Towards stock assessment of Jack Mackerel in the South Pacific, based on data from commercial vessels

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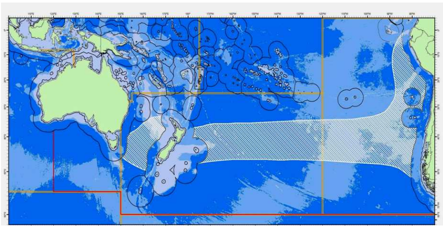

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Summary

A recently developed international fishery for Jack Mackerel (*Trachurus murphyi*) in the South Pacific has instigated a need for Dutch participation in research into this fish and fishery. A three-year study was therefore commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality and the PFA (Pelagic Freezer trawler Association). Within this study a pilot project for feasibility of stock assessment using acoustic techniques onboard commercial vessels was executed by IMARES and results are presented in this report. The project of which a second phase has started in October 2008 aims at providing a roadmap towards the use of commercial data for stock estimates.

In 2007 a feasibility study was executed which delivered a first exploration of the method and recommendations for setting up a self sampling programme. In this study echo sounding data of a commercial fishing fleet were generated by a simulation model and used to evaluate the suitability of such data as indicator for the stock size.

This initial study indicated that there is potential in trying to estimate the relative stock size of Jack Mackerel in the South Pacific based on commercial data only. A simple but effective software tool was developed to simulate both scientific and commercial activities on a given stock. The main conclusions from this exercise were that in general, using a commercial acoustic survey biomass estimates lead to an over-estimate of the stock. However, this over-estimation tends to have a constant pattern and could therefore theoretically be accounted for. The accuracy of these estimates is very much affected by the distribution pattern of Jack mackerel in the area as well as by search techniques of the fishing fleet. Field data is therefore required to quantify this accuracy. The amount of data to be collected from PFA vessels remains uncertain. In this starting phase, the focus was on simulating fishing behaviour of a single vessel. That means that no interaction between vessels has been included in the model and as a result no fleet behaviour can be modelled yet. This question can therefore only be answered in a next phase.
In February 2008 all stakeholders discussed the results and agreed on the necessity of a follow-up project which has started in October 2008.

Assignment

Wageningen IMARES was requested to write a report containing:

- An exploration of possibilities for stock assessment of Jack Mackerel in international waters outside the EEZ of Chile. This stock assessment is required for investigation of effects of the fishery on the South Pacific ecosystem and biodiversity.
- An advice for a work plan to come to a solid assessment of stock size and distribution, based on data from commercial vessels (VMS, acoustic data, catch data, fish data).

Methodology

The methods used involved expert knowledge, the development of simulation tools and basic data gathering. Based on the experience of working with other stocks and fisheries outside the EU, it was decided that new and novel techniques should be developed to investigate the potential for surveying a fish population, with abundance data collected by a fleet of fishing vessels. This required an integrated and transparent approach.

A simulation tool was developed to explore how information collected by a commercial fleet could likely to be used as an index of abundance. Furthermore, the likely biases from this kind of data were explored and compared to those of regular scientific acoustic surveys.

Jack mackerel ecology and Dutch fisheries in international waters outside the Chilean EEZ were inventoried; focussing on relevant information needed for stock assessment and stock distribution estimates. Simultaneously, available techniques for data collection onboard commercial vessels were inventoried using results from the ICES study group "Collection of acoustic data from fishing vessels". The protocols available are in general directly applicable to the Dutch trawlers.

Acoustic data collected by echosounders onboard form the basis of a biomass estimate of Jack Mackerel. This data has been simulated in the tool but has not been collected from the vessels at this stage. Vessel Monitoring by Satellite (VMS) data and catch data from 2007 has been made available by the industry and the Dutch Inspection Service. VMS data contain positions of vessels. With this hourly updated data, information can be generated on spatial distribution of the fleet. Since VMS data from only one vessel has been received, this data has not been used in the model study at the time of writing. Both biological data and trawl information are needed to convert acoustic information into quantitative fish abundance. These data have not been used in the model since this exercise is standard and could be implemented easily. Fishermens' behaviour has been simulated but only in a very general way. To make this behaviour more realistic, fishermen have been sent an interview which has not been returned and implemented at this stage.

Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 December 2009. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. The last certification inspection was held the 16-22 of May 2007. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2000 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2009 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation, with the last inspection being held on the 12th of June 2007.

1. Introduction

1.1 Background

A recently developed international fishery for Jack Mackerel (*Trachurus murphyi*) in the South Pacific has instigated a need for Dutch participation in research into this fish and fishery. As a result of international agreements, all fisheries are obliged to operate under the precautionary principle and the ecosystems approach. To conform to these principles and approaches, this study was commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality and the PFA (Pelagic Freezer trawler Association). This research is to be carried out under the auspices of the South Pacific Regional Fisheries Management Organization (SPRFMO). After the Russian government requested the EU for co-financing a large research programme in international waters, the EU tasked the Dutch government to consult the Russian government since no EU money was available at that time. No practical financial solution could be found and subsequently, the Dutch government and the PFA agreed on a (limited) Dutch research programme. Both IMARES and CMR (Corten Marine Research) were requested to participate.

This three-year project consists of 3 parts: (1) an observer program carried out by CMR; (2) financing of the FAO working group on Jack Mackerel in the South Pacific; and (3) a pilot project for feasibility of stock assessment using acoustic techniques onboard commercial vessels. The latter (3) aims at providing a roadmap towards the use of commercial data. The first steps are described in this report.

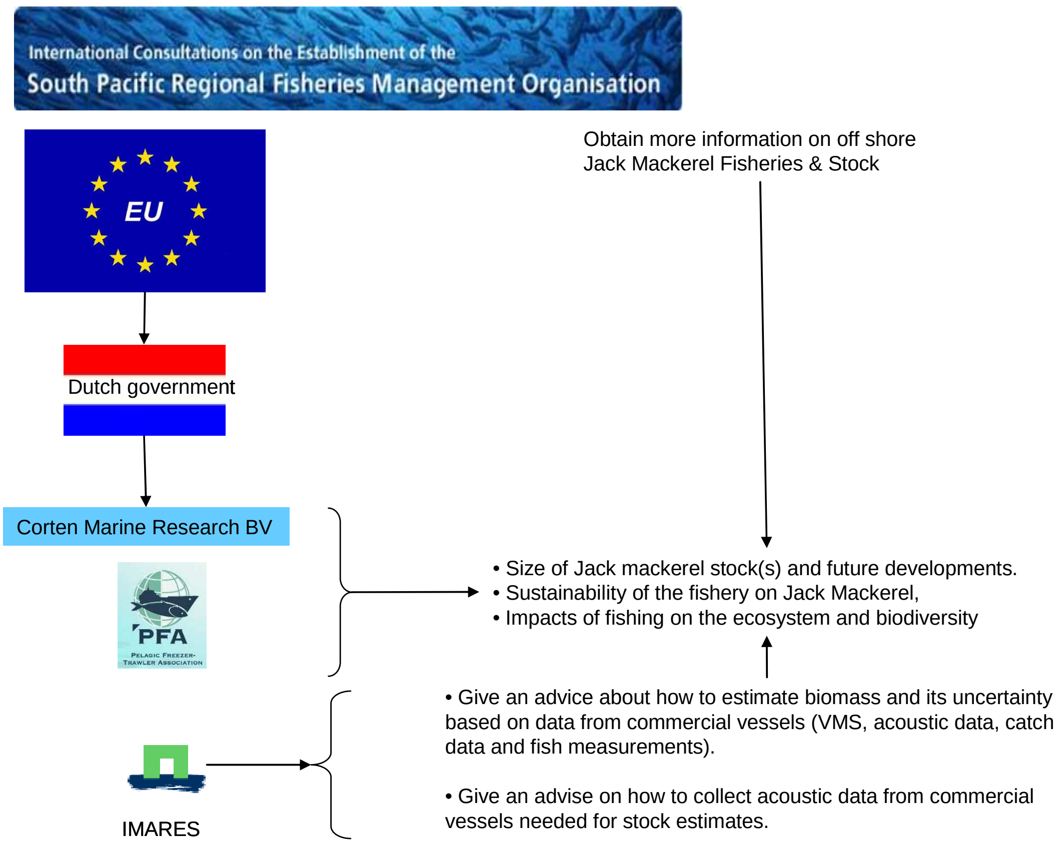

Figure 1. Structure of the project

1.2 Research questions

For sustainable management of the fishery and the Jack Mackerel populations in the South Pacific, information is required on:

- **The size of Jack Mackerel stock(s) and the population dynamics of these stock(s).** Although Jack Mackerel constitute a large resource, there have been concerns at a regional (assumed stock) level. The Chilean stock of Jack Mackerel (*Trachurus murphyi*) is currently considered to be fully exploited and, given the moderate productivity of this species, caution with respect to any increases in fishing mortality is needed. It is however unclear whether other Jack Mackerel in the region are components of this stock, or separate with their own dynamics.
- **The sustainability of the fishery on Jack Mackerel.** It is unclear at present what exploitation rate this fish population can sustain.
- **The impacts of fishing on the ecosystem and biodiversity.** In the South Pacific Ocean, Jack Mackerel constitute both predator and prey to a wide range of other organisms. What impact would an increased harvest have on the system as a whole?

Taking the above into account, IMARES has been asked to investigate the sampling strategy and protocols for data collection required to provide the most accurate and useful information for sustainable management within available resources.

In European waters, both commercial and research vessel data are available for stock assessment. Outside the Chilean EEZ however, no research vessels are available and no monitoring of the Jack mackerel stock has been performed in the past. As shown in table 1, trawlers have the advantage of their continuous presence in the area and their knowledge of the system. Thus, a combination of both commercial and research vessels survey would be ideal to study fish stocks in general. However, if only general information is required on the main concentrations, the need for research vessels in the area is not as strong. Generally spoken, the more accurate the biomass estimate needs to be, the more it relies on well calibrated research vessels. This strategy design is visualised in figure 2.

Table 1. Typical differences between trawlers and research vessels for biomass estimates.

	Trawlers	Research vessels
Systematic coverage of total area	-	+
High spatial resolution of areas of high abundance	+	?
Surveying areas of low abundance	-	+
Calibrated equipment needed for quantitative use and annual and between-vessel comparisons	-	+
School size selectivity	-	+
Number of observations in time	+	-
Coverage in time	+	-
Data quality as a high priority	-	+
Flexibility and quick response times	+	-
In situ knowledge of the system	+	-

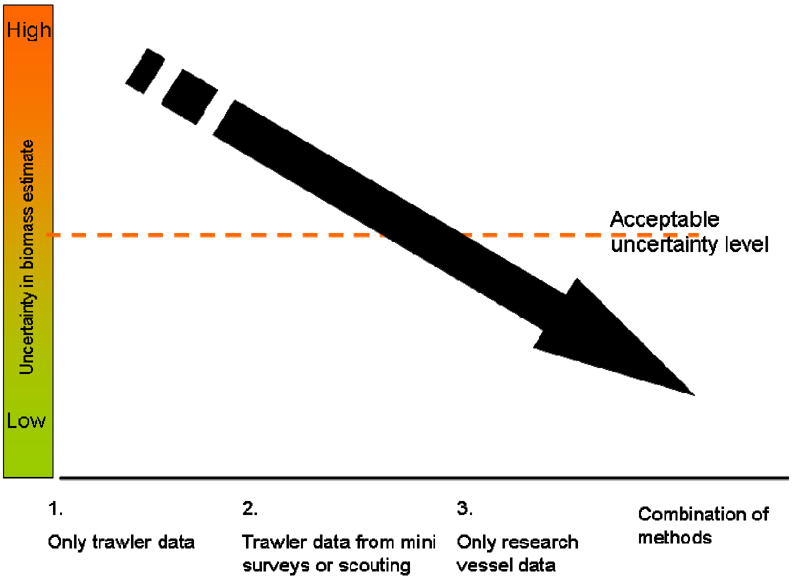

Figure 2. Basic strategies for the collection of acoustic data in behaviour and biomass estimate studies. The uncertainty in biomass estimates is dropping when combining survey methods. Which approach to use depends on the scientific question and the accepted uncertainty level in the study, indicated by the dotted line.

In Chilean waters however, there are no research vessels available and stock information has to come from the commercial fishing vessels themselves. Two possibilities are then put forward:

1 **To use data from non-directed fishing vessels.** There will be no interference in the daily fishing operations.

2 **To execute min-surveys during non-fishing time.** In the Dutch Jack Mackerel fisheries large factory freezer trawlers (110-140m) have periods of down time as the catch is processed. By utilizing this time, scientific acoustic (mini-)surveys could be carried out between commercial-fishing operations without compromising fishing success. Using fish processing time could be useful for getting a higher accuracy in biomass estimates. The approach available through the ICES Study Group on Collection of Acoustic Data from Fishing Vessels has proven to work well for small-scale acoustic surveys related to areas of high catch rates and is cost-effective because the vessel "pays for itself" by fishing commercially. The major limitation is that the boundaries of the survey area are determined by the time available during processing, which is related to the size of the catch and the time required to search for a suitable location for the next commercial trawl.

In order to choose the appropriate approach, a theoretical model is developed within this project to test the value of the easiest solution: using data from non-directed fishing operations (1).

Innovative approach of this research
In the past, it was argued that *undirected* commercial surveys could not be used for biomass estimates since the uncertainty ranges are much too high. Most commercial surveys therefore use the approach of executing min-surveys during their fishing operations. The approach in this pilot study is different in that respect that the high uncertainty ranges are taken as given. The simulation as described in chapter 2 may very well point out that using undirected data collection (1) already delivers a biomass index within acceptable uncertainty ranges.

The above lead to the following research questions:

1 How accurate are the estimates of stock abundance derived from fishing vessel data? Do they give a better image of stock abundance than the scientific survey indices and if there is a bias caused by only targeting large concentrations, can this be accounted for later in the analysis?

2 Is the accuracy of these estimates affected by the distribution pattern of Jack Mackerel?

3 Can fish processing time be used for scientific min-surveys on Jack Mackerel aggregations and does this approach lead to a more accurate stock estimate?
4 Which amount of information provided by the Pelagic Freezer trawler Association (PFA) is needed to have an acceptably accurate estimate of stock abundance?

Whilst research vessels can provide a random design with standardised methods, resulting in a less biased survey, the survey power of a fleet of commercial vessels will be greater, both spatially and temporally. Commercial vessels are more cost-effective than research vessels if research activities can be combined with commercial fishing covering part or all of the running cost of the vessel. The use of commercial vessels requires communication and collaboration between the PFA and scientists, which is usually beneficial to both parties (Rose, 1997).

1.3 Project structure

To answer the research questions an integrated approach was required which involved close collaboration between the PFA, managers and scientists. Stock assessments in the EU heavily depend on research but such an approach is not feasible for the Chilean waters at this moment. Therefore a commercial survey approach is developed that is scientifically robust, cost effective, simple and transparent.

The goal of this project is to develop a roadmap towards a Jack mackerel assessment using data from commercial vessels:

- Exploration of the method: using a theoretic model to compare biomass estimation based on surveys and commercial data. To get a grip on whether commercial fleets can provide acoustic time series which are precise enough to act as an index of abundance, and acknowledging that they will be biased, a simulation approach is required.
- Exploration of the method: if the theory shows that this data can be used:
    - Which data types are essential to collect onboard?
    - How should field data be collected onboard?
- Exploration of the method: How large is the bias when using field data?
- Perform a real survey

The project uses existing knowledge and experience in IMARES and the fishing industry, simulation tools and novel approaches to address the following:

- The utility of analysing commercial acoustic data to provide information on the abundance of Jack Mackerel.
- The development of a cooperative approach to collecting and analysing data.
- The actual quality and quantity of data required to gain information on the fish and fisheries.
- Communication of findings and transparency of methods.
- Future research needs and tasks.

Basic existing information is described in appendices
For existing knowledge on Jack Mackerel see Appendix A. To begin to understand the fisheries on Jack Mackerel as a starting point, VMS and catch data were inventoried (see Appendix B). The project is carried out using expertise from the ICES Study Group for Collection of acoustic data from fishing vessels; from the Rastrillo-project which was aimed at stock abundance estimates of Jack Mackerel in the <200 nautical mile zone off the Chilean coast and from cooperative research in the Dutch demersal fishery on cooperation between scientists and fishermen (F-project). Skippers were interviewed on their field knowledge of Jack Mackerel fisheries (interview format can be found in Appendix F)

Problem definition is acknowledged by both scientists and fishermen
This project requires cooperation on data delivery and modelling methods. How the PFA and scientists can work on Jack Mackerel stock estimates has to be defined by involved fishers, fishers' representatives and scientists. To ensure realistic expectations and avoid surprises, a meeting was therefore organised on the 23rd of August 2007 with the fleet managers, directors of vessel owners, the chairman of the PFA and scientists. The problem

was defined together with the subsequent objectives of the project as described in chapter 1. In the final week of December, when all skippers were ashore, a meeting was held at IMARES to discuss the project approach with pelagic skippers.

1.4 Project limitations and considerations

Scientific limitations
This was a preliminary study, limited to a modelling and simulation approach because of lack of quantitative data on the fleet dynamics. Most of the assumptions within the study are based on the acknowledgment that the work must be carried out under the technical and practical situation onboard the Dutch freezer trawlers.

Implications for cooperative approach
For successful cooperative research, guidelines are described by Johnson and Densen (see Appendix C). These guidelines have been translated into a work plan for this project to be carried out in cooperation with PFA fishers in Chile.

In more and more fisheries cooperative research is carried out in order to collect data and scientific information. Direct benefits of cooperative research are found in improved science; improved relevance of research; improved communication of the results, incorporation of new data sources; and reduction of costs of science (Johnson and Densen, 2007). Indirect benefits are better relationships between fishers and scientists; acceptation of science and management in the industry; capacity building; adaptive or alternative management approaches; income to industry and maintenance of infrastructure.

This project is of particular interest because both Government and fishing industry are cooperating in financing this project. Furthermore it involves ongoing and fairly large-scale industry participation in which it is very difficult to communicate face to face with involved skippers. It is therefore essential to make clear arrangements without leaving any indistinctness.

Some general remarks:
- PFA fishers need to be involved in all stages of the project. They are part of the project and their opinion and input is essential to the result.
- To create a strong basis in the industry, it is very important that also members *not involved* know what the objectives are, why the approach is chosen and what the meaning of the outcome is. This project has therefore been presented at the annual pelagic fisheries meeting in December 2007.

1.5 Deliverables

This report presents:

- A roadmap towards Jack Mackerel assessment from commercial vessel data containing:
    - Advice on cooperative approach in data collection (Chapter 2.2).

    - Advice on a practical approach in collecting acoustic and biological data onboard fishing vessels (Chapter 4).
    - A summary of available techniques for analysing acoustic data from fishing vessels (Chapter 4).
- A software tool that simulates both scientific survey indices and commercial fleet indices (Chapter 2.1). It has the option to adjust Jack Mackerel distribution patterns, vessel behaviour and a scientific survey setup.
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2. Testing the method: scientific surveys compared with commercial surveys

2.1 Objective of the simulation tool

Scientifically, the main objective of the simulations is to test the information value of acoustic data gathered from commercial fishing vessels (pelagic trawlers) in comparison with information gathered from a scientific acoustic survey as indicated by figure 3. The benefit of a simulation is that the true abundance of the fish stock is known, and the abundance indices obtained by the methods can be directly compared with the true values. This approach allows to vary many parameters in the model and to test their influence on the accuracy of the indices. In this way the questions from paragraph 1.2 can be addressed.

Commercial fishing vessels 'sample' fish stocks with a much higher spatio-temporal coverage than scientific surveys, because of their number and of the number of hours they spend at sea. However, data collected by these fishing vessels are biased towards big schools of fish, not always collected in a standard way or not available to the scientists, which hampers its use for stock assessment purpose. Furthermore, even when such data are available, they may be hard to analyse because scientists do not know the catchability (the link between catch rate and fish abundance) and have no idea of its variation in time and between vessels.

In the framework of the present project, fisheries information of very high spatial and temporal resolution collected by PFA trawlers targeting Jack Mackerel off Chilly may be available to scientists. The data would consist of acoustic records (echo sounder and sonar) which are not affected by uncertainties in catchability.

2.2 The tool explained

The simulator generates both a virtual fish stock represented by schools and fishing vessels. The latter move on a virtual ocean according to a very simplified searching behaviour. A technical description of this simulation tool is described in Appendix D. To simplify the situation, the ocean was divided into numerous small cells, comparable with pixels on a TV screen.

School simulation
Each school occupies one cell of a two dimensional grid, representing the fishing area. Each school has been given a known biomass. How schools are distributed over the area totally depends on the true field situation, but for the time being a clustered distribution was chosen to represent Jack Mackerel: in some areas schools are abundant while in other areas the number of schools is lower or absent.

Vessel simulation
Each fishing vessel permanently scans the cells around him; moves to the cell with the largest school and fishes it; or goes straight ahead if no school is found. The resulting track of a vessel during a fishing trip has a "spaghetti-like" shape, with a very complicated trajectory when a vessel fishes on a cluster of schools, and a straighter trajectory when the vessel has fished down a cluster and searches for a new one (figure 3).

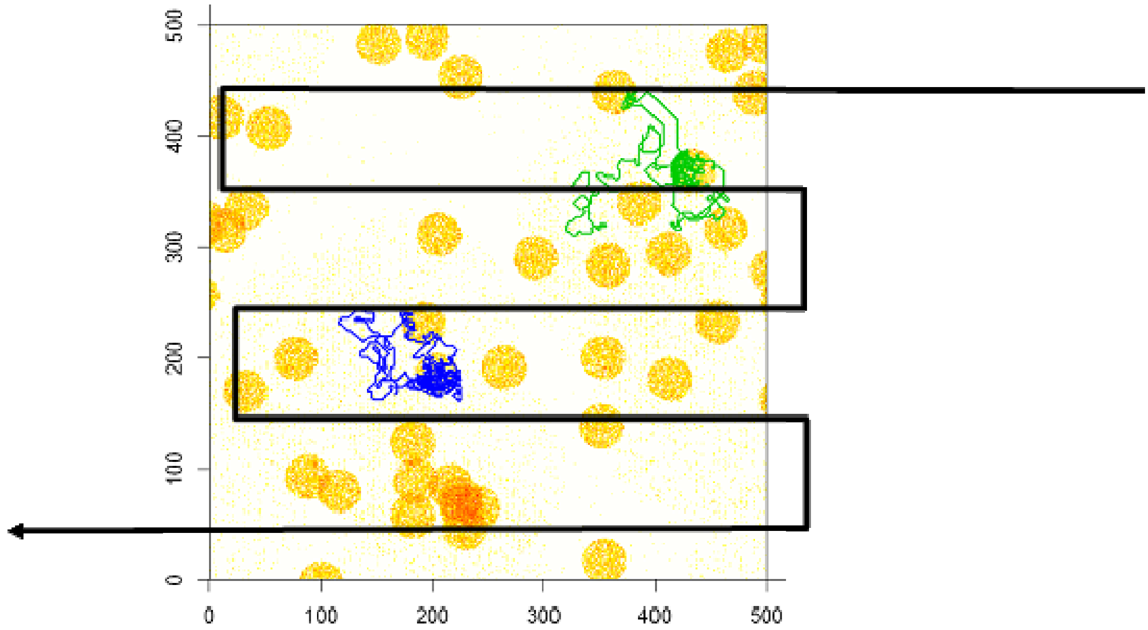

Figure 3: example of fish distribution (indicated by the dots) and of path of two commercial vessels fishing on this stock (indicated by the spaghetti-like lines). The black line shows a typical scientific survey design.

2.3 The first test runs of the tool

Setup of the test run
24 different fish stocks were generated, representing 24 years of the same stock having random stock size. These stock changes are indicated in figure 4a. Then, for each year, the fishing behaviour of 5 vessels, each fishing a 1000 time units was simulated. A scientific survey, following horizontal transects for 500 time units on the same stock was also simulated (A scientific survey is believed to cover the area in less time than commercial vessels do). The simulation was then repeated 5 times for each individual year, having the vessels start at different locations. In this way variability of the indices obtained on the same dataset could be studied.

To calculate the observed biomass index, the sum of the biomass of individual schools seen by the both scientific and commercial vessels was divided by the time spent at sea.

Results of the test run
Results of these first runs suggest that the average value of the scientific survey index provides a very good description of the variation in stock size. These indices are shown as the black line in figure 4c. The difference between maximum and minimum values observed (R-square values, indicated by the width of the grey band) after each virtual survey was larger for the commercial index than for the scientific survey (compare figure 4b with figure 4c), suggesting that the commercial index is less accurate. Also the results indicate that no matter the differences between scientific and commercial survey, the overall trends of both indices seem to be rather equal.

Summarizing, the number of schools seen by the scientific vessel at each repetition in a particular year is very similar and thus, the index is quite accurate. The index from the fishing vessels also performed relatively well, but has a lower correlation with stock size than the scientific survey index.

More runs are needed, using more complex/real data to see whether these results hold in a actual field situation.

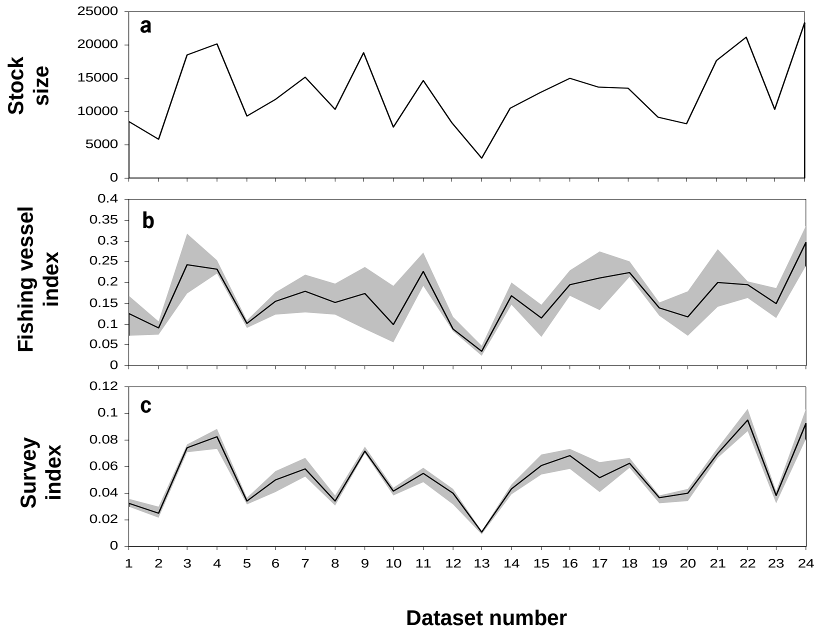

Figure 4: A) shows the true stock size throughout 24 different years. B) shows the biomass index and its bias as seen by the commercial fleet. C) shows the biomass index and its bias as seen by the research vessel. The black line represents the average of the values obtained for 5 simulations on each dataset and the grey band is the range between the minimum and maximum value (R-square value).

2.4 Further developments of the tool

In order to test the accuracy of an abundance index which would be calculated from real pelagic trawlers' data, the simulator needs to be developed by feeding it with realistic data.

For the moment, the simulator works without realistic spatial and temporal dimensions. There are several improvements that need to be carried out first:

- Firstly, the simulator needs to use realistic dimensions: The average size of the schools is needed to set the cell size of the model. The spatial extent of the area where Jack Mackerel is fished must also be determined. The size and shape of the area scanned by the sonar must be represented more realistically.
- Secondly, vessel behaviour in the current simulation is very simplified. To make it more realistic, fishing strategy of the skippers must be known in more detail, as well as the extent to which skippers cooperate with each other.
- Finally, a more realistic fish distribution must be used in the simulations, with eventually a representation of seasonal migrations of the stock.

3. What needs to be done in practice?

Non-PFA information required
The distribution pattern of Jack Mackerel needs to be studied. The Chilean research group has generated a spatial movement model of jack mackerel (Arcos et al, 2001).

Field data collection: vessel selection & participation
It might be difficult to select a vessel for cooperation. There are both advantages and disadvantages for participation, which can result in too much effort or too few skippers willing to participate. Vessel selection should

be based on available equipment onboard; willingness to participate; and expertise of the skipper and crew. If there are difficulties in making the selection, the vessel owner should make the final decision.

An advantage for skippers and crews of participating in this research project is that their insight in Jack Mackerel behaviour and fishery will increase. Skippers, but mainly the fishing industry as a whole, may also benefit greatly by contributing to overall scientific understanding of the stocks and improved management. They may be seen by the public as demonstrating a commitment to conservation and sustainability (Dalen et al., 2007).

A possible disadvantage for a vessel to participate is that regular fishing activities might be disturbed by research activities. If feasible (as discussed in section 4.1), skippers could be requested to steam across certain transects for acoustic measurements, during freezing periods. Also extra input of effort by the skipper or crew might be necessary for carrying out the research. Forms should be filled in; possibly fish have to be measured; data need to be transferred to IMARES; etc.. An extra request might be to calibrate acoustic equipment in near shore areas, which cannot be done during fishing. For this activity, certainly (financial) compensation is necessary.

3.1 Vessel data required

Vessel owners and skippers are responsible for data collection onboard and for sharing their expertise where necessary with involved scientists. It is very important that data are collected in a standardised and consistent manner, in order to ensure comparability of the data. To this end, manuals and verbal instructions should be used for proper instruction of fishers (and/or observers). The manuals will also be made available as checklists.

VMS data

VMS data are needed for 3 reasons:

- Fishers are expected to be fishing in the core area of the Jack Mackerel distribution; so theoretically, VMS data could also indicate the location of the Jack Mackerel core distribution area.
- VMS data indicate the time spent at sea available for a possible acoustic ‘snapshot’ of the area .
- Another application of VMS data is found in extrapolation of the amount of fish seen on the echosounder by a pre-selected vessel towards other vessels which do not collect acoustic data.

VMS data needs to be provided by the Inspection Service of the vessel’s flag country on a regular basis, after a request from IMARES. Data from all vessels fishing in the South Pacific has already been made available for 2007. New requests need to be made for 2008 fishing operations. Data from all vessels owned by the PFA and fishing in the South Pacific should be made available.

Acoustic data

Acoustic data is needed for the following reasons:

- Are the basis for giving an abundance estimate of Jack Mackerel in the fished areas;
- can give information on spatial distribution of the species;
- can give information on schooling behaviour (vertical migration, school size etc.).

Priority is to collect quality 38 kHz ES60 echo integration data on Jack Mackerel aggregations from commercial fishing vessels while they are searching and fishing. This will result in large volumes of relatively unsupervised backscatter data being collected and stored on the vessel. Effort has been made outside this project to automate this process for large volume acoustic data analysis and to provide a standardised manual for logging acoustic data using commercial equipment. IMARES scientists should clearly communicate the value of following a few key acoustic system setup guidelines towards using their vessel’s data in stock estimates. The crew carries out the logging of data, for which a protocol is available and shall be provided (see Appendix E). This protocol has been developed outside this project and has been adapted to be used onboard pre-selected Dutch freezer trawlers (by G. Patchell). Acoustic data from the SIMRAD ES-60 echosounder can be of generally high quality and could be analysed using the same software and methods as data from scientific echosounders. However, acoustic research from commercial vessels will be limited to periods of relatively good weather because of their use of hull-mounted transducers. The issue of calibration of echo sounders also needs to be addressed. This is a minimum requirement for inter-ship comparisons, and also to prevent creep in the signal over time. The research to be done is relatively new for this fleet, so as a trial, acoustic data should only be collected onboard one vessel. If required, data could also be collected onboard other vessels in a later stage. SIMRAD ES60 echo-sounder data should be logged continuously during every trip, from start to end of the trip. If it is logistically possible to collect data from more vessels and if the simulation model requires more data, extra vessels can be included in the models' acoustic logging sample.

Biological samples
The examination of fish catches will indicate the size distribution of Jack Mackerel, which is important in converting acoustic signals into fish numbers and biomass. A standard relationship already exists for Jack Mackerel within the EEZ of Chile and can probably be used for the offshore areas as well. Fish measurements can probably be carried out by observers from CMR. Nevertheless, a short manual for biological sampling (fish length/weight) needs to be written. Especially when juveniles are discarded, it is important to sample the whole catch including discards and not only the landings. Data requirements depend on variation of catches within the area. If there is a lot of variation in average fish length or weight, more data are required.

Logbook data
Logbook data, containing catch-weight per haul, are used to find a relationship between acoustic observations and school size, densities, catchability, species composition and other characteristics of Jack mackerel schools. These data should be made available for all vessels, all trips and every haul and be provided by CMR.

Qualitative information on fishing behaviour
Qualitative data on the fishery near Chili can be used to improve the models used for exploration of feasibility of applying commercial data for a reliable stock assessment. Furthermore, advice on how to manage the fishery can be better tuned to practice. Data available at IMARES on fisheries are mostly quantitative (logbooks and VMS). For better interpretation of those data, qualitative information are required on fishers' behaviour. Better interpretation of quantitative data will lead to more insight in the fishery and improved research by scientists. A questionnaire has been sent to the skippers (through the vessel owners), aiming at collecting global qualitative information on the fishery in the South Pacific by Dutch freezer trawlers (see Appendix F). Questions have been allocated to the following themes:

- Setup of the fishing trip
- Fishermens' behaviour during the fishing trip
- Known knowledge on Horse Mackerel schools and behaviour
- Fishermens' willingness for cooperation

3.2 Data collection, processing & analysis: what needs to be done

Before research analyses are carried out, scientists and fishers should discuss the format in which results should be presented. A difficulty in this matter, is that the involved fishers are mostly at sea, and not able to attend meetings. It is therefore essential to make clear agreements beforehand with both skippers and ship owners at the beginning of 2008.

Then the following main steps are to be taken:

Preparations:

1. Based on installed hardware and willingness of the skipper, one vessel needs to be picked for a try-out. The hardware used onboard needs to be able to collect raw acoustic data files. Therefore Simrad ES60 echosounders need to be installed. To keep in mind: Standard scientific acoustic surveys require the use of calibrated echosounders. This is not the case for commercial fish finding where skippers are able to intuitively calibrate what they see on the sounder with what they expect to catch.
2. Acoustic data should be sent to the scientific institute after each trip, whereas trawl data can be sent by email.
3. Since the amount of acoustic data will be very large, a software program called EchoLab, specially developed for this type of commercial data, needs to be tested in advance. This software handles multiple acoustic data files and delivers a rough estimate of the observed biomass.
4. A software script needs to be developed to perform quality checks on all received data from the vessel(s). Most of these scripts have already been developed in other projects.
5. Acoustic data need to be converted into fish biomass. Therefore the mean length of Jack Mackerel in the fishing area should be known as well as the relationship between the size of the echo and the size of

the fish. Acoustic target strength (TS in dB) was derived using the TS-length relationship TS=18 log10 (L) - 74 (Lillo, 1996);

Descriptive analysis:

6. First descriptive results of what has been gathered need to be presented as a Trip report which should be sent to the vessels' contact persons as soon as available. Outputs from the checks should be:
   - Spatial maps of fishing operations (source: VMS or logbooks)
   - Average length of catch by trip/haul (source: measurements of average fish length)
   - Acoustic data: vessel tracks with acoustic abundance information and if applicable: typical echograms
   - Catches – spatial plots of catch (weight), time series of catch
   - Observations of other species etc.

Stock analysis:

7. Field data described on paragraph 5.1 should be put into the simulation model to get more fisheries and ecological realism.

3.3 Presentation of results: what can we expect?

The main remit of this project is the collaboration between scientists and fishers to improve the estimation of the Jack mackerel stock size. To ensure true collaboration, none of the processes must be "top down" nor should the decision making process be a linear one. So the presentation of results must not occur at the end of the project, or at the end of each fishing season, but be an ongoing process in both directions.

To improve the presentation of the information, the first results of the project and their implications need to be discussed with the participating stakeholders. Before results are presented to the ministry, the outline of the final document needs to be discussed with the PFA and CMR.

4. Conclusion and the Future

4.1 What has been accomplished?

This initial study was a preliminary investigation using a simulation tool and expert knowledge to improve the estimation of Jack mackerel abundance from data collected by commercial vessels. The developed tool is believed to be able to assess the changes in abundance in Jack mackerel with commercial vessels. Although the simulations where very simplistic and many assumptions where made there is no indication that this tool would be unsuitable for this exercise. However, further development is needed to fully test our hypothesis.

The main questions from Chapter 2 can now be answered.

- *How accurate are the estimates of stock abundance derived from fishing vessels data? Do they give a better image of stock abundance than the scientific survey indices?* In general, using a commercial survey leads to an over-estimate of the stock having more bias around the mean stock estimate. However, this over-estimation tends to have a constant pattern and could therefore theoretically be corrected.
- *Is the accuracy of these estimates affected by the distribution pattern of Jack Mackerel?* Yes, it is very much affected by the distribution pattern of Jack mackerel in the area as well ass by search techniques of the fishing fleet. Field data is therefore required to quantify this accuracy.
- *What amount of data provided by PFA is needed to get an accurate stock abundance estimate?* In this starting phase, the focus was on simulating fishing behaviour of a single vessel. That means that no interaction between vessels has been included in the model and as a result no fleet behaviour can be modelled yet. This question can therefore only be answered in a next phase.

4.2 Future potential developments

The collaboration between science and the industry including data collection and analysis will be an ongoing process. Research needs may change with time, but a dedicated research direction is required to answer questions about the use of commercial vessels to sample fish populations. Importantly techniques developed for Jack mackerel, may well be applicable to other similar fisheries(!).

As innovations in scientific fisheries research and data collection continue, we move forward making better, more informed decisions. In this project we see the following potentials:

- Combining acoustic data (small detection range) with sonar data (wide detection range) would be extremely useful during the statistical extrapolation of the ES60 acoustic survey "line" to the broader area. So performing school detection on sonar data as well as on standard ES60 echosounding is advisable. The EK60 data yields the density and biomass information, while the sonar yields size and position (and also velocity) across a much wider area near the surface.

- The Dutch fleet finds it difficult to localize the Jack Mackerel in late autumn when arriving on the spawning grounds. The use of satellite imagery in Jack Mackerel fisheries outside the Chilean EEZ could help understand temperature driven migration patterns to and from the spawning areas. Although this method did not prove to be very successful in Mauritanian fisheries, the opportunity should at least be considered.

On the long term, this cooperative research project might be used as a pilot study for other cooperative projects between the pelagic industry and IMARES. Methods and analyses applied for the fishery in the South Pacific could also be applicable to other fisheries like for herring and blue whiting.

Increasing the use and thus value of commercial fishing data might lead to more cost effective management of other pelagic species as well. Advantages of cooperative research (see section 4.1 and 4.2.2) are similarly applicable in the long term. By far the most important task for both scientists and fishermen remains to increase insight in Jack Mackerel behaviour to allow a sustainable fisheries.

5. References

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WGRFMO - Information describing Chilean jack mackerel (Trachurus murphyi) fisheries relating to the South Pacific Regional Fishery Management Organisation

Referees and Authors

Rapport C077/08
Project Number: 4391103002

This report has been professionally prepared by Wageningen IMARES. The scientific validity of this report has been internally tested and verified by another researcher and evaluated by the Scientific Team at Wageningen IMARES.

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Signature:

Date: November 2008

Approved: Dr. ir. T.P. Bult
Head of Fisheries Department

Signature:

Date: November 2008

Number of copies:		8
Number of pages	~	41
Number of tables:	~	1
Number of graphs:	~	4
Number of appendix attachments:	~	6

Appendix A. Biology of jack mackerel (*Trachurus murphyi*)

An extensive report was used to collate the description of the biology of jack mackerel (WGRFMO, 2007). Most of the text below was derived from this report, unless stated otherwise.

Figure 2.1. Jack mackerel, *Trachurus murphyi*.

General stock description

There have been a number of competing stock structure hypotheses, and up to four separate stocks have been suggested:

- a Chilean stock which is a migrating stock with respect to the high seas;
- a Peruvian stock which is also a straddling stock with respect to the high seas;
- a central Pacific stock which exists solely in the high seas; and
- a southwest Pacific stock which straddles the high seas and both the New Zealand and Australian EEZs.

However, further collaborative research is required to confirm and/or clarify this hypothesized stock structure as a basis for effective management regimes.

Spatial distribution

Chilean jack mackerel is a migrating pelagic species which inhabits the Southern Pacific Ocean, and constitutes the most important fishery for Chile. Jack mackerel is distributed widely between Chile, New Zealand and Tasmania.

The phrase "jack mackerel belt" is used to describe the distribution *of T. murphyi* across the South Pacific (Figure 2.2). The jack mackerel belt has a north-south breadth of 10 to 15 degrees latitude across the southern sub region of the southeast Pacific Ocean and southwest Pacific Ocean. This varies with season due to the migrational pattern.

Chilean jack mackerel exhibits a strong seasonal migration pattern. In early spring they migrate offshore towards the reproductive oceanic habitat, extending along the southeastern Pacific, but mainly in oceanic waters off central Chile from 32° to 40° S and beyond 90°W. During summer they migrate onshore due to food availability in coastal areas. During fall and winter, jack mackerel aggregates in compact schools in coastal and oceanic waters off central Chile (south of 40°S).

From hydrographic surveys and fisheries data it appeared that there is a relationship between the distribution of jack mackerel and 'mesoscale eddies', i.e. circular patterns in ocean currents (Hormazabal et al 2004). This is illustrated by Figure 2.3. Mesoscale eddies, depending on their direction of rotation, intensity and temporal evolution, can produce a significant marine plankton concentration available for higher trophic levels.

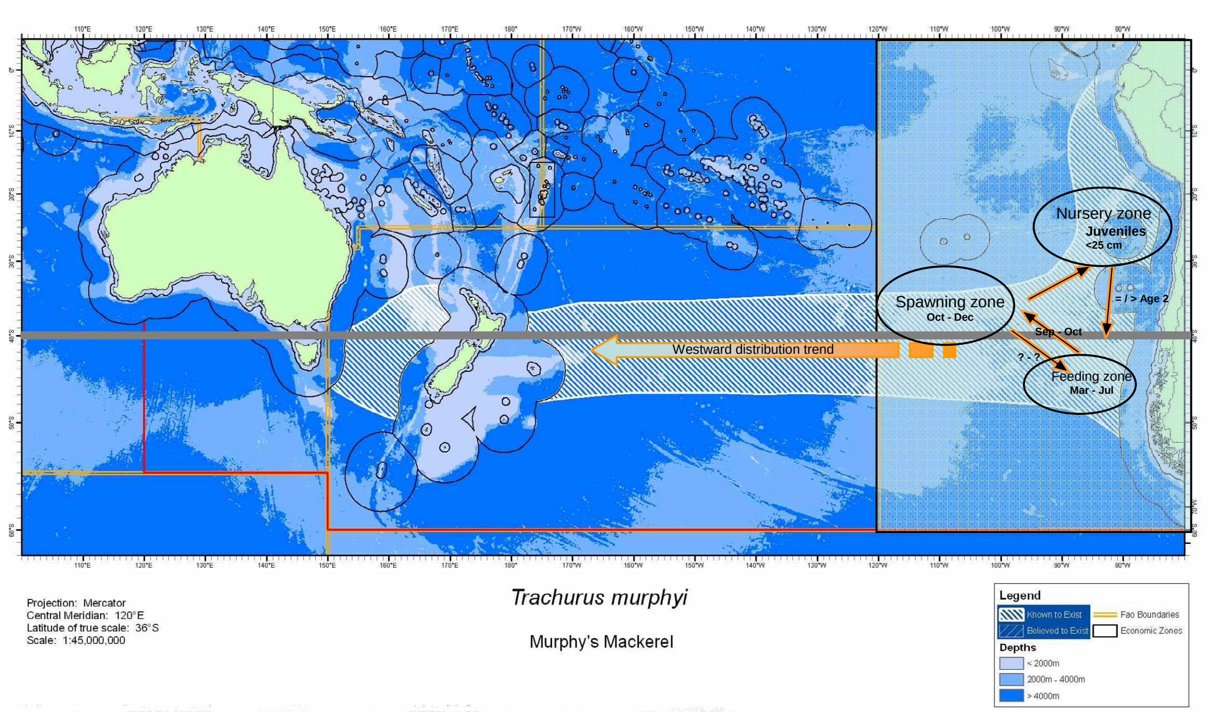

Figure 2.2. "Jack mackerel belt": distribution of Jack mackerel on the high seas in the South Pacific.

Spawning

Spawning of jack mackerel occurs between October and December, although it can extend from September to February. First spawning takes place when the fish reach a length of 20-25 cm. The bulk of jack mackerel spawning occurs in oceanic waters off central Chile, centred between 80 - 90°W and 33-38°S (Nuñes et al 2004).

References

— S. Hormazabal, S. Núñez, D. Arcos, F. Espindola & G. Yuras, 2004. Mesoscale eddies and jack mackerel distribution. Gayana 68(2) supl. t.I. Proc.: 291-296.
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Appendix B. Fisheries on jack mackerel

Fisheries development

Since the start of the fishery in 1950 the majority (~75%) of the global catch has been taken by Chilean vessels predominantly within the EEZ of Chile. During the period 1978-1990 the fleet of the former USSR took a catch of ~10 million tonnes in the high seas area. Between 1994 and 2002, most of the Chilean catch of jack mackerel (*Trachurus murphyi*) was taken within the EEZ, but in 2003 and 2004 32% and 28% was taken outside the EEZ. In 2004 the Chilean catch was ~363 million tonnes from the high seas within the South Pacific region. In recent years other flags including China, Netherlands, Republic of Korea, and Russia have taken catches on the high seas in the South Pacific region. At the western extent of the distribution range, the high seas catch is much smaller (New Zealand catches of <1 tonne in 2005). It is not currently possible to accurately quantify high seas catches as reporting is incomplete and those data that are reported do not separate between high seas and within EEZ catches.

Management

Currently, with an exception for Chilean vessels, there are no management measures in place for jack mackerel fisheries on the high seas (although all New Zealand and Australian flagged vessels that may take this species as an occasional by-catch, are regulated by a high seas permitting regime). Due to the nature of the straddling Chilean stock, the same regulatory controls that apply within the Chilean EEZ also apply on the high seas. These controls include maximum catch limits per vessel owner and minimum size limits. On the website of the science working group (SWG) of the Regional Fisheries Management Organisation (RFMO) in the South-Pacific area all information on management of these stocks presented here can be found (http://www.southpacificrfmo.org).

Current status of PFA fisheries

Effort distribution

Haul-by-haul logbook data from 5 Dutch owned freezer trawlers fishing in Chilean waters were used to plot the distribution of the fleet in 2007 (Figure B.1). Most hauls were carried out between 30-45°S latitude and 78-110°W longitude. Figure B.2 shows how the fleet shifted its distribution throughout the year. Early in the year the vessels are relatively close to the coast, then they move up north and during summer they move to the west. There is no clear spatial pattern in haul frequency, which indicates that the vessels do not fish in fixed areas (Figure B.3).

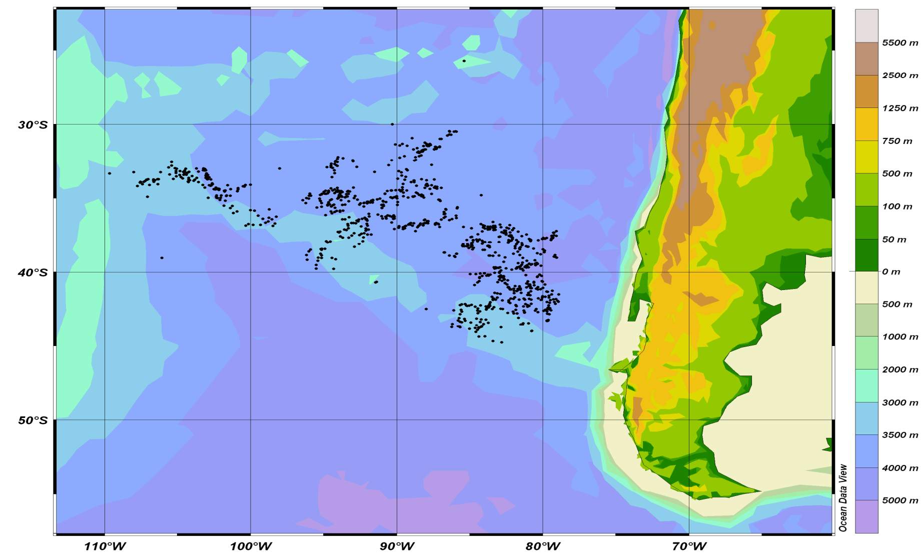


Figure B.1. Fishing positions (black dots: start of haul) of Dutch freezer trawlers off the west coast of Chile. The colours indicate bathymetry of the areas (see legend).

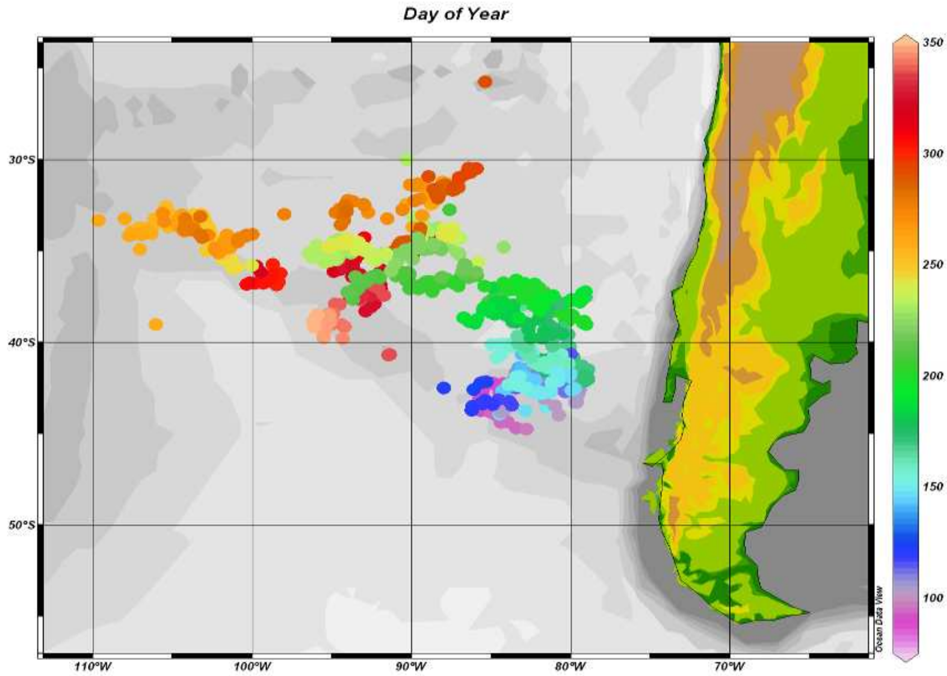


Figure B.2. Fishing positions throughout the year by Dutch freezer trawlers off the west coast of Chile. Colours of the dots indicate in which time of the year a position was trawled (see legend).

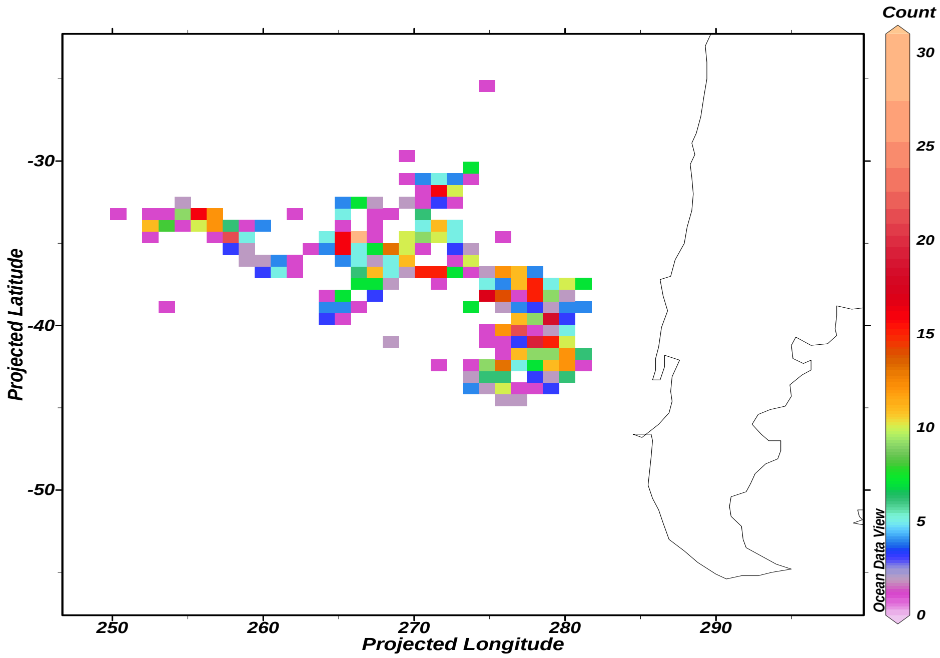


Figure B.3. Distribution of haul frequency of Dutch freezer trawlers off the west coast of Chile. The colours indicate the numbers of hauls carried out per area (see legend).

<u>Jack Mackerel catches</u>

The haul-by-haul logbook data were used to plot the jack mackerel catch distribution of the fleet in 2007 (Figure B.4). Highest catches are observed in the areas relatively close to the coast, in the period June – August (Figure B.6). The most abundant catch amount was around 7500 tonnes per haul (Figure B.5).

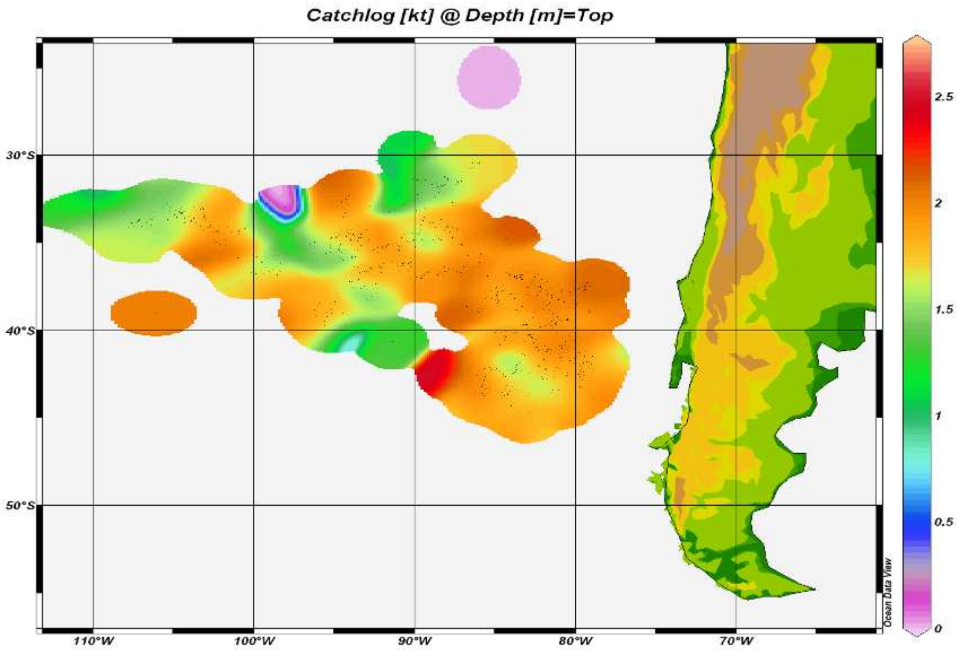


Figure B.4. Distribution of Jack Mackerel catches by Dutch freezer trawlers off the west coast of Chile. Catches are expressed on a logarithmic scale.

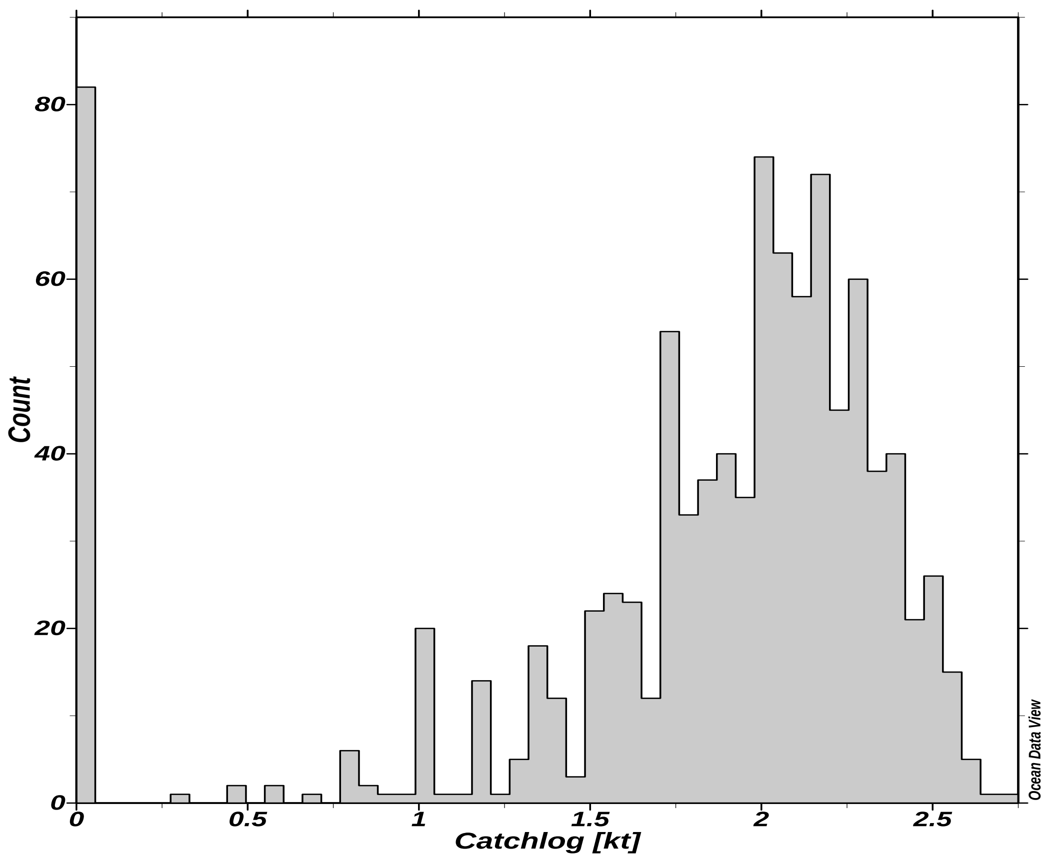


Figure B.5. Frequency distribution of Jack Mackerel catch by haul. Catches are expressed on a logarithmic scale.

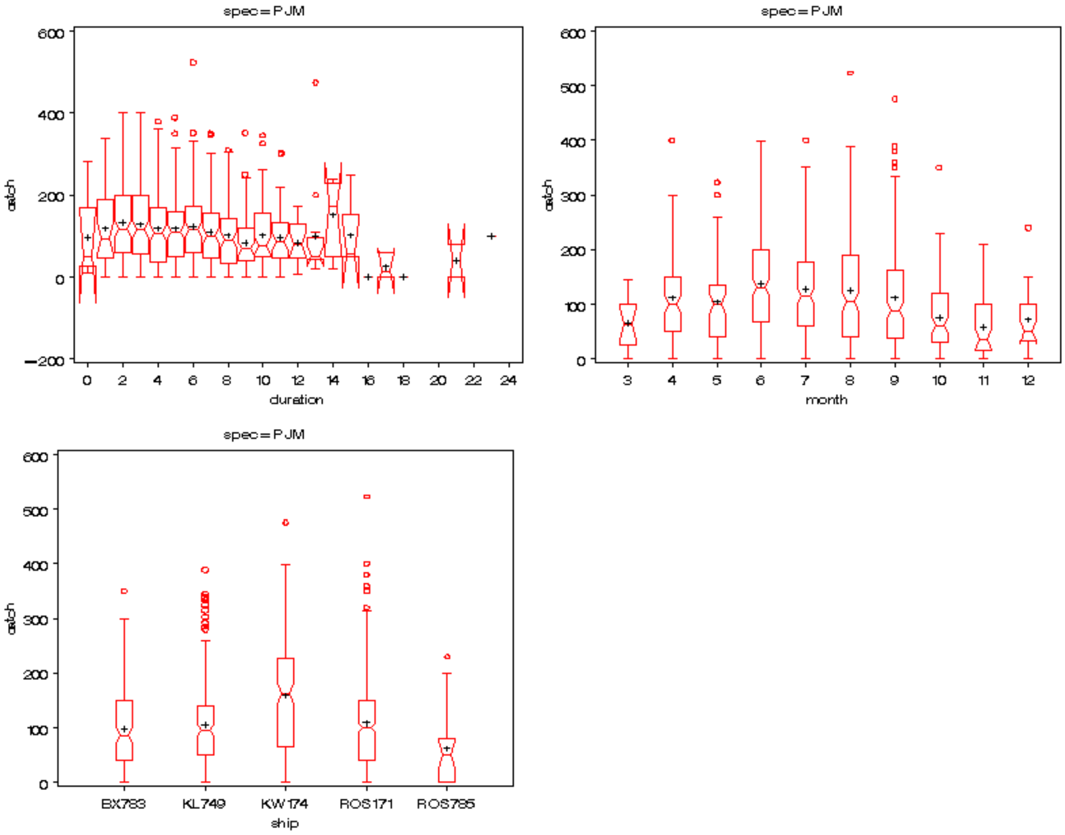


Figure B.6. Jack mackerel catch by haul duration (upper left panel); by month (upper right panel); and by vessel (lower panel).

Relation to the environment

Dutch freezer trawlers registered water surface temperature in the haul-by-haul logbooks. As the vessels follow the migrating Horse Mackerel to the north-west, the sea water temperature during fishing increases (Fig. B.6). Although most catches were obtained at temperatures between 13 and 14 °C (Fig. B.7). Figure B.8 shows that there is no clear optimum temperature for the highest catch sizes.

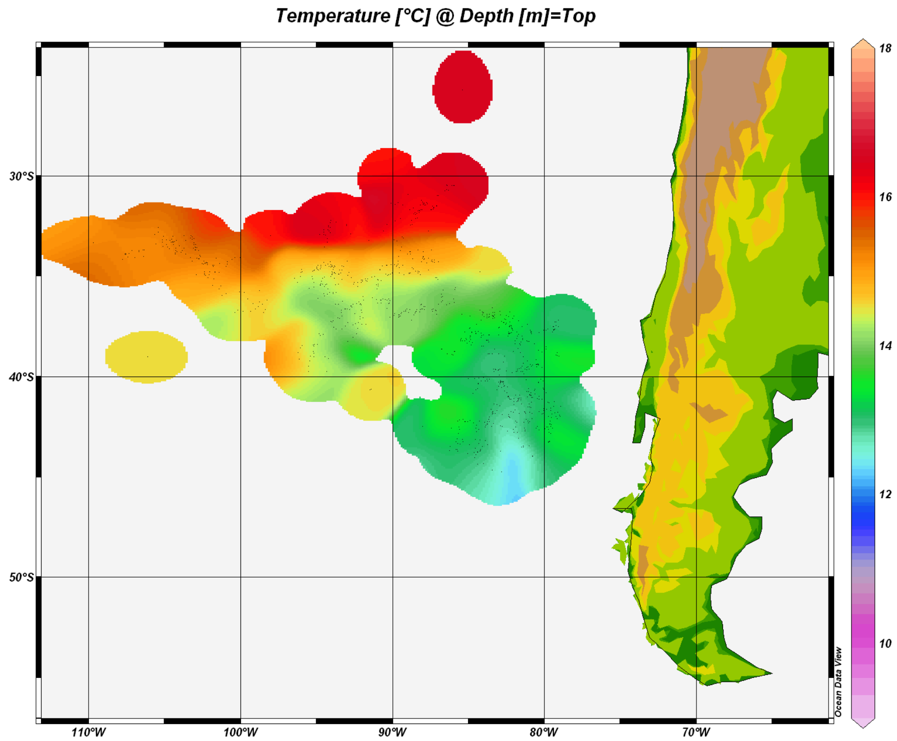


Figure B.7. Map showing that the sea water temperatures measured by PFA vessels during fishing operations are increasing when following the migrating Horse Mackerel to the North-West. Note: temperature is measured in various seasons.

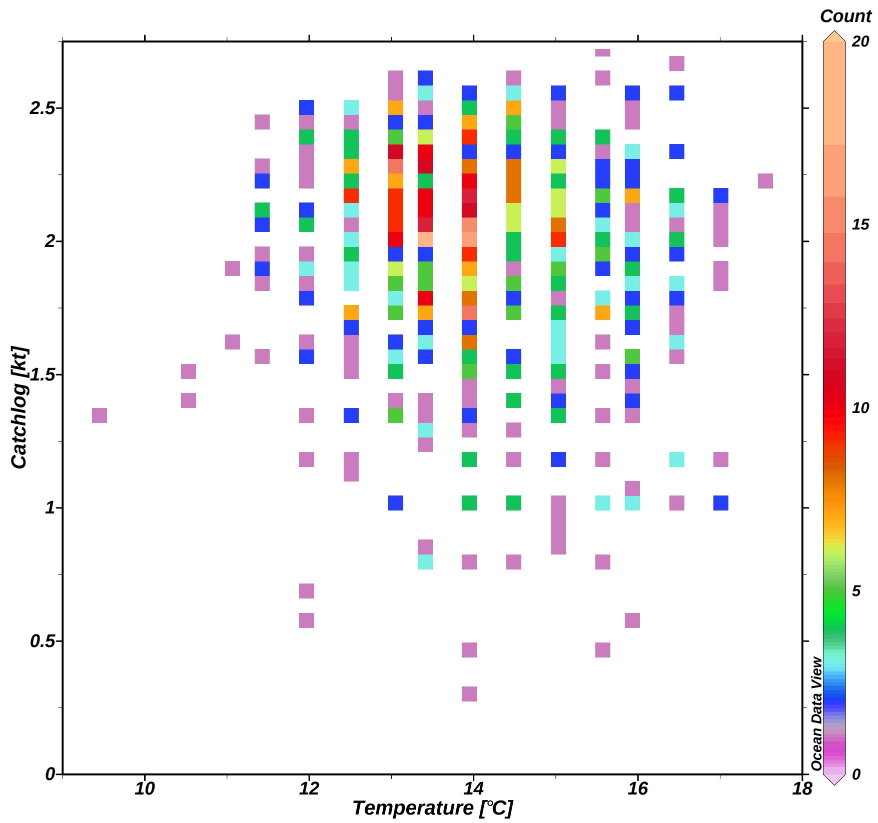


Figure B.8. Jack Mackerel catch (logarithmic scale) in relation to temperature. The color-bar indicates an increasing amount of trawl hauls at a specific temperature.

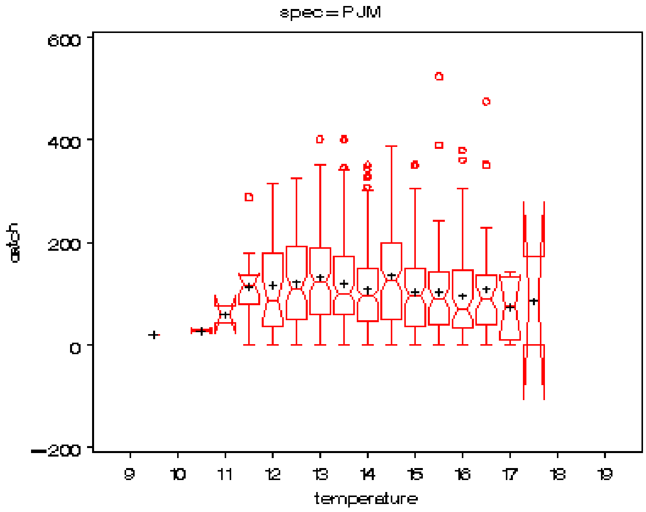


Figure B.9. Mean catch size at different sea water temperatures. Temperatures <11 and >17 have not enough data points to estimate correct confidence intervals. More data points are needed here.

Appendix C. Guidelines for Organizing Cooperative Research

Source: (Johnson and Densen, 2007).

Stage	Guidelines
All Stages	• Have fishermen involved in all stages of research • Include those who are most likely to use the data (e.g., managers or stock assessment scientists) • Communicate to fishing industry at large about the project
Problem Identification/Research Objective	• Reserve ample time to develop a clear and shared problem description • Deduce the objective clearly from the problem description • Formulate the assumptions • Articulate what meaning the results will have and how they could be used (guard the neutral position of science here)
Research Approach/Design Specification	• Assess technical feasibility and the statistical power of the observation scheme • Appraise the budget (time, money) • Allocate the research effort for fishermen and scientists • Write a grant proposal to appropriate funding agencies
Data Collection	• Cooperation between fishermen and scientists on board • Instruct fishermen on how to collect data, emphasizing consistency and standardization of techniques • Make fishermen confident that their task is properly done
Data Processing/Analysis	• Data need to be reviewed for data quality control purposes (e.g., auditing and peer review) • Provide the crew directly with the first results obtained during an individual fishing trip (i.e., raw data) • Allow industry participants to review preliminary results • Discuss the format for presenting the results
Communication of results	• Communicate the significance of the results to the fishermen involved in the project • Discuss the meaning of the outcome and the way the outcome should be communicated to the fishing industry • Communicate the objective, approach and meaning of the outcome (distribution of flyers, presentations at meetings, and use of industry trade papers) • Provide final report/data to appropriate end users (e.g., managers, stock assessment scientists) • Assure a clear demarcation between results (neutral) and the management implications (value laden) • Publish on the outcome of the study in common

Appendix D. Technical details on the simulation

Introduction

In this study echo sounding data of a commercial fishing fleet, targeting pelagic schools of fish distributed over a large area, are generated by a simulation model and used to evaluate the suitability of such data as indicator for the stock size. The main aim of the simulations is to test the information value of acoustic data gathered from simulated virtual commercial fishing vessels (pelagic trawlers) searching for fish schools in comparison with similar information gathered from a survey based acoustic data collection by a vessel that is following a transect in the area. The study is limited to a modelling approach because of lack of quantitative data on the real fleet and resource at the moment. The simulation model to generate a virtual fish stock and of the search behaviour of fishing vessels is implemented in R software.

Materials and Methods

A virtual Jack mackerel population is generated in a bi-dimensional spatial environment. This resource is represented as a collection of schools distributed in the fishing area. The function rMatClust from the R 'spatstat' package library was used to create a number of fish school clusters inside a rectangular window representing their distribution area. Then a number of schools are generated as random points, with a Poisson distribution, placed inside a disc of a variable radius centred on the parent cluster points. In this way the resource is static and is characterized by the level of aggregation: from uniform to clustered depending on the radius of the clusters (see figure C1A).
Quadrat counting in the generated point pattern divides the window into quadrats and counts the numbers of points in each quadrat to summarize the spatial distribution pattern. In this way the originally generated point pattern of fish schools is effectively transformed into area data that can be used in further analysis and simulations. The disadvantage being, losing much of the spatial details, is reduced because the quadrats can be sized to a suitable size for meaningful interpretation of the results. Now the fish abundance is defined as the counted number of schools in one quadrat or cell and this abundance can by observed by a fleet vessel in one time step (see figure 1B).
For quadrats of equal area, the counts from a completely random distribution pattern should follow a Poisson distribution. This means the complete spatial randomness (CSR) hypothesis can be tested by a chi-square goodness of fit test. One of the simplest indices of quadrat counts is the index of dispersion, motivated by the equality of the mean and the variance of the Poisson distribution.

$$\mathrm{ID} = \frac{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}{n \cdot \overline{Y}}$$

Where $\overline{\mathrm{Y}} = \frac{1}{n}\sum_{i=1}^{n}(Y_i)$, and i=1,….,n; are n quadrats of equal size

Under CSR, this has an approximate X^2_{n-1} distribution. ID>1 indicates clustering, ID<1 regularity.
The virtual fish population described above is subject to the searching and harvesting activity of a fleet of pelagic trawlers active in the same bi-dimensional spatially explicit environment. The vessels are modelled as single and autonomous items in the fishery system, that are able to search for the resource for fish schools and fish them if encountered. The location of a vessel is given by the coordinates of the quadrat in the spatial grid it occurs in at a certain time step. Such a vessel perceives the occurrence of fish schools in its current location and some neighbouring quadrat grid cells. Fish present in the current location is yielded, while acoustic observations in their immediate environment determine the movement to one of its neighbouring cells the next time step. In principle the information of 8 surrounding cells could be used, but practically the acoustic beamer is directed according to the fishing direction so the density of fish in only 5 cells is perceived (figure C2). The moving behaviour of the vessel depends on the fish schools located in the scanned grid. If no school is located in neighbouring grid cells, the vessel continues in the direction it had during the previous time step. If there is one neighbouring cell with at least one school the vessel moves to it and harvest the school. If there are several neighbouring cells with schools, the vessel moves to

the cell with the highest fish abundance (most schools). A special situation occurs when a vessel moves to a border. In that case scanning is limited to only 3 neighbouring cells.
The fleet behaviour described above is coded in the model by the next sequence of events for each time step successively for each vessel :

1. *Scanning*
- According to the current vessel position and direction, the 5 cells of the scanned area and their value are selected from the quadrat grid.
2. *Selecting the next cell to move to*
- The cell with the highest value in the scanned area is selected. If the highest value is found in 2 cells, the cell corresponding to the smallest change in direction is selected. If the change of direction is the same for the two cells, one of these two cells is selected randomly. If all the cells are empty (or have the same value), the vessel continues straight-ahead
3. *Recording the new state :*
- At the end of the time step, the new grid location, the direction from previous location and the value in the cell are stored. The cell is fished and gets a new value of zero.

The behaviour of a research vessel performing an acoustic survey following parallel transects was also simulated. The vessel starts to move from the south-west corner of the fishing area and then follows a transect in direction east until the border of the area is reached. The vessel goes then in direction north over a distance of 1/10 of the length of the transect. It turns then in direction west and performs a new transect until the border of the area. The vessel continues to make transects until it reaches the northern border of the area. The positions and the values in the cells visited along the transect are recorded but the cells are not fished.

Results

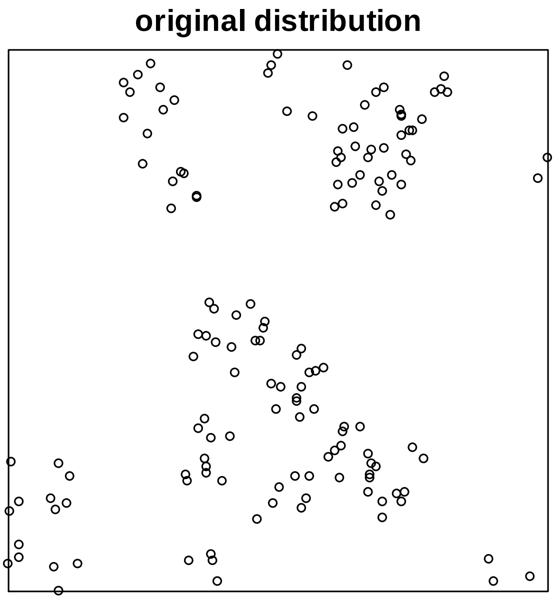
The series of fixed resource distributions that were used in the study in order to minimize the simulation variability when evaluating fleet behaviour are shown in figure C3 The reference levels used are noted from 1 to 4, starting from a *random* distribution, an *aggregated* distribution, a *heterogeneous clustered* distribution and a *second heterogeneous* distribution with a smaller cluster size.
The average number of schools per quadrant was 0.200, 0.200, 0.251 and 0.152 fish schools per quadrat for distribution 1 to 4 respectively with variances of 0.200, 0.848, 0.296 and 0.214.
The analysis started by simulating surveys in the area by 10 transects in the east-west-east direction. The number of quadrats surveyed uniformly in this way amounted to 5250. This is approximately 2% of the total number (250 000) of quadrats. The results of this sampling was 0.20, 0.20, 0.25 and 0.17 for distribution 1 to 4 respectively with a sample variance of 0.20, 0.85, 0.28 and 0.24.
The next step was to simulate fishing activity of the commercial fleet and record the schools fished during a fishing trip, during which 5250 quadrants were visited. The average number of schools per quadrant recorded by a single fishing vessel was 0.48, 0.64, 0.59 and 0.38 for distribution 1 to 4 respectively with a variance of 0.02, 0.02, 0.14 and 0.17. The path a single fishing vessel could follow depending on the underlying resource distribution is depicted in figure C4

Discussion and conclusions

The preliminary results of this study show that it is possible to simulate the dispersal of fish schools and the vessel behaviour of a pelagic fleet targeting them, given predefined control rules of the search behaviour and the subsequent direction the vessel follows when active in an area where the resource is distributed.
A wide range of possible resource distributions were used and the results made clear that, irrespective of the selected distribution of the resource, using acoustic information proportional to catch per unit of effort always leads in a positively biased estimate of local stock abundances. The abundance estimates were 2-3 times as high as the true fish or school abundances. This means that misleading echo-sounding information from the commercial fleet has to be processed and transformed to suitable data and where necessary supplemented with track data resulting from survey information.
An important result of the study is that the simulation model is able to generate the consequences of various resource distributions in combination with fleet and/or survey vessel behaviour for using acoustic data for generating stock indices. By simulation, various scenario's of the effectiveness of the value of acoustic information can be optimized given the spatial distribution of the fish stock and fleets behaviour supplemented with a limited number of acoustic surveys.

It is expected that it is possible to generate realistic and useful data with the simulation model. To develop a model with relevant practical results it is necessary to incorporate the available relevant knowledge on the local Jack mackerel distribution and the area covered by fleet vessels targeting the resource in real fisheries. Sensitivity analysis will then reveal the main factors that effect the biases in the estimation of stock abundances

Once the simulation model is validated and calibrated for real world data the optimal scenarios for acoustic data gathering of the fishing fleet with additional echo survey sampling can be generated. In this way a tool is generated that makes it possible to connect the spatial and temporal aspects of fish stock distribution with individual fishing vessel behaviour in response to this distribution with respect to fishing. Moreover, it can be evaluated whether data from echo sounding devices need to be processed to get unbiased information on stock indices. It might be possible to use the side scanning information from the acoustic beam to generate abundance indices on quadrats left and right from where the stock is fished from.



quadrat_count

0	0	0	0	1	1	0	0	0	3	0	0	1	0	0	0	0	0	0	0
0	0	0	0	2	1	1	0	0	0	0	0	0	2	0	1	3	0	0	0
0	0	0	0	1	1	0	0	0	0	1	1	2	1	4	1	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	3	3	3	0	0	0	0	1
0	0	0	0	0	1	3	0	0	0	0	0	3	2	3	0	0	0	0	1
0	0	0	0	0	0	2	1	0	0	0	0	2	2	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	3	0	4	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	2	0	2	3	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	2	1	0	0	0	3	1	1	0	0	0	0	0
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1	1	1	0	0	0	0	0	0	1	2	1	0	2	3	0	0	0	0	0
1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
2	0	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	1	0	0
1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1

Figure C1. A. Picture of the resource distribution originally generated. B. Picture of the quadras of the resource distribution depicted in Figure 1.

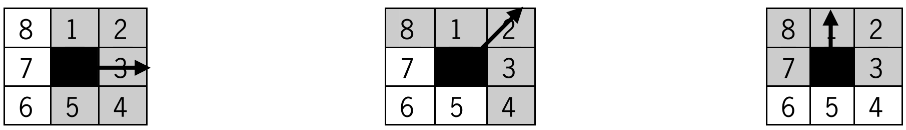

Figure C2: coding for the 8 possible directions depending on the location grid cell (in black) by the vessel and illustrations of the shape of the scanned area (in grey) for a vessel heading in the directions 3, 2 and 1 (black arrows).

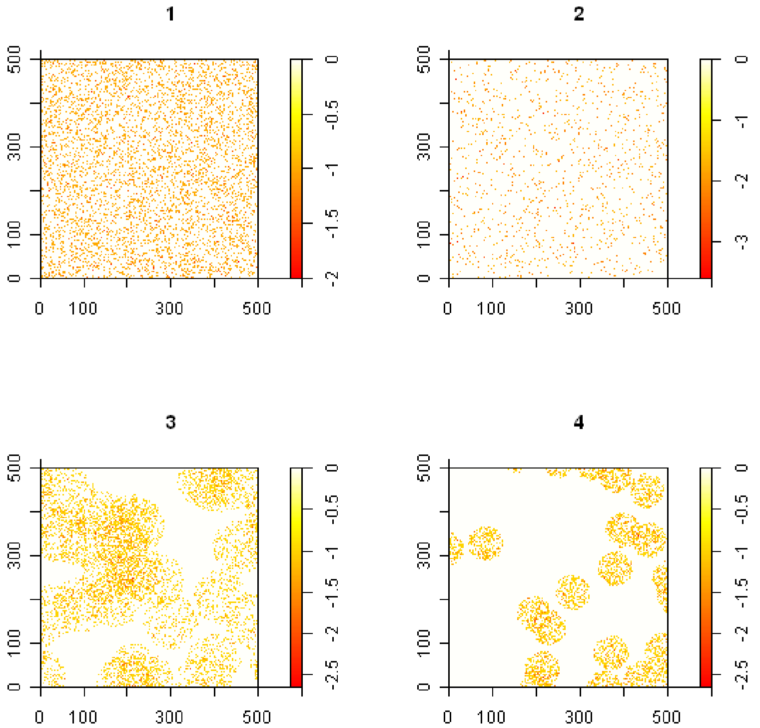

Figure C3: Mapping the resource distribution that were used for the simulations. Numbers noted refer to the different levels of aggregation: (1) random; (2) agregated; (3) & (4) clustered.

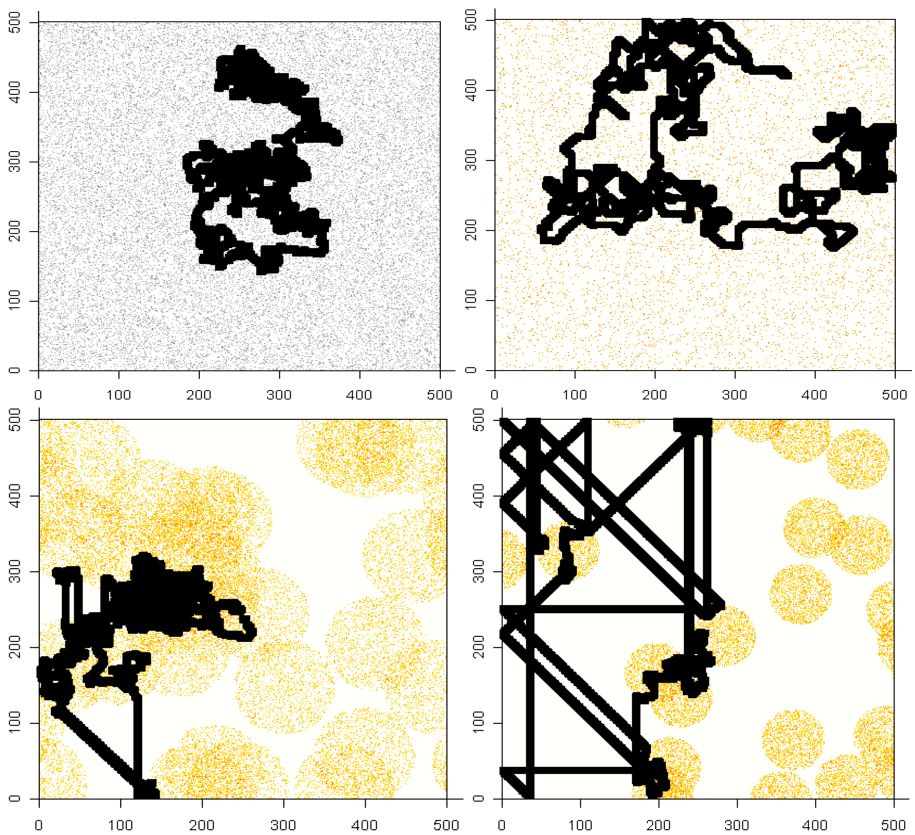

Figure C4: Illustration of the path a commercial vessel follows harvesting fish schools given the fleet behaviour simulated: scanning the surrounding grid and selecting the quadrat with the highest density. (1) random; (2) aggregated (might be difficult to see in this illustration); (3) & (4) clustered.

Appendix E. Current status for collecting acoustic data from trawlers

Background on acoustic data collection from fishing vessels and setting the standards

Fishery scientists throughout the world are now using fishing vessels to collect acoustic data in support of multiple objectives. This approach has been successful in many instances, and often the cooperative (industry/agency) nature of the work brings additional benefits. In fact, some types of objectives can only be addressed through the use of acoustic systems installed on fishing vessels (e.g. improved characterization of fishing effort, studies of fish/fishery interactions). Conversely, some fishing vessels are unsuitable for collecting acoustic data in support of any scientific objectives, and some fishing vessels may be suitable only for specific types of research. Radiated vessel noise and its impact on fish behaviour, and vessel design or operating conditions that constrain acoustic system performance may be of particular importance.

In 2003, ICES established a study group (Study Group on the Collection of Acoustic Data from Fishing Vessels (SGAFV)) to evaluate the collection of acoustic data from fishing vessels and provide appropriate recommendations. Experts from 12 countries participated in the work of the study group during its three-year term. The SGAFV prepared a written ICES Cooperative Research Report during its three annual meetings and by correspondence between meetings.

Standardized methods and protocols have been developed for routine acoustic surveys aboard research vessels. However, recommended methods and guidelines for collection of acoustic data from commercial vessels did not exist, and objective criteria for matching data collection procedures with research objectives or for evaluating data quality were lacking until 2007. While commercial vessels equipped with calibrated commercial sounders are suitable for collecting data in support of some specific research and survey objectives, use of these platforms and instruments are not always appropriate.

Use of sonars and multibeam echosounders on top of classical echosounders:
A huge advantage of sonars and multibeam echosounders over conventional echosounders is their ability to look omni-directional (360°) instead of only downwards. Conventional fishing vessel sonars are difficult to calibrate, and so abundance estimation is difficult; data recording can also be difficult. However, abundance can be estimated by comparing sonar recordings of schools and size of the trawl catches, when the whole school has been caught (e.g. the fisher's way of getting experience). Further, when echo integration data from conventional echosounders are available, the school dimensions can be correlated with echo abundance when crossing the school. Data that can be collected during fishing vessel sonar studies include school height, school width, speed and direction of schools, and trawl catch. Echo integration from conventional echosounders can supply additional support (Misund, 1997).

Multibeam echosounders can provide useful spatial and temporal information on aggregation size and distribution in a manner similar to sonar systems. Within recent years they have become a better choice for acoustic work that requires accurate measurement of relatively low-amplitude echoes (as is required for echo integration). Fishery scientists began using multibeam echosounders (sonars) in the 1990s (Melvin et al., 2003). These systems were designed to collect bathymetric data over an area wider than is possible with conventional downwards-looking echosounders. Most multibeam systems are designed for mapping the seabed, but have a limited dynamic range and poor low-amplitude echo measurement accuracy.
More recent multibeam systems do have the dynamic range and amplitude accuracy necessary for backscatter measurement, and some of these systems are available on commercial fishing vessels. Note, however, that the calibration of a multibeam system is a significant undertaking (Foote et al., 2005).

Appendix F. IMARES Interview on fishing behavior

Doel van het interview

Inzicht krijgen in het visserijgedrag van pelagische trawlers in Chili

Bij IMARES beschikken we over steeds meer harde getallen (logboeken en VMS gegevens), maar in mindere mate over informatie over het gedrag van vissers. Met dit interview willen we achterhalen wat beweegredenen zijn van vissers om een visreis uit te voeren op de manier waarop zij dat doen.

Meer inzicht in het visserijgedrag zorgt ervoor dat het onderzoek dat bij IMARES wordt gedaan beter kan worden uitgevoerd. In dit specifieke geval kunnen modellen die nagaan of trawlerreizen ook gebruikt kunnen worden voor een betrouwbare bestandsschatting realistischer worden opgezet en advies over het beheer van de visserij kan beter worden afgestemd op de praktijk.

In dit stadium van het onderzoek is alleen nog maar globale informatie nodig over de visserij in Chili. Bij een vervolgproject zal dieper worden ingegaan op specifieke onderwerpen.

Opbouw

Deze enquête bestaat uit 20 meerkeuze vragen over de volgende onderwerpen:

- opzet van een reis (begin, eind, duur);
- indeling van een reis (vaarrichting; zoeken naar vis);
- uw kennis over horsmakreel en scholen in het visgebied bij Chili

Aan het eind is ruimte opengelaten waar u aanvullende informatie kwijt kunt of vragen kunt uitschrijven die niet in de vakken passen.

Vertrouwelijk

Uw informatie zal vertrouwelijk worden behandeld. Bij presentatie van resultaten zullen de gegevens van meerdere schippers samengenomen worden, en zullen geen namen van schippers/schepen worden genoemd.

Bedankt voor uw medewerking!

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💻 floor.quirijns@wur.nl

Algemene informatie

Scheepscode	
Schipper	

Opzet van een visreis

Bij alle vragen zijn meerdere antwoorden mogelijk.

1. Wie bepaalt waar het schip gaat vissen? *Hier gaat het om het visgebied waar het schip heen stoomt als de haven is verlaten, dus niet de positie waarop de netten worden uitgezet*	
☐ De reder, altijd ☐ De schipper, in het volgende geval:	☐ Meerdere personen, namelijk:
2. Hoe wordt bepaald waar het schip gaat vissen? *Hier gaat het om het visgebied waar het schip heen stoomt als de haven is verlaten, dus niet de positie waarop de netten worden uitgezet*	
Op basis van… ☐ positie van andere schepen ☐ informatie uit een vorige reis ☐ informatie over de verspreiding van de doelsoort	☐ Anders, namelijk:
3. Hoe dicht vissen schepen in het algemeen bij elkaar?	
☐ Binnen elkaars sonarbereik. ☐ Buiten elkaars sonarbereik.	☐ Anders, namelijk:
4. Wanneer wordt een reis beëindigd?	
☐ Als de maximale opslagcapaciteit van het schip is bereikt. ☐ De reizen hebben altijd dezelfde tijdsduur. ☐ Als de vangsten tegenvallen. ☐ Als de prijzen voor de vis gunstig zijn.	☐ Bij slechte weersomstandigheden. ☐ Andere reden:

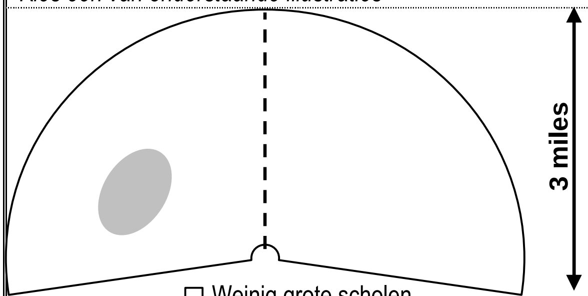
Tijdens de visreis

Bij alle vragen zijn meerdere antwoorden mogelijk.

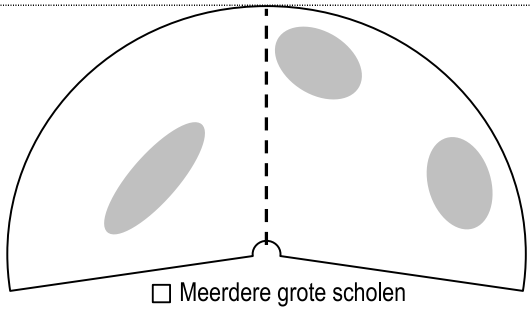
5. Wordt tijdens het stomen naar de visgrond al gezocht naar visconcentraties?	
☐ Ja, door middel van: ☐ Sonar ☐ Echolood ☐ Aanpassen vaarroute ☐ Anders, namelijk:	☐ Nee
6. Welke informatie gebruikt u vooral bij het zoeken naar visconcentraties?	
☐ Sonar ☐ Informatie van andere schepen van dezelfde rederij ☐ Informatie van schepen van een andere rederij	☐ Logboeken ☐ Plotter ☐ Andere informatie:
7. Hoe vaart men tijdens het zoeken naar visconcentraties?	
☐ Zig-zag ☐ Rechte lijn	☐ Langs dieptelijnen ☐ Anders, namelijk:
8. Wanneer wordt besloten het net uit te zetten? ☐ Als de sonarbeelden laten zien dat er voldoende vis zit ☐ Als de echoloodbeelden laten zien dat er voldoende vis zit ☐ Anders namelijk:	
9. Hoe wordt de vaarrichting tijdens het vissen bepaald?	
☐ Op basis van akoestische informatie ☐ Op basis van dieptelijnen ☐ Op basis van golfhoogte en richting	☐ Er wordt altijd een vast patroon aangehouden ☐ Anders, namelijk:
10 Wanneer wordt besloten het net te halen?	
☐ Wanneer in de directe omgeving geen vis meer te zien is op sonar en echolood ☐ Wanneer de kwaliteit van de vis in het geding komt ☐ Op basis van de verwerkingscapaciteit	☐ Wanneer de netsondes aangeven dat het net vol zit ☐ Anders, namelijk:
11. Wanneer besluit men na een trek om naar een ander visgebied te gaan?	
☐ Wanneer geen commercieel interessante scholen meer te zien zijn op de sonar ☐ Wanneer de kwaliteit van de vis in dat gebied tegenvalt ☐ Wanneer elders goede vangsten worden gedaan	☐ Na elke vriesperiode gaan we naar een ander gebied. ☐ Anders, namelijk:
12. Hoe lang ligt het schip stil tijdens het invriezen?	
☐ meestal tussen de en uur ☐ dat wisselt sterk	☐ Anders, namelijk:

Kennis over horsmakreel en scholen

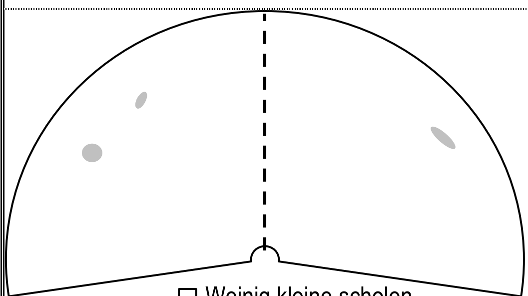
13a. Wat is een typisch sonarbeeld wanneer het schip in een goed visgebied is?
Kies één van onderstaande illustraties



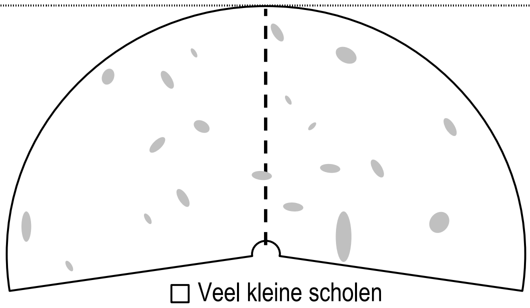
☐ Weinig grote scholen



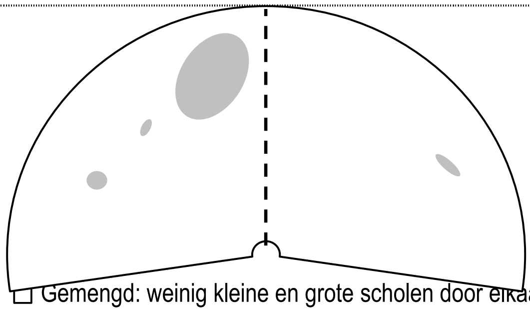
☐ Meerdere grote scholen



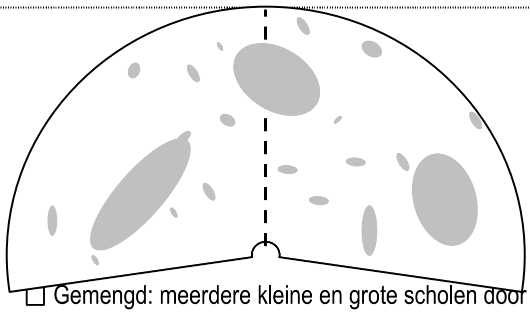
☐ Weinig kleine scholen



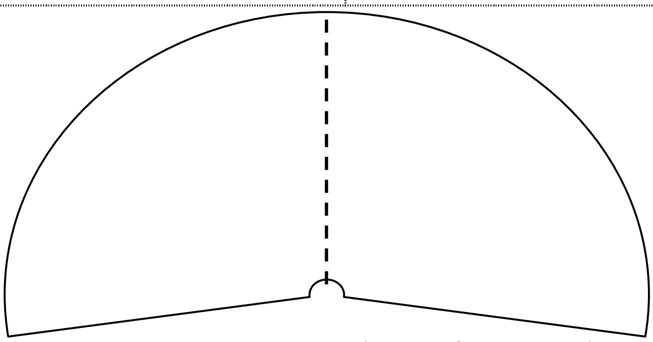
☐ Veel kleine scholen



☐ Gemengd: weinig kleine en grote scholen door elkaar heen



☐ Gemengd: meerdere kleine en grote scholen door elkaar heen

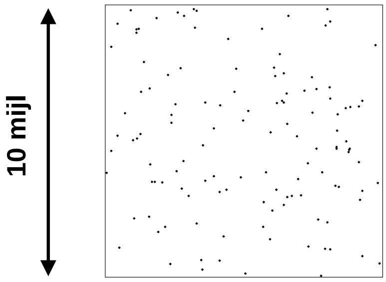


☐ Anders, namelijk: (maak zelf een tekening)

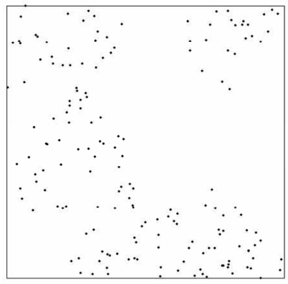
13b. Hoe ver is uw sonarbereik?

Tijdens het zoeken: zeemijl
Tijdens het vissen: zeemijl

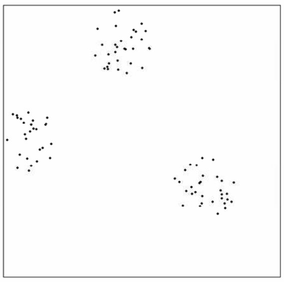
14a. Hoe zijn scholen volgens u op kleine schaal (tot 10 mijl) verdeeld over het gebied?
Kies één van onderstaande illustraties



☐ Scholen gelijkmatig verdeeld over het gebied



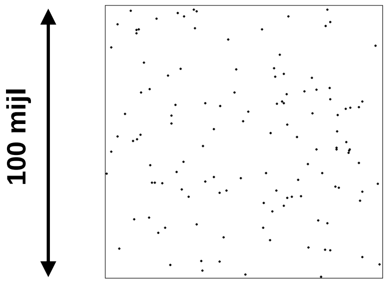
☐ Scholen verdeeld in grote groepen



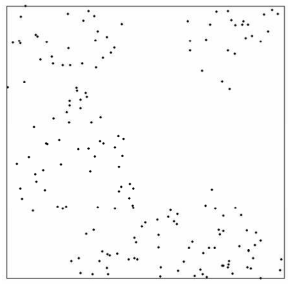
☐ Scholer [illegible] van elkaar gescheiden door lege gebieden

☐ Anders, [illegible] vak hierboven hoe het er volgens u uit ziet)

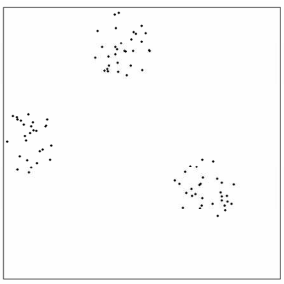
14b. Hoe zijn scholen volgens u op grote schaal (tot 100 mijl) verdeeld over de ruimte?
Kies één van onderstaande illustraties



☐ Scholen gelijkmatig verdeeld over het gebied



☐ Scholen verdeeld in grote groepen (als blauwe wijting)



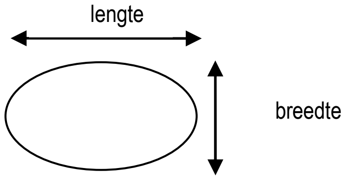
☐ Scholer [illegible] van elkaar gescheiden door lege gebieden (als Noordzeeharing)

☐ Anders, [illegible] vak hierboven hoe het er volgens u uit ziet)

15. Hoe groot zijn gemiddeld de scholen die u tegenkomt?

Lengte (afstand?):
Breedte (afstand?):
Hoogte (afstand?) :

Eventueel uitgedrukt in gewicht: ton



16. Zijn er veel verschillen in <u>dichtheid</u> (aantallen vis per m^3) van de scholen?

☐ Ja,
☐ Nee,
☐ Dat verschilt: per seizoen of per gebied. Toelichting:
☐ Onbekend:

17. Hoe diep zitten de scholen overdag?

meter

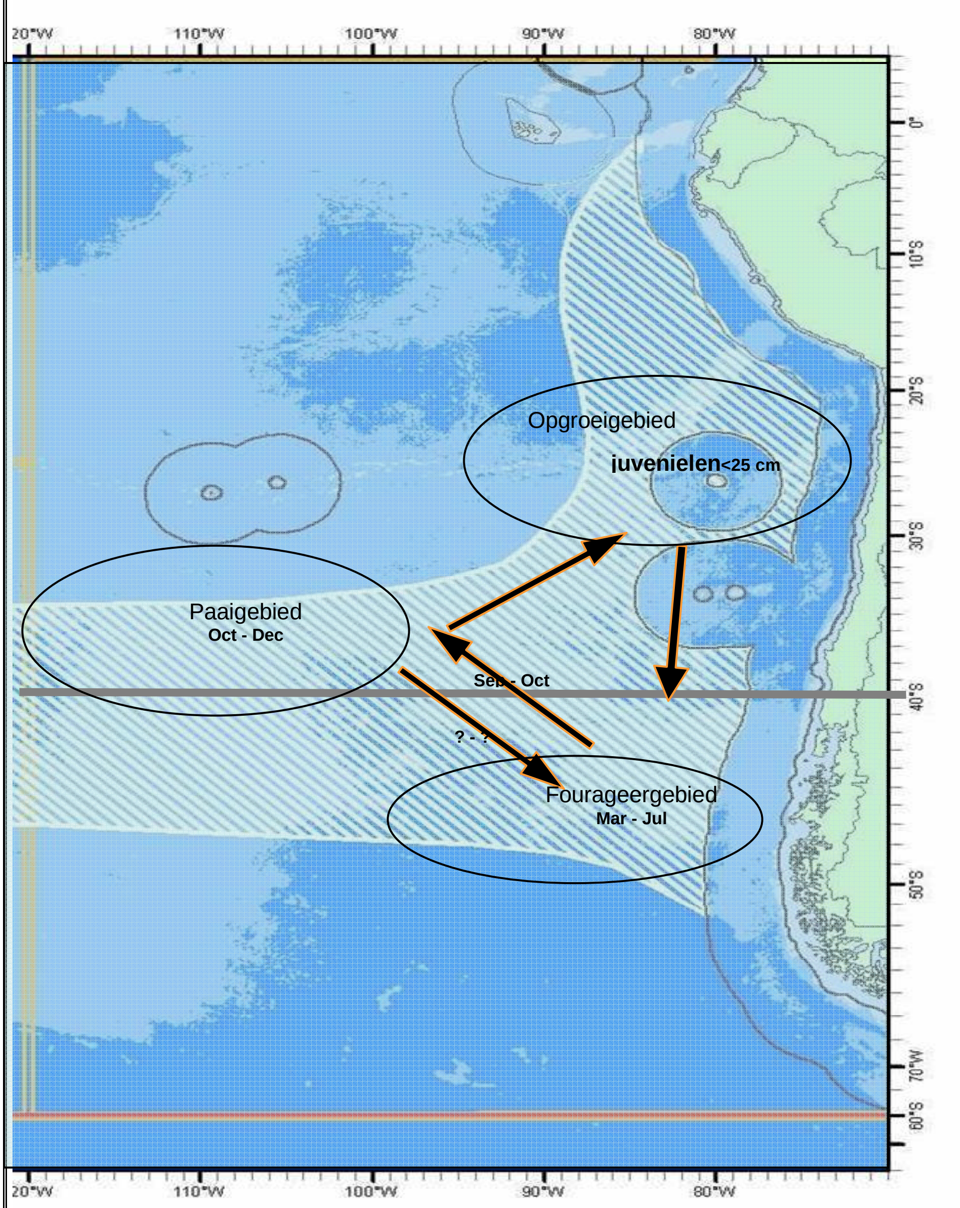
18. Hoe diep zitten de scholen ‘s nachts?

meter

19. Hoe zeker bent u ervan dat de vloot de kern van het visgebied bevist?

☐ Heel zeker. Toelichting:
☐ Redelijk zeker. Toelichting:
☐ Niet zo zeker. Toelichting:

20. Herkent u onderstaand migratiepatroon van horsmakreel?



☐ Ja
☐ Nee
☐ Daar heb ik geen zicht op

Uw medewerking

21. Denkt u dat met behulp van uw sonar- of echoloodgegevens een betere biomassaschatting van horsmakreel in het visgebied gemaakt zou kunnen worden?
☐ Ja ☐ Nee ☐ Daar heb ik geen zicht op
22. Bent u bereid de sonar- en echoloodgegevens beschikbaar te stellen voor onderzoek?
☐ Ja ☐ Nee
23. Denkt u dat er op uw schip vriestijd gebruikt kan worden om verkennende korte transecten te varen voor onderzoek?
☐ Ja ☐ Nee. Toelichting:
24. Bent u bereid onderzoekers aan boord te nemen tijdens een van uw reizen?
☐ Ja ☐ Nee. Toelichting:

Overige opmerkingen
