) is quite similar to the real ones (Figure 8) which suggests that the realism of the simulator has been improved. Hence we can be confident that the simulator reflects, to some extent, the way the resource is sampled by the fishing fleet in reality and that our conclusion regarding the accuracy of abundance indices are valid.

However, a number of necessary simplifications were made, which still limit the realism of the simulator, and show the limit of this exercise. Firstly, the spatial resolution of 1 nmi may not be appropriate to represent the behaviour of a fishing vessel. Indeed, fish schools are distributed on a much finer scale and the decision of changing direction or to start fishing might be triggered by the detection of a specific aggregation. In the model, the fishermen base their decision on the average biomass in a 1nmi² cell, which is of a limited realism. Secondly, although efforts were made to better represent the resource, significant improvements are still needed. For North Sea herring, only a part of the stock distribution, corresponding to the Dutch part of the acoustic survey, was represented in the simulator. It is not sure if the characteristics of the spatial distribution (relatively regular and evenly distributed aggregation) would be the same if the data from all participating countries was used. For blue whiting, the simulator uses a static resource, while the fishery and the acoustic survey are sampling a migrating stock. In reality there is a chance that a fish aggregation is sampled several times in different locations while the fish migrates during the fishing season. This potential source of bias was not taken into account in the present analysis. Although technically not impossible, developing a code to represent blue whiting migration represents a substantial effort, and running this code together with the fishing simulator would duplicate the running time.

Usefulness of the indices

The simulations results suggest that the abundance indices tested may be more accurate for herring than for blue whiting. This may be partly due to the fact that the range of abundance variation in herring was larger than for blue whiting. But this also indicates that the accuracy of the indices may be dependent on the characteristics of the spatial distribution of the resource. Earlier simulations on a fictive resource had already indicated that the accuracy of abundance estimates derived from commercial acoustic data would be poor for very patchy distributions, in which case a very high sampling effort would be required to improve the accuracy of the estimates (Brunel et al. 2010).

The distribution of herring in the simulator is representative only of a portion of the stock where the abundance is rather uniformly distributed (figure 11). The fishing effort is hence evenly distributed and the data collected represents the whole (simulated) stock. In contrast, blue whiting is distributed in denser aggregations along the shelf edge and on a wider area. Large parts of the distribution are not sampled by the simulated fishing fleet (see example on figure 12).

In order to confirm this result, simulations should be run on more accurate abundance distribution maps of North Sea herring, encompassing the whole summer distribution area of the stock. This requires gathering the acoustic data from all the institutes involved in the survey. This should be done for a number of years (for instance 4 year as done here for blue whiting).

The results of the simulations highlighted some proprieties of the four indices tested:

- Absolute abundance estimates :
    - the suitability of this index to represent the abundance depends on the characteristics of the spatial distribution of the resource.
    - This index is more sensitive to the amount of information collected than to the biomass of the stock.
    - It is expected that this index gives an accurate measure of the biomass of the stock in the area visited by the fishing vessels, but this should be further investigated using the simulator. The proportion of the stock not covered by the fishing vessels is unknown and likely to be variable from year to year.
- Average density :
    - This index seems more suited to monitor abundance (regression against true abundance for blue whiting shows a steeper slope), but is still quite imprecise (for blue whiting).
    - The absolute value of the index is less sensitive to the sampling effort
    - The precision of this index is however sensitive to the sampling effort

- Area covered by the stock
    - Appears to be a bad descriptor of stock abundance. For herring the area covered is inversely related to abundance, which might be explained by the fact that when abundance is low, the vessels spend more time searching for dense enough fish aggregations, and hence cover a wider area than when abundance is high.
    - Index proportional to the amount of data collected

- Surface occupation index
    - Might be potential abundance index for herring, but the relationships with abundance is not linear
    - Does not require calibration

A range of potential applications of the simulator could not be investigated during this project. Within future projects, the simulator could be used to investigate the usefulness of performing mini surveys during catch processing time. The simulator can also test the interest of exploring less interesting areas for fishing (e.g. a quick visit to Rockall bank) to improve the abundance indices. Finally, simulation can also examine scenarios where the fishing vessels are used to collect data in complement of the survey in order to improve the reliability of the survey estimate.

5. Conclusions

5.1 Technical achievements

The main achievement of the project was to demonstrate the feasibility of the whole data collection process at a real scale. It has now been proven that a large amount of data with quality standards suitable for scientific use can be collected from the pelagic fishing fleet.

For the first time, echosounder calibration has been carried out on pelagic freezer trawlers. This was a crucial step, since the possibility of using in a quantitative way the data collected was pending on the success of echosounder calibration. Although some material development was needed for this operation, no major difficulty was encountered during the four calibrations performed. However, organising the calibrations has proven quite complicated. If calibrations were achieved, they also had to be executed under increased time constraints due to the nature of the fishing trip. If calibration took place before fishing, there was an urge to reach the fishing grounds as quickly as possible. On the other hand, if calibration took place after fishing operations had halted, the vessel wanted to return to the harbour as quickly as possible. This required Imares staff to be well trained and experienced and to come prepared with a good set of calibration equipment. Furthermore, since the availability of the vessels is often known only a few days in advance, it required great flexibility from the scientists who had to coordinate travel and transport logistics with heavy material at short notice. In addition, performing calibrations is relatively expensive (usually 3 working days for a team of 2 people plus travel expenses).

This raised the question of how calibrations should be organised if this approach was eventually implemented on a regular basis. Different options are presented in Table 4. Calibration by scientists would be possible only for a limited number of fishing trips, which implies that data collected would be restricted to a small number of well-defined case studies. An alternative would be self-calibration (i.e. calibration carried out regularly by the crew), which would duplicate the amount of potential data. Going towards self-calibration, however, requires a dedicated effort, involving technical developments (calibration equipment, software) and training the crews. Due to the lack of specific expert knowledge of fishing vessel crews, a control & helpdesk system may still need to be put in place in emergency cases. This would guarantee assistance if unforeseen problems arise and check accuracy and usefulness of executed calibrations to guarantee optimal data quality.

Table 4: possible options regarding calibration and their consequences

Options	No calibration	Calibration by	
		Scientists	Fishermen
Data quality	Bad	Good	Good but requires quality check
Advantages	Easiest option	In house experience and equipment	Large amount of data available
Problems	Impossible: - To compare data from different vessels - To quantify fish biomass	- Costly -Scientist availability limited -Applicable only for a particular case study (one species, one fishery)	Requires - building more calibration equipment - software development - training the fishermen
Potential applications	Mapping presence of the fish	All potential applications	

Data collection for the 6 fishing trips went reasonably well. As for calibration, a good communication between scientists and the fleet managers is crucial to be able to install and retrieve the hard disks in time when the vessels return to port. Several potential problems related to the data logging process and to the quality of the data collected have been identified during this project. This highlighted the need for a real-time control of the data logging (either on-board by the crew, or land based). This would allow detecting and quickly solving any data collection problems (such as the absence of GPS positions during two herring fishing trips). Some improvement in data quality may also be achievable by minor changes on the vessel's equipment, and by implementing more complex algorithms for the processing of the raw data. Finally, as the amount of data collected will be continuously growing, it will be necessary to set up a proper database system to store this data.

Finally, these achievements were possible thanks to the good participation of the fishing industry, who offered to use their vessels, and showed great interest in the different aspects of the project. This is a very encouraging sign for the continuation of this new approach.

5.2 Progress on abundance estimation and remaining uncertainties

The final aim of collecting commercial acoustic data was abundance estimation. While it appears after this project that fish biomass might be accurately measured along the vessel's track, how to derive an abundance estimation for the whole stock remains uncertain. The main hindrance toward abundance estimation is the inappropriate sampling distribution, imposed by the fishing activity (good coverage of the fishing grounds, but poorer or no coverage elsewhere).

The results from the fisheries simulator suggest that the possibility of accurately estimating the abundance of a stock based on commercial acoustic data depends on the characteristics of the spatial distribution of the species. For species present in dense aggregations (such as blue whiting, silver smelt and mackerel at some time of the year), the fishery concentrates on these aggregations and the searching activity is potentially quite limited. In this case, only a limited proportion of the stock is properly sampled. For species which are more evenly distributed, on the contrary, searching activity may represent a higher proportion of the fishing trip, and a larger proportion of the stock is sampled in the end. The simulator results suggest that the abundance indices will not be very representative in the first case, while they may well be in the second case.

This simulator is a useful tool to investigate the accuracy of different types of abundance indices, but it still may be considered too simplistic. The main shortcoming is the absence of movement of the resource, which in the case of a migrating stock such as blue whiting, may limit the validity of the results presented here. In this case, it is highly probable that fish are double counted which would lead to an overestimation of the absolute biomass. The bias for the other indices is unknown. The real usefulness of abundance indices derived from commercial acoustic data can only be assessed when a real time series is available, allowing for comparison with other abundance estimates.

However, even if this data eventually proves not completely useful to estimate abundance of the whole stock, it gives a reasonably accurate biomass estimate for the area sampled by the fishery. This type of information, though not directly usable for stock assessment, may very well be used in combination with survey information. Since the location and timing of the fishing activity are not planned beforehand, it seems difficult to really incorporate sampling by commercial vessels in the design of the survey. But information from echosounders on commercial fishing vessels could be used to complement the survey (i.e. adding them when location and time correspond) and hence reduce the uncertainty of the survey estimates. In case of problems with a survey leading to an impossibility to get a complete coverage, commercial acoustic data may be useful to get a biomass estimates for the areas not covered.

5.3 Widening the scope of potential applications

The potential applications of acoustic data collected during commercial fishing trips are not restricted to stock abundance estimation. Table 5 gives an overview of the different types of applications.

Scientific software, provided that calibrated acoustic data from different frequencies are recorded and little noise problems present, is able to assign a probability for the species composition of a given aggregation, based on the difference of signal at different frequencies[4]. Also based on the use of multi-frequencies, new algorithms are now able to filter out the signal corresponding to zooplankton and provide a biomass estimate (Fässler et al. 2012). It is also possible to derive a range of descriptors of fish schools from the echograms (e.g. size, shape, depth descriptors).

Hence, possible applications range from (fish and plankton) abundance estimation, spatial distribution and species overlap mapping, and describing fine scale distribution and other characteristics of fish schools. This information is very valuable to better monitor and understand the functioning for pelagic ecosystems which is essential for the development of the ecosystem approach to fisheries management. In the context of the Marine Strategy Framework Directive, a series of indicators for the GES[5] descriptors 1, 3 and 4 (biological diversity, commercial fish and food webs respectively) can be derived from this type of information.

Table 5 : different applications for acoustic data collected during fishing trips.

Aim	**Product**	**Limitation**	**Use**	**Accuracy**	**Calibration required?**
Abundance	Biomass estimation	Representative of the core area	Complement to survey	Good for the core area, Bad for the periphery	YES
	Index to year to year variations	Potential biases	Stock assessment and management	Unknown, (under investigation), depends on the species	YES
	NB : These abundance indices could be potentially improved if some time (e.g. fish processing time) was dedicated to perform additional transects				
	Frequency of occurrence of the fish	Only qualitative	Limited	Unknown (under investigation)	NO
Species identification	Software to automatically identify species	Need multi frequency sounder (>= 4 frequencies)	Avoid by-catch Reduce discards	Potentially Good	YES
Fish distribution	Description of fish schools	Time consuming	Better knowledge of Fish ecology and fishermen behaviour	Good	YES if interest in biomass, otherwise NO
	Species overlap	Requires information on species	Better understanding of species interaction	Good	
Ecosystem monitoring	Zooplankton distribution and abundance	Requires multi-frequency sounders	Better knowledge of fish ecology	Good	YES

4 Another project currently running at IMARES is aiming to adapt this scientific software so that it can be used in real time on pelagic fishing vessels. The aim is to reduce catches of unwanted species.

5 Good Environmental Status

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Justification

Rapport: C021/13

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The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: Niels Hintzen

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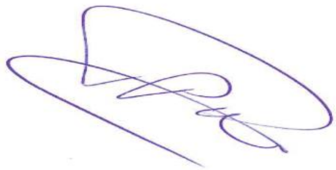
Signature:

Date: 1st February 2013

Approved: Tammo Bult

Head of the fisheries department

Signature:



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