dst^2

Development of structurally detailed statistically testable models of marine populations

Consolidated Progress Report: 1 January 2000 to 31 December 2000

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Project summary

Report structure

This first dst^2 progress report is separated into this summary, a short description of the status of each workpackage and a collection of documents describing in more detail progress on individual components of each workpackage.

The workpackages are in 5 groups:

Number	WP group	Workpackages
1	Data warehouse	1.1-1.7
2	Structural models/programming	2.1-2.4
3	Estimation and inference w/programming	3.1-3.2
4	Estimation of parameters outside program	4.1-4.3
5	Case studies	5.1-5.3

Following these short summary subsections, the following sections summarise the current state of work for each workpackage. Within each workpackage status description, "time to completion of workpackage" refers to the current estimate of total time left to completing the package, i.e. from 1. January, 2001. Each workpackage also contains an estimate of the amount of time initially intended for the workpackage along with the current estimate of time allotted to it, to date. Further, each workpackage lists the status of all deliverables in some detail.

Several annexes are included with this report. These annexes describe completed, current or planned work relating to the workpackages.

Status of project as a whole

Data bases (WP 1)

The data for implementing the models will be set up in the form of a data warehouse. All important aspects of development of the data warehouse are proceeding as planned. Thus, initial data descriptions are available; XML and CORBA approaches have been tested; initial data sets are available on schedule and the main components of the data warehouse are now defined.

Items behind schedule in this group of tasks are the validation of the MRI data base and CORBA testing (SCUI). This is in both cases due to lack of manpower and will simply proceed at a slower pace than originally envisioned. As described in workpackage group 1, this has no effect on other parts of the project. Since DIFRES has been able to design and implement components of the data warehouse without reference to CORBA, this delay has not impeded the project as a whole either.

Models (WP 2 and 3)

Only few model components are due at this time, but for the most part these are ahead of schedule. For instance, models for growth increments and proposals for process error implementations are now being tested using novel methods.

Items lagging include the formal definition of the model in state-space form. This has no effect on any other aspects of the project. A first step towards the formulation of a general model has been taken. A model formulation for a single species and a single area is available which is being integrated into a state space framework in 2001. Furthermore, the model is being generalised for multi species and multi areas.

Computer program (WP 2 and 3)

The model is being implemented as a computer program combining mathematical models of the biology with statistical estimation techniques. The computer program has been named Gadget and is currently in an alpha stage. Having been distributed to members with a few iterations, the current version is 0.0.4. It is envisaged that a beta version (1.0.0) will be distributed in 2001. The beta version should contain tested parallel estimation along with tested growth update mechanisms.

It is thus seen that programming is largely on or ahead of schedule. At the same time it has been found that several complex issues need to be addressed in more detail than originally envisaged. For example, although aspects such as parallelisation are likely to be implemented well ahead of schedule, it has been found that the syntax for describing model variables needs to be redefined and a parser written. Similarly, programs need to be specially developed for investigating sensitivity of solutions to perturbation in the parameter space, etc. Each such addition comes at some cost, but at present they do not delay the project.

Status of objectives

The 4 primary objectives driving the current project were described in the technical annex and are summarised here for clarity.

Objective 1 of the project is to collect relevant data and to provide objective means of analysing these. The intention is to assemble relevant data in a highly-disaggregated form in a database format which is designed to hold many different classes of data but which can provide summarised data extractions in a format amenable to the analytic routines.

Work towards this objective has been the focus of most efforts during the first year of the project. Fulfilling the objective includes programming and design as well as organising data.

In terms of database design and programming, this work has been coordinated by DIFRES with considerable input from FRS and this is described in WP 1.1-1.7. Given how well the DIFRES work has proceeded, the design and programming portions of this objective are being met. Further, as seen in WP1, the data preparations are also well under way.

Objective 2 is to validate present estimates of the stock sizes, exploitation histories and the associated uncertainties for a number of case studies, using statistically appropriate models that include detailed descriptions of growth, migration and predation.

Although most of the project is aimed towards this objective in the longer term, work directly on this will not commence until much later in the project. Any evaluation on how this objective is being met must wait until the third year of the project or so.

Current work in this context focuses on the development of statistical models. In particular, this involves development of appropriate likelihoods and methods for comparing them.

Objective 3 is to evaluate whether, when and how increased complexity in models enhances the ability to provide management advice in: (a) Advising on effects of closed area restrictions (b) Advising on the state of the stocks and annual catch forecasts (c) Advising on small-scale fishery effects such as local depletion of forage species.

This objective will only become the focus of work in the last two years of the project. In the meantime, however, several approaches to evaluating appropriate model complexity have been and will be investigated. It is fairly well known that effects of some model components can be quite confounded and thus the corresponding parameters poorly determined. Current work at MRI focuses on identifying such confounding and investigating precisely what the effects of the various parameters is on all model components as well as on all likelihood components. This is a prerequisite for evaluating the adequacy and estimability of complex models, since it has been found that chasing too many parameters can and will lead to spurious estimates when the data inadequately determines the model as a whole. This is obvious in simple models but the effects can be quite surprising in models of the form considered here.

Objective 4 is to evaluate and validate some current perceptions of limit reference points for safe exploitation of key resources, using models which take spatial concerns and multispecies interactions into account. Current stock management advice is based on comparison of population parameters with biological reference points that are all evaluated on an aggregate-model, single-species basis. The objective will be met when a comparison of the consequences of stock management based on simple-model advice and management based on detailed-model advice has been drawn for at least one case study.

Although work on this objective was not due to start until 2002, Annex I describes work completed to date. It is seen that the work has already resulted in some suggestions on how to proceed with multispecies reference points.

Status of deliverables

A deliverable indicates completion of a specific piece of code, evaluation of methods, completion of data sets or test runs etc. Completion of deliverables is indicated within each workpackage.

The following table lists the deliverables due during the first year, along with their status.

Deliverable	Quarter	Status
D1.4.1: Prototype data sets for Gadget and prototype data warehouse views.	Q3	Complete
D1.5.1: Design of data warehouse views.	Q4	Preliminary design in place. SQL interface available.
D1.5.2: Design of the database structures.	Q4	Complete
D2.4.1: Mathematical formulation of general populations dynamics models in state space form.	Q3	Single species formulation complete and available in form of printed document (see Annex)
D2.4.2: Corresponding general population dynamics program modules.	Q4	Complete
D2.4.3: Prescription to incorporate relevant prior information into population dynamics models.	Q4	Preliminary stage

In total there are 58 deliverables in this project, of which only the above 6 are due at this time. Other deliverables are not pulled out for examination here, but it is clear in the body of this report that work is progressing on or ahead of schedule on most of the remaining deliverables.

Status of milestones

Milestones refer to completion of major tasks within the project. The milestones for dst^2 are:

M1: Table definitions. Complete definitions are available for all tables to be seen in the final data warehouse. This is a prerequisite for programming the data warehouse.

These definitions are now complete for all the fundamental data to be put into the data warehouse. This includes all current data sets used in fish stock assessments, along with biological samples which refer to regular single-species research.

Not included in this first round are the data on stomach contents and from acoustic surveys. Handling of these is postponed until later in the project.

The remaining milestones are to be reached later in the project.

M2: Data entry for the case studies completed. This is a prerequisite for loading the data warehouse.

This should be complete by mid-year 2001, at least in a comprehensive enough manner to allow development and testing for all case studies. Naturally, some debugging of tools and further data validation will continue into the third year of the project, but the basis should be complete on time.

M3: Prototype structural elements and inference tools defined and programmed. This is a prerequisite for being able to test some of the detailed models.

This milestone is due at the end of 2002. Some of the elements and tools exist after this first year of the project. Notably, maximum likelihood estimation can now be undertaken, but needs to be better developed for parallel computer architectures in order to make the largest models feasible.

M4: Prototypes implemented for the case studies and developed further.

This milestone is due at the end of 2002. Some prototypes are already complete and are being developed further . Others are in their earlier stages but on schedule.

M5: Appropriate parameterization for case-study models chosen by statistical hypothesis-testing. In particular this implies that model fitting procedures are available.

This milestone is due at the end of 2003.

M6: Evaluation of implications of new models compared with simpler models completed.

This milestone is due at the end of 2003. Initial tests indicate that this will require the full length of time indicated, since this is a very complex issue indeed. Basically, this refers to comparing models where the likelihood function is a composite of many individual components, which is a non-trivial statistical problem. To add to the confusion, issues such as how to weight individual components are still unsolved. Approaches to this are being developed (see Annex G.1)

The time table for the project as a whole, including milestones, is given in Fig. 1. It is seen that only the first milestone, M1, was due in 2000.

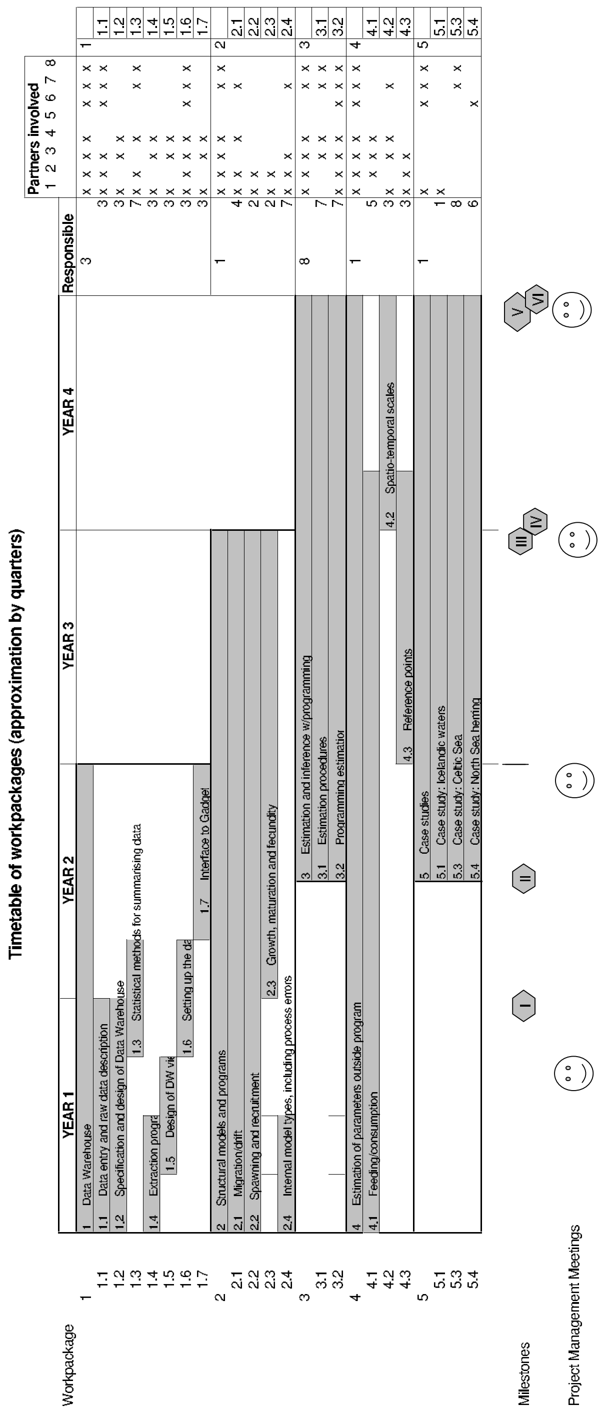

Figure 1: Time table

The next steps

The following table lists the 18 deliverables which are due in 2001.

1.1	D1.1.1	Corrected, documented data base for Icelandic waters.	Q5	Currently ongoing at a delayed pace
1.1	D1.1.2	Corrected, documented data base for North Sea herring.	Q5	Ongoing. Database nearly complete. Data are being prepared for population of the Warehouse.
1.1	D1.1.4	Corrected, documented prototype data base for the Celtic Sea.	Q5	Ongoing, expected to be completed in 2001
1.2	D1.2.1	DW design.	Q5	Almost complete.
1.3	D1.3.1	Algorithms and a set of SQL programs to be used for taking the raw data and converting the data into summaries useful for ecosystem modelling.	Q7	Ongoing at DIFRES.
1.6	D1.6.1	Each institute provides descriptions of the data storage format used.	Q6	Almost complete.
1.6	D1.6.2	Known techniques of DW implementation using XML are described and tested	Q6	Well underway.
1.6	D1.6.3	CORBA technology described in detail and tested.	Q6	Simple tests finished by SCUI. To continue in 2001.
1.6	D1.6.4	The results of using CORBA and XML compared.	Q7	Not yet started.
1.6	D1.6.5	Final choice of DW software set up, tested and distributed.	Q8	On schedule. Note that further iterations may be needed in order to incorporate further data sets
3.1	D3.1.1	Mathematical descriptions of estimation methods for model components.	Q8	Will start as scheduled mid 2001
3.1	D3.1.2	Descriptions of goodness-of-fit tests for composite likelihoods.	Q8	Preliminary results will be presented mid-year 2001.
3.2	D3.2.1	Program modules to carry out estimation for likelihood and Bayesian estimation.	Q8	Likelihood part well underway. Bayesian part not started.
3.2	D3.2.3	A program which can utilise parallel processing for improved performance.	Q8	Alpha version ready.
5.1	D5.1.1	Prototype data sets for the area around Iceland.	Q6	First set available.
5.1	D5.1.2	Prototype model run (Iceland).	Q7	Ongoing. Single species run available but not fully evaluated.
5.2	D5.2.1	Prototype data sets for the Celtic Sea area.	Q6	On schedule. Prototype data sets are being put together from the raw data set
5.3	D5.3.1	Prototype model run for North Sea herring.	Q7	Prototype runs concerning the Herring case study due to start in June 2001

The initial proposal contained more case studies than the adopted contract and hence the case studies have been renumbered. Notably, the Technical Annex did not have a workpackage 5.2. For ease of numbering, workpackages 5.3 and 5.4 have been renumbered 5.2 and 5.3, respectively.

Contents

1 Workpackage group: Data warehouse

1.1 Workpackage: Data entry and raw data description

Start date or starting event: February 2000

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1,2,6,7,8

Total planned person-months per partner: 1(120), 2(2), 3(6), 4(3), 6(14), 7(3), 8(0.5)

Person-months completed to date (estimate): 1(24), 2(1), 3(0), 4(0), 6(12.56), 7(), 8(0.5)

Time to completion of workpackage (current estimate): 36

Objectives

To enter, correct and document raw data in the institutional data bases in order to have the foundations required for compiling the data warehouse.

To create the basis for the data warehouse

Description of work conducted to date

The main point and most important part of this workpackage is to "get the raw data in order" so as to enable its inclusion in the various data warehouses. In some case studies (listed below) the data are international in nature and therefore institutions have needed to coordinate exchange formats at the raw data level.

This workpackage is largely complete except for MRI which has undertaken a greater task under this item in terms of revision of the institutional data base.

Initially, it was envisioned that each institute would provide a comprehensive description of its data bases, in order that subsequent links to the data warehouses could be based on these descriptions.

During the first project year it has been found that a better approach is for the various institutes to provide ASCII files in standard format as input to the various data warehouses. Thus, the definitions of the ASCII files largely replace the need for comprehensive definitions of the institutional data bases and the formal data descriptions from each institute are of secondary importance.

MRI (1):
Work has been done towards Deliverable D1.1.1 and is ongoing. A quality control system has been designed and implemented for the data base. This entails taking the entire institutional data base year by year, verifying the entries and re-entering data if found to be incorrect. The institutional data as a whole are stored in formats ranging from paper through ASCII files, simple database formats up through an Oracle data base. All recent years are in the Oracle data base but important biological data before 1985 has been in ASCII files, yet with a database structure, and relational operators defined to work on these files. This set of years needs to be verified and entered into the Oracle data base. Initial tests have focused on these earlier years, whereas current efforts are directed towards revising the more recent years. The earlier years are considered quite important since they will provide much longer time series of population abundance and this may stabilise estimates of various quantities normally difficult to estimate using short time series.

Although initially intended to be mostly completed during the first year of the project, temporary lack of manpower has resulted in some delay, pushing completion for this task somewhat into the future.

For MRI, the workpackage has therefore been split into several parts, the first being construction of tools for data verification, testing of those tools by revision of earlier data and of the main groundfish survey for 1985-2000. This part is now complete.

The second part of the workpackage for MRI is to complete the revision of the data base for the period 1985-2000. This part is currently underway and will proceed in parallel with the development of modelling tools. Initial tests of those tools for the case studies in Icelandic waters will use preliminary data sets.

A description of the existing database is available at the MRI website, http://www.hafro.is.

IMR (2):
Norwegian herring catch and survey data for 1991 - 1998 have been assembled, and were sent to Aberdeen for inclusion in the DW in early February 2001. (D1.1.2)

DIFRES (3):
Danish data have been extracted from the Danish institutional database and delivered to the administrator of The North Sea herring database. (D1.1.2)

FRS (6):
The composition of the North Sea Herring Data Base has been agreed and the data acquired. The content of the corrected data base is described below. Scottish, Norwegian and Danish data have been assembled and are now available in electronic format. Dutch data were needed for the database to be complete. As there is no Dutch partner on the project, negotiations were undertaken to obtain these data, which are also available in electronic format.

Raw Data Documentation

Landing data are available in Excel format. the starting year and spatial resolution varies with the data set origin. It is 1985 for Scottish data and 1990 or 1991 for the rest of the data set. The spatial resolution is the ICES square for Scottish and Dutch data but only division for Norwegian and Danish data. The temporal resolution is also variable. It is day (i.e dates are available) with number of hours of effort for Scottish data, but month for Norwegian and Dutch data and quarter for Danish data.

Temperature and salinity observations are available in Excel format from 1900 to present. Coordinates of stations (DD) and dates of observation are recorded. Zooplankton data are available in Excel format for 1961-85. Data for 1985 to present are being extracted.

Water movements data have been modelled with daily resolution on a 14 x 14 km grid.

Catch Sample data are available in Excel format for the various periods. The starting year varies between 1980 and 1991, whereas the ending year is 1999 or 2000. Length-age keys are referred to ICES divisions or to 'herring sampling areas'. The area of interest for the NS Herring case study is divided in 10 sampling areas.

Tagging data are available in Excel format for the period 1950-1988. Coordinates of release and recapture location are rounded to the minute.

Acoustic survey data are available in Excel format for the period 1984-1999. These include age-length keys. Their spatial resolution is the ICES rectangle.

Juvenile density data (number/square meter) are available in Excel format for the period 1977 - 2000. Coordinates (DD) of observations are available.

CEFAS (7):
Located alternative sources of diet composition data, larval distribution data etc. from the literature.

IFREMER (8):
The basic French data for the Celtic Sea for the years 1991-1998 has been collated in an ACCESS data base. It consists of port sampling data, landings information, log book data and scientific survey data. Descriptions for the sampling protocols and the available data are provided in Annexes A.1, A.2, A.3 (D1.1.4)

Deliverables

The outcome of this work will be corrected data bases containing the raw data which form the bases for the data summaries used in the data warehouses.

D1.1.1: Corrected, documented data base for Icelandic waters. Q5

D1.1.2: Corrected, documented data base for North Sea herring. Q5

D1.1.4: Corrected, documented prototype data base for the Celtic Sea. Q5

Milestones and expected results

This is work towards milestone M2.

1.2 Workpackage: Specification and design of Data Warehouse

Start date or starting event: February, 2000

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1, 4

Total planned person-months per partner: 1(5), 3(11), 4(12)

Person-months completed to date (estimate): 1(2), 3(2), 4(1.5)

Time to completion of workpackage (current estimate): 3 months

Objectives

To design coordinated modules and structures of the DW along with programs for import and export.

Description of work conducted to date

DIFRES has had the lead on this workpackage with considerable input from all participating organisations, much of which was obtained during the two major meetings in 2000, as well as through electronic communications.

An overall systems architecture has been agreed upon. The idea of extracting raw data from institutional databases directly to the data warehouse was proven impossible. There were three reasons for this: 1. Not all institutions are able to make their databases accessible from the Internet. 2. Not all institutions are willing to make their raw, disaggregated, data available to outside institutions. 3. Some data are not stored electronically. So a different approach has been chosen: The goal of this work package has been redefined as to design a data warehouse build upon a data structure that serves both the needs of a database internal to institutions and needs of a data warehouse containing joined data. Data should be uploaded to the data warehouse at a suitable aggregation level. The extraction and aggregation of raw data from institutional databases are left to the institutions themselves.

The data warehouse has been designed to be used as an internal institutional database and as an Internet based data warehouse. A web based interface serves well in both of these cases. So does a CORBA solution.

So far the main effort has been put on the web-based interface because, contrary to the CORBA solution, it can be used without specially developed client side software. The resulting data warehouse software is described in Annex B.1

The data structure of the data warehouse has been carefully designed to fit the three study case databases (See WP 1.1). To make the database more general it enables data storing in more than one aggregation level. The design of the data structure is described in Annex B.2

FRS has chaired the Warehouse Users Group, which had the task of contributing to specifying warehouse functionality and appearance from the point of view of the end users. The users group has produced a specification report. This, together with informal but frequent consultations, has been used by DIFRES to design the Warehouse accounting for user's needs. The structure of a total of 11 tables and 17 look-up tables has been agreed. Look up tables for the Warehouse require further consultations among partners and are in the process of being constructed.

Deliverables

D1.2.1: DW design. Q5

Milestones and expected results

This is work towards milestones M1.

1.3 Workpackage: Statistical methods for summarising data

Start date or starting event: October, 2000

N^o of the partner responsible: 7

N^{o}s of other partners involved: 1, 2, 4, 8

Total planned person-months per partner: 1(6), 2(3), 4(3), 7(2), 8(0.5)

Person-months completed to date (estimate): 1(2), 2(0), 4(0), 7(0), 8(0.5)

Time to completion of workpackage (current estimate): 6

Objectives

To define the computational methods to be used when computing the summary tables to be used in the data warehouses.

Description of work conducted to date

All work on this workpackage is towards deliverable D1.3.1, due in 2001. This has only started at MRI and IFREMER.

As described elsewhere, at MRI, work is ongoing on the development of SQL programs to extract data from the database and calculate appropriate summary statistics, which involves some choice of summary statistics. Initially, most summaries are computed as sums and averages, awaiting further theoretical work, which will be undertaken and completed in 2001.

The procedures currently used at IFREMER are as follows.

Summarising haul data from stratified scientific surveys: The French groundfish survey has a stratified random design. Strata are defined by latitude and depth. It is proposed to estimate population numbers per statistical rectangle by assuming a common uniform distribution for all rectangles in a given strata.

Summarising commercial data: Information on French commercial fishing is available by fishing trip. Monthly data is obtained by summing over all trips that started in a given month.

Deliverables

D1.3.1: Algorithms and a set of SQL programs to be used for taking the raw data and converting the data into summaries useful for ecosystem modelling. Q7

Milestones and expected results

This is work towards milestones M2.

1.4 Workpackage: Extraction programs (prototypes)

Start date or starting event: February, 2000

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1, 4

Total planned person-months per partner: 1(5), 3(8), 4(3)

Person-months completed to date (estimate): 1(5), 3(1), 4(0)

Time to completion of workpackage (current estimate): 0

Objectives

To define and write prototype programs to extract data from raw data bases into data warehouse tables and Gadget data files.

Description of work conducted to date

This workpackage is completed along with deliverable D1.4.1, resulting in several example Gadget data files as well as a generic viewing tool into the data warehouse. All these are based on prototype programs which produce files and views in a quick manner, but which can not be used for final "production" versions.

Thus, these prototypes allow testing of how data can be loaded into the data warehouse, various extractions from same, as well as Gadget runs based on data extracted into Gadget files. The latter bypasses the data warehouse, is both cumbersome and non-portable and needs to be modified so that Gadget files are extracted directly from the data warehouse. This is highly complex and is therefore done separately in workpackage 1.7.

Prototype programs have been developed in Splus by MRI to generate example data sets for a number of species, in particular for haddock which serves as an initial example (see Annex).

In all, the prototype programs have been used to generate single species datasets for cod, haddock, redfish, plaice, catfish, shrimp, capelin and Greenland halibut. A Multi-species dataset has been created for a prototype cod-shrimp-capelin model.

These prototype programs are not readily portable to other systems or databases and must be considered prototypes for the purpose of obtaining initial Gadget files for prototype model runs.

The first prototype of the data warehouse has been implemented by DIFRES. The purpose of this data warehouse is both to serve as an internal data warehouse to the institutions and also to serve as a joined warehouse to be used for cross-institutional sharing of data. The interface to the data warehouse is web based. Data uploading and downloading can be done both internal to the institutions and from the Internet.

Data sent to the data warehouse are extracted from institutional databases by the institutions themselves. An exchange format for uploading data to warehouse has been designed (Described in Annex B.3). Data can be uploaded to the data warehouse using the web-based interface. Data can be downloaded from the data warehouse using a general data extraction routine that will extract any data from the warehouse.

Deliverables

D1.4.1: Prototype data sets for Gadget and prototype data warehouse views. Q3 **Complete**

Milestones and expected results

This is work towards milestones M1, M4.

1.5 Workpackage: Design of DW views and structures

Start date or starting event: April, 2000

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1,4

Total planned person-months per partner: 1(12), 3(7), 4(12)

Person-months completed to date (estimate): 1(1), 3(2), 4(0.5)

Time to completion of workpackage (current estimate): 6

Objectives

To design the data structures of the data warehouse.

To develop a modern data warehouse using CORBA technology.

To design an Internet based program that can report the content of the data warehouse in a predefined set of views.

Description of work conducted to date

All the main aspects of this workpackage are on schedule, notably the overall design of the data structures, which are complete. The work here has been led by DIFRES, building on input from other partners during meeting and electronic mail. As with other aspects relating to the data warehouse, work has focussed on the basic data needed to make a database which serves the fundamental Gadget runs. Thus, this phase has not included acoustic or stomach content data. Such further data sets will be developed at a later stage during the project, partially under other work packages.

The CORBA technology has been delayed for several months due to manpower problems. These aspects of this workpackage will be developed during 2001.

The data warehouse internal data structures have been designed at DIFRES (completing deliverable D1.5.2). The data structures of the data warehouse serves as an universal format, to be used with both a local institutional data warehouse and a combined data warehouse giving a joined view of data from more than one institution. The data sets and the data structures of the data warehouse are described in Annex B.2

The first prototype of the data warehouse has been implemented. It is described in Annex B.1. So far no predefined data extraction criteria have been included, although the interface has been prepared for such.

Deliverables

D1.5.1: Design of data warehouse views. Q4 **Preliminary design in place. SQL interface available.**

D1.5.2: Design of the database structures. Q4 **Complete**

Milestones and expected results

This is work towards milestones M1, M4.

Milestone M1 is complete when this workpackage is complete.

1.6 Workpackage: Setting up the data warehouse

Start date or starting event: End of 1.5

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1,2,4,6,7,8

Total planned person-months per partner: 1(24), 2(3), 3(32), 4(24), 6(14), 7(1), 8(0.5)

Person-months completed to date (estimate): 1(8), 2(1), 3(6), 4(2), 6(1.87), 7(), 8(0.3)

Time to completion of workpackage (current estimate): 3

Objectives

To provide the data description, links and formats required to implement the DW programs for all case studies in a unified manner.

To implement and test the security software, browser- and e-mail-based import software and SQL based data warehouse export software to Gadget at selected sites.

To implement and test CORBA technology at selected sites.

To evaluate and select a technology for the DW.

To implement the DW at all sites.

Description of work conducted to date

The first meeting in 2000 indicated that there was less of a need for a comprehensive description of all institutional data bases than initially perceived. The reason for this was the development of an ASCII standard for exchange of tabular data between the data bases and the data warehouses. These standardised tables are described in the minutes to the Madrid meeting (see Annex) and largely supersede deliverable 1.6.1.

MRI (1):
A description of the current institutional data storage format is available at the MRI homepage, as needed towards deliverable D1.6.1.

The data base engine, PostgreSQL, to be tested as a basis for the data warehouse, has been set up and tested under Solaris, as a preliminary to testing CORBA at the MRI.

For the final data warehouse, links are being developed into the institutional data base using SQL programs. These programs extract data from the databases. The data are presented in tables suitable for import into the data warehouse, either through an ASCII file interface, or through direct links between data bases.

This development is designed to be generic, i.e. as independent of species, areas and time periods as possible. For this reason, revisions of data in the MRI database will not affect development work for the data warehouse, as the SQL programs can be rerun at any point in time, pumping the most recent data into the warehouse.

Whether the link between the data warehouse and the MRI database should be "live" or through ASCII tables depends on the outcome of performance tests which can only be undertaken after the full data warehouse has been implemented.

IMR (2):
The “Bormicon Users Manual” has been updated and includes documentation of the data format used in Flexibest along with a proposed extension to the data format. The Gadget program will be able to use both formats.

DIFRES (3):
As a common data storage format has been agreed upon, the goal of this sub work package has shifted towards the design of this common format and a format for exchanging data. The data storage format is described in Annex B.2 and the exchange format is described in Annex B.3

SCUI (4):
CORBA technology has been set up and links to different data bases have been tested, as described in Annex C, thus working towards D1.6.3. Subsequent work will be joint between SCUI and MRI, further testing of CORBA with PostgreSQL at MRI, organised by SCUI.

FRS (6):
Tables derived from the North Sea Herring raw data (described in 1.1.2) are being created in PostgreSQL format. Before the Warehouse is fully operational, ASCII files will be a temporary input source for the model. Therefore, views are being created from these tables corresponding to the agreed database structure. ASCII files are easily derived from these views.

CEFAS (7):
Agreed common database format between French and UK teams (e.g. definitions of metiers, bottom types, survey inputs etc.).

IFREMER (8):
Work towards D1.6.1 has been carried out for the French contribution to the Celtic Sea example. A description of the available raw data, its storage format (ACCESS data base) and the links between tables are given in Annex A. Currently the data for the years 1981-1998 is accessible.

Deliverables

D1.6.1: Each institute provides descriptions of the data storage format used for all data sets to be used as a basis for the DW. Q6

D1.6.2: Known techniques of DW implementation using XML are described in detail and tested. Q6

D1.6.3: CORBA technology described in detail and tested. Q6

D1.6.4: The results of using CORBA and XML compared to select the appropriate technology. Q7

D1.6.5: Final choice of DW software set up, tested and distributed. Q8

D1.6.6: Data warehouse for Icelandic waters. Q9

D1.6.7: Data warehouse for North Sea herring. Q9

D1.6.9: Data warehouse for the Celtic Sea. This will include biological sampling data for the period 1984-1999 and tagging data. As such the data warehouse will be incomplete but will demonstrate the future potential for further incorporation of data, once available. Q9

Milestones and expected results

This is work towards milestones M4, M5, M6.

Milestone M4 is complete when this workpackage is complete.

1.7 Workpackage: Interface to Gadget

Start date or starting event: End of 1.6

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1,4

Total planned person-months per partner: 1(18), 3(10), 4(12)

Person-months completed to date (estimate): 1(2), 3(1), 4(0)

Time to completion of workpackage (current estimate): 12

Objectives

To define and write procedures to extract data from data warehouses into the file formats which are used by the assessments and hypothesis testing modules.

Description of work conducted to date

This workpackage is not due to start until Q1, 2001. As a result only preliminary studies have been undertaken as to what facilities need to be provided, i.e. examples of procedure definitions.

Deliverables

D1.7.1: Software to set up all data and parameter files for Gadget. Q9

Milestones and expected results

This is work towards milestones M5, M6.

M1 needs to be completed before this workpackage can be completed.

2 Workpackage group: Structural models

2.1 Workpackage: Migration/drift

Start date or starting event: February, 2000

N^o of the partner responsible: 4

N^{o}s of other partners involved: 1, 2, 7

Total planned person-months per partner: 1(8), 2(12), 4(45), 7(6)

Person-months completed to date (estimate): 1(1), 2(0), 4(10), 7(0)

Time to completion of workpackage (current estimate): 24

Objectives

To develop a migration model for use in Gadget.

To evaluate the data needs for estimating migration parameters.

To identify potential environmental variables that might lead to a better understanding of fish migration and larval drift.

Description of work conducted to date

A basic migration model is currently fully developed, involving matrices where each entry describes the migration probability between adjacent regions. Most entries will be zero, since most regions are either not adjacent or other prior knowledge dictates that migration can not occur. Other entries represent parameters which potentially can be estimated. Since this is now a part of the current Gadget distribution, 0.0.4, deliverable D2.1.1 is complete.

MRI (1):
Recent work (2000) has involved allowing the proportions which migrate between areas to vary from year to year, yet in a time series fashion, so that too much variability in migration is penalised. This type of flexibility is an essential addition to the current framework since the migrations do vary but there is not enough data to estimate annual migration completely freely.

Current and immediate future work involves testing the estimability of these parameters, including estimation of the variance of the point estimates.

IMR (2):
IMR has taken on to develop a migration model based on one or more gravity centers, taking capelin, cod, herring and harp seals in the Barents Sea as a working example. This work is scheduled for 2001.

SCUI (4):

1. Project definition, identification of factors and forces determining migrations and spatial distributions, such as environmental features like temperature distributions, boundaries between warm and cold water masses and oceanic currents, and "internal variables" such as state of maturity and energy reserves.

2. Development of a simple initial version of a discrete individual based model. The model is based on the hypothesis that the velocity of each fish is determined by two forces: a tendency to follow the movements of its neighbours and random changes in speed and direction. By an appropriate choice of probability density functions for these random changes, the fish can be made to move either as a coherent school towards a specified point or area (migrations mode), or to move in small schools in different direction (feeding mode). In addition, boundaries are defined, such as depth contours, certain isotherms, current boundaries, which the fish tend to move along, but do not cross.

3. Initial work in defining a continuous model of density and velocity as a function of time, location (and "physiological state"); definition and mathematical formulation of the relevant forces influencing spatial distributions.

4. Compilation of a bibliography of works relating to migrations and spatial distributions.

cf Annexes D.1, D.2, D.3

CEFAS (7):
No action so far.

Deliverables

D2.1.1: Initial, simple migration model. Q4. **Complete**

D2.1.2: A proposed mathematical model formulation for use in Gadget, based on comprehensive theoretical analysis of the biolological and physical properties of the system, e.g. currents and temperature. Q12

D2.1.3: Evaluation of reduction in variances as a result of reducing uncertainty in different data sources, including tagging data, survey indices and hydrographic information, using simulation with Gadget. Q12

Milestones and expected results

This is work towards milestones M5, M6.

Parts of this task will provide input to milestone M3.

2.2 Workpackage: Spawning and recruitment

Start date or starting event: February, 2000

N^o of the partner responsible: 2

N^{o}s of other partners involved: 1

Total planned person-months per partner: 1(18), 2(88)

Person-months completed to date (estimate): 1(1), 2(32)

Time to completion of workpackage (current estimate): 24

Objectives

To formulate a description of the recruitment process in order to have a model of the full life-cycle of each species.

Description of work conducted to date

MRI (1):
Gadget 0.0.4 includes a simple spawning module, developed at MRI, but this has not been tested yet.

IMR (2):
One of the main goals of this subtask is to produce models, which could predict spawning distribution of Norwegian spring spawning herring and the coherent recruitment. These models are based on the assumption that both spawning distribution and recruitment is influenced by environmental factors, stock size and -structure (length composition, condition). The first task (in year 2000) has been to model the recruitment based on historic data. Different stock-environment recruitment models have been fitted to a time series of spawning stock-, spawning distribution-, recruitment- and temperature data extending back to 1907. The models show highly significant effects of both spawning stock and temperature. The inclusion of the temperature term in the Beverton-Holt or Ricker models removes the autocorrelation from the residuals, and improves the models fit to the data. In addition to a traditional temperature index from the Barents Sea (the average annual temperature in the Kola transect), a new index has been developed, based on the temperature in the larval drift trajectories during the early larval life. This more direct index fits the models slightly better than the indirect Barents Sea index. The next task (in year 2001) will be to model the spawning distribution, given the present migration pattern with wintering in northern Norwegian fjords and a southward spawning migration to

spawning grounds at a range of 1500 km along the coast.

Another goal of this subtask is to link survival and growth of Northeast Arctic cod at different life stages to environmental and ecological factors. An inverse relationship between the average fish length in a cohort at the 0-group stage and at age 2 has been found (Helle et al. 2001). Indications of density-dependent growth have also been found (Ottersen et al. 2001). In addition, relationships between amphipods, capelin and cod in the Barents Sea, which may be quite important for cod recruitment, have been investigated (Dalpadado et al. 2001). In calculations of survival at different life stages, the earlier work on analysis of recruitment indices for Northeast Arctic cod (Helle et al. 2000) can be utilised. The aim is to develop a mathematical model for use in prediction of recruitment (number of fish, average size) of Northeast Arctic cod.

References:

Helle, K., Bogstad, B., Marshall, C. T., Michalsen, K., Ottersen, G., and Pennington, M. 2000. An evaluation of recruitment indices for Arcto-Norwegian cod (Gadus morhua L.). Fisheries Research 48: 55-67.

Dalpadado, P., Borkner, N., Bogstad, B., and Mehl, S. 2001.
Distribution of Themisto (Amphipoda) spp. in the Barents Sea and predator-prey interactions. ICES J. Mar. Sci. (accepted).

Helle, K., Pennington, M., Bogstad, B. and Ottersen, G., 2001.
Some environmental factors that influence the growth of Arcto-Norwegian cod from the early juvenile to the adult stage. Environmental biology of fisheries (submitted MS)

Ottersen, G., Helle, K., Bogstad, B., 2001.
Do abiotic mechanisms determine interannual variability in length-at.age of juvenile Arcto-Norwegian cod? Can. J. Fish. Aq. Sci. (submitted MS).

Deliverables

D2.2.1: A module to describe the recruitment process. Q12

Milestones and expected results

This is work towards milestones M3, M5, M6.

2.3 Workpackage: Growth, maturation and fecundity

Start date or starting event: February, 2001

N^o of the partner responsible: 2

N^{o}s of other partners involved: 1

Total planned person-months per partner: 1(12), 2(30) , 4(28)

Person-months completed to date (estimate): 1(1), 2(13), 4(0)

Time to completion of workpackage (current estimate): 24

Objectives

To evaluate different models of growth and maturation including dispersion of length at age, and models for effective fecundity related to nutritional state as well as maternal effects on recruitment.

To model the relationship between growth and consumption taking into account body size and metabolic costs, in order to make predictions of growth in the short term.

Description of work conducted to date

This workpackage is not due to start until January, 2001. Some work, however, has been undertaken and the workpackage is thus a bit ahead of schedule.

MRI (1):
It has been found that the growth implementations in Multspec and Bormicon (and therefore also in Fleksibest) are nondifferentiable and even discontinuous. This can of course cause severe problems in estimation under certain circumstances. A model has therefore been developed to implement the growth update in Gadget in a parametric form, using a combination of a beta and binomial distributions to decide on the proportions of fish increasing their lengths by a certain number of length groups. This is described in Annex E.1. This model will be further developed and tested in 2001 and 2002. The effects of parameters on the final length distributions, comparisons with data, estimability etc need to be verified in considerable detail. This work has been initiated by various sensitivity analyses, cf Annex G.2.

IMR (2):
Correlation and simulation analyses show that for Northeast Arctic (NA) cod the total lipid energy (TLE, kJ) contained in the livers of mature females is proportional to total egg production (Marshall et al. 1999) making TLE a potential predictor of recruitment. Accordingly, the TLE of NA cod was estimated for a fifty one-year time period (1946-1996) using:

- estimates of numbers at length derived from historical age/length keys and virtual population analysis (VPA) estimates of numbers at age
- predictions of the proportion mature and weight at length which were made using statistical models having capelin stock biomass as the independent variable
- observed values of the liver condition index

A significant, linear relationship between TLE and recruitment to age-3 was observed which contrasted with the indeterminate relationship between spawner biomass and recruitment (Marshall et al. 2000). The temporal trend in TLE suggests that the reproductive potential of the NA cod stock has been in decline since the mid 1970's. A multiple regression model was developed having TLE, mean temperature, and mean alongshore wind stress as independent variables explained approximately 43of the variation in recruitment. This process-based model is qualitatively similar to a model developed by Ottersen and Sundby (1995) using spawner biomass as an index of reproductive potential. The predicted recruitment to age-3 for the 1996, 1997 and 1998 year-classes were consistently lower than the survey-based predictions that are used in the assessment. In future, the utility of models which blend process information (e.g., total egg production, temperature, wind stress) and survey information (e.g., relative abundance of juveniles) will be examined.

Short-term prognosis of growth of Northeast Arctic cod have been presented to the ICES Arctic Fisheries Working Group (Ajiad, 2001).

References:

Ajiad, A. 2000. Individual growth prediction of Northeast Arctic Cod. WD 5, ICES Arctic Fisheries Working Group, Copenhagen 22-31 August 2000.

Marshall, C.T., Yaragina, N.A., Lambert, Y. and Kjesbu, O.S. 1999. Total lipid energy as a proxy for total egg production by fish stocks. Nature 402: 288-290.

Marshall, C.T., Yaragina, N.A., Ådlandsvik, B., and Dolgov, A.V. 2000. Reconstructing the stock/recruit relationship for Northeast Arctic cod using a bioenergetic index of reproductive potential. Can. J. Fish. Aquat. Sci. 57: 2433-2442.

Ottersen, G., and Sundby, S. 1995. Effects of temperature, wind and spawning stock biomass on recruitment of Arcto-Norwegian cod. Fish. Oceanogr. 4: 278-292.

Deliverables

D2.3.1: Mathematical models of the growth and maturation process. Q12

Milestones and expected results

This is work towards milestone M3.

2.4 Workpackage: Internal model types, including process errors

Start date or starting event: February, 2000

N^o of the partner responsible: 7

N^{o}s of other partners involved: 1,2,3,7

Total planned person-months per partner: 1(2), 2(6), 3(4), 7(6), 8(2)

Person-months completed to date (estimate): 1(6), 2(1), 3(2.1). 7(), 8(0.5)

Time to completion of workpackage (current estimate): 3

Objectives

To define appropriate internal population models.

To incorporate process error through time series models within Gadget

Description of work conducted to date

MRI (1):
A modelling environment has been created by which the user can insert the concept of a process error in various different places in the model. Thus, it is possible to assume that a parameter, β is not just a fixed and unknown number, but rather that this number may vary from year to year in a time series fashion, so that each β_y comes from a Gaussian distribution. Alternatively, these numbers may be considered instances of a random walk, so that $\beta_y - \beta_{y-1} \sim n(0, \sigma^2)$. This is currently implemented by adding a sum of squares to the overall likelihood function which is optimised during a Gadget run. This completes D2.4.2.

IMR (2):
A mathematical description of Fleksibest, which is a single-species assessment application of a Gadget-type model, is under publication (Frøysa et al., 2001) Annex F This is an important step towards deliverable 2.4.1.

References:

Frøysa, K. G., Bogstad, B., and Skagen, D. W. 2001. Fleksibest - an age-length structured fish stock assessment tool with application to Northeast Arctic cod (Gadus morhua L.). Fisheries Research (accepted).

CEFAS (7):
Relevant and extensive literature concerning state-space models and the Kalman Filter has been gathered and references entered into bibliographic database, in order to formulate a series of similar procedures for each component (e.g. mortality, catch-at-age, recruitment) of the GADGET model. The plan is to draft review paper following meeting of French/UK teams May 6-8 2001.

Deliverables

D2.4.1: Mathematical formulation of general populations dynamics models in state space form. Q3

D2.4.2: Corresponding program modules. Q4 **Complete**

D2.4.3: Prescription to incorporate relevant prior information into population dynamics models (model structure, parameter distributions, etc.). Q4

Milestones and expected results

This is work towards milestone M3.

3 Workpackage group: Estimation and inference

3.1 Workpackage: Estimation procedures

Start date or starting event: July, 2001

N^o of the partner responsible: 7

N^{o}s of other partners involved: 3,4,7,8

Total planned person-months per partner: 1(24), 2(12), 3(4), 4(16), 7(7), 8(6)

Person-months completed to date (estimate): 1(6), 2(1), 3(1.2), 4(0), 7(0), 8(0)

Time to completion of workpackage (current estimate): 36

Objectives

To identify the probability distributions, likelihood functions and prior distributions appropriate to mathematical descriptions of fish population dynamics.

To specify the range of circumstances under which different methods of parameter estimation may be used, together with guidance on the calculation of appropriate confidence statements.

To model and program simulation procedures describing the marine ecosystem, using a detailed, structured approach.

To define and test methods to verify goodness-of-fit measures for general likelihood functions in a highly nonlinear framework.

To list, evaluate and propose methods for statistical testing of hypotheses in Gadget.

Description of work conducted to date

It is well known that probability distributions appropriate for fisheries data tend not to be of standard form, e.g. data tend not to be i.i.d., tend to be non-Gaussian and generally both overdispersed and spatially correlated.

When evaluating models, the selection of parameters and model components sometimes lends itself to ordinary statistical testing procedures, as in variable selection in multiple regression. In the present setting, the combination of composite likelihood functions (different data sets), a highly complex nonlinear model and confounding of parameters make the question of model evaluation a highly worthwhile task.

Prior distributions on parameters have been postponed until such time that likelihood functions have been adequately defined for most data sets.

Methods for formal testing of goodness-of-fit have indicated that few standard statistical assumptions hold for fisheries data sets (including surveys). These results are, however also confounded with whether the models are able to properly predict the mean. For example, an overly parsimonious growth model without process error can easily underpredict the mean length at age for a yearclass throughout its lifetime. Thus, before goodness-of-fit methods can be formally introduced into the models, two steps are needed: First the g.o.f. methods need to be tested in a simple manner using the data as directly as possible, and this approach will also give information on the appropriate p.d.f for the data. Secondly, the models need to be fitted with increasing numbers of parameters until such stage that the model is considered fully parameterised. At this stage, the rejection of g.o.f. tests should be taken as indicators of a need to reevaluate the likelihood functions.

MRI (1):

Considerable effort has been put into the selection of likelihood functions and current work involves the development of appropriate likelihood functions for length distributions (where it is easy to see from the data that e.g. multinomial distributions are not at all appropriate).

The choice of adequate model complexity has also been found to be an extremely difficult one, and considerable work has been put into this question at the MRI. It turns out that although the usual (asymptotic) F-tests are in principle adequate for comparing nested models, this is not true if the data come from overdispersed distributions and the likelihood functions do not reflect this adequately. Therefore, these tests need to be preceded by an analysis of overdispersion and appropriate probability distributions, cf E.2. This work is underway.

Methods for parameter estimation now being developed for Gadget include BFGS which will give the Hessian matrix of the parameters at the optimum. Although the methods currently work, giving convergence to the optimum of the likelihood function, the present state of estimation is that sensitivity of solutions along with model consistency and determinacy needs to be evaluated before any attempt is made to evaluate and interpret the Hessian matrix, which is a prerequisite for using it for subsequent confidence statements. Sensitivity analysis are therefore underway.

Interpretation of results, including goodness-of-fit and standard errors of parameters are quite dependent on how correctly the likelihood function is specified. Work underway includes investigation of how weights to different likelihood components can be assigned in an objective manner, cf Annex G.1.

IMR (2):
Some likelihood functions have been programmed and tested (Frøysa et al. 2001, ICES 2001).

References:

ICES 2001. Report of the Workshop on Fleksibest - an age and length based assessment tool, Bergen 16-19 January 2001. ICES C.M. 2001/ACFM:09.

DIFRES (3):
A stochastic multispecies fish population dynamics model has been developed and the probability distributions and likelihood functions have been defined along the following lines. The model is formulated in terms of ordinary differential equations ODE's) , as described in "K.P Andersen and Ursin, A Multispecies extension to the Beverton and Holt Theory of fishing, Meddeleser fra Danmarks Fiskeri- and Havundersøgelser, Vol 7, pp.319-435,1977". The model is parameterized by a flexible number of technical parameters and thereby allowing easy reparameterisation of different degrees of parameter freedom. The model parameters are estimated using the maximum likelihood method and the variance/covariance matrix is estimated by the inverse Hessian matrix. The model is described in Annex G.3

CEFAS (7):
No action so far.

IFREMER (8):
The generalisation of the single species formulation provided by Frøysa et al to a multi species and multi area situation is underway. This will lead to a formulation using the state space concept. The general model formulation is a precursor for exploring different estimation procedures.

Deliverables

D3.1.1: Mathematical descriptions of estimation methods for model components. Q8

D3.1.2: Descriptions of goodness-of-fit tests for composite likelihoods. Q8

D3.1.3: Implementations and tests of different estimation procedures in different scenarios. Q12

D3.1.4: Algorithmic description of estimation methods and goodness- of-fit tests to facilitate programming both within and outside of Gadget. Q12

Milestones and expected results

This is work towards milestones M3, M5 and M6, with M3 completed half-way through the workpackage.

3.2 Workpackage: Programming estimation

Start date or starting event: July, 2001

N^o of the partner responsible: 7

N^{o}s of other partners involved: 1,2,3,4,6,7,8

Total planned person-months per partner: 1(36), 2(12), 3(4), 4(16), 6(4), 7(6), 8(3.5)

Person-months completed to date (estimate): 1(6), 2(1), 3(3.1), 4(0), 6(0), 7(0), 8(0)

Time to completion of workpackage (current estimate): 36

Objectives

To program statistical (maximum likelihood) estimation of unknown parameters in these simulations.

To evaluate several different minimization algorithms and select algorithms for use with Gadget.

To obtain a general version of Bayesian analysis as an option in Gadget.

To incorporate processes formulated in Tasks 2 and 4 into the collection of modules.

To evaluate the possibilities of using parallel processing on a network of processors when estimating very many parameters in a complex multispecies spatially disaggregated model.

To evaluate the effects of incorporating automatic differentiation in the minimisation algorithms in Gadget and implement the possibility.

Description of work conducted to date

MRI (2):

Initial modules for maximum likelihood estimation within Gadget have been developed, first using simple direct search (Hooke and Jeeves) on a single computer, but secondly a parallel estimation method using Simulated Annealing, Hooke&Jeeves and BFGS for searching towards a global optimum, fast zooming towards the optimum and final close search and Hessian estimation. The procedures should be considered in an alpha stage as indeed Gadget as a whole. The composite algorithm will be completed in 2001.

IMR (2):
Some work towards implementing a parallel minimisation algorithm for BORMICON on IMR computers have been carried out, but this algorithm is not yet in use in regular BORMICON/Gadget work at IMR. Evaluation of minimisation algorithms and choice of parameter settings in those is in progress.

DIFRES (3):
A preliminary object oriented analysis and design of the system has been performed. The test of simple biomass dynamics models have been implemented using the object-oriented features of the scientific computing environment Matlab. ODE solving and optimizing objects have been implemented as well. Different ODE solver algorithms and optimizer algorithms will be tested. The first test cases are about to run - leading to a slight re-design of the application in near future. Simple Lotka-Volterra biomass/predation models and Schaeffer biomass dynamics models have been identified for test usage of the program structure.

CEFAS (7):
No action so far.

Deliverables

D3.2.1: Program modules to carry out estimation for likelihood and Bayesian estimation. Q8

D3.2.2: A selected (composite) minimisation algorithm. Q12

D3.2.3: A program which can utilise parallel processing for improved performance. Q8

D3.2.4: An evaluation of the effect of parallelisation. Q12

D3.2.5: A set of standard fisheries examples that can be used to check that algorithms are correctly implemented and that results are consistent with those obtained using commercially available software. Q10

Milestones and expected results

This is work towards milestones M3 and M6, with M3 completed half-way through the workpackage.

4 Workpackage group: Estimation of parameters outside program

4.1 Workpackage: Feeding/consumption

Start date or starting event: February, 2000

N^o of the partner responsible: 5

N^{o}s of other partners involved: 2, 3, 4

Total planned person-months per partner: 2(3), 3(8), 4(4), 5(58)

Person-months completed to date (estimate): 2(0), 3(1.3), 4(0), 5(2)

Time to completion of workpackage (current estimate): 26)

Objectives

To develop a multi-species spatially explicit feeding/consumption model based on habitat and diet selection with an evolutionary fitness basis

To estimate sampling error of stomach contents data in the NS Stomach Sampling data base.

Description of work conducted to date

IMR (2):
The contribution from IMR is limited to providing data as necessary and advise on the usage of data. So far, no involvement of IMR has been requested.

UiB (5):
The work conducted by UiB to date relates to deliverables D4.1.1, D4.1.2 and D4.1.3. The work related to D4.1.1 and D4.1.2 is to develop a multi-species spatially explicit feeding/consumption model based on habitat and diet selection with an evolutionary fitness basis. A linked cod-capelin model is currently being developed. The spatial model uses input data from an ocean circulation model, and to date the main work has been associated with developing computer code for linking the biological model with the physical model. The biological model relies on a bioenergetics growth model, and there exists a bioenergetics model suitable for cod, but not for capelin. Some work has therefore been invested into modifying a herring bioenergetics model to better suit capelin. Once these composite parts of the model have been established, the next step will be to have the cod-capelin model up and running and then include a model of juvenile herring. This model will then produce spatially resolved growth and predation fields for cod, capelin and herring in the Barents Sea. Eventually (towards M3) the model output will be compared with observations on distribution of all three species and cod consumption of the prey species. The work related to D4.1.3 is to compare the output from D4.1.1 and D4.1.2 to data from the Barents Sea stomach database. This database has been subject to extensive data cleaning. A detailed description of the spatial and temporal variation in stomach sampling effort in the period 1984-1997 is compiled. At the moment, methods for estimating consumption of capelin and herring by individual cod is developed and tested out.

DIFRES (3):
Estimation of the distribution or the variance of the relative stomach will be carried out for the North Sea using data collected in ICES Stomach Sampling Project 1991. The work done in 2000 has been focused on the construction of a database and software constituting the basis for simulation of the probability distribution of relative stomach contents.

These comprehensive datasets from this project has been transferred from the Dutch Fishery Institute, RIVO, to DIFRES. Extraction of data, aggregating and combination of various sources of information (e. g. weights in the stomachs and ALK) is with the existing software restricted to purposes related to the existing MSVPA. RIVO has been contacted to get the software used for aggregation, but RIVO has deprecated any attempt to use and modify their software for use in this project. It thus has been necessary to develop new software to enable this basic handling of data. Furthermore, the procedures used by ICES Multispecies Working Group for estimation of average stomach contents of prey species by age for the predators by age has been reconstructed as well. These data are used in the MSVPA for estimation of suitability parameters. SAS has been used for the construction of a flexible database and for implementation of models. This model for aggregation of data to the level of the total North Sea and sub-areas includes both weighting of individual samples within a local area, weighting of calculated stomach data from each local area using predator densities, and a transformation of length information to ages for both predators and preys.

RIVO has supplied observed stomach data for 1991 for the species cod, haddock, whiting and

Saithe, but not mackerel. Furthermore data on predator and prey densities and ALK have been extracted from ICES, 1997. The aggregation model has been implemented in SAS and data on the format used by the MSVPA can now be calculated for the whole North Sea area or by combinations of ICES roundfish areas. Details concerning the methodology are given in Annex H

The estimation of variance using the bootstrap technique has been initiated. The bootstrapping technique will be used as a first attempt for estimation of the distribution of the relative stomach contents. Such an exercise requires a full implementation of all manipulations done for the aggregation of the individual samples. The aggregation method used previously for the calculation of the North Sea MSVPA stomach data are briefly described in ICES (1997), and has previously been done by RIVO.

References: ICES 1997. Database report of the stomach sampling project 1991. ICES Coop. Res. Rep. No. 219.

Deliverables

D4.1.1: Age- and size-dependent growth and predation mortality for cod, capelin and juvenile herring in the Barents Sea. Q9

D4.1.2: Distribution of cod, capelin and juvenile herring in the Barents Sea. Q9

D4.1.3: Estimates of cod's consumption of capelin and herring related to prey density, stock overlap and physical factors. Q9

D4.1.4: Estimation of the distribution or the variance of the relative stomach contents. Q9

D4.1.5: Final vital statistics to Gadget: Q12

Milestones and expected results

This is work towards milestones M3 and M5.

4.2 Workpackage: Spatio-temporal scales

Start date or starting event: January, 2003

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1, 3, 4, 7

Total planned person-months per partner: 1(6), 3(10), 4(6), 7(10.8)

Person-months completed to date (estimate): 1(0), 3(1.3), 4(0), 7()

Time to completion of workpackage (current estimate): 36

Objectives

To investigate the adequate spatial and temporal scales to be used in Gadget.

To explore the importance of spatial inhomogeneity for the assessments North Sea fish stocks.

To identify the extent of the spatial and temporal distribution of species within the Celtic Sea.

Description of work conducted to date

This workpackage is not due to start until 2003.

MRI (1):

Work has not started on this workpackage.

DIFRES (3):
The MSVPA and MSFOR algorithms have been used to explore the importance of spatial inhomogeneity for the assessments of North Sea fish stock. However, a full spatially disaggregated MSVPA is not technically possible, and a more simple approach was applied. Results for the traditional one-area MSVPA was combined with quarterly data on stock distribution data (IBTS data) by ICES Roundfish Area, spatial disaggregated catch (STCF database) and stomach contents data (task 4.1.) to estimate local food suitability coefficients and fishing mortalities (see Annex H for details). These values can then be used in a multispecies catch projections (MSFOR) for evaluation the importance of spatial inhomogeneity.

For the North Sea 1991 is the only year for which all the type of data mentioned are available. The method described has been applied to the division of the North Sea in two are sub-areas, a northern and a southern part. The method seems to work properly and the estimated fishing mortalities by sub-area were reasonable, except for a few cases where the STCF catches were taken in a sub-area with no fish (according to the IBTS). No further analysis of local fishing mortality or food suitabilities have been done.

CEFAS (7):
Considered long-term temporal patterns of species abundance in survey data and commercial landings data. Drafted paper intended for publication in Journal of Applied Ecology: The effects of exploitation and environmental change on the trophic structure of the Celtic Sea fish community Annex J.

Deliverables

D4.2.1: Effects of different levels of disaggregation in Gadget. Q14

D4.2.2: Quantification of the importance for fish stock assessment of spatial disaggregation. Q14

D4.2.3: Estimation of the distribution or the variance of the relative stomach contents. Q14

D4.2.4: Estimates of biological parameters required as inputs to WP 5.2. Q10

Milestones and expected results

This is a part of the work towards several milestones (M3-M6).

4.3 Workpackage: Reference points

Start date or starting event: January, 2002

N^o of the partner responsible: 3

N^{o}s of other partners involved: 1, 2

Total planned person-months per partner: 1(6), 2(3), 3(12)

Person-months completed to date (estimate): 1(0), 2(0), 3(5)

Time to completion of workpackage (current estimate): 48

Objectives

To develop multispecies biological reference points

To indicate how medium-term simulations can be conducted in Gadget

Description of work conducted to date

This workpackage is due to start in 2002.

IMR
So far, no work directed towards dst2 has been done by IMR.

DIFRES
In order to identify reference points that might be useful in a multispecies context for the North Sea the response of a suite of biological reference points for Baltic cod and sprat to observed changes in natural mortality and growth have been examined. The work is described in Annex I The Baltic ecosystem is much simpler than the North Sea ecosystem. In the Baltic cod, herring and sprat dominate the fish fauna. Cod is the most important fish predator and sprat is an important prey for cod. Large changes in the biomass of cod and sprat have occurred in the Baltic over the last 25 years with resulting changes in natural mortality and growth.

The results show that biological reference points in general were much more sensitive to changes in natural mortality than to growth variation. For Baltic cod reference points based on per recruit calculations such as $F_{0.1}$ and $F_{40\%}$ were thus relatively insensitive to changes in growth. For sprat, a prey species, reference levels for fishing mortality were sensitive to changes in natural mortality caused by changes in cod abundance. Cod is a cannibalistic species, and for cod itself it is possible to subsume cannibalism in the stock recruitment relationship provided the resulting mortality on young cod depends only on the abundance of older cod. In this situation a conservative level of fishing mortality that will prevent growth overfishing and ensure stock replacement can be identified. However, cannibalism is likely also to depend on the abundance of alternative prey. If the abundance of alternative prey changes cannibalism might change as well and this will affect the biological reference points for cod.

In general the biological reference points based on stock recruitment data (F_{high}, F_{med}, F_{low}) or stock recruitment relationships (F_{loss}, F_{msy}) would be adjusted in a conservative direction in response to changes in predation and growth. The reference levels for fishing mortality would thus decrease with lower growth and higher predation rates. In contrast the reference points based only on per recruit calculations (eg $F_{0.1}$ and $F_4 0\%$) would be adjusted in a risky direction with changes in growth and predation. Increases in predation or decreases in growth would thus result in an increase in the reference level of fishing mortality. For prey populations it seems therefore appropriate to condition the reference levels for fishing mortality on predator abundance, for instance by defining an upper level of total mortality.

Deliverables

D4.3.1: Definition of multispecies reference points for North Sea fisheries and sustainable multi fleet fisheries. Q12

Milestones and expected results

Results from this task include multispecies reference points and proposals on how to conduct medium-term simulations from Gadget.

5 Workpackage group: Case studies

5.1 Workpackage: Case study: Icelandic waters

Start date or starting event: July, 2001

N^o of the partner responsible: 1

N^{o}s of other partners involved:

Total planned person-months per partner: 1(96)

Person-months completed to date (estimate): 1(1)

Time to completion of workpackage (current estimate): 36

Objectives

To implement prototype models for Icelandic waters, based on a common program base and the data warehouse for the region.

Description of work conducted to date

MRI (1):
Prototype datasets have been generated as a part of Workpackage group 1 and prototype model runs are being developed.

Deliverables

D5.1.1. Prototype data sets for the area around Iceland. Q6

D5.1.2. Prototype model run. Q7

D5.1.3. Proposed generic model improvements (to be programmed in workpackage 3). Q9

D5.1.4. Prototype data warehouse with data for this case study based on definitions in workpackage 1. Q9

D5.1.5. Adopted model run on adopted data set: Proposed model explains data adequately. Q16

D5.1.6. Answers to case study questions: Hypothesis tests conducted with Gadget and have obtained directions on importance of complexity in models. Q16

Milestones and expected results

This workpackage is a part of the work towards milestones M4, M5 and M6.

5.2 Workpackage: Case study: Celtic Sea

Start date or starting event: July, 2001

N^o of the partner responsible: 8

N^{o}s of other partners involved: 7

Total planned person-months per partner: 7(11), 8(15)

Person-months completed to date (estimate): 7(), 8(3)

Time to completion of workpackage (current estimate): 36

Objectives

To implement models for selected species in the Celtic Sea that incorporate both spatial and temporal information on the stocks.

To validate model system components and incorporate into a prototype system for the evaluation of closed areas.

To consider management parameters such as total biomass by area, spawning stock biomass (SSB) by area, and catch by metier by area.

Description of work conducted to date

CEFAS (7):
Gathered database of stomach contents data for Celtic Sea fish, and considered how species might be divided into functional groups for the purpose of modelling, on the basis of Bray-Curtis similarity coefficients and hierarchical agglomerative clustering.

Started constructing preliminary Ecopath food-web model of the Celtic Sea and assimilating groundfish survey data, diet data and fishery data. Also started gathering data on growth parameters and locating possible sources of benthos data. Plan to evaluate the effect of aggregating or disaggregating different model components, and/or isolating individual target species. Considered whether fishery target species are also ecologically important species.

Considered relationship between fish size and trophic level in Celtic Sea and North Sea fish Annex J.

Deliverables

D5.2.1. Prototype data sets for the area. Q6

D5.2.2 Adopted model run for each species based upon agreement with existing historical data and knowledge of the fishery. Q16

D5.2.2 Comparison of externally estimated parameters with values obtained using the GADGET modelling approach. Any difference in the estimates obtained to be explored. Q12

D5.2.3 Comparative evaluation of simple model approach (single species) and complex model approach (multi-species). Q14

Milestones and expected results

This workpackage is a part of the work towards milestones M4, M5 and M6.

5.3 Workpackage: Case study: North Sea herring

Start date or starting event: Completion of North Sea Herring components of the Data Warehouse.

N^o of the partner responsible: 6

N^{o}s of other partners involved:

Total planned person-months per partner: 6 (50)

Person-months completed to date (estimate): 6(0)

Time to completion of workpackage (current estimate): 36

Objectives

To implement prototype models for North Sea herring, based on a common program base and a data warehouse for the area and species in question, and to investigate the appropriateness of current short- and medium-term management approaches.

Description of work conducted to date

This workpackage is not due to start until mid-year 2001 when prototype runs are due to start.

Deliverables

D5.3.1. Prototype model run. Q7

D5.3.2. Proposed generic Improvements (to be programmed in WP 3). Q9

D5.3.3. Adopted model run on adopted data where the model explains data adequately. Q16

D5.3.4. Evaluations of key project objectives for case study:

D5.3.4.1.Validation of conventional estimates of stock size and exploitation rates using the 'gadget' modelling approach, and exploration of main points of difference. Q16

D5.3.4.2. Comparative evaluation of complex-model and simple-model approaches to estimating short-term catch forecasts and stock sizes. Q16

D5.3.4.3. Validation of existing management approaches for North Sea herring. Q16

Milestones and expected results

This workpackage is a part of the work towards milestones M4, M5 and M6.

A Celtic Sea Data

A.1 Description of the French groundfish survey (EVOHE)

The French ground fish survey in the Celtic Sea (ICES divisions VIIf,g,h,j) and Bay of Biscay (ICES divisions VIIIa,b) (EVHOE) is conducted annually in October-November. The research vessel RV Thalassa (74 m and 2200 kW) is in operation since 1997.

Since 1997 the objectives of this survey are

- to determine the distribution and relative abundance of all fish species and selected species of shellfish within the survey area, particularly those of commercial importance;
- to determine the distribution and abundance of pre-recruits of the main commercial species to derive recruitment indices;
- to monitor changes in the populations of commercially important species independent of commercial fisheries data and to monitor changes in species which are currently not of commercial importance;
- to collect data for the determination of biological parameters.

Survey design

The survey area is stratified according to latitude and depth. Three geographical areas are identified in the Celtic Sea and five depth zones are used (31-80, 51-120, 121-160, 161-200 and 201-400 m). The ten strata are divided into units of 25 square nautical miles. Stratified random sampling of these units is used. Overall 85 hauls are carried out. Hauls positions are extracted from a database of clear tows from French, English and Dutch surveys in the Celtic Sea.

Technical set up

A 36/47 GOV trawl is used with a 20 mm mesh codend liner and a ground rope with 10-20 cm rubber discs. Plane oval trawl doors of 1300 kg are used. Gear geometry is monitored using Scanmar. Haul duration is 30 minutes and towing speed 4 knots. Fishing is mainly restricted to daylight hours. No Exocet kite is used but additional floats have been added instead. Average horizontal gear opening is 20 m and 4.1 m vertical opening.

Biological sampling

The whole catch of all hauls is sorted by species. A certain number of fish are measured for all species. The number measured is adjusted to ensure good coverage of the whole length range. Ageing is carried out for a selection of species. For ageing the following sampling schemes are used for each haul.

whiting	1/10 per sex
megrim	1 individual per cm length class per sex and up to 6/cm for the whole area (bay of Biscay and Celtic Sea)
cod	all individuals
angler fish	all individuals
hake	1 individual per cm length class per sex and up to 8/cm for each area (bay of Biscay and Celtic Sea)
Ling	all individuals
Pollack	all individuals

Raw data tables

Table 1: Haul information (Station_EVOHE):

Name	Type(ACCESS)	Commentaires
Survey	text(6)	
Vessel	text(10)	
Day	octet	
Month	octet	
Year	text(4)	
Statistical rectangle	text(10)	
Stratum	text(3)	
Station name	**text(5)**	**Key**
CAPTOT	real	Total catch in kg
HF	text(5)	Time at beginning of haul
SONDF	integer	Depth at beginning
LATF	text(10)	Latitude at beginning
LATFDD	Real	latitude at beginning (in decimal degrees)
LGF	text(10)	longitude at beginning
LGFDD	Real	longitude at beginning (in decimal degrees)
HV	text(5)	Time at end of haul
SONDV	integer	Depth at end
LATV	text(10)	Latitude at end
LGV	text(10)	Longitude at end
LATVDD	Real	latitude at end (in decimal degrees)
LGVDD	Real	Longitude at end (in decimal degrees)
TYPECHAL	Text (12)	Trawl type
LFUNE	integer	Length of cable in m
VMAX	Real	Maximum speed (knots)
VMIN	Real	Minimum speed (knots)
OUVV	Real	Vertical trawl opening
OUVA	Real	Distance between wings
OUVP	Real	
LGB	integer	
MINF	integer	
MAXF	integer	
CAP	real	Cruising direction in degree
VCHALF	real	Over ground tralw speed
VBATF	real	
DIRVENT	integer	Wind direction
VENT	real	Wind speed m/s.

Table 2: Total catch data(CAPTURES_TOTALES_parSEXE):

Name	Type (ACCESS)	Comments
Id_Capt	**integer long**	**Key**
Station	text(5)	eg.: B0988 or B1236
Codend liner	text(4)	-999 for missing values, 1 = none
Genus	text(4)	
Species	text(3)	
Sex	text(1)	M(male),F(female),N(no specified),U(unknown)
Weight	real	Weight in kg
Number	integer	Count or estimate for large numbers

Table 3: Length measurements (MENS_CM):

Name	Type(ACCESS)	Comment
Id_Mens	**integer long**	**Key**
Strata	text(4)	Geographic strata (eg.: Cc3)
Station	text(5)	Unique station number (eg.:D0904)
Genus	text(4)	(e.g.: SARD)
Species	text(3)	(e.g.: PIL)
Sex	text(1)	M(male), F(female), N(not specified), U(unknown)
Length	real	Length in cm (lower cm)
Number	real	Number of individuals

Age readings

CTD data

References

Borges et al. (1999). Sesits Projet. Evaluation of demersal resources of Southwestern europe from standardised groundfish surveys. DG XIV Study contract 96-029.

A.2 Description of port sampling program for French Celtic sea fisheries (Arpège)

Sampling design

The following gives a description of the port sampling scheme used. Sampling is stratified by metier. Each metier is sampled in a specific harbour. In general, one box per market category is measured.

Note that in 1992 there was a change in market categories (EEC categories).

Species	**stock area (ICES areas)**	**type of measurements**	**Sampling design**	**Comment**
cod	VIIe-k	length age	1 trip of a demersal trawler from Lorient per month. 1 trip of a nephrops trawler, alternatively from St Guénolé and Loctudy, per month.	
hake	northern	length age	1 trip of a demersal trawler from Les Sables d'Olonne per month. 1 trip of a demersal trawler from La Rochelle per month.	Age readings are OK for first groups only. Samples from Celtic Sea and Bay of Biscay should be used together
megrim	VIIe-k	length age sex	1 trip of a benthic trawler from Concarneau per month.	
monkfish	VIIb-k	length age (dorsal radius)	1 trip of a large boat from Concarneau per month. 1 trip of a small boat from Concarneau per month.	there is a continuum between the Celtic Sea stock and the Bay of Biscay stock.
nephrops	VIIb,c,j,k	length sex	1 trip of a nephrops trawler from Concarneau per month. 1 trip of a nephrops trawler alternatively in St Guénolé and Loctudy per month.	
whiting	VIIe-k	length age	1 trip of a demersal trawler from Lorient per month. 1 trip of a nephrops trawler, alternatively from St Guénolé and Loctudy, per month.	

Raw data tables

Table 1: Sample data (unite_echantillonnée):

Name	ACCESS	Comments
IDNS_UNITE_ECHANT	**integer long**	**Sample identification number, key**
C_SECTEUR_PECHE	Text(3)	fishing area
C_ESPECE_STAT	integer	Species code (IFREMER)
AN_UNITE	integer	year
MOIS_UNITE	octet	month
JOUR_UNITE	octet	day
TRIMESTRE	octet	quarter
C_SECTEUR_CIEM	text(6)	ICES areas
C_ENGIN	integer	gear code
C_NAVIRE	integer long	vessel number
C_LIEU	text(3)	sampling port code
C_CAT_LOC	text(2) Null	commercial category (harbour specific)
C_CAT_TER	text(3)	local commercial categories (subdivisions)
C_ETAT	text(2)	code for state (1=fresh)
C_PRESENTATION	text(4)	code for presentation (emptied or whole)
FACTEUR_ELEVATION	real	raising factor
IND_TRI_PATRON	text(1)	indicator for boat specific categories (1=yes; 0=no)
PDS_ELEVATION	real	weight for raising sample (-999=missing)

Table 2: Sample data (cptage_unite)

Name	ACCESS	Comments
ID_CPTAGE	**integer long**	**identification number, key**
IDNS_UNITE_ECHANT	integer long	identification of the sampling unit
C_TAXON	text(7)	species code
C_SEXE	text(1)	sex (M=male ,F=femelle,N=not sexed)
BORNE_INF	real	lower bound of length class
NB_IND_CLASSE_UE	integer long	number of individuals

Table 3: Sample unit (box) weight (poids_unite)

Name	ACCESS	Comments
IDNS_UNITE_ECHANT	**integer long**	**identifiant unique d'une unité**
C_TAXON	**text(7)**	**species code**
C_SEXE	**text(1)**	**sex**
PDS_CALCULE	real	calculated weight of sampling unit
PDS_OBSERVE	real	observed weight of sampling unit
PDS_UTILISE	real	weight used for raising of sample(calculated or observed weight multiplied to give weight of unemptied individual)

Lookup tables

Table 4: ICES areas (div_ciem)

Name	ACCESS	Comments
ID_SECT	**integer long**	**key**
C_SECTEUR_PECHE	text(3)	fishing sector
C_SECTEUR_CIEM	text(6)	ICES sector

Table 5: Weight-Length relationship (relat_taille_poids)

Name	ACCESS	Comments
C_SECTEUR_PECHE	**text(3)**	**fishing sector**
C_ESPECE_STAT	**integer long**	**species number**
ANNEE	**integer long**	**year**
C_TAXON	**text(7)**	**taxon**
C_SEXE	**text(1)**	**sex**
NO_TRIMESTRE	**octet**	**quarter**
PARAM_A_RELAT	real simple	parameter a
PARAM_B_RELAT	real simple	parameter b
L_ORIG_RELAT	text(80)	data source

References

Goudou, O., Garren, F., Battaglia, A., Moguedet, P. (2001). Providing a framework to improve the assessment of the main demersal and pelagic fisheries in Western European Waters (FIEFA). Interim report. EU Study contract 97-0059.

A.3 Description French landings and logbook data

Logbook and landings data for French fishermen operating in the Celtic Sea (ICES area VII except VIId) for the years 1991-1998. The data for the 30 most important (in weight) species are provided.

Raw data tables
all data have been stored in a data base (ACESS). Names in brackets give the table names.

Table 1: Basic trip data (marees)

Name	ACCESS	Comment
IDNS_MAREE	**Long integer**	**identifier for trip**
C_NAVIRE	integer long	number for main vessel
AN_DEPART	integer	year (start of trip)
MOIS_DEPART	Small integer	month (start of trip)
JOUR_DEPART	Small integer	day (start of trip)
C_PAYS_MAREE	integer	country code for sale (250= France)
C_TYP_LIEU_MAREE	text (1)	type of sale (C=fish auction)
C_LIEU_MAREE	text(3)	town of sale
AN_RETOUR	integer	year (end of trip)
MOIS_RETOUR	small integer	month (end of trip)
JOUR_RETOUR	small integer	day (end of trip)
INDIC_RGPT_MAREE	text (1)	indicator for grouped trips = O (yes) or N (no)
NB_MAREES_RGPEES	integer	number trip that have been grouped
DUREE_TOTALE	real	total trip time in hours (transit + fishing time)
TPS_PECHE_TOTAL	integer	total fishing time in hours
INDIC_RGPT_NAVIRE	texte (1)	indicator for grouped vessels = O (yes) or N (no)
NB_NAVIRES_RGPES	small integer	number of grouped vessels

Fishing sequences (sequences_peche)
A fishing sequence is defined by the fishing gear used and the ICES rectangle the operation takes place in. If either of them change, a new sequence starts. Hence each fishing trip consists of one or more sequences.

Table 2: Fishing sequences (sequences_peche)

Name	ACCESS	Comment
IDNS_MAREE	Integer long	trip identifier
IDNS_SEQPEC	**Integer long**	**identifier for sequence**
C_ENGIN	text (3),	gear type
C_SECTEUR_CIEM	text (6),	ICES sector, empty if statistical rectangle known
C_SECTEUR_PERE	text (6)	ICES sector, empty if statistical rectangle unknown
C_LATITUDE	small integer	latitude of statistical rectangle
C_LONGITUDE	text (2)	longitude of statistical rectangle
C_DECOUPAGE	text (2)	IFREMER specific area
TPS_PECHE_SEQUENCE	integer	fishing duration in hours for fishing sequence

Table 3: Estimated catch per fishing sequence (esti)

Name	ACCESS	Comment
ID_ESTI	**long integer**	**identifier, key**
IDNS_MAREE	long integer	trip identifier
IDNS_SEQPEC	long integer	fishing sequence identifier
IDNS_ESPECH	long integer	identifier
C_ESPECE_STAT	long integer	species code
ESTIMAT_CAPTURE	real	proportion of total catch taken in given sequence

Associated fishing vessels (navass)
The fishing vessel given in 'marees' table can be accompanied by other vessel which are identified in this table.

Table 4: Associated fishing vessels (navass)

Name	ACCESS	Comment
IDNS_MAREE	**Long integer**	**trip identifier**
C_NAVIRE	**Long integer**	**identifier of associated vessel**

Table 5: Basic sales data (ventes)

Names	ACCESS	Comment
IDNS_MAREE	long integer	trip identifier
IDNS_VENTE	**long integer**	**sales identifier, key**
AN_VENTE	Integer	year of sale
MOIS_VENTE	Small integer	month of sale
JOUR_VENTE	Small integer	day of sale
C_PAYS_VENTE	Integer	country code
C_TYP_LIEU_VENTE	text (1)	type of sale (C=auction)
C_LIEU_VENTE	text (3)	place of sale

Table 6: Sales data per species (seqven_nnnn)

Name	ACCESS	Comment
ID_SEQVEN	**long integer**	**identifier, key**
IDNS_VENTE	Long integer	sale identifier
C_ESPECE_STAT	Integer	species code
C_PRESENTATION	text (4)	presentation code
C_CAT_LOC	text (2)	locale commercial category
POIDS	Long integer	weight in 100g (as sold)
MONTANT	Long integer	value in French franc
POIDS_PLEIN	Long integer	weight in 100g (estimated for whole fish if they were sold emptied)

Table 7: Basic vessel data (navst)

Name	ACCESS	Comment
C_NAVIRE	**Long integer**	**number of main vessel**
INDIC_NAV_FICT	texte (4)	indicator whether real vessel
C_TYP_NAVIRE	integer	type CRTS
AN_CONSTRUCTION	integer	year of vessel construction

Table 8: Detailed vessel data (navst)

Name	ACCESS	Comment
ID_NAVCAR	**integer long**	**identifier, key**
C_NAVIRE	long integer	number of main vessel
INDIC_NAV_FICT	text (4)	= Vrai if real vessel, = Fict if not
AN_DEBUT	integer	year of beginning of vessel modifications
MOIS_DEBUT	small integer	month of beginning of vessel modifications
JOUR_DEBUT	small integer	day of beginning of vessel modifications
AN_FIN	integer	year of end of vessel modifications
MOIS_FIN	small integer	month of end of vessel modifications
JOUR_FIN	small integer	day of end of vessel modifications
NOM	text (30)	vessel name
C_QAM	text (2)	immatriculation district
TONNAGE	long integer	gauge brute in 0.01 t
PUISSANCE	integer	power in kw
LONGUEUR	integer	length in cm

Lookup tables

Table 9: Fishing gear

Name	ACCESS	Comment
CODE_ENGIN	**text (3),**	**gear code**
LIBE|l|l|C|E	text (70),	french gear name
DESCRIPTION	text (70),	english gear name

Table 10: Species definitions

Name	ACESS	comment
CODE_ESPECE	**integer**	**species code**
LIBE|l|l|C|E	text (30)	french species name

Table 11: ICES sector

Name	ACCESS	comment
CODE_CIEM	text (6)	ICES sector code
LIBE|l|l|C|E	text (50)	ICES sector name

B Datawarehouse Description

B.1 Web UI working paper

DST2
Data Warehouse (version 1)
Web UI working paper

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Section for Software Development

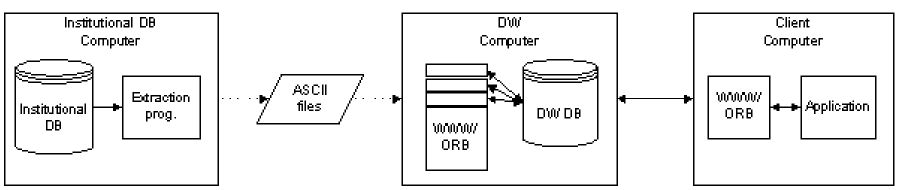
1. Introduction

Version 1.0 of the Dst2 data warehouse is a web-based solution for collecting and storing data for ecosystem modelling. This version is meant as a prototype rather than a final solution. Hence only a basic set of functionality will be provided with this version.

This paper gives a description of the system with emphasis on the user interface. The underlying database structure is described in the paper "Dst2 Database description (version 1)" and format for exchanging data is described in "Dst2 Data exchange format (version 1)".

2. Requirements

The data warehouse should serve both the needs of a database internal to institutions and needs of a data warehouse containing joined data. Access to the DW should be possible both from internal networks and also the Internet. By choosing a web based system both requirements will be fulfilled. In the figure below the basic architecture is outlined.



This model can easily be extended later with the CORBA solution, an email interface and more.

Data are extracted from the institutional DBs with extraction programmes developed by the institutions themselves. This way the institutions are in control their raw data and they decide at which aggregation level their data should presented in the DW.

In the very first version of the DW, a CSV ASCII file format will be used. This format is described in the paper "Dst2 Data exchange format (version 1)".

The one key element of the DST2 DW is the underlying database. The structure of this database should be shared by the three study case DBs:

1. Icelandic water

2. North Sea Herring
3. Celtic Sea

And the structure should also be applicable to other databases. The underlying database structure is described in the paper "Dst2 Database description (version 1)".

From the client side of view both uploading and downloading of data is made through a Web interface using a standard browser (The system will be tested with Microsoft Internet Explorer 5+ and Netscape Navigator 4.7+).

3. Platform and system setup

The web application is developed on an open source platform: Redhat Linux 7.0 running Apache web server version 1.13, Php 4.03 and Postgresql 7.0.

During development the hardware platform is a 266 MHz Pentium 2 with 128Mb of RAM. Test may show if this is sufficient when the system goes into a production environment.

When installing the Dst2 web application, copy the main folder into the servers webfolder, be sure that php extension and postgresql database[1] are installed. Edit php.ini so it contents session_autostart=1.

4. Use Cases

Version 1 of the DW will provide functionality limited to the very basic:

1. A security system, allowing users logging in at different security levels.
2. An administrative function (for administering users and user rights).
3. Data upload function.
4. Data query function.
5. Data download function.

For this version three different groups of users have been identified. Each user group has its own menu and restrictions.

Userlevel 1: Administrator (Full access)
Userlevel 2: Writer (Upload)
Userlevel 3: Reader

[1] For futher infomation see Database documentation

The following diagrams illustrates each user's options.

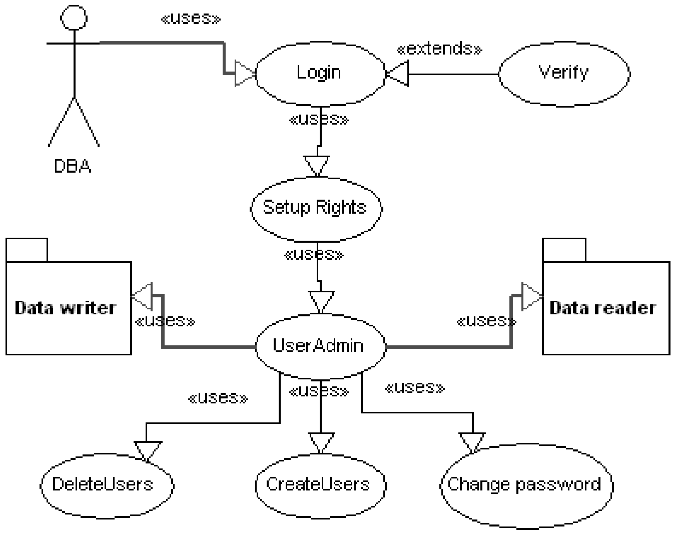


Figure 1: User case for Administrator

The administrator has the same rights as the writer but is also allowed to add, edit and delete users for the system.

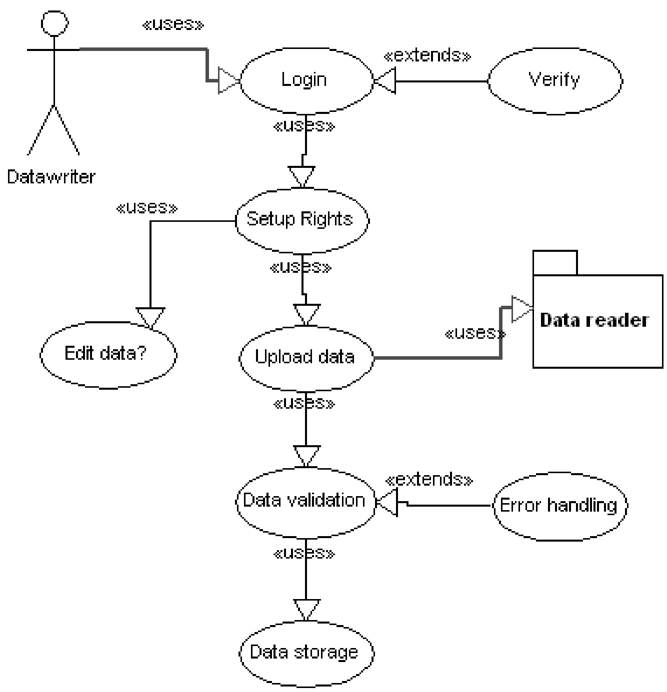


Figure 2: User case for writer

The writer is allowed to upload data and use following sqlcommands:
Select, Update, Insert

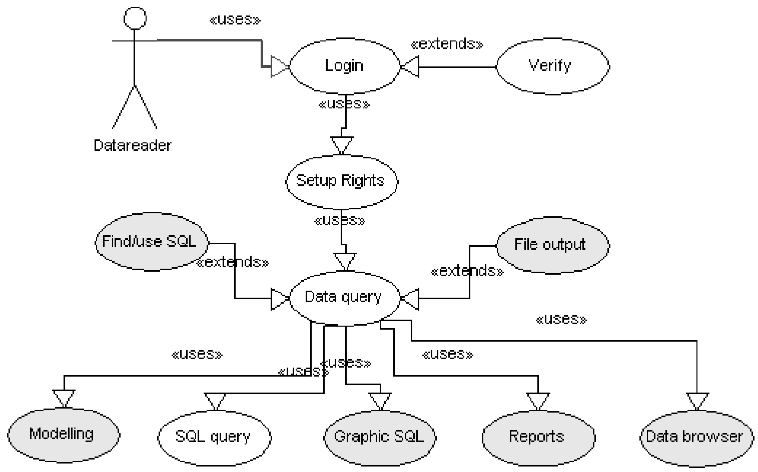


Figure 3: User case for reader (Gray boxes are for later releases)

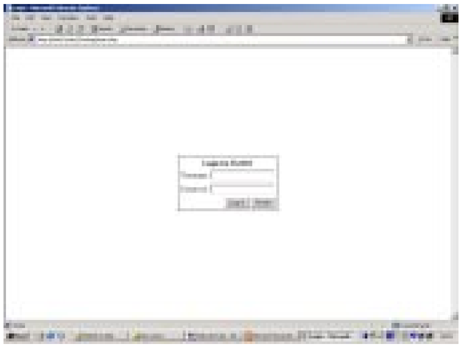
The reader has only the permission to use the select sql-statement .

5. Program organisation

Figure 4: Program organisation for Dst2

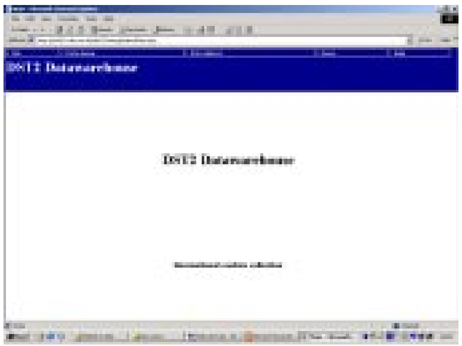
The diagram illustrates the contents of files in the first release. This structure can be modified later if it shows improvement.

6. Wui (Web user interface)



Login

The user type username and password. Comment: Here the user type userId and password then click "login". If the user type "Admin" as UserId with the right password then the user is directed to administration for users.

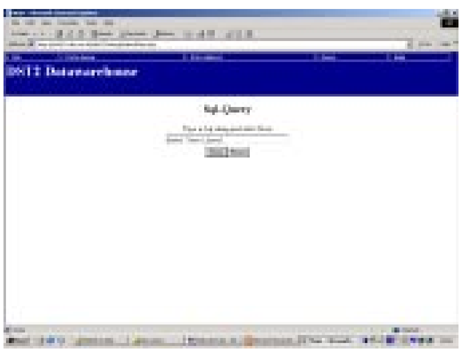


Main

In top users can choose from a menu which fuction is needed.
(Logout, Data Query, Upload[a], Users[b], Help)

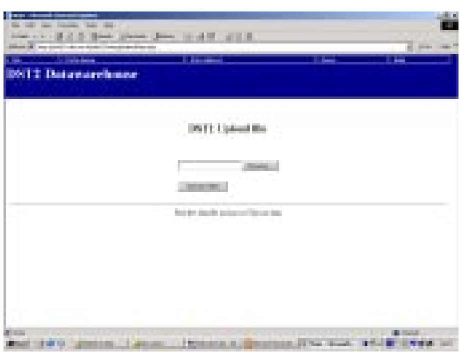
[a] This item is available for Administrators and Writers

[b] This item is only available for Administrators



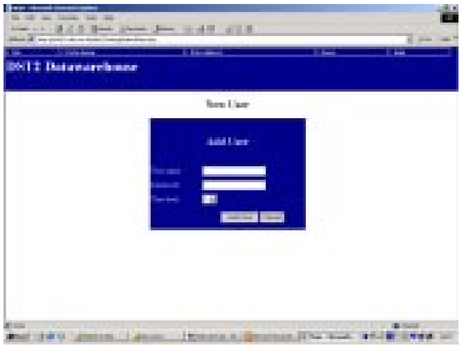
Sql Query (Data Query)

In this dialog the user type in a sql-string and press "show", then a dynamic table is created with the contents.



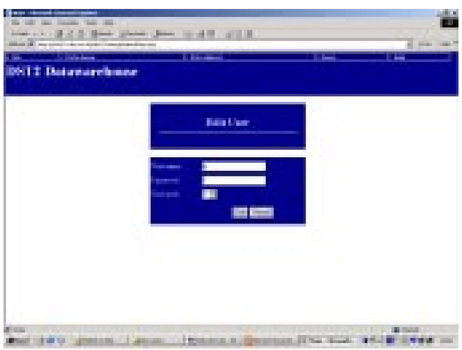
Upload

Here the user can upload a table for the database.
The file is validated so it match in the database.
After the upload a logfile is created with the result.



Add User (Users)
The administrator can here add new users to Dst2 and decide userlevel.

Edit User (Users)
First the administrator choose a user and press edit and press edit. Here after it is possible to change the user's attributes.



Delete User (Users)
If the administrator wants to delete a user then He first chooses one and presses "Delete user".

DST2
Database description (version 1)

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26-02-2001
Danish Institute for Fisheries Research
Department of Information Technology

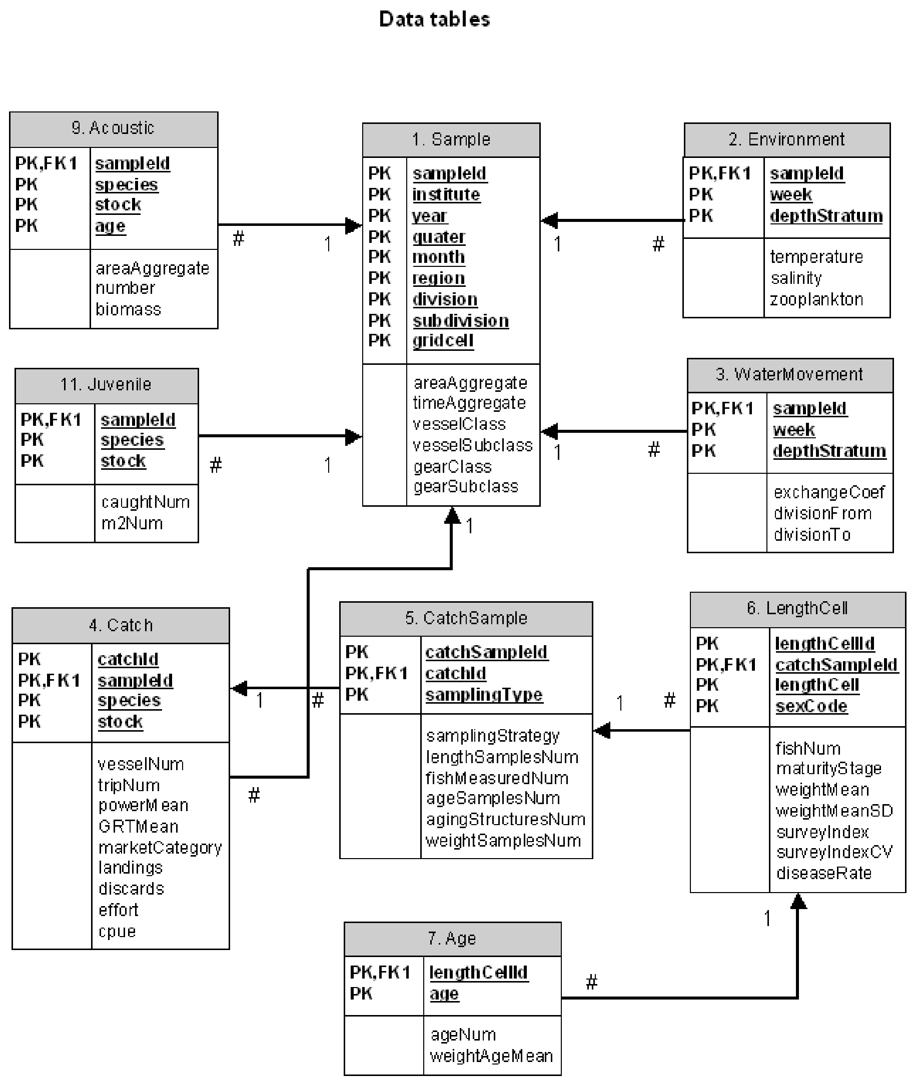
1. Introduction

This database description is based on the draft of DW structure/functionality by Alessandro Gimona (29/08/2000). The tables 1-7 have been normalized in a relational structure. An introduction to normalization is given in appendix 1. The tables 8-11 contains aggregated data not directly related to tables 1-7, and these tables have not been normalized. They are special datawarehouse tables. In order to have consistent data in the tables, many data fields are related to a lookup table which holds the valid codes, a description of the code and eventually other attribute data. The lookup tables are prefixed with L_ .

2. Database structure

The database tables are divided in three groups, the relational data tables (1-7), the additional tables (8-11) and the lookup tables. The tables in the first group do not follow the scheme from the draft exactly because the tables have been normalized. The corresponding table number in the original draft are displayed as a reference.

3. Normalized tables



The arrows means "contained in" or "related to", i.e. for each record in the table Sample there are 1 to many (1..#) records related to this sample record in table Catch. For each Catch record there are 1 to many related records in the table CatchSample and so on. PK stands for Primary Key, for most tables the primary key is composed of several data fields. In order to reduce the amount of redundant primary key data in the tables, the primary key is represented by a virtual primary key. The virtual primary key is the first field in the primary key list for each table. Tables with no tables related to it, do not have a virtual primary key. I.e. the primary key in table Sample is composed by 8 fields, but in the tables witch relates to Sample, the virtual primary key (sampleId) is used as the foreign key instead of the 8 fields. This makes it much easier to manage the data in the database.

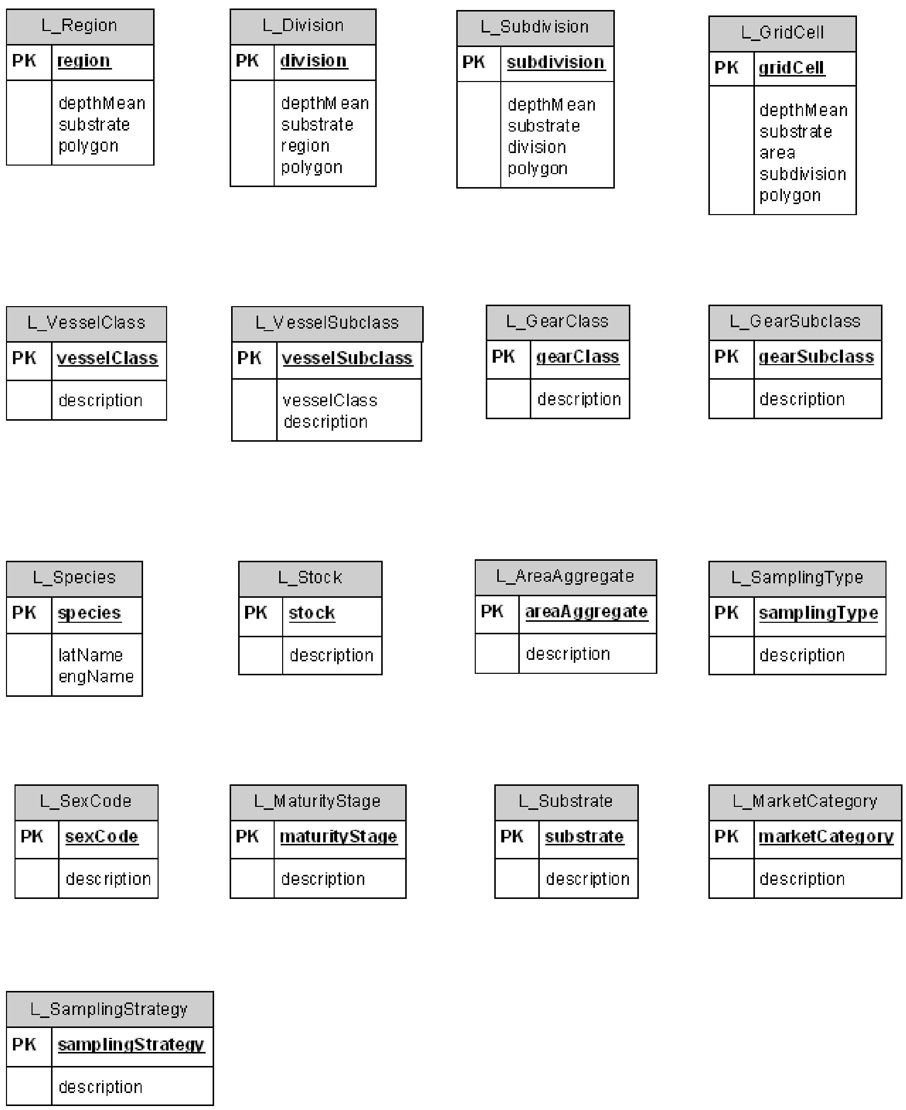
The definition of the primary key sets is essential for the whole database model. In table LengthCell for example there is a field named sexCode. This field must be part of the primary key set because if the sexcode says "male" then the fishnum and weight ect. must be for the male part of the fish in the lengthCell and not for all the fish in the lengthCell. Thus the primary key sets picture the underlying data model.

Other tables

8. AgeGroups	
PK	**institute**
PK	**year**
PK	**region**
PK	**division**
PK	**subdivision**
PK	**gridCell**
PK	**quarter**
PK	**month**
PK	**species**
PK	**stock**
PK	**sexCode**
PK	**age**
PK	**samplingType**
	areaAggregate
	sourceYear
	marketCategory
	vesselClass
	vesselSubclass
	gearClass
	gearSubclass
	maturityStage
	fishMeasuredNum
	fishLengthMean
	fishWeightMean
	surveyIndex
	surveyIndexCV
	catchNum
	stockNum
	diseaseRate

10. Tagging	
PK	**tagLabel**
PK	**species**
PK	**stock**
	yearReleased
	quaterReleased
	monthReleased
	regionReleased
	divisionReleased
	subdivisionReleased
	gridCellReleased
	lengthReleased
	weightReleased
	yearRecaptured
	quarterRecaptured
	monthRecaptured
	regionRecaptured
	divisionRecaptured
	subdivisionRecaptured
	gridCellRecaptured
	lengthRecaptured
	weightRecaptured

Lookup tables



4. Table definitions

The following is an overview of the field definitions, key status and lookup references. For many fields we have no idea of the datatype and string length ect. These fields have been given the datatype C(10) for the moment.

Table 1: Sample

field	description	datatype	key	lookup table
sampleId	virtual primary key	long	VPK	
institute	sampling institute	C(10)	PK	
year	sampling year	integer	PK	
quarter	sampling quarter	integer	PK	
month	sampling month	integer	PK	
region	region	C(10)	PK	L_Region
division	division	C(10)	PK	L_Division
subdivision	subdivision	C(10)	PK	L_Subdivision
gridCell	gridCell or subsubDivision	C(10)	PK	L_GridCell
areaAggregate	space aggregate code	C(10)		L_AreaAggregate
timeAggregate	time aggregate code	integer		
vesselClass	vessel class	C(10)		L_VesselClass
vesselSubclass	vessel subclass	C(10)		L_VesselSubclass
gearClass	gear class	C(10)		L_GearClass
gearSubclass	gear subclass	C(10)		L_GearSubclass

Table 2: Environment

field	description	datatype	key	lookup table
sampleId	foreign key from Sample	long	PK, FK	
depthStratum	depth stratum	double	PK	
week	week number	integer	PK	
temperature	temperature in Celsius	double		
salinity	salinity scale	double		
zooplankton	zoop. mg dry weight/m3	double		

Table 3: Water movement

field	description	datatype	key	lookup table
sampleId	foreign key from Sample	long	PK, FK	
depthStratum	depth stratum	double	PK	
week	week number	integer	PK	
exchangeCoef	exchange coefficient	double		
divisionFrom	from division	C(10)		L_Division
divisionTo	to division	C(10)		L_Division

Table 4: Catch

field	description	datatype	key	lookup table
catchId	virtual primary key	long	VPK	
sampleId	foreign key from Sample	long	PK, FK	
species	species code	C(10)	PK	L_Species
stock	fish stock code	C(10)	PK	L_Stock
vesselNum	number of vessels	integer		
tripNum	number of trips	integer		
powerMean	mean power of vessel, KW	integer		
GRTMean	mean GRT	integer		
marketCategory	EU market category	C(10)		L_MarketCategory
landings	fish landings in kg	long		
discards	fish discards in kg	long		
effort	fish effort in hours	long		
CPUE	CPUE in tons/hr	double		

Table 5: CatchSample

field	description	datatype	key	lookup table
catchSampleId	virtual primary key	long	VPK	
catchId	foreign key from Catch	long	PK, FK	
samplingType	type of sampling	C(10)	PK	L_SamplingType
samplingStrategy	sampling strategy	C(10)		L_SamplingStrategy
lengthSamplesNum	number of length samples	long		
fishMeasuredNum	number of measured fish	long		
ageSamplesNum	number of age samples	long		
agingStructuresNum	number of aging structures	long		
weightSamplesNum	number of weight samples	long		

Table 6: LengthCell

field	description	datatype	key	lookup table
lengthCellId	virtual primary key	long	VPK	
catchSampleId	FK from CatchSample	long	PK, FK	
lengthCell	the length cell	integer	PK	
sexCode	sex code for fish	C(10)	PK	L_SexCode
fishNum	number of fish	long		
maturityStage	maturity stage	C(10)		L_MaturiryStage
weightMean	mean weight	double		
weightMeanSD	SD of mean weight	double		
surveyIndex	survey index	double		
surveyIndexCV	CV of survey index	double		
diseaseRate	disease rate	double		

Table 7: Age

field	description	datatype	key	lookup table
lengthCellId	FK from LengthCell	long	PK, FK	
age	age of fish (year)	integer	PK	
ageNum	number of fish	long		
weightAgeMean	mean weight of fish	double		

Agegroups: We suppose that this is an aggregated view of the content of the DB (or a DW output file), not a table related to the other tables. Please indicate whether our assumption is true or not.

Table 8: AgeGroups

field	description	datatype	key	lookup table
institute	sampling institute	C(10)	PK	
year	sampling year	integer	PK	
quarter	sampling quarter	integer	PK	
month	sampling month	integer	PK	
region	region	C(10)	PK	L_Region
division	division	C(10)	PK	L_Division
subdivision	subdivision	C(10)	PK	L_Subdivision
gridCell	gridCell or subsubDivision	C(10)	PK	L_GridCell
species	species code	C(10)	PK	L_Species
stock	fish stock code	C(10)	PK	L_Stock
sexCode	sex code for fish	C(10)	PK	L_SexCode
age	age of fish (year)	integer	PK	
samplingType	type of sampling	C(10)	PK	L_SamplingType
areaAggregate	space aggregate code	C(10)		L_AreaAggregate
sourceYear	source year	integer		
marketCategory	EU market category	C(10)		L_MarketCategory
vesselClass	vessel class	C(10)		L_VesselClass
vesselSubclass	vessel subclass	C(10)		L_VesselSubclass
gearClass	gear class	C(10)		L_GearClass
gearSubclass	gear subclass	C(10)		L_GearSubclass
maturityStage	maturity stage	C(10)		L_MaturiryStage
fishMeasuredNum	number of measured fish	long		
fishLengthMean	mean length of fish	double		
fishWeightMean	mean weight of fish	double		
surveyIndex	survey index	double		
surveyIndexCV	CV of survey index	double		
catchNum	number of fish in catch	long		
stockNumAge	num.of fish in stock at age	long		
diseaseRate	disease rate	double		

Acoustic: We assume that this is an input file to the DB, and propose that it will be linked to the Sample table in the same way as the Catch table.

Table 9: Acoustic

field	description	datatype	key	lookup table
sampleId	foreign key from Sample	long	PK, FK	
species	species code	C(10)	PK	L_Species
stock	fish stock code	C(10)	PK	L_Stock
age	age of fish	long	PK	
areaAggregate	space aggregate code	C(10)		L_AreaAggregate
number	number of fish	long		
biomass	biomass of fish	double		

Tagging: We assume that the Tagging tabel must include other information like species, stock, lenghtReleased, lenghtRecaptured, weightReleased, weightRecaptured, or other information on the condition of the animal. Please indicate whether this is true or not.

Table 10: Tagging

field	description	datatype	key	lookup table
tagLabel	tag label	C(10)	PK	
species	species code	C(10)	PK	L_Species
stock	fish stock code	C(10)	PK	L_Stock
yearReleased	year released	integer		
quarterReleased	quarter released	integer		
monthReleased	month released	integer		
regionReleased	region released	C(10)		L_Region
divisionReleased	division released	C(10)		L_Division
subdivisionReleased	subdivision released	C(10)		L_Subdivision
gridCellReleased	gridCell released	C(10)		L_GridCell
lenghtReleased	length released	double		
weightReleased	weight released	double		
yearRecaptured	year recaptured	integer		
quarterRecaptured	quarter recaptured	integer		
monthRecaptured	month recaptured	integer		
regionRecaptured	region recaptured	C(10)		L_Region
divisionRecaptured	division recaptured	C(10)		L_Division
subdivisionRecaptur	subdivision recaptured	C(10)		L_Subdivision
gridCellRecaptured	gridCell recaptured	C(10)		L_GridCell
lenghtRecaptured	length recaptured	double		
weightRecaptured	weight recaptured	double		

Juvenile: We assume that this is an input file to the DB, and propose that it will be linked to the Sample table in the same way as the Catch table

Table 11: Juvenile

field	description	datatype	key	lookup table
sampleId	foreign key from Sample	long	PK, FK	
species	species code	C(10)	PK	L_Species
stock	fish stock code	C(10)	PK	L_Stock
areaAggregate	space aggregate code	C(10)		L_AreaAggregate
caughtNum	number of caught juvenile	long		
m2Num	number per m2	long		

Table 12: L_AreaAggregate

field	description	datatype	key	lookup table
areaAggregate	space aggregate code	C(10)	PK	
description	description of code	C(80)		

Table 13: L_Division

field	description	datatype	key	lookup table
division	division	C(10)	PK	
depthMean	mean depth to bottom	double		
substrate	substrate type	C(10)		L_Substrate
polygon	polygon of Division	polygon (build in type)		
region	region of division	C(10)		L_Region

Table 14: L_GearClass

field	description	datatype	key	lookup table
gearClass	gear class code	C(10)	PK	
description	description of code	C(80)		

Table 15: L_GearSubclass

field	description	datatype	key	lookup table
gearSubclass	gear subclass code	C(10)	PK	
gearClass	gear class	C(10)		L_GearClass
description	description of code	C(80)		

Table 16: L_GridCell

field	description	datatype	key	lookup table
gridCell	gridCell code	C(10)	PK	
depthMean	mean depth to bottom	double		
substrate	substrate type	C(10)		L_Substrate
area	area of gridCell	double		
polygon	polygon of gridCell	polygon (build in type)		
subdivision	subdivision of gridCell	C(10)		L_Subdivision

Table 17: L_MarketCategory

field	description	datatype	key	lookup table
marketCategory	EU market category	C(10)	PK	
description	description of code	C(80)		

Table 18: L_MaturityStage

field	description	datatype	key	lookup table
maturityStage	maturity stage	C(10)	PK	
description	description of code	C(80)		

Table 19: L_Region

field	description	datatype	key	lookup table
region	region	C(10)	PK	
depthMean	mean depth to bottom	double		
substrate	substrate type	C(10)		L_Substrate
polygon	polygon of Region	polygon (build in type)		

Table 20: L_SamplingStrategy

field	description	datatype	key	lookup table
samplingStrategy	sampling strategy	C(10)	PK	
description	description of code	C(80)		

Table 21: L_SamplingType

field	description	datatype	key	lookup table
samplingType	type of sampling	C(10)	PK	
description	description of code	C(80)		

Table 22: L_SexCode

field	description	datatype	key	lookup table
sexCode	sex code	C(10)	PK	
description	description of code	C(80)		

Table 23: L_Species

field	description	datatype	key	lookup table
species	species code	C(10)	PK	
latName	latin name	C(80)		
engName	english name	C(80)		

Table 24: L_Stock

field	description	datatype	key	lookup table
stock	fish stock code	C(10)	PK	
description	description of code	C(80)		

Table 25: L_Subdivision

field	description	datatype	key	lookup table
subdivision	subdivision	C(10)	PK	
depthMean	mean depth to bottom	double		
substrate	substrate type	C(10)		L_Substrate
polygon	polygon of SubDivision	polygon (build in type)		
division	division of subdivision	C(10)		L_Division

Table 26: L_Substrate

field	description	datatype	key	lookup table
substrate	survey index	C(10)	PK	
description	description of code	C(80)		

Table 27: L_VesselClass

field	description	datatype	key	lookup table
vesselClass	vesselClass code	C(10)	PK	
description	description of code	C(80)		

Table 28: L_VesselSubclass

field	description	datatype	key	lookup table
vesselSubclass	vesselSubclass code	C(10)	PK	
vesselClass	vessel class of subclass	C(10)		L_VesselClass
description	description of code	C(80)		

DST2
Data exchange format (version 1)

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27-02-2001
Danish Institute for Fisheries Research
Department of Information Technology

Data exchange format

The exchange format is tabulator (TAB) separated ASCII text files. A missing value is represented by a _ (underscore). Each data line holds the data for one record, thus all data lines must be unbroken. The first field in a data line denotes the table name code. The sequence of the data fields in the data lines must obey the fixed field sequence described in this document. The file can also have some header lines with a free format, describing the content of the file.

1. Data tables

A file can have one type of record, i.e. a file with only Sample data or several types of data records. However the data must be stored in the database in a specific order in order to ensure that the data can be related correctly. I.e. a catchSample record cannot be inserted in the database before its related Catch record and Sample record has been inserted, because a catchSample record is related to a Catch record, which again is related to a Sample record. In this way the consistency of the data in the database is ensured.

Table codes for the data tables:

table	table code
1: Sample	SAM
2: Environment	ENV
3: WaterMovement	WAM
4: Catch	CAT
5: CatchSample	CAS
6: LengthCell	LEC
7: Age	AGE
8: AgeGroups	AGG
9: Acoustic	ACO
10: Tagging	TAG
11: Juvenile	JUV

An example of an exchange file with data record is shown in the appendix. The examples shown are with fictive data.

table 1: Sample

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, areaAggregate, timeAggregate, vesselClass, vesselSubclass, gearClass, gearSubclass

table 2: Environment

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, week, depthStratum, temperature, salinity, zooplankton

It can be seen that this record is related to the sample record shown before, because the "sample" part of the ENV record has the same values.

table 3: WaterMovement

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, week, depthStratum, exchangeCoef, divisionFrom, divisionTo

Example:

It can be seen that this record is not related to the sample record shown before, because the year field in the "sample" part of the WAM record has another value (1995)

table 4: Catch

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, species, stock, vesselNum, tripNum, powerMean, GRTMean, marketCategory, landings, discards, effort, cpue

table 5: CatchSample

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, species, stock, samplingType, samplingStrategy, lengthSamplesNum, fishMeasuredNum, ageSamplesNum, agingStructuresNum, weightSamplesNum

table 6: Lengthcell

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, species, stock, samplingType, lengthCell, sexCode, fishNum, maturityStage, weightMean, weightMeanSD, surveyIndex, surveyIndexSD, diseaseRate

table 7: Age

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, species, stock, samplingType, lengthCell, sexCode, age, ageNum, weightAgeMean

table 8: Agegroups

tableCode, institute, year, quarter, month, region, division, subdivision, gridCell, species, stock, sexCode, age, samplingType, areaAggregate, sourceYear, marketCategory, vesselClass, vesselSubclass, gearClass, gearSubclass, maturityStage, fishMeasuredNum, fishLengthMean, fishWeightMean, surveyIndex, surveyIndexCD, catchNum, stockNum, diseaseRate

table 9: Acoustic

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, species, stock, age, areaAggregate, number, biomass

table 10: Tagging

tableCode, tagLabel, species, stock, yearReleased, quarterReleased, monthReleased, regionReleased, divisionReleased, subdivisionReleased, gridCellReleased, lengthReleased, weightReleased, yearRecaptured, quarterRecaptured, monthRecaptured, regionRecaptured, divisionRecaptured, subdivisionRecaptured, gridCellRecaptured, lengthRecaptured, weightRecaptured

table 11: Juvenile

tableCode, institute, year, quarter, month, region, division, subdivision, gridcell, species, stock, areaAggregate, caughtNum, m2Num

Lookup data tables are updated in the same way as normal data. The order in which the tables are updated is not important. There are many lookup tables, so each lookup table is identified by its full name. Some lookup tables have the field polygon, which is not reported via text files. Some tables i.e. L_GearSubclass include a reference field (i.e. gearClass) to a parent lookup table. The appendix shows an example of a lookup data exchange file including an example of each lookup table. The data exchange formats are:

L_AreaAggregate

tablecode, areaAggregate, description

L_Division

tablecode, division, depthmean, substrate, region

L_GearClass

tablecode, gearClass, description

L_GearSubclass

tablecode, gearSubclass, gearClass, description

L_Gridcell

Tablecode, gridCell, depthMean, substrate, area, subdivision

L_MarketCategory

Tablecode, MarketCategory, description

L_MaturityStage

Tablecode, MaturityStage, description

L_Region

Tablecode, region, depthMean, substrate

L_SamplingStrategy

Tablecode, samplingStrategy, description

L_SamplingType

Tablecode, samplingType, description

L_SexCode

Tablecode, sexcode, description

L_Species

Tablecode, species, latName, engName

L_Stock

Tablecode, stock, description

L_Subdivision

Tablecode, subdivision, depthMean, substrate, division

L_Substrate

Tablecode, substrate, description

L_VesselClass

Tablecode, vesselClass, description

L_VesselSubclass

Tablecode, vesselSubclass, vesselClass, description

Data validation

The data validation program will check, that there are no missing data for the key data fields, and that all data, which are associated with a lookup table, has a legal value from this lookup table (see the database description).

Appendix: Test files

```
Test data for the DST2 database


SAM DIFRES 1995 1 2 5 53 _ _ 2 2 _ _ _ _
CAT DIFRES 1995 1 2 5 53 _ _ SPRAT _ 1 3 _ _ _ 1300 200 _ 50
CAS DIFRES 1995 1 2 5 53 _ _ SPRAT _ 1 2 20 200 20 0 0
LEC DIFRES 1995 1 2 5 53 _ _ SPRAT _ 1 5 M 3 1 250 25 _ _ 0
SAM DIFRES 1998 1 2 5 53 _ _ 2 2 _ _ _ _
ENV DIFRES 1998 1 2 5 53 _ _ 43 10 12.45 34.2 135.2
WAM DIFRES 1998 1 2 5 53 _ _ 43 10 4.2 35 36
CAT DIFRES 1998 1 2 5 53 _ _ COD _ 1 3 _ _ _ 1300 200 _ 10
CAS DIFRES 1998 1 2 5 53 _ _ COD _ 1 2 20 200 20 0 0
LEC DIFRES 1998 1 2 5 53 _ _ COD _ 1 5 M 3 1 250 25 _ _ 0
AGE DIFRES 1998 1 2 5 53 _ _ COD _ 1 5 M 4 10 119
JUV DIFRES 1998 1 2 5 53 _ _ PLA _ 1 134 1430
ACO DIFRES 1998 1 2 5 53 _ _ COD _ 3 2 1200 1430
AGG DIFRES 1996 2 5 _ 52 5201 _ COD _ F 2 2 3 1993 _ _ _ _ _ 2 10
150 1150 10 1 1100 100000 5
TAG 187372 SALMON _ 1994 4 10 _ 36 3604 _ 15 12 1998 2 5 _ 32 3202
_ 220 300
```

```
L_AREAAGGREGATE _ Not known
L_AREAGGREGATE 0 Region level
L_AREAAGGREGATE 1 Division level
L_AREAAGGREGATE 2 Subdivision level
L_AREAAGGREGATE 3 Gridcell level

L_DIVISION 55 5 2 5
L_GEARCLASS 6 Some gear class
L_GEARSUBCLASS 4 6 Some gear subclass
L_GRIDCELL 145367 4 5.4 2 34 5530
L_MARKETCATEGORY 3 Some market category
L_MATURITYSTAGE 3 Some maturity stage
L_REGION 3 21 3
L_SAMPLINGSTRATEGY 3 Some sampling strategy
L_SAMPLINGTYPE 5 Some sampling type
L_SEXCODE F Female
L_SEXCODE M Male
L_SEXCODE X Mixed
L_SPECIES COD Gadus morhua Cod
L_SPECIES SALMON Salmo salar Salmon
L_SPECIES SPRAT Sprattus sprattus Sprat
L_STOCK _ Not known
L_SUBDIVISION 3320 25.5 3 33
L_SUBSTRATE 1 Sand
L_VESSELCLASS 3 Some vesselclass
L_VESSELSUBCLASS 3 1 Some vessel subclass
```

C Cuttle

Table of contents

Keywords

English keywords

CORBA (Common Object Request Broker Architecture)
OMG (Object Management Group)
Java
Data warehouse
Database

Icelandic keywords

CORBA (Common Object Request Broker Architecture)
OMG (Object Management Group)
Java
Vöruhús gagna
Gagnagrunnur

1 Introduction

This paper presents results of an experiment evaluating a CORBA and Java solution to linking multiple heterogeneous data bases and extracting data from them.

2 The problem at hand

The incentive of this work is the project: "Development of Structurally Detailed Statistically Testable Models of Marine Populations" sponsored in part by the 5th framework program of the European Union – Quality of Life and Management of Living Resources.

One of the objectives of this project is to collect relevant data and provide objective means to analyze the data, in particular to assemble highly heterogeneous forms of data in a database format designed to hold many different classes of data and to provide the capability to summarize data extractions in a format amenable to analytic routines, i.e. "data warehouses". The data warehouses will be defined generically but implemented for three chosen case studies and will include commercial effort information, data from biological samples of catches and from surveys, aggregated to appropriate small scale areas, time steps, species, age and length groups. The warehouse will contain aggregate values, yet at sufficient level of detail so as to avoid the need to examine raw data for detailed analysis. The data warehouses will be set up locally but the objective is to obtain a joint view into several warehouses for coordinated work on data from more than one institution. It is a requirement that the solution for combining these disparate datasets be platform-independent and appropriate security issues must be addressed. The overall design of the data warehouse consists of not only the database structure itself, but also the technology behind: inserting and extracting data to/from the database, data transformation (aggregation) and the Internet based interface. The overall design will be divided into subdesigns covering each of these issues. The users of the data warehouses need to know the structure of the information stored in the warehouse. This will be provided through a number of predefined search criteria in the warehouse or stored in a metadatabase and presented to the user by a web browser. The design of the database structures is a trade-off between redundant data and performance, complex structures and automated storage of data etc. This work will therefore be based on experience in database design and the input/output formats specified in earlier tasks.

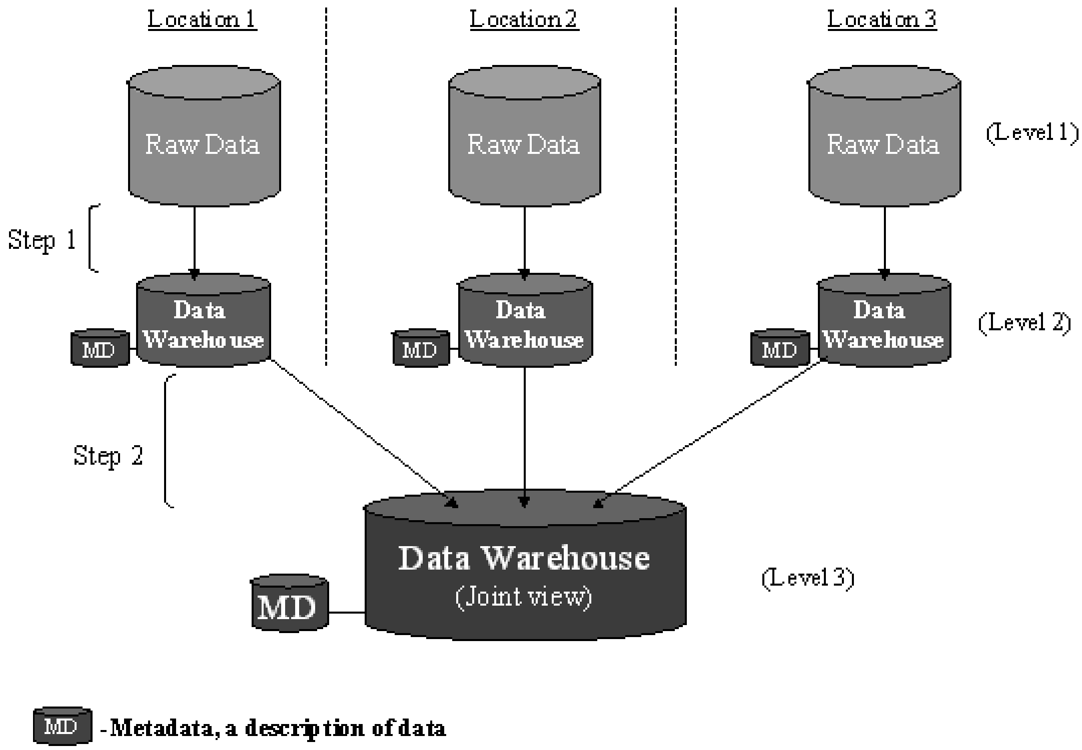


Diagram 2.1. Visual representation of the whole system

Above is a visual representation of what databases are in the system and the steps taken to achieve the final goal, a data warehouse comprised of all the data warehouses in the system. Building a data warehouse from raw data is a well understood process and is commonly practiced. Data extraction between levels 1 and 2 is done locally and therefore no special communication is needed. Platforms between locations can differ greatly. Difference can be between operating and/or database systems. Hence the real problem is not how to build the joint data warehouse, but rather the technical implementation of the communications between the various platforms.

This paper will focus on the technical implementation of the communications needed in step 2 of the above diagram.

3 Proposed solution

Now comes the question of how to approach the problem. Like many program related problems there seem to be endless ways of solving them if they are solvable. With all the tools available it is getting hard to choose the right one for the job, but with CORBA [OMG '99] and Java[2] [Java '99] an elegant solution can be implemented. These technologies are discussed in more detail in the next section.

The problem obviously calls for a client/server architecture of some sort. CORBA

[2] Java is a programming language of choice, CORBA solutions can be implemented in most major programming languages.

is perfectly suited for this [OMG '99]. Since many operating systems will be involved Java is a good implementation language [Java '99].

Below is a simple visual representation of what the system might look like.

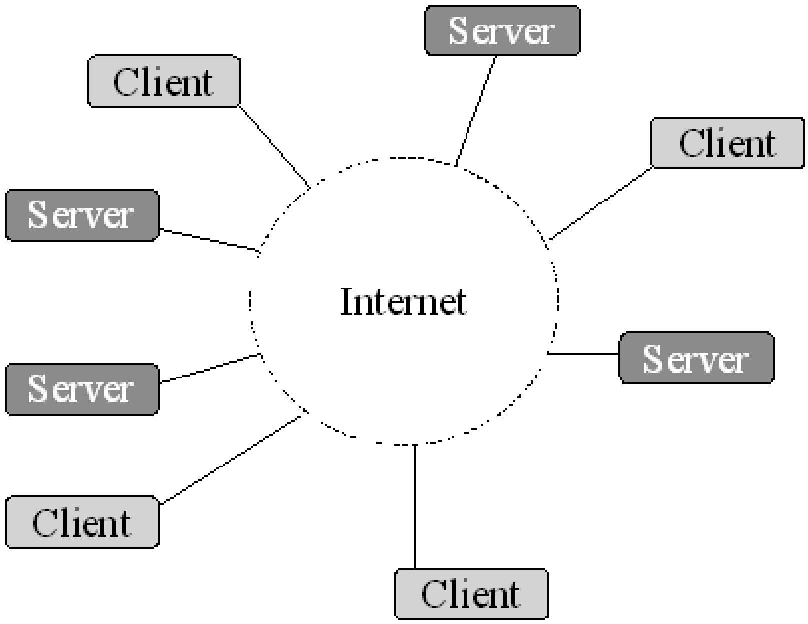


Diagram 3.1. A simple schematic representation of the system.

The above is just the standard client/server layout and is just to get us started. In the above diagram the servers would reside at 'level 2' on diagram 2.1 and the clients would be any program communicating with the servers. In diagram 2.1 the client resides at 'level 3' and communicates with all the servers gathering data for the data warehouse at that level. The server objects are here representing a computer(s)[3] providing services to the clients. The service they provide is to receive requests from client objects and return information to the requestor. All the server objects provide identical services and only differ in the information stored in their databases[4].

The idea is that clients can obtain any information from the servers and their databases by knowing only their location, their 'address'. The addresses of all the servers in the system could be located at a single location. The address will be of the form
"protocol://server_IP_address:Port_Number/location_of_object/ object_name.ior".

An example of an address would be
"http://198.548.448.002:15000/CuttleProject/QR_Server.ior".
Along with the address of the server there will be the name of the institution

[3]Many computers can work together on an intranet to provide the services or it can be a single computer.
[4]Although in the proposed solution it is anticipated that a server object, represented in the above diagram, is composed of one database and one server, it is certainly possible to have a server with many databases. But that would be a waste of effort and unnecessarily raise the complexity of the system.

that manages the database and a general description of what data the database has to offer.

Since this information is critical to the whole system it is important that it be accessible at all times. Therefore it should reside on a web page on a stable server, instead of having a service that distributes the information.

But how do the clients and servers communicate? That's where CORBA comes in. This is best explained by expanding the previous diagram:

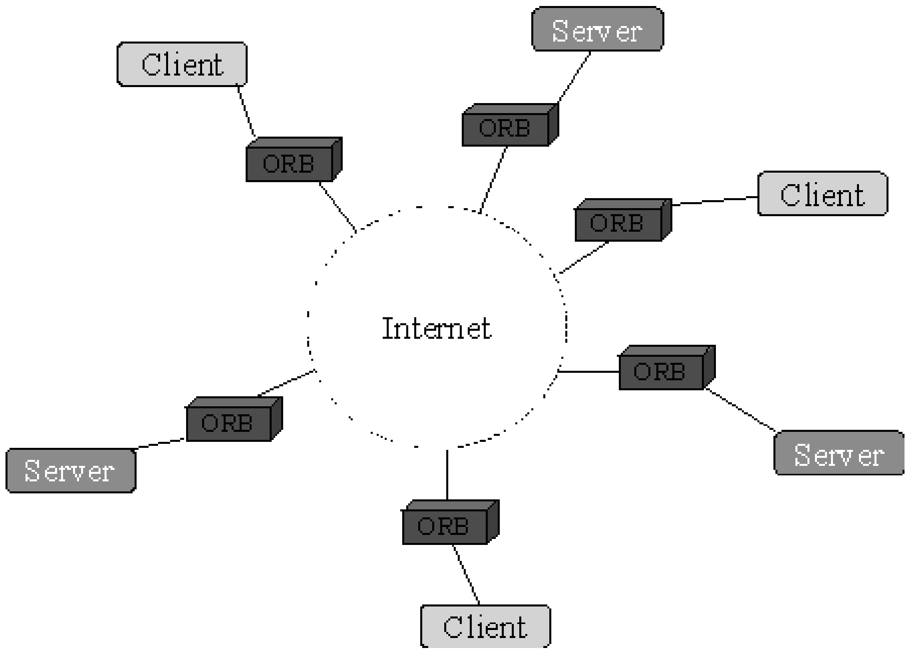


Diagram 3.2. This diagram shows where the ORB fits into the system.

CORBA is itself a standard, standardized by OMG [OMG '99], but the working product of the standard is called an "ORB"[5]. By using CORBA, calling a remote procedure and getting the information back becomes almost child's play. The clients and servers communicate through the ORBs. The ORBs can communicate with one another over the Internet, hiding the complexity of the communications from both the clients and servers. To put it simply (but not completely accurately), the client talks to the ORB like it were the server and the ORBs take care of calling the actual server and getting the return data back to the client. This setup could be compared to the telephone system. The clients and servers would be people speaking, the ORB would be the telephone and the Internet would be the telephone system. You just talk into the headset and don't care how your voice is carried through relay stations, cables or satellites, that is the responsibility of all the electronic gadgets.

The next thing to consider is what services the servers will provide to the clients.

The first thing the client must do is to get the address of the server and contact it. The client gets the address information from a web page that will reside on

[5] More detailed explanation of CORBA can be found in the next section.

a stable Internet-server[6]. Using the address obtained the client can contact the server.

On the server side a service will be running all the time waiting for incoming requests from clients. This service must be located at the address specified on the web page.

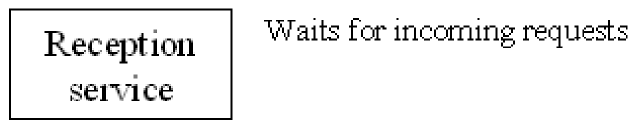


Diagram 3.3. The reception service.

The second thing the client does, after contacting the server, is to request access to the database. If the reception service decides that the client can have access, it gives the client a connection to an object (Query retriever) that will service the client from then on.

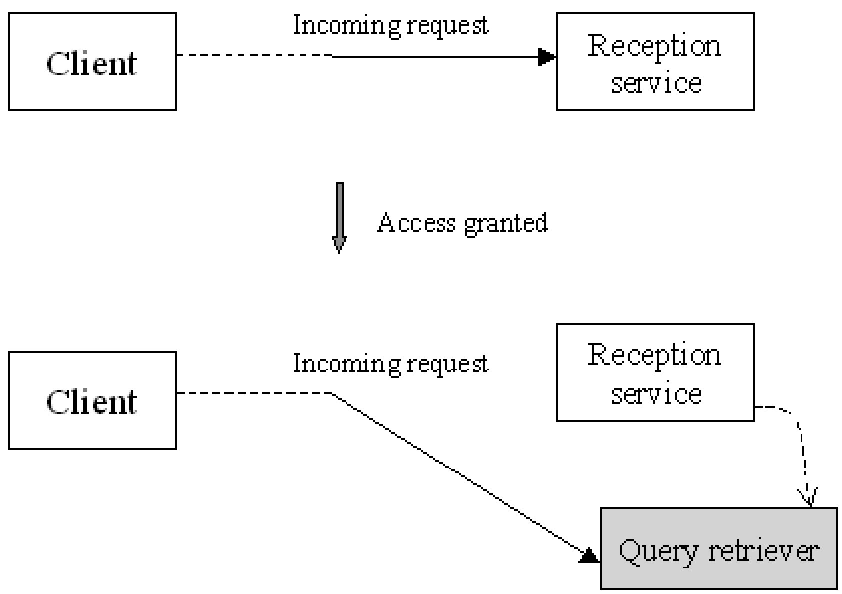


Diagram 3.4. Demonstrates how client gets access to the Query retriever.

Since the client knows nothing about the database it must get detailed information on what the database has to offer and what the database looks like. A description of data is called 'metadata'. The metadata describes the structure of the database. It also includes the names of the tables and columns in the tables and their names. The metadata is constructed using a help tool ("Metadata Builder"). It is then stored as a file and sent to the client upon its request. So before anything else is done the client must get this description.

[6]The address information could be accessed from a service running at a known location, but since this information will not change rapidly a web page will do just fine. Using a web page will avoid complexity and it will be very stable.

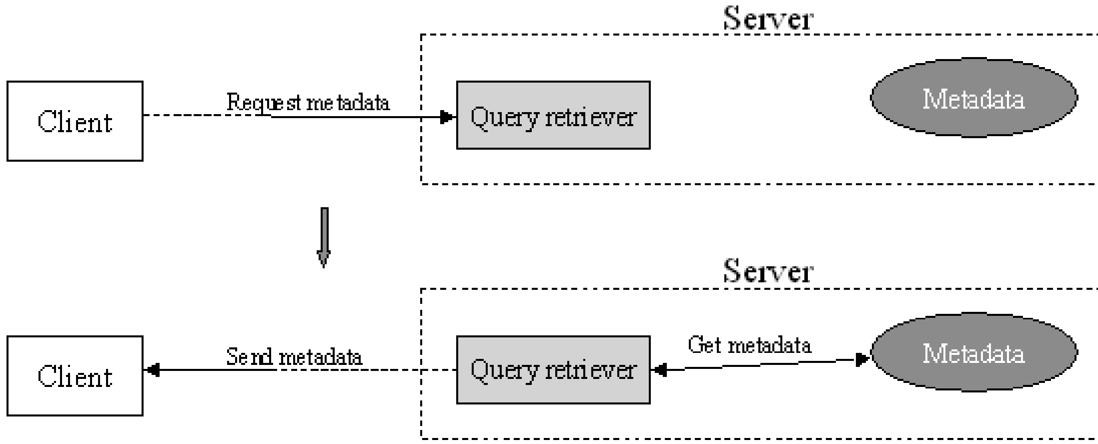


Diagram 3.5. Demonstrates the location of the metadata and the client acquiring the metadata.

In the last phase the client builds a query from the description that it has received and asks the server to execute the query and return the data. The query will be written in SQL, based on the metadata.

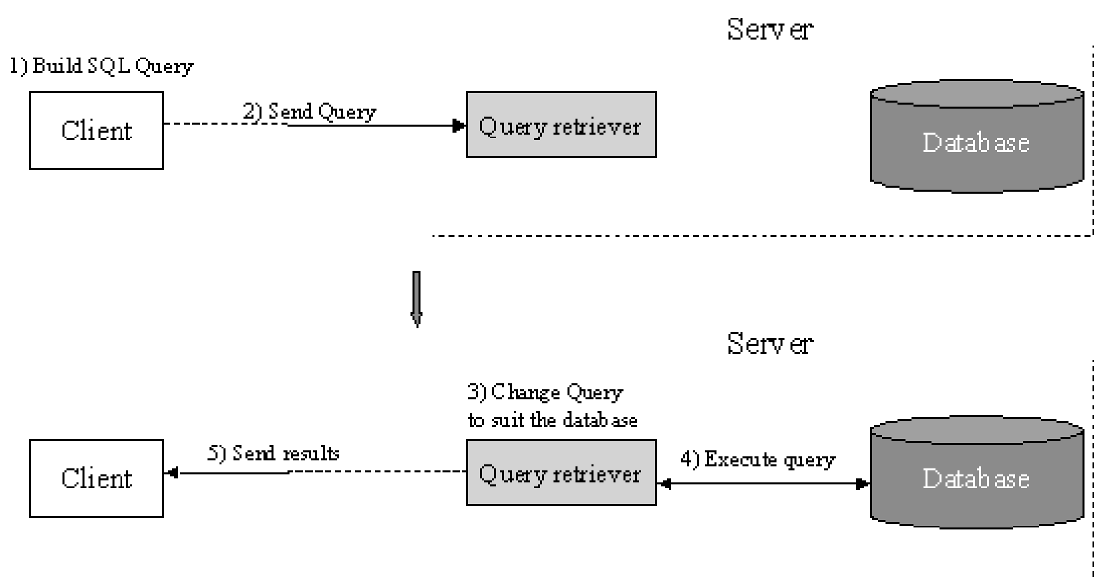


Diagram 3.6. Show the sequence of events that take place when query is executed.

Note that in the third step of the above diagram it is anticipated that the query be altered. This is due to slight differences in database systems. The query that the client builds will be according to a standard, possibly the ANSI SQL standard. Many database drivers support ANSI SQL and do not require any changes to the query.

Now it is possible to build a picture of the objects and services that need to reside on the server:

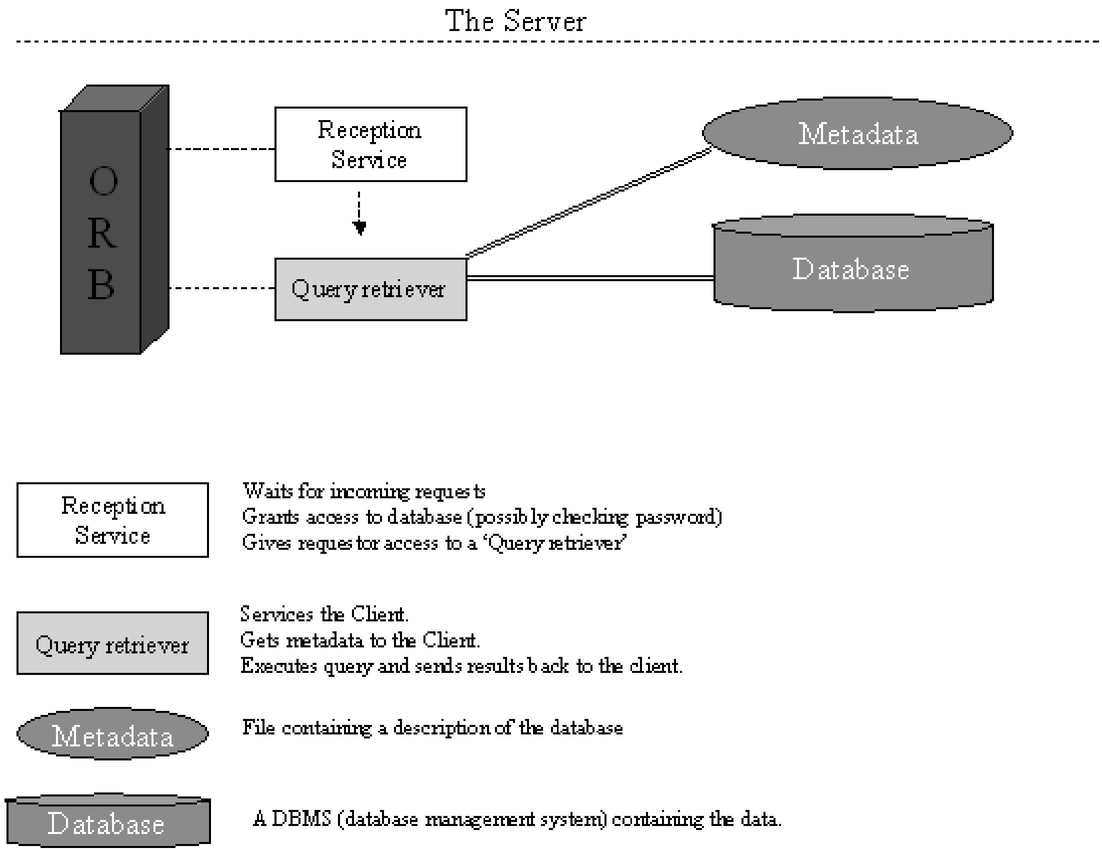
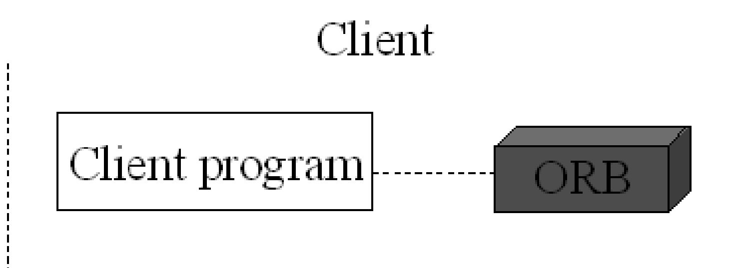


Diagram 3.7. Show all the components of the server and their functions.

The client is more easily represented:



DDiagram 3.8. The client connected to an ORB.

The client is just a single program that can be running on any computer that has an ORB. The client can get the locations of all servers in the system from the web page.
It can contact the servers, get the metadata, send a query to the server and receive the resulting data from it. The client program will be able to display the data received and save it to a file or local database[7]. Since this document focuses mainly on the internal workings of the system, interface design will not

[7]Note that the client could be a servlet. A servlet is a Java program that is capable of producing dynamic web pages. It would not accommodate all the same functions but it would give the possibility of putting the system on the Internet.

be discussed in any detail.
The data residing in the databases around the world will be expected to differ greatly, but many databases will have similar data dealing with the same criteria. These similar databases will be standardized. There is no need to get anxious about standardizing the databases. Changes to the databases themselves will be minimized by having a simple table translation mechanism on the server side. The client will then be able to connect to the servers that contain similar data, and query them all at the same time.[8]

Using this setup we are able to query databases individually, as well as a set of similar databases at the same time.

Now we have the complete system:

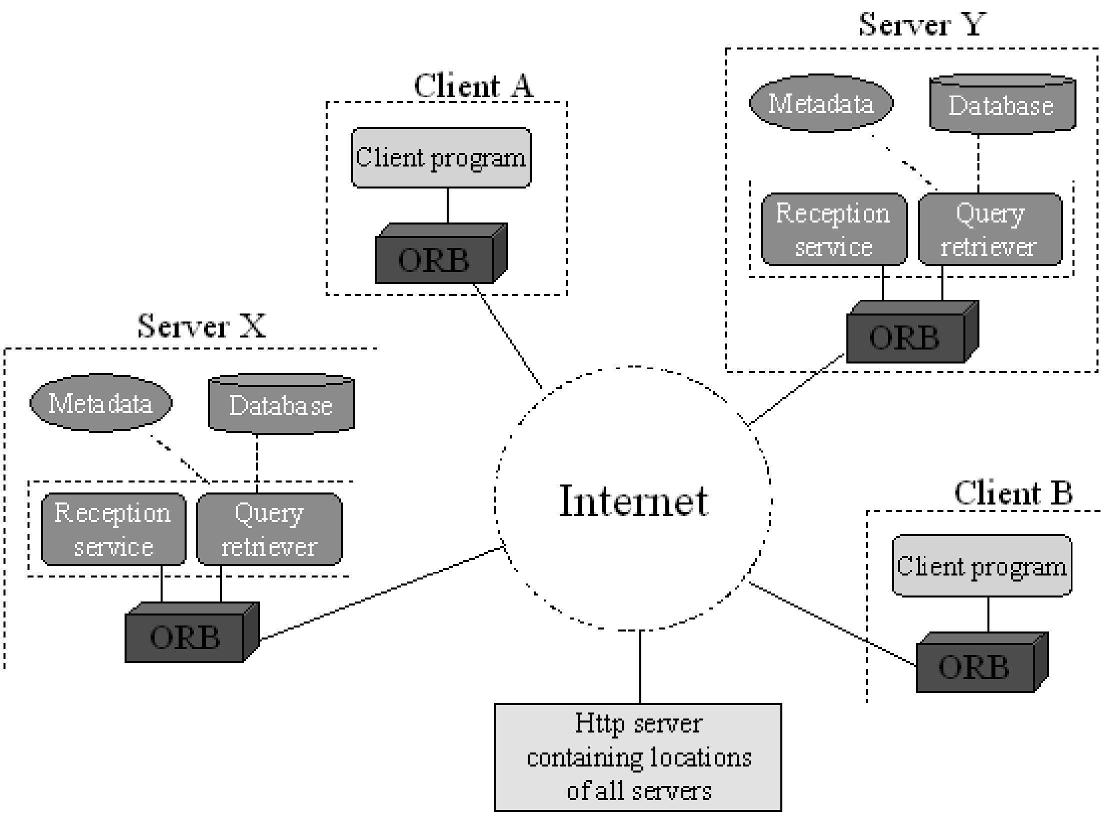


Diagram 3.9. The complete system

4 Technology to be used

Following are short explanations of the technologies needed to implement the proposed solution. CORBA [OMG '99] and Java [Java '99] are the technologies chosen for this solution because they both stand for high portability and are using the cutting edge of what computer technology has to offer today.

[8]The database structure need only be the same, table names can be converted at will on the server side.

4.1 CORBA

CORBA stand for Common Object Request Broker Architecture. CORBA is a standard devised and maintained by OMG (Object Management Group)[OMG '99]. Hardware and software manufacturers that back and participate in the CORBA standard are in excess of 700 [Mow & Ruh '97]. It is this large number of companies that give it one of its best qualities, e.g. stability. The CORBA standard is now being adopted in part by ISO because of its growing support and popularity [Mow & Ruh '97].
At its simplest, CORBA describes how objects (basically pieces of code), communicate with each other. It does not matter where the objects are, they can be on the same computer, on the same intranet or connected to the Internet. It also does not matter in what programming language they are implemented, because the implementations are all built around a single definition. The key here is the definition. Definitions are written in IDL (Interface Definition Language) and are a part of the standard [OMG '99]. The whole CORBA standard is vast and complex, but luckily most of what the programmer needs to know is in the IDL part of the standard. The rest of the standard is to do with how the objects communicate, locate each other, pass parameters, invoke methods and so on.

Here visually presented are the components that make up the CORBA standard:

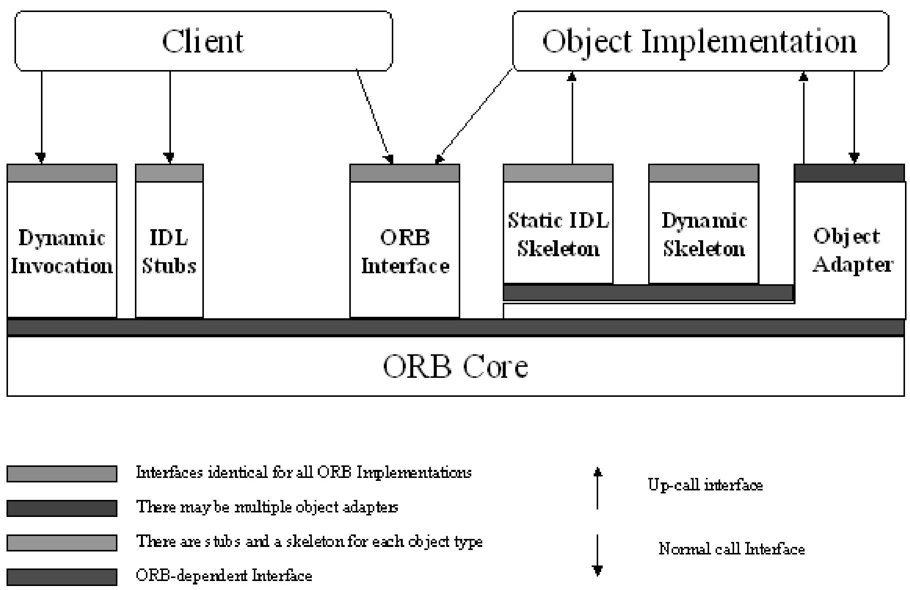


Diagram 4.1. The CORBA standard [OMG '99]

This looks very complex but it is not. To get a rough idea of how CORBA works you need only to pay attention to a few things on the diagram. Below the things that have the greatest complexity have been excluded and a little added to help explain it.

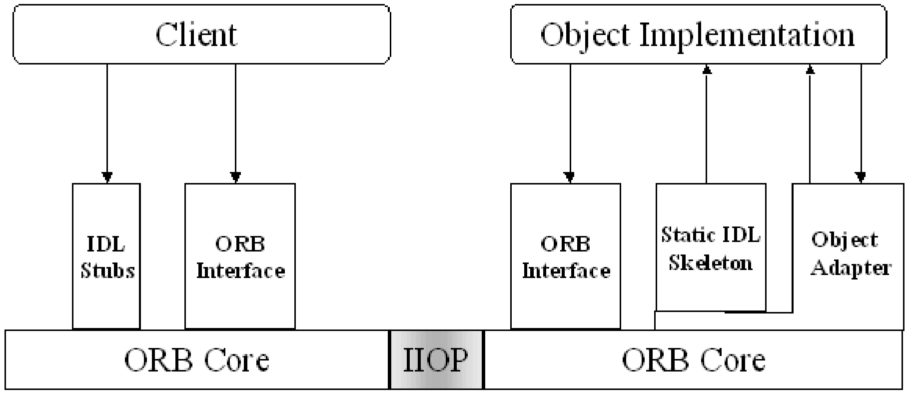


Diagram 4.2. Simplified CORBA with added IIOP

Lets first look at the "**Client**" and "**Object implementation**". The goal of this whole thing is for the client to call (invoke) a method in the object implementation and receive data from it. This is just the basic client/server setup. To stress the point that the client and object implementation need not reside on the same computer the ORB Core has been split in two, joined by IIOP (Internet inter-ORB protocol). The IIOP makes it possible for ORBs to communicate using a TCP/IP connection. Not only is possible for the ORBs to reside on different computers but the two ORBs do not need to be from the same manufacturer. ORBs from all manufacturers can communicate with one another, using the IIOP part of the CORBA standard. It is also possible to have the client and object implementation on the same computer, but then there would only be one ORB core. In this project the client could be located anywhere in the world and the object implementations would reside on servers near the databases.

The first step in making this all possible is to write an IDL [OMG '99] [Mow & Ruh '97], a definition of the objects that run on the servers. In the definition the objects are described, what methods are provided and what data they return and so on. After writing the definition, the object can be implemented using any programming language that has an IDL compiler. From the IDL that was written the **IDL Stub** and the **Skeleton** (dynamic and static) can be compiled. The skeleton resides on the server side and gives the object adapter information on how to call the implementation. The IDL stub resides on the server side and knows how to call the object implementation. The ORB core (and IIOP) is what connects the whole thing together. When a client wishes to invoke a method on the server side it simply 'talks' to the IDL stub as it where the object implementation. The stub works as a proxy for the server object. Through the ORB and the Object adapter the IDL stub calls the implementation and gets back the data, which is then returned to the client. All this complexity is hidden from the client program and as far as it is concerned everything resides on the same computer. The server side implementation is equally simple. All that needs to be done on the server side is to implement the object and register it with the object adapter. That is, just telling the object adapter where the implementation resides.

This is of course a simplified explanation of the CORBA standard and how it works. CORBA provides standard services, such as security and much more [OMG '99]. With CORBA you can find implementations that you did not even know were there before and use those objects [Mow & Ruh '97]. This is done by using dynamic invocation, interface repository and a lot of other things that one need not be concerned with to get a rough idea of how CORBA works.

There are other standards that compete with the CORBA standard. And the word 'compete' is used in a very broad sense. There is not really any competition. No other standard has the backing of so many hardware and software companies and organizations. One of CORBA's biggest rivals is the standard DCOM (and COM) developed by Microsoft. A newly created group now maintains the DCOM standard, but only until recently Microsoft was the only implementor of the DCOM standard. Besides the fact that DCOM does not have the backing of nearly as many manufacturers as CORBA, DCOM can only be used on Windows operating systems (95/98/2000/NT) [Mow & Ruh '97]. CORBA on the other hand has been implemented on a wide variety of operating systems including UNIX, Linux and Windows [OMG '99]. DCOM has a number of other shortcomings including limited garbage collection and many others factors which will not be discussed here.

4.2 Java

Java [Java '99] is a programming language that has seen considerable action in the last few years. Java is a relatively new language based on a not so new idea. Many years ago IBM developed the concept of the virtual machine. A virtual machine is a piece of software that runs on a computer and looks itself like a computer to other programs. Programs run on this virtual machine and the virtual machine translates instructions between the programs and the actual computer.

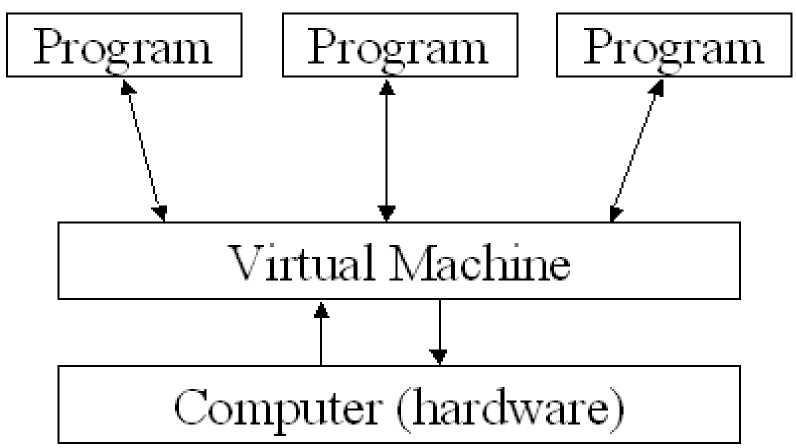


Diagram 4.3. The IBM virtual machine.

The original purpose of this idea was to be able to run multiple operating systems on one computer at the same time. It proved to be very sluggish, but with recent advances in processor technology and rapidly increasing computing power this idea has in fact been implemented and is slowly gaining popularity.

In the year 1994 Sun Microsystems put this concept to practical use with the development of Java. The basic idea behind Java is to be able to write a program that can be run on any operating system that has a Java virtual machine.

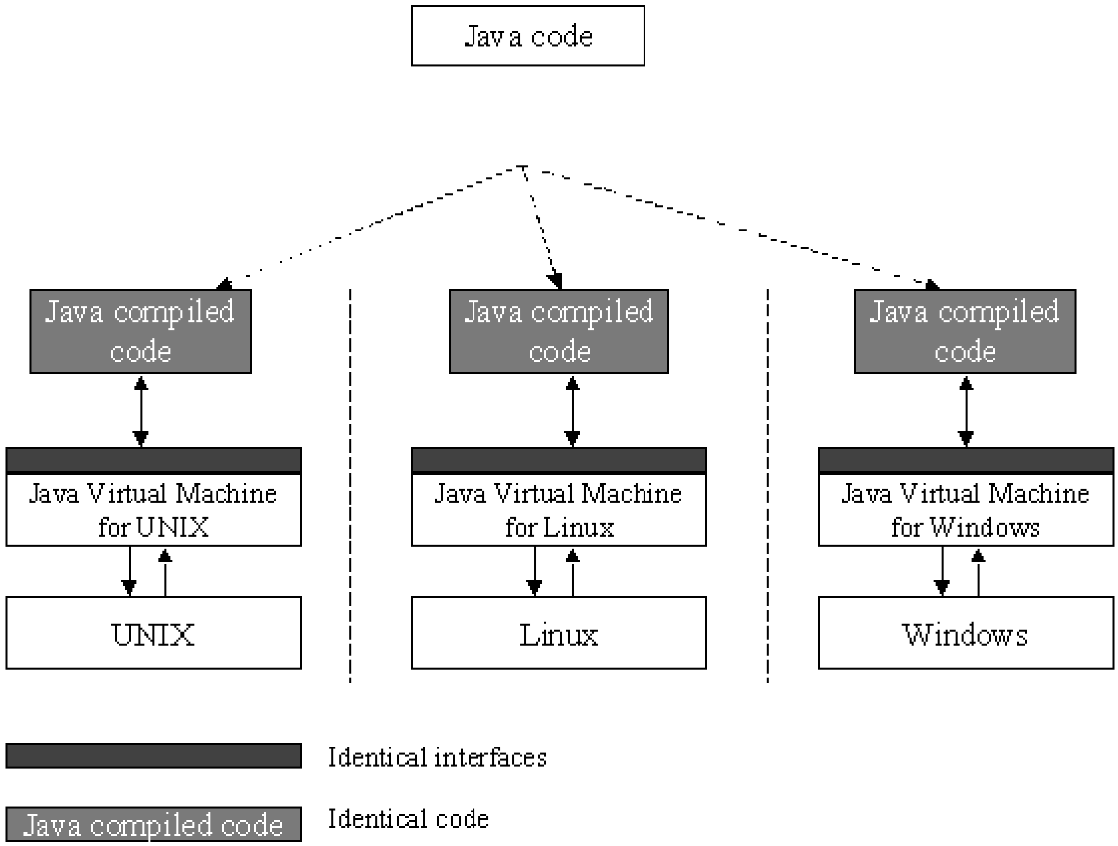


Diagram 4.4. Same Java compiled code running on tree different operating systems.

Java virtual machines have been made for all major operating systems including UNIX, Linux and Windows [Java '99].
Many people are deluded by the idea that Java is only for writing applications that run on the web, i.e. applets. Java is in fact a fully flexed programming language but due to its unique security features and portability it has been used to garnish the Internet with both useful and fancy applications (applets) never before possible. Java servlets can be also be used to replace CGI (Common Gateway Interface) scripts to produce dynamic web pages[9]. Using servlets instead of CGI has many advantages including security and performance improvements.
In the first years of Java it was considered inferior to languages such as C++ when considering the speed of the applications. Although it is true that Java applications run slower than applications written in languages that compile to native code it is mostly due to the interface part of the programs. Java virtual machines and Java compiler technologies are rapidly improving and the performance gap between Java and native code is narrowing at a furious pace. There are features

[9] See Appendix C.1

of Java that make it more desirable than other programming languages. First there is the portability that has been mentioned before. Standard security features in Java far exceed features in other programming languages. Security was one of the main goals in the design of the Java language, and to this day no glitches have been found in Java security[10] [Java '99]. Java has an extensive number of class libraries. These libraries provide the programmer with ways to do a lot of common tasks. One of the best features of Java is its class libraries that deal with communication. Java was designed in the Internet age and has therefore provided the programmers with easy to use communication classes.

Java also has powerful garbage collection. This feature is often overlooked when comparing speeds with other programming languages. The Java virtual machine takes care of the garbage so the operating system does not have to. When running native code on operating systems, it is up to the program and the operating system to take care of the garbage collection. Unfortunately garbage collection is very poor on some operating system such as Windows (95/98/NT). Windows systems (95/98/NT) must be reset frequently (every few days) due to uncontrollable garbage accumulation. This problem would not exist if garbage collection were as powerful as the one Java provides or if all the programs were implemented in Java. So performance is not only question of raw speed but also stability. When garbage collection is not efficient, programs become slower when run for long periods of time, and can even paralyze the operating system and all other applications that run on the same system.

So Java is a major contender among programming languages, as long as graphical speed is not the greatest concern (although that may change in the foreseeable future due to technologies like JIT-compiler).

5 Proof of concept

Now it is time for the "put your money where your mouth is" phase. In previous sections there has been a lot of praising CORBA. It has been stated that the problem can be solved quite easily using this technology. It has even been compared to child's play.
To show that these statements are not made without foundation, a prototype of the proposed solution must be built showing that these claims are indeed true.

5.1 What needs proofing

Using the structure of the system described in section 3, it must be shown that clients can contact and extract data from the databases residing on the server side.
Showing that a client can query multiple databases of different types at the same time is also an issue, so that needs to be shown possible. Also the reverse, that a server can service multiple clients at the same time.

[10] Rumors of Java applet security faults have been reported. After extensive reading on the subject, it was found that this security problem was actually due to Microsoft's ActiveX.

To show that using CORBA and Java is indeed a simple way to solve this problem you will need to know a few things. I have no prior experience of working with CORBA. I have very little experience in using Java (my largest Java program to date had no more than 400 lines of code). I have had no experience in connecting a program to a database. I will have less than 6 weeks to learn the skills necessary and complete the working prototype. With this in mind it should be obvious that these technologies are indeed simple to use and well suited for this project, that is if I am able to complete the prototype in these few weeks.

5.2 How to prove the concept

CORBA and Java will be used to complete the prototype. The prototype will have all the major parts of the system described above. Due to the limited time to complete the project it will understandably be kept as simple as possible. The user interface of the system will be of secondary importance and time will be spent mostly working on functionality rather than good looks.

On the server side all the functionality described earlier will be implemented. Simple interfaces for setting up the services on the server side will also be implemented. These interfaces help configure the connection to the database, setting up translation for the specified database and the metadata that describes the database.

On the client side all the functionality described earlier will be implemented, except the option to save the data received. The data received will of course be displayed. Saving the data to file or database is simple but it requires added complexity to the interface and a slice of the limited time. No tools will be implemented to build the queries, so the queries must be manually constructed.

In the fully finished system the interface would make use of the metadata to help the user build his query. The making of an elegant interface possible of doing such a thing would take much more time than available. The metadata is of course used to help the user build the query and so serves its intended purpose.

5.3 Tools of choice

In order to implement the system the right tools for the job are needed. Visibroker [Bor '99] and JBuilder [Bor '99] have been chosen for CORBA and Java needs respectively. Both these products are from Inprise® [Bor '99](also known as Borland®). Following are short reasons why these products were chosen.

5.3.1 Visibroker The primary reason for choosing Visibroker is its reputation of being easy to install and work with. Visibroker comes with Gatekeeper® . Gatekeeper can work as an http server for the server objects, thereby making it unnecessary to set up an http server while developing the system. Visibroker is very simple to set up and has handy configuration tools along with various smart tools to make development easier.

5.3.2 JBuilder – JDK 1.2

JBuilder3 is one of the latest Java development tools and uses the latest Java libraries from Sun Microsystems. JBuilder3 uses Java2 (JDK 1.2) which is the new standard for Java. During the development of the system all the non-visual components will use only JDK1.2 libraries for maximum development portability[11]. JBuilder libraries will however be used for visual components.

6 The Finished product

The development of the prototype actually went better than expected. Although it has rough looks it has all the functionality that it was intended to have.

The system was developed on a local intranet. The intranet is run by a Windows NT Server 4.0 and all the workstations are running Windows NT 4.0. For database needs Oracle 7.3.3 and Access '97 were used. Although the system was not tested over the Internet there is no reason to think that there will be any difference, except for connection speed. All communication protocols used between the objects of the system are the same, regardless of whether they are over an intranet or the Internet.
To much amazement there were absolutely no problems with Visibroker and the CORBA side of the implementation. Within minutes of installing Visibroker the first CORBA program was up and running. With a few hours of reading Visibroker documentation and experimenting all the knowledge needed to start implementing the prototype was accumulated. Quickly the basic structure and communication was in place. From that point on functionality was gradually added to the skeleton. Most of the problems encountered were due to inexperience with Java, but not with the products themselves.
It should be mentioned here that during development changes were made and functionality added between the client and server objects (the CORBA part). These changes only took a few minutes to implement. Had for example a TCP/IP connection been used instead of CORBA[12] these same structural changes would have taken hours, if not days to make. This shows the brilliance of the CORBA way, not to mention object-oriented programming in general.

6.1 The server side

To get the program running on the server side a short program was written that does the necessary registration of the 'Reception Service' object. This service does not have any security features implemented, such as password checking or load checking. It simply gives a client access to a 'Query Retriever' object upon its request.

A simple interface was made to set up the necessary parameters and data needed to start and run the services on the server side.

[11] All development tools use JDK and can be ported between development tools without trouble.
[12] The ORBs basically use a TCP/IP connection to communicate, but this completely hidden from the programmer.

This interface helps the user to set up the basic database connection properties. These properties include JDBC driver information, username and password. Included is a simple interface to edit a translation table. By having such a translation table, table and column names can be published under any name and then changed to actual table and column names just before the query is executed. This allows actual names used in the database to be in, for example Spanish, but published in English. This translation table is also intended to deal with the minute differences in database systems. For example Access uses the keyword 'As' in its SQL statements, but Oracle does not.

Included in the interface is a simple 'metadata builder'. This part of the interface makes writing the metadata quite easy. All the user has to do is input the names of the tables and the program builds the metadata by querying the database. The user is then given an opportunity to edit the metadata and add a description if desired.

6.2 The client

The interface for the client is primitive, but for the purpose of demonstration it does the job. The client has two basic parts. The first part deals with the query portion. There one can connect to the servers, write a query and view the data that was returned. The second part deals with choosing the servers and getting the metadata for the databases.

The steps the user must take to query a database are the following. First choose one or more databases to query and get the metadata for that/those databases. Secondly the user connects to the databases. Finally the user writes an SQL query based on the metadata and then executes the query. If the query was correctly executed the data is displayed in a tabular form.
To see a more detailed view of the program take a look at appendix C.2, where there are several screenshots of the program and instructions on how to use it.

7 Further development

7.1 What needs to be added to complete the product

If you have taken a look at the prototype you will realize that much needs to be done to make the program more user friendly. The server side of the program has all the functionality needed for the final product. During development little attention was paid to the speed of the implementation and emphasis was placed on getting it to work. There are several areas where speed can be improved.

The setup of the server can be greatly simplified. Information from the database driver can be used to generate the translation tables, either completely automated or with a setup wizard. This information can also be used to make the metadata construction even simpler than it is in the prototype.

The interface of the client program was built to demonstrate the proper functionality of the communication mechanism. In the fully realized product the client would be a highly specialized program designed to gather data from all the databases and store them properly in the data warehouse. It would however communicate in much the same way as the prototype client does.

7.2 Getting data to the end-user

After the basic structure is in place there are several feasible ways of getting the data to the end-user.

One possibility is to have a Java servlet running near the data warehouse (at 'level 3' on diagram 2.1), giving access to the data via common internet browsers.

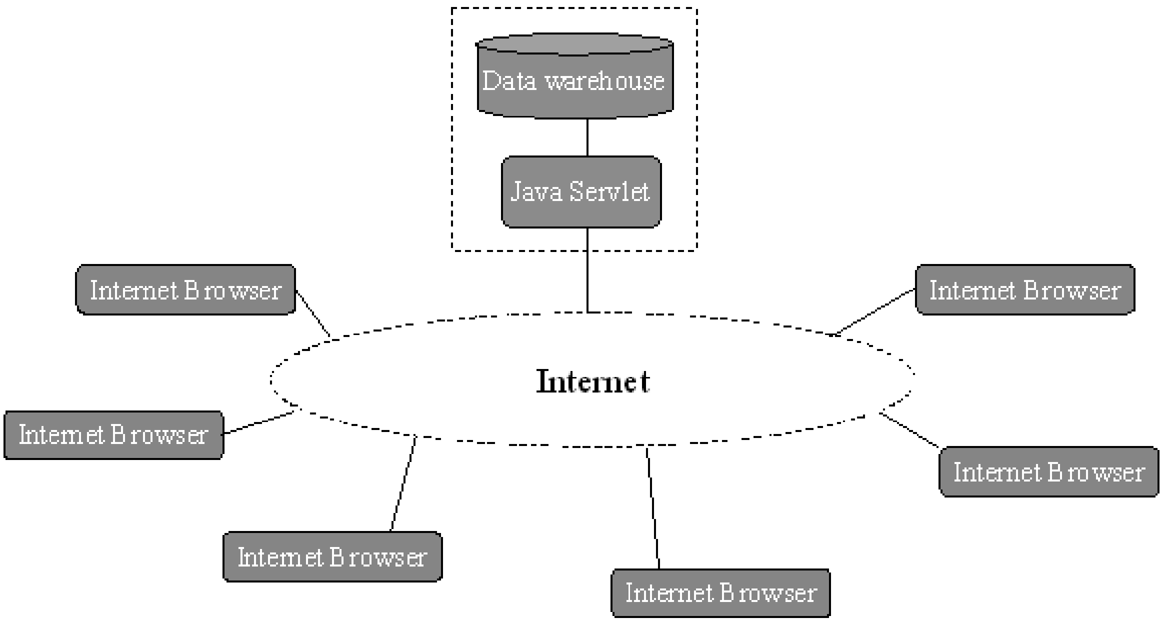


Diagram 7.1 Users get access via Internet Browsers

A Java servlet is a program that runs on an Internet or intranet server and produces dynamic web pages. With dynamic web pages produced by a servlet a user can view the data through a web browser. It is also possible for a servlet to produce a file containing the data witch can then be fetched by the user. Using this setup great security can be reached. For instance users can be granted access levels based on usernames and passwords issued to them.

Another possibility is to have a program on the user machine query the data warehouse.

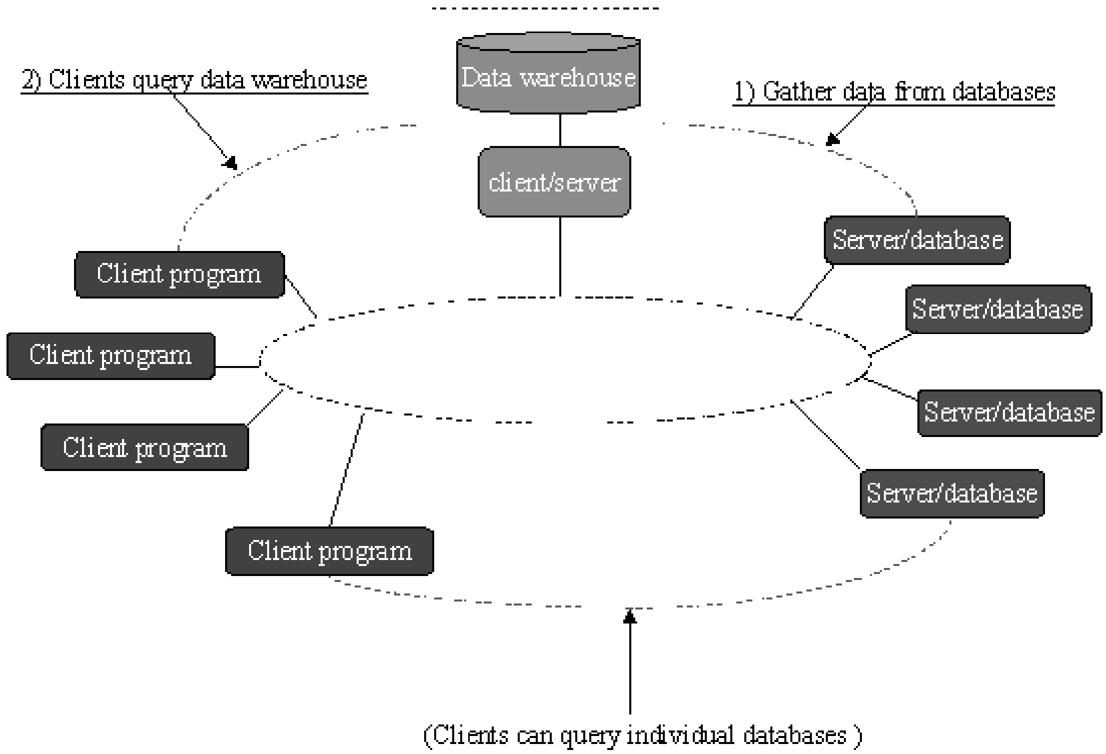


Diagram 7.2. Clients can query the data warehouse or individual databases.

Having a program query the database(s) offer greater flexibility than the previous idea. It does however come at a cost. The user is required to have an ORB installed on his system and possibly Java Runtime Environment, if the program is implemented in Java.

This configuration does have its merits. The client program can directly store the data received to the users database. The user can query individual databases as well as the data warehouse (the joint data warehouse). More options and control can be given to the user without compromising security.

Joining these two possibilities is the third option. By doing so the user is offered different ways of accessing the data based on his or her needs.

8 Conclusion

I hope that you are as convinced of CORBA's ability to solve this problem as you are convinced that I should not write essays for a living.

I hope that you appreciate that all this, writing the essay and completing the prototype, was done in a very short time. The intended purpose of this paper was not to produce a refined product, but to show that CORBA is indeed a desirable technology for solving the problem at hand.

I found CORBA (Visibroker) extremely simple to use and perfectly suited for building distributed systems.

I believe that implementing the system in a similar way as described in this essay is by far the best choice. Due to the structure and the simplicity of CORBA the system can grow as needs arise. With CORBA, programs can be implemented in any major programming language to suit everyone's needs. My choice of Java as implementation language is based on the idea that all programs need only be implemented once and can be run on all major operating system. This ability is indeed desirable when many operating systems are expected to be involved in the system.

I guess the only thing I can say is: "I believe that using CORBA is a feasible way to solve the problem".

C.1 Abbreviations and related technologies

1. Applet - A Java program that runs in a web browser.

2. Client – A program that uses services provided by a server.

3. IIOP - Internet inter-ORB protocol. A protocol that ORBs use to communicate. This protocol allows ORBs from different manufacturers to communicate and work together.

4. Intranet – A network of computers, usually owned by a single company or organization. Usually within a single building or buildings geographically close to one another.

5. JDBC – Java Database Connectivity. Enables Java programs to use databases.

6. ODBC – Similar to JDBC, but can only be used on Windows based systems.

7. JIT compiler – Just In Time compiler. Compiles much used code to native code to enhance performance. (Does not change the Java code)

8. Middleware – Software that usually enables other incompatible software to work together.

9. Server – A piece of software that provides services to client programs.

10. Servlet - A Java program that runs on a web server and is used to create dynamic web pages. Similar to CGI, but has better security and better performance.
11. TCP/IP – Is the standard communication protocol for communicating, sending and receiving information over an Internet or an intranet connection.

12. CORBA: Common Object Request Broker Architecture.

13. ORB: Object Request Broker. Basically the working product of the CORBA standar. (i.e. the CORBA standard implemented)

14. CGI : Common Gateway Interface. A scripting language used to produce dynamic web pages for the Internet. CGI scripts can be implemented in a wide variety of programming languages including Pearl and C. CGI has been used for many years. It has serious security and speed problems and is inferior to Java Servlets in both aspects.

15. Native code : Code that is dependant on a machine's instruction set (i.e. machine architecture and operating system)

16. Metadata: Description of data. Describes structure and type of the data.

C.2 The Prototype

Running the programs

The system is split into two parts, the client and the server. The two parts can run on the same computer or separate computers connected by an intranet or the Internet. Below are screen shots from the system. Included with the screen shots are instructions on how the program is used.

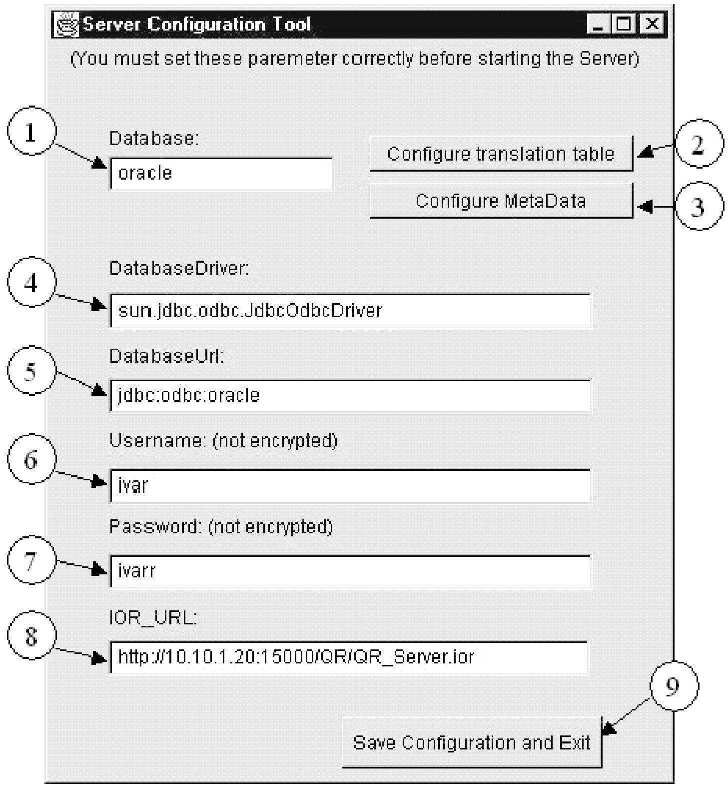
The server

In order to run the server we must first pay attention to the general setup of the computer. Java runtime environment 1.2[13] or later must be installed on the computer along with Visibroker 3.3. or later. An accessible database must be installed on the computer or on the local intranet. A proper JDBC driver must be supplied and properly installed on the computer[14]. For setup instructions see the documentation included with these products.
The server program does not have an interface. To start the server the following steps must be taken (if you are running Windows).
1) Open DOS and move to the installation directory.
2) Configure the server – see "server configuration"
3) Start Gatekeeper® . This is done by typing "start Gatekeeper" at the DOS prompt.
4) Start the Server program by typing "start vbj Server" at the DOS prompt.

Server Configuration

Included with the server program is a server configuration utility. To start the server configuration type "java ServerConfiguration" at the DOS prompt. Having done so the following interface will appear.

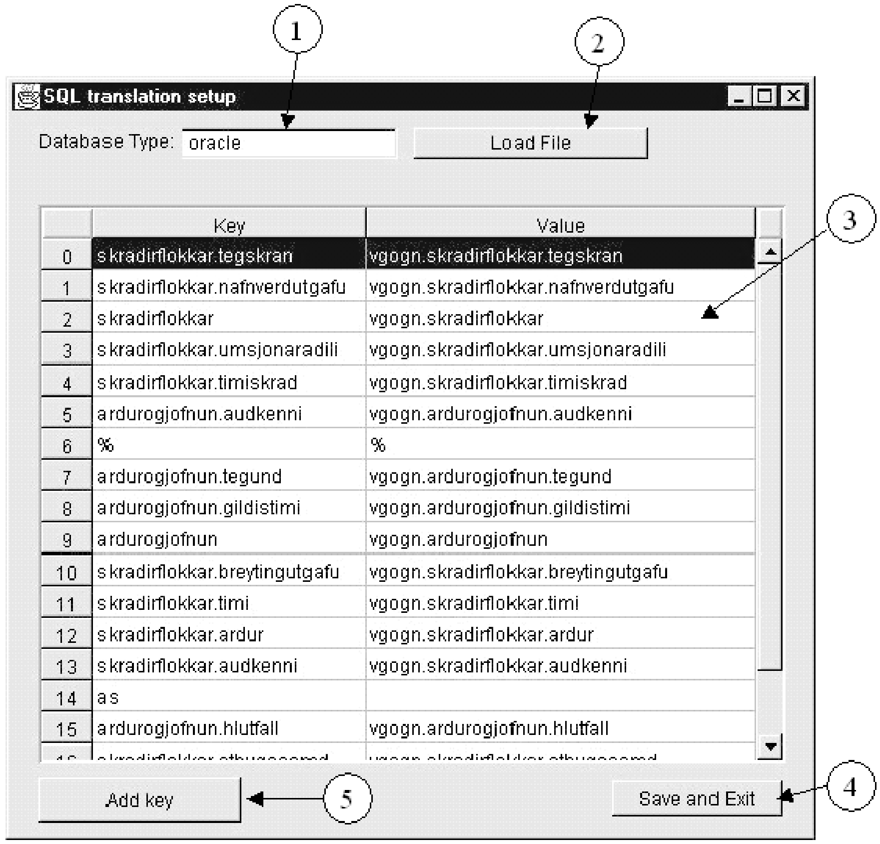
[13] The program has not been tested for earlier versions of Java. Visibroker does only require that Java 1.7.* be installed.
[14] If the database is to accessed with ODBC an JDBC-ODBC bridge must be supplied. JDK 1.2.* from Sun Microsystems includes an JDBC-ODBC bridge driver.



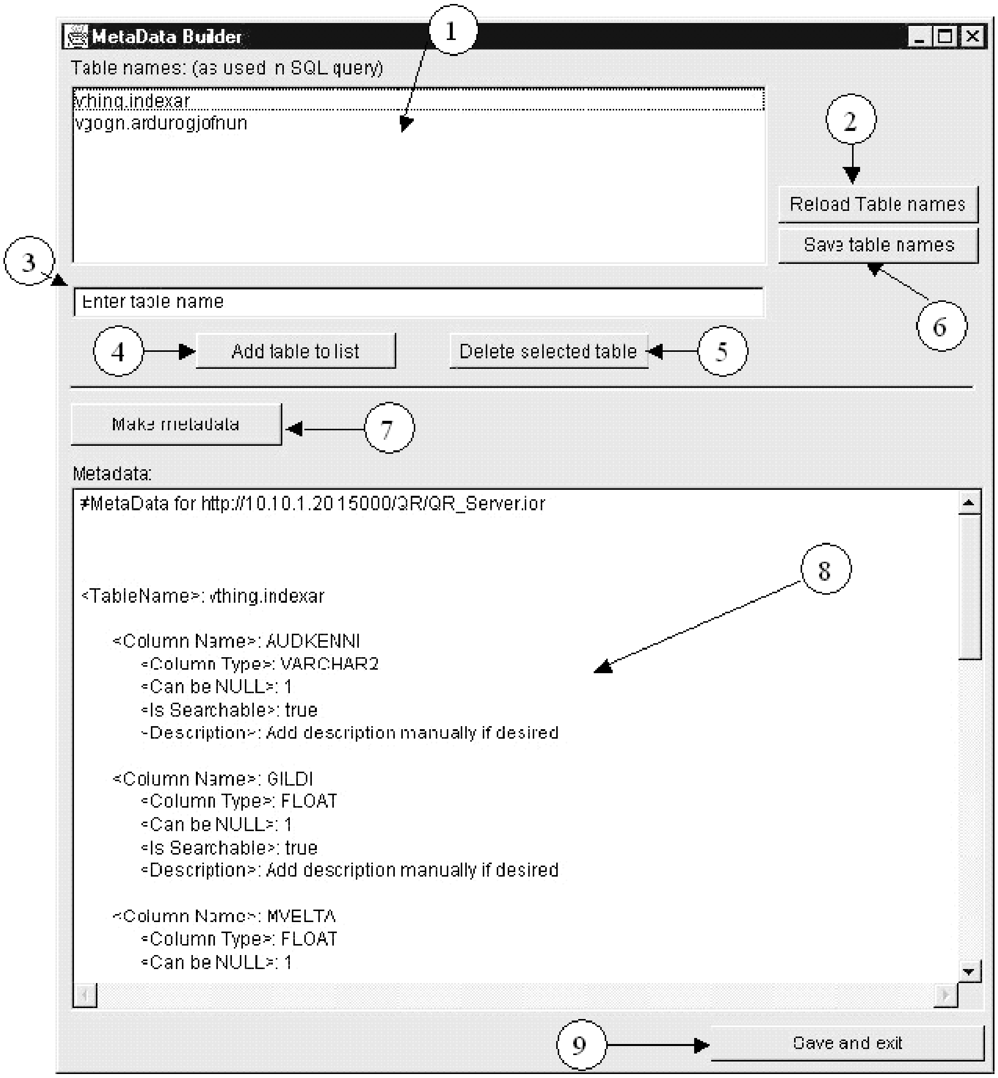
<u>*Screenshot 1.1.*</u> The main window of the server configuration tool.

1) What type of database the server will be connecting to. This is to allow for query altering to suite the database. As you can see I was connecting to an Oracle database when this shot was taken.
2) Opens the "SQL translation setup" window. See screenshot 1.2.
3) Opens the "Metadata Builder". See screenshot 1.3.
4) Points to the driver location within the driver package.
5) The database connection string
6) Username to access the database.
7) Password to access the database with username 6)
8) Specifies the address that the server will reside at.
9) Saves the information and closes the Server Configuration Tool.

All these parameters must be specified correctly before attempting to start the server program. To set these parameters correctly one must have detailed knowledge of the system that the program will be running in. In a fully finished product these parameters will be set automatically or with the help of setup wizards.



1) The type of database that the server will be connecting to. This field is automatically set when the window is opened.
2) By pressing this button one can reload the settings or change field 1) and load the table for that database.
3) The translation table itself. ‘Key’ and ‘Value’ can be a table name or an SQL keyword. Note that Oracle does not use the keyword ‘as’ and therefore it is replaced with an empty string or a space. ‘Key’ can be any table name. For instance, table might be published under the name “Student” but its real name in the database can be “Nemandi” (Icelandic for student). This feature allows the data to be published in any language and eliminates the need for changing the database itself to do so. It also allows for the possibility of querying the same database in many different languages, by having several servers running on the same machine at different ports or by passing the preferred language as a parameter along with the query.
4) Saves the translation table and exits this window.
5) Adds a new key to the table, which is the edited manually.



1) A list of table names that the metadata will be constructed from.
2) Reloads the table names, in case you make a booboo.
3) Shows the currently selected table name or a name of table to be added to list.
4) Adds the table name in 3) to the list (Does not allow duplicates).
5) Deletes the selected table name in the list (which will be shown in (3)).
6) Saves the names of the tables in the list to a file.
7) Connects to the database and outputs a metadata description to 8)
8) A text field that shows the metadata. After making the metadata it is possible to edit the metadata manually if desired. (The above diagram shows only the automatically generated metadata i.e. it has not been altered.
9) Saves the metadata and table names and exits.

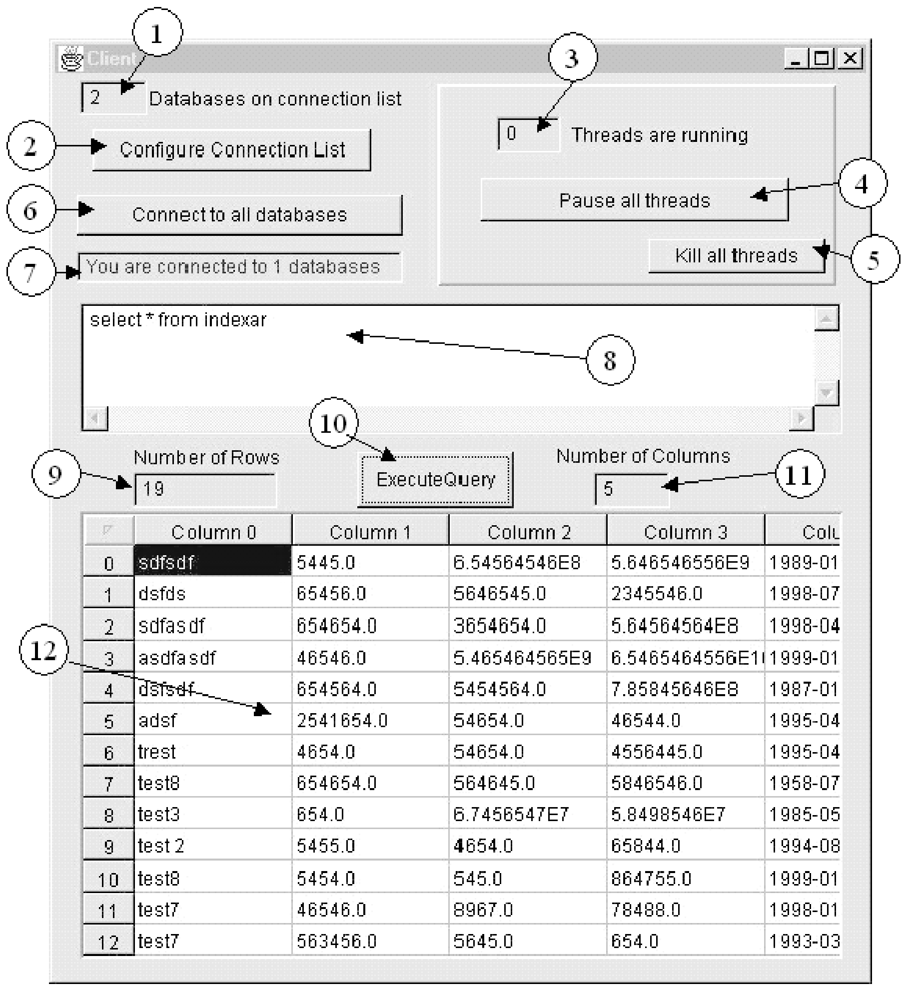
The metadata builder is almost completely automated and greatly simplifies the work of constructing the metadata. The only information needed by the Metadata Builder are the names of the tables. The metadata only needs to be manually altered if the tables are to be published under different names and if no additional information about the data is needed to access it.

Although the interfaces are rather crude in design and functionality they only require a little know-how. They basically have all the functionality that is needed by the complete product. (In a fully finished product all these configurations will probably be set with the help of a setup wizard.)

Having configured and started the server the server will wait for incoming requests by a client program.

The client

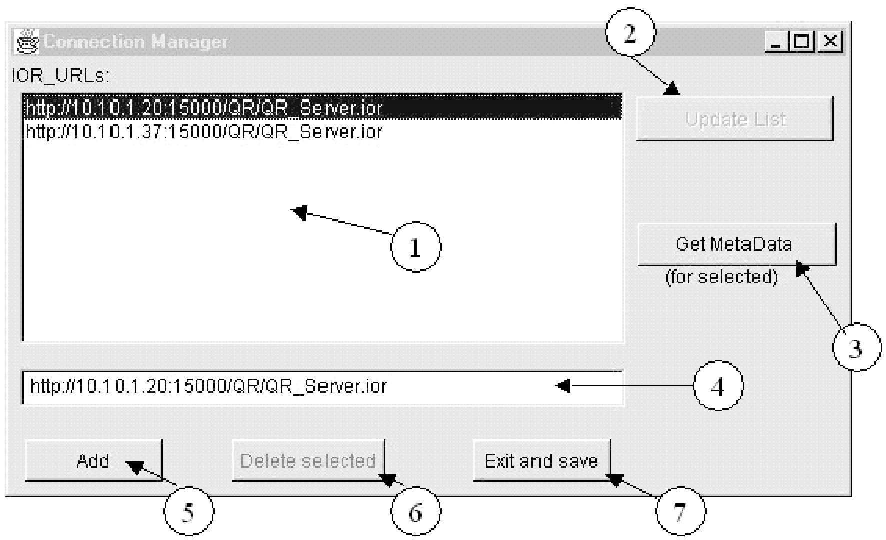
To run the client, all the same software must be set up as in the server, except for the database system. To run the client, go to the setup directory and type "java Client". The client will start and you will get the following interface.



Screenshot 2.1. The main interface of the client.

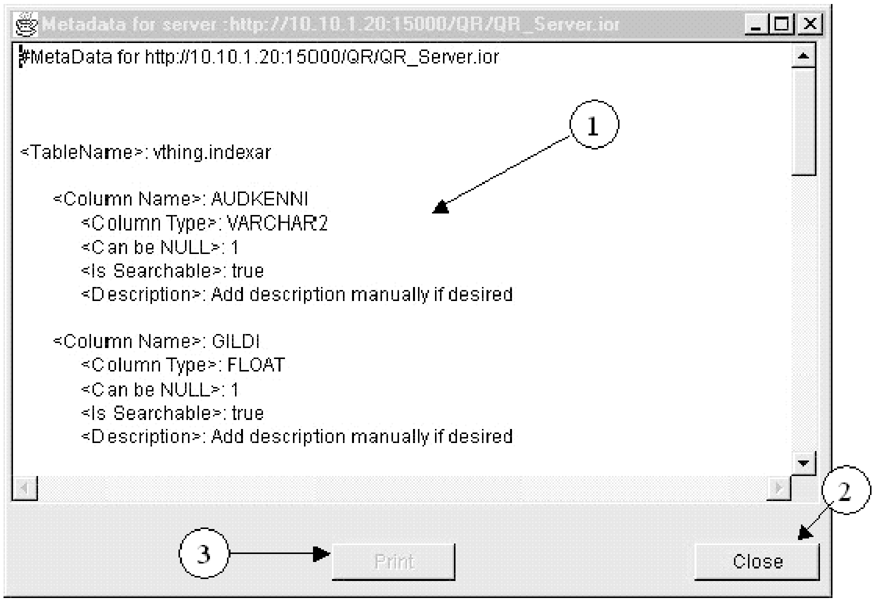
1) Shows you how many servers are on your connection list. When 6) is pressed the client will attempt to connect to all those databases.
2) Opens the connection manager. See screenshot 2.2.
3) Shows how many databases the client is querying.
4) Pauses all querying of the databases.
5) Stops all querying of the databases

6) Pressing this makes the client attempt to connect to all the databases on the connection list.
7) Shows how many databases the client is actually connected to. In this screenshot you can see that the client was only able to connect to one out of two databases (the other one was not running)
8) A textbox for entering the SQL query that you want to use to query the database(s).
9) Shows how many rows of data have so far been retrieved from the servers. This number is incremented as the client receives data from the servers.
10) Executes the query in 8). This button is only active when the client is connected to one or more servers.
11) Shows the number of columns returned.
12) Table that shows the data received from the servers. This table is actually hidden when the servers are being queried. Hiding this table when the client was receiving the data increased speed greatly. This is also the reason for adding 9) and 11), so it could see how things were progressing.



Screenshot 2.2. Interface to configure the connection list.

1) The list containing the addresses of the remote servers.
2) This was intended to get the list of all available servers from a web page. I did not have time to finish the function. All the addresses are stored in a file and this file can be found on a web page and replaced manually.
3) Gets the metadata for the server (database) selected. See screenshot 2.3.
4) Shows the address of the selected server or an address of a server to be added.
5) Adds the address in 4) to the connection list (does not allow duplicates).
6) Deletes the selected server address
7) Saves the list of addresses and closes the window.



Screenshot 2.3. A simple window showing metadata information.

1) The metadata for the database.

2) Closes the window.

3) For demonstration purposes.

To access and query a remote database you would take the following steps.
1) Open the connection manager and find the database(s) you want to query. Delete from the list all the databases you do not want to query.
2) Get the metadata for the databases you wish to query.
3) Connect to the databases by pressing the "Connect to all databases" button. (When the databases are connected the "Execute query" button will be enabled and connection status will be displayed.)
4) Write a query based on the metadata of the databases that you are querying.
5) Press the "Execute query" button. When the query is finished the number of running threads will be 0 and the data will appear in the table (if any data is returned)

With a little cosmetic surgery and a little added functionality this prototype could actually be a very usable product. Simple isn't it?

C.3 References

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D Migration model

D.1 Migration model - some concepts

Purpose with model.

- Formulation and bettter understanding of the mechanisms and factors governing migrations and spatial distributions
- To develop a tool for testing of hypothesis about migrations and spatial distributions
- Construct a migration module as a part of a larger "multispecies ecological model".

Model will be generic, i.e. not specific for a particular area or species.

Possible factors affecting direction, timing and speed of spawning migrations:

- Location of the spawning grounds and feeding grounds
- State of maturity (or physiological state). Fish may halt their migration (e.g. at a cold/warm water boundary) until a certain physiological threshold is reached, or alternatively take a different route. The physiological state may be a function of temperature and feeding conditions during the previous summer.
- Sea currents (wind direction may influence currents). Sea currents influence the speed of the migration but the edges of certain currents may also act as a boundary along which the migrating schools travel (e.g. capelin travel along the eastern edge of the East-Greenland Current in their northward feeding migrations.)
- Boundary between warm and cold water and certain isotherms. Fish may not cross certain cold/warm water boundaries or isotherms (e.g. -1?C).
- Size of stock. Most likely to influence feeding migrations, but spawning may vary in space and time with the size of the spawning stock.
- Different mechanisms at work in spawning and feeding migrations.
- Food density and distribution unlikely to affect spawning migrations

Required features of a migration model (?):

- A number of runs to the spawning grounds, possibly along different routes.
- Part of the stock may undertake feeding migrations; part may stay in the same location more or less.

- Location of spawning (and route) depends on the physiological state (state of maturity) of the females
- Route follows the boundary between warm and cold water masses.
- Variable speeds, but geographical path "fairly" constant, but timing may vary.
- Parameterization such that model can be tested on available data.
- Migration model should be coupled to models of food consumption, growth and maturity.
- Crossing of cold/warm water boundary delayed until maturity threshold is reached.

Question: Is it possible to use the same model but with different parameter value (or functions) for both spawning migrations and feeding migrations and/or spatial distributions due to feeding? For example, will the stochastic spatial interaction model be sufficient if spawning migrations are characterized by a low noise value and a prespecified mean direction in the random term, and feeding migrations/distributions by a high noise value together with a mean direction determined primarily by food density.

Required specifications

- Define the overall domain within which the stock remains at all times (boundaries; latitude north and south, and longitude east and west)
- Define the different types of boundaries: Permanent boundaries: depth contours (land masses) Variable zero flux boundaries: specified isotherms, current boundaries Boundaries which are only crossed when value of "internal variable" exceeds a given threshold, e.g. some cold/warm water boundaries like off Southe-East Iceland
- Specify behaviour at boundaries, i.e. do schools move along boundaries or are they "reflected of them (the former more likely)
- Specify velocity field of sea currents and its dependence on time
- Cruising speeds of schools
- "Overall" direction of migration. May apply more to spawning migrations, feeding migrations are probably more or less governed by temperature and food distribution. Define an attracting point or attracting region. Another possibilty is to define an attracting path but the former is probably simpler.
- How the density distribution of food (plankton) affects the movements of the fish schools (applies to feeding migrations, limited effects in the case of spawning migrations)
- How the fish affect the (local) density of food (feeding movements)

Equations of motion - some suggestions and thoughts

Continuous model:

$$\frac{\delta \rho}{\delta t} + \nabla \cdot (v\rho) = 0 \qquad \text{(continuity equation)}$$

$$\frac{\delta v}{\delta t} + (v \cdot \nabla) v = \frac{1}{\rho}\ (Forces) \qquad \text{(velocity equation)}$$

Specification of *Forces*:

Alignment forces and directional force.

How to direct the "schools" to a specified area:
Define an attracting point or area.
Define an attracting path.

Continuous model and attracting point.

$$\frac{D\mathbf{v}}{Dt} = a(\mathbf{v}_{\mathrm{g1}} - \mathbf{v}) + b(\mathbf{v}_{\mathrm{g2}} - \mathbf{v}) + \ldots$$

where the two guiding velocities (reference velocities) the average velocity in a neighbourhood of the point $\mathbf{x}$ and a velocity given by the present position and an attracting point $\mathbf{x}^*$ (which may be a random point in a region)

$$\mathbf{v}_{\mathrm{g1}} = \frac{\mathbf{x}^* - \mathbf{x}}{\|\mathbf{x}^* - \mathbf{x}\|} v_c$$

where v_c is some average cruising speed. The average velocity in a neighbourhood Ω in R^2 is

$$\mathbf{v}_{\mathrm{g2}} = \frac{\iint_\Omega \rho(\xi, t)\boldsymbol{v}(\xi, t)\mathrm{d}\xi}{\iint_\Omega \rho(\xi, t)\mathrm{d}\xi}$$

Alternatively

$$\mathbf{v}_{\mathrm{g2}} = \frac{\iint w(\boldsymbol{x}, \xi)\rho(\xi, t)\boldsymbol{v}(\xi, t)\mathrm{d}\xi}{\iint w(\boldsymbol{x}, \xi)\rho(\xi, t)\mathrm{d}\xi}$$

where one possible kernel $w(\boldsymbol{x}, \xi) = w(\xi - \boldsymbol{x}) = 1$, if $|\xi - \boldsymbol{x}| < R$, and zero othewise.

The velocity equation can be written as

$$\frac{D\mathbf{v}}{Dt} = (a+b)\Big(\frac{a\mathbf{v}_{\mathrm{g1}} + b\mathbf{v}_{\mathrm{g2}}}{a+b} - \mathbf{v}\Big) + \ldots$$

and thus the overall guiding velocity is the weighted average of the two separate guiding velocities.

Temperature potential

Need to define temperature contour lines (isotherms). Specify reaction of fish to temperature. Possiblities:

1. Define a range within which the fish like to stay.
2. Specify increased avoidance of "more and more extreme temperatures."
3. Specify isotherms which the fish will not cross.

Temperature function T(x,y). Define preferred temperature range (T_l,T_h). We may then define a force field

$$\boldsymbol{F} = \mathrm{g}(T(\boldsymbol{x}))\nabla T(\boldsymbol{x})$$

where the function g(T) is positive if $T < T_l$; zero if $T_l < T < T_h$; and negative if $T > T_h$.

Internal variable (physiological variable, e.g. energy state, state of maturity)

Density can be stuctured according to internal state (m) as well as by location, i.e. $\rho(t,x,y,m)$. The continuity equation becomes

$$\frac{\delta\rho}{\delta t} + \nabla_x \cdot (\boldsymbol{v}\rho) = -\frac{\delta}{\delta m}(G\rho)$$

where $\frac{\mathrm{d}m}{\mathrm{d}t} = G(E,m,)$ and E is the internal energy reserve, governed by $\frac{\mathrm{d}E}{\mathrm{d}t} = F(m,\boldsymbol{v},..)$

D.2 Description of Forces

The forces which act on fish and fish schools can be divided into the following groups:

1. Passive forces (currents).
2. Active forces:
   (a) long time forces
      - external (environmental) forces, i.e. temperature, salinity gradients, food gradient, predator avoidance, etc.);
      - internal (genetic) forces (attracting points or domain for (spawning, food) migration, memory, etc.)

   (b) short time forces (force for grouping fish in schools, average speed, food, predator avoidance).

Passive force can be obtained from the velocity field of currents. We can suppose that this velocity field is independent of time or that it depends on time very weakly.

The behavior of environmental forces is that these forces act along gradients of temperature $\boldsymbol{T(t,x)}$, salinity $\boldsymbol{S(t,x)}$, food density $\boldsymbol{Z(t,x)}$, predator density $\boldsymbol{Y(t,x)}$ towards the best conditions for all these factors. For example if $\boldsymbol{T^*(t)}$, $\boldsymbol{S^*(t)}$ are the best temperature and salinity at time $\boldsymbol{t}$, then the corresponding forces could be taken proportionally to such expressions as -$\nabla\boldsymbol{(T(t,x)-T^*(t))^2}$, and -$\nabla\boldsymbol{(S(t,x)-S^*(t))^2}$, respectively, where $\boldsymbol{x}$ is a point of space. The directions of these forces are to the points where the magnitude of difference between real factor and the best factor is the least. In case of food our force is proportional to and has the direction of $\nabla\boldsymbol{Z(t,x)}$, in case of predators it is proportional to and has the direction of -$\nabla\boldsymbol{Y(t,x)}$.

Analogously, in the case of internal forces. Let $\boldsymbol{d(x,\Theta)}$ be the distance between the point $\boldsymbol{x}$ and the spawning zone $\boldsymbol{\Theta}$. Then the attracting force is proportional to the expression -$\boldsymbol{\omega(t)}\nabla\boldsymbol{d(x,\Theta)}$, where $\boldsymbol{\omega(t)}$ is the coefficient of the degree of attraction, this coefficient depends on time, because at some times of the year this coefficient is equal to 0 when we have no attraction to the spawning zone (eg. after spawning period, feeding migration), and it becomes not equal to 0 only at time of spawning migration, or shortly before that time. We could consider the average previous path (the location at the same time in previous years) we could consider as attracting points for the memory.

Let $\boldsymbol{\zeta(t-T)}$ be the average position of the points (fish) at times $\boldsymbol{t-T}$, where $\boldsymbol{T=1,2,\ldots}$ years. This average path is some function of the position density at previous times, for example the space integral over all domain of the function $\boldsymbol{x\cdot\rho(x,t-T)}$ over all density, where $\rho(x,t)$ is density of fish in the point $\boldsymbol{x}$ at the time t. Let $\boldsymbol{d_1(x,\zeta(t-T))}$ be the distance between the point $\boldsymbol{x}$ and the average path $\boldsymbol{\zeta(t-T)}$. Then the memory forces at time $\boldsymbol{t}$ could be expressed as -$\boldsymbol{\omega_1(t)}\nabla\boldsymbol{d_1(x,\zeta(t-T))}$.

The short time forces have the property that they act for a short time, and corresponding movement, due to stochastic nature of these forces, has some random noise. We include the food abundance and predator risk we include in both short and long time groups of forces. It depends on the problem under consideration what is more appropriable. In the both cases the forces are the same.

When we consider movement of such objects as fish, birds, etc. we consider these objects as objects which move in some groups, schools, flocks, etc. So, we have present some force of grouping. This force depends on the density of objects in the following way. If density of group is higher than some optimal density ρ^* , then this force acts so as to spread objects to the areas with lower density, if density is lower than ρ^* , then this force acts in the direction of higher density for grouping in higher dense groups. For such a force we could consider such expression $-\rho(t, x)(\rho(t, x) - \rho^*) \cdot \nabla \rho(t, x)$.

T.Vitsek and A Czirok considered a discrete variant of the force which acts according to some averaging of velocities with some noise. More precisely they considered the following properties

$$\mathrm{v}(t + \Delta t, r_i(t + \Delta t)) = E(\mathrm{v}(t, r_j(t)) \mid r_j(t) \in U(r_i(t))) + \xi_t, \tag{1}$$

where $\mathbf{v}(t, r_j(t))$ is the velocity of the j-th particle at time t, $r_j(t)$ is the position of this particle at that time, $E(v(t, r_j[t)) \mid r_j(t) \in U(r_i(t)))$ is the average speed of such particles which are within the surrounding area $U(ri(t)) = y :\mid y - ri(t) \mid < R$, ξ_t is the random noise.

If we let Δt tend to 0, we get the system of algebraic equations

$\mathrm{v}(t, r_i(t)) = E(v(t, r_j(t)) \mid r_j(t) \in U(r_i(t)))$.

This system has the following property. If we can connect two points $r_k(t)$ and $r_l(t)$ using the broken line with the corners in the points $r_j(t)$ and the maximum length of all links of this broken line less than some number R, then this two points belong to the same group. The velocity of the points in the same group is equal one to another, but the velocity in different groups could be different. So, we have the same speed in some fixed group. This result is confirmed experimentally as asymptotic behavior of the system (1) in A Czirok, T.Vitsek and S.Hubbard investigations.

Density

Consider a small domain V in n-dimensional Euclidean space (n=2) with the boundary S.The particles move into or out of this domain over its surface or boundary. If dS is an element of this surface (the magnitude of dS being the area of the element and its direction the outward normal) and $\mathbf{u}(t, x)$ is the velocity at the position of this element, it is the the component of u parallel to dS that transfers particles out of V. Thus, the outward density flux (density flow per unit time) though the element is $\rho \mathbf{u} \cdot dS$, where ρ is the density of particles. Hence, the number of particles lost from all the volume V is equal to:

$$\int_S \rho u \cdot dS.$$

We also have that the total number of particles in volume V is:$\int_{\boldsymbol{V}} \boldsymbol{\rho \cdot dV}$**.**

Hence,

$$\frac{d}{dt}\int_V \rho \cdot dV = \int_V \frac{d}{dt}\rho \cdot dV = -\int_S \rho u \cdot dS.$$

In case when we do not have any mortality or other sources of appearance or disappearance of particles. Since we are interesting in density balance at the point, rather than over an arbitrary finite volume, we allow $\boldsymbol{V}$ to shrink to an infinitesimal volume. Hence, using the mean principle we get that:

$$\frac{\partial}{\partial t}\rho = -\lim_{V \to 0}\int_S \rho u \cdot \mathrm{d}S.$$

That is

$$\frac{\partial \rho}{\partial t} = -\mathrm{div}(\rho u). \tag{2}$$

This gives the general expression representing particle number conservation. In the case of fish movement this equation is the conservation of the number of fish without any another sources of appearance or disappearance of fish (i.e. without mortality, fishing, etc.) Suppose the coefficient of mortality is equal to a number μ. Then, the number of particles lost from all the volume V equals

$$\mu \int_V \rho \cdot dV + \int_S \rho u \cdot dS$$

and making the same transformation, we get the equation for conservation of the number of particles in the form

$$\frac{\partial \rho}{\partial t} + \mathrm{div}(\rho u) = -\mu \cdot \rho. \tag{3}$$

The mortality rate could depend on time, position, and density of particles. For example we can consider as the constant value of this parameter to be logistical value according to the logistical expressions in Lotka-Volterra models.

Velocity

We start from fundamental properties of movement which depend on position and velocity. Newton's equations are

$$\frac{dx}{dt} = u, \qquad\qquad m\frac{du}{dt} = F.$$

where $\boldsymbol{x}$, $\mathbf{u}$ are the position and velocity of the point, $\boldsymbol{m}$ is mass. In our variant the mass is proportional to the density of particles(fish), so, the second equation we can rewrite as:

$$\rho\frac{du}{dt} = F.$$

Using the stochastic behavior of forces which act on fish, birds, etc., we can separate the stochastic part of this forces, and get the stochastic variant of Newton's law

$$\rho \cdot \mathrm{d}u = F \cdot \mathrm{d}t + \mathrm{d}W(t),$$

where $\boldsymbol{W(t)}$ is a Wiener process. The differential for velocity we can write in the form $\frac{du}{dt} = u_t + u\nabla u$, or $du = (u_t + u\nabla u) \cdot dt$.

The boundary conditions for velocity we take to be

$$(u, n)|_{\partial\Omega} = 0,$$

where $\boldsymbol{n}$ is the outward normal to the boundary $\boldsymbol{\partial\Omega}$ of the domain $\boldsymbol{\Omega}$. For all problems we include also the initial conditions for densities and velocities of particles

$$u(0, x) = u_0(x), \qquad\qquad \rho(0, x) = \rho_0(x).$$

.

The forces to be considered could be of the following kind:

1. Behavior of fish, for example grouping of the fish in schools, movement with some average speed, etc. This is the short time behavior, and we can separate short time forces and long time forces as the non-stationary and stationary forces. Stationary forces are the forces that are constant forces in time, but non-stationary forces will depend on time and other characteristics of system of particles. The grouping fish in schools is the behavior of the system of movement of fish under some stationary forces, and grouping force. In accordance with this we could write the equation for velocity as:

$$\rho \cdot (u_t + u\nabla u) \cdot dt = (-\rho(\rho - \rho^*)\nabla\rho + F) \cdot \mathrm{d}t + \mathrm{d}W(t),$$

   where ρ^* is the average density of fish in fish schools, $\boldsymbol{F} = \boldsymbol{F(x)}$.

2. Interaction between prey and predator.

(a) Let the prey be zooplankton with density $\boldsymbol{Z(t,x)}$, and the predator be fish with density ρ. Consider the equation for zooplankton density in the form

$$Z_t + U\nabla Z = \nu\Delta Z + P(Z) - E(Z,\rho),$$

where ν is the diffusion coefficient, mostly caused by turbulence of currents, $\boldsymbol{U}$ is the velocity field of sea currents, $\boldsymbol{P(Z)}$ and $\boldsymbol{E(Z,\rho)}$ are the logistic functions for growth-mortality, and grazing by predator with density ρ. Then we have, for example (S.Petrovskii, H.Malchow)

$$P(Z) = -aZ(Z - Z_1), \qquad E(Z,\rho) = \upsilon\frac{Z}{Z + Z_2}\rho.$$

The equation for density of predators we express in the form

$$\rho \cdot (u_t + u\nabla u) = \lambda\Delta u + \alpha\nabla Z + F,$$

the force $\boldsymbol{\alpha\nabla Z}$ in this equation means that the attracting points for movement of fish are the points with higher food and zooplankton densities.

(b) The prey and predator are fish of different kind, for example capelin and cod, larvae and fish. Let ρ_1 and ρ_2 be the densities of predator and prey, respectively, and $\mathbf{u_1}$ and $\mathbf{u_2}$ be their they velocities. Then we get the following equations:

$$\rho_1 \cdot (u_{1_t} + u_1\nabla u_1) = \lambda_1\Delta u_1 - \alpha_1\nabla\rho_2 + F_1,$$

$$\rho_2 \cdot (u_{2_t} + u_2\nabla u_2) = \lambda_2\Delta u_2 + \alpha_2\nabla\rho_1 + F_2,$$

and the equations for conservation of density

$$\rho_{1_t} + \operatorname{div}(\rho_1 u_1) = -\mu(\rho_1,\rho_2)\cdot\rho_1,$$

$$\rho_{2_t} + \operatorname{div}(\rho_2 u_2) = 0.$$

3. Movement of fish to the different attracting points we could be expressed in a similar way with the force for grouping and other forces, i.e. forces which act as memory, as the attraction to the spawning grounds etc.

There are some interesting problems of analysis relating to the comparison of different forces that act on particle systems. Also there are a lot of other questions, for example, about the stationary state of particle systems, about collapse, aggregation, blow-up of solutions, questions about local and global solvability, uniqueness of solution, approximation, asymptotic and numerical methods for solving these problems.

D.3 Collective motion and phase transition

Primary model

The model consists of a collection particles moving on a plane, within a square cell with periodic boundary conditions. The particles are constructed to be self-propelling, with a prescribed unchanging magnitude of velocity v. Their direction is given by the average direction of motion of particles found to be within a local neighbourhood, together with the addition of a random component, whose size is linearly related to η. These two features can be thought of as modelling the non-perfect matching of a particles velocity to that of its near neighbours.

For unit time step and local neighbourhood unit radius, the model has three free parameters : η (noise amplitude), ρ (density) and v (magnitude of velocity).

This simply defined system has two distinct phases, which can be obtained by varying the free parameters, mainly the noise amplitude or density. For the case of high density and small noise the motion of the particles becomes ordered, all particles aligning themselves in roughly the same direction. Whereas for small density and noise the particles tend to form small groups moving coherently in random directions. These phases may be compared to the two typical migrations of fish stocks. Spawning migrations, where the fish all move to a spawning area, and feeding migrations, where smaller schools swimming independently of each other around the feeding area.

Mathematical model

A square cell is defined by its side length L, and the boundaries are taken to be periodic.

At time t = 0, the N particles have
(i) a randomly distributed position in the cell,
(ii) the same magnitude of velocity, v, and
(iii) a randomly distributed directions θ_ι.

The velocities $\underline{v}_i$ of all of the particles are then determined simultaneously at each time step. The position of the i th particle, at time step t+1, is given by

$$\underline{x}_i(t+1) = \underline{x}_i(t) + \underline{v}_i(t)\mathrm{d}t, \qquad (1)$$

where dt is the size of the time step.

Velocity $\underline{v}_i(t+1)$ has absolute value v and a direction $\theta_i(t+1)$, which where obtained from

$$\theta_i(t+1) = <\theta(t)>_{ir} + \mathrm{d}\theta_i. \qquad (2)$$

where, if P is some property of the particles within the system, $<P>_{ir}$ denotes the average of property P of the particles within a circle of radius r surrounding particle i, including particle i. $< \theta(t) >_{ir}$ denotes the average direction, given by

$$< \theta(t) >_{ir} = arctan[\sum_j sin(\theta_j(t)) / \sum_j cos(\theta_j(t))], \qquad (3)$$

where the j th particle is within the neighbourhood of particle i. That is

$$(x_i - x_j)^2 + (y_i - y_j)^2 \leq r^2. \qquad (4)$$

$d\theta_i$ is a random number chosen with uniform probability from the interval $[-\eta/2, \eta/2]$.

The density of the system is defined as $\rho = \mathrm{N}/\mathrm{L}^2$.

Simulation

A numerical simulation of the system was undertaken, and the results of two such simulations are given in figures 1 and 2, showing the two phase types. The short continuous curves in the figures show the particles trajectory for the last 20 time steps.

The values of the parameters used in the simulations which produced these figures are stated below : $dt = 1$, $v = 0.03$, $\mathrm{N} = 300$, $r = 1$, $\eta = 0.1$,

(a) $\mathrm{L} = 25$, $(\rho = 0.48)$ small density, small noise
Particles tend to form groups moving coherently in random directions.

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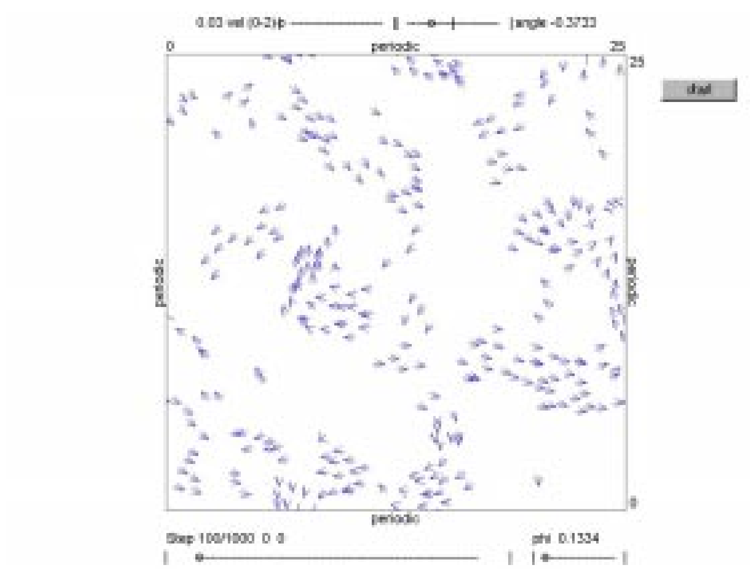

Figure 1:

(b) L = 5, ($\rho = 12$) high density, small noise
Motion is ordered, in a random direction. The final direction is not prescribed, but is determined by initial conditions.

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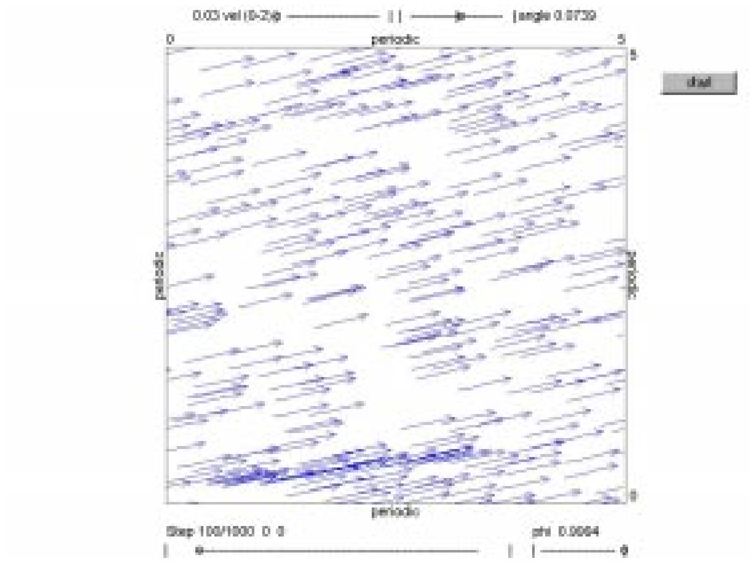

Figure 2:

The system maybe characterization by the definition of the absolute value of the average normalised velocity, v_a,

$$v_a = 1/(N.v)|\sum_{i=1}^{N} \underline{v}_i|. \tag{5}$$

The average normalised velocity, v_a, will be close to zero in the case of the small coherent groups. It will increase in value as the system becomes more ordered, eventually being very close to one for the case of ordered motion.

The transition from a disorderly moving phase to a phase with almost uniform motion can be observed by reducing the amplitude of the noise in the system. Figure 3 shows the variation of the average normalised velocity, v_a, with the noise amplitude, η/π, for three different configurations. The systems only differ in cell size L, and the number of particles N, but in such a way that the density is constant, all other parameters are kept constant. Each curve denotes the average of 10 simulations at the relevant system configuration.

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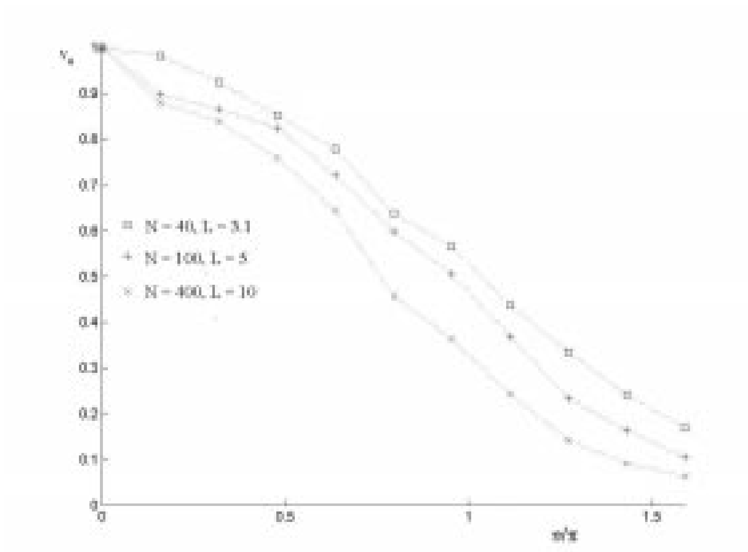

Figure 3:

The system is considered to be on a steady state when the cumulative average, V_a,

$$V_a(\tau) = (1/\tau)\int_0^{\tau} v_a(t)dt, \tag{6}$$

converges. V_a is considered to have converged when, after some initial time, the percentage change in V_a is smaller than some prescribed constant,

$$|1 - V_a(\tau + 1)/V_a(\tau)| < \varepsilon. \tag{7}$$

Secondary model

Several changes and additional features have been implemented to the initial model. These are currently under investigation.

Domain

The domain is no longer confined to a simply connected square region. Both an outer and inner boundary can be defined by a series of piecewise linear boundaries.

Boundaries

Boundary conditions have been extended, and as well as the periodicity, no includes a trailing boundary condition. See figures (4) and (5).

When a particle comes into contact with a "trailing" boundary its direction is changed so that it is orientated in the direction of the boundary itself. Of the two possibilities, the final direction which causes least deviation from the original orientation is taken.

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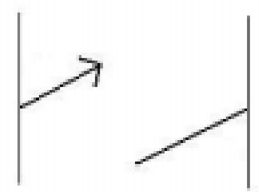

Figure 4: periodic boundary condition

Figure 5: trailing boundary condition

Speed variation

The absolute value of the velocity can also be altered in a similar way to the process used to change the velocity direction, in term of averaging over a local neighbourhood and the addition of a random component.

Velocity $\underline{v}_i(t+1)$ has absolute value obtained from

$$v_i(t+1) = \{v(t)\}_{ir} + \mathrm{d}v_i, \tag{8}$$

where $\{-\}_{ir}$ denotes the average speed of the particles in the local neighbourhood, of radius r, around particle i,

$$\{v(t)\}_{ir} = 1/n_i. \sum_j |\underline{v}_j|. \tag{9}$$

where particle j is within the local neighbourhood of particle i, and n_i denotes the number of such particles.

$\mathrm{d}v_i$ is a random component chosen with uniform probability from the interval $[-\mu/2, \mu/2]$.

Equation (3) is still used to calculate the average angle. But now that the speed of each particle is not homogeneous, the use of equation (3) is equivalent to the resultant angle of the summing of all the unit vector velocities of particles in the local neighbourhood.

The absolute value of the average normalised velocity, v_a, given in equation (4), is redefined in the obvious way as

$$v_a = 1/N.|\sum_{i=1}^{N} \underline{v}_i/v_i|. \quad (10)$$

Sub-domain

As well as the main domain, a rectangular region defined by its boundaries position and type, there is a rectangular sub-domain whose boundaries can also be defined in both position and type. The initial positions of the particles are distributed uniformly throughout this sub-domain, with the particles being confined to this sub-domain until some externally specified time.

Migration

It is desirable to make the particles move, "migrate", in a particular direction or to a predefined point. Three methods have been considered in this task, asymmetric noise, preferred direction, and preferred point.

(i) Migration point

The noise in the initial model was uniformly distributed. For the case of migratory behaviour a non-symmetric noise distribution is considered to make the particles move towards a migration point.

The distribution is given by the probability density function

$$P_m(\theta) = 0.5(1 + k_1.k_2\theta/\pi), \quad (11)$$

with

$$\theta \in (-\pi, \pi], \quad k_1 \in [0, 1], \quad k_2 \in [-1, 1]. \quad (12)$$

k_1 is an externally provided distribution parameter. A zero value giving uniform distribution, and a value of one giving the maximum asymmetry to the probability distribution.

k_2 is linearly related to the difference between the current orientation of the particle, θ, and the angle of the migratory point from the particle, θ_0,

$$k_2 = (\theta - \theta_0)/\pi + 2m, \quad (13)$$

with m chosen such that the third of conditions (13) is satisfied.

The probability density given in equation (11) is a skewed linear distribution, which can be interpreted in the following way. Assuming k_1 is non-zero, else the distribution is always uniform, when the migration point is in the right half plane, relative to the particles position and orientation, then $P_m(\theta)$ implies that the noise is more probably to the right than the left. Similarly it is more probably to the left than the right when the migration point falls in the particles left half plane. That is the noise is more likely to bre in the direction of the migration point.

There is also a migration radius, once the distance between the particle and the migration point is less than the migration radius, inside the migration region, then the noise for that particle is taken as uniform.

Figures 6 to 9 show four stages of a system with migratory behaviour. These figures shows the system while the noise is still uniform, while the particles are "migrating" to the migration region, and when "migration" is "complete".

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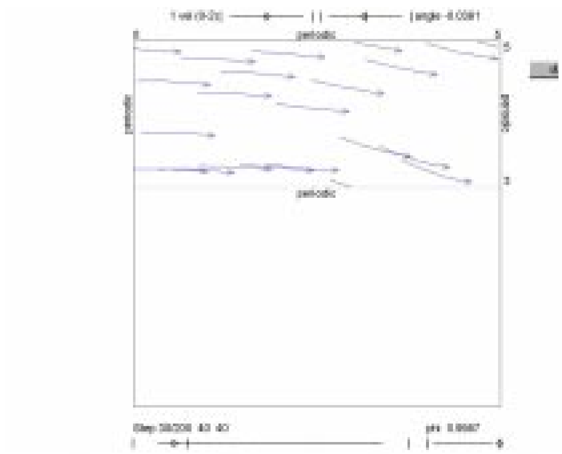

Figure 6:

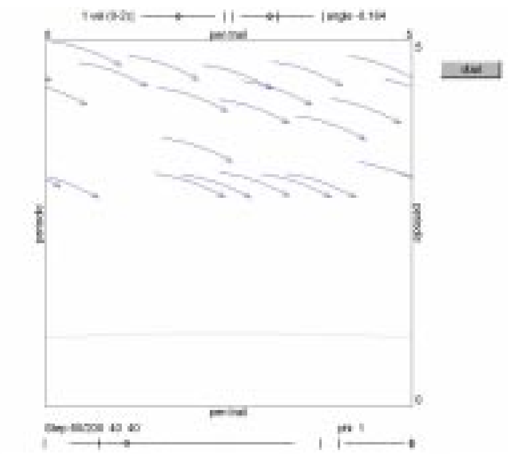

Figure 7:

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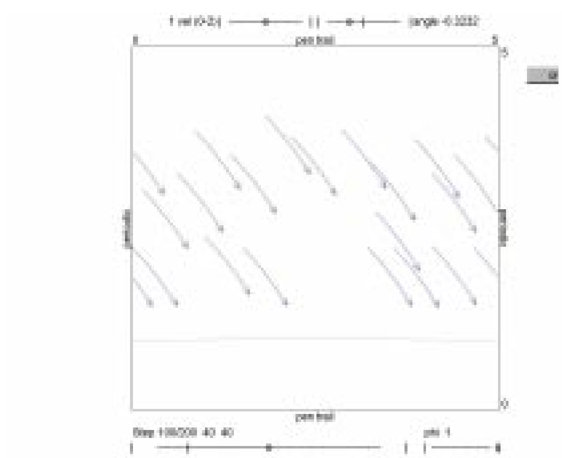

Figure 8:

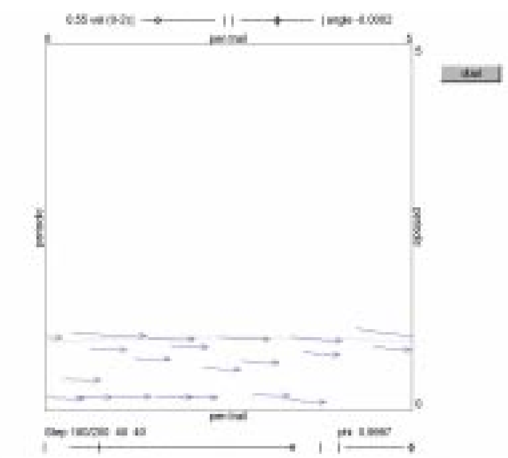

Figure 9:

Figure 6 shows the particles confined to an upper portion of the domain, with uniform noise. In figure 7 the particles are no longer confined, and the noise is now asymmetric. The migration point is defined to be on the vertical centre line of the domain, but below the lower boundary. The directions of the particles has changed towards the migration point. Figure 8 shows further movement towards the migration point, while in figure 9 most of the particles are in the migration region, and move with uniform noise again.

(ii) and (iii) Preferred direction and preferred point

The velocity of each particle can be combined in a weighted average with some predefined velocity. Given

$$e_i(t+1) = \phi_i \underline{p}_i + (1-\phi_i)\underline{v}_i(t+1),$$

(14)

$$\phi_i \in [0,1],$$

where p_i is the prescribed velocity of particle i, and $\underline{v}_i(t+1)$ is the velocity defined by the application of equations (2) and (8), local average direction and speed with some noise components. Then the new direction is now given by,

$$\underline{\theta}_\iota(t+1) = arctan[\underline{j} \bullet e_i(t+1)/\underline{i} \bullet e_i(t+1)], \quad (15)$$

where $\bullet$ denotes the standard scalar product, and $\underline{i}$ and $\underline{j}$ are unit vectors in the x and y directions respectively.

For low ϕ_i, $e_i(t+1)$ reflects the flocking behaviour, local averaging of the earlier model. For a high value of ϕ_i, $e_i(t+1)$ reflects individualistic behaviour, a preference to travel in the direction of $\underline{p}_i$.

If $\underline{p}_i$ is taken to be a vector in the direction of the migration point from each particle, then the particles will migrate to a preferred, prespecified, point. But $\underline{p}_i$ can also be defined as a single vector for all of the particles, which would result in them all migrating in the direction of $\underline{p}_i$.

Initial conditions

The initial distribution of both the speed and the direction of the particles can set be to non-uniformity.

The initial angle is given by a von Mises distribution, with probability density function

$$P_m(\theta) = 1/(2\pi . I_0({k_\theta}^0))exp({k_\theta}^0 cos(\theta - \theta_0)), \quad (14)$$

with $\theta \in [\theta_{0min}, \theta_{0max}]$. ${k_\theta}^0$ is the initial angle distribution parameter.

The initial speed is given by a truncated normal distribution, with probability density function

$$P_n(v) = 1/(A_0({k_v}^0))exp(-{k_v}^0(v - v_0)^2), \quad (15)$$

with both $v \in [v_{0min}, v_{0max}]$, and $0 \leq v_{0min} \leq v_{0max} \leq 2.{k_v}^0$ is the initial speed distribution parameter, and

$$A_0({k_v}^0) = \int_0^2 P_n(v)dv. \quad (16)$$

Further considerations

A local neighbourhood forward weight, or elongated, proportional to particles speed.

A combination of repulsive (collision avoidance) and attractive (flock centring) “forces” could be employed to ensure that the particles position themselves at a preferred distance to their neighbours. Flock centring correctly allows simulated flocks to bifurcate.

When there is the possibility of more than one “force” acting on the particle, the simplest way to combine them is through a simple sum. But care must be taken as simple summing of “forces” can lead to cancelling, prioritised “force” allocation is needed.

In reality the complexity of each particles “decision” about future velocities does not grow with the size of the school or flock. Simple models are $O(N^2)$, N is population size, as each particle has to check to see if each other particle is in its neighbourhood.

E Some submodels

E.1 An implementation of growth

Gunnar Stefánsson

1. Introduction

Early models of fish population dynamics tended to focus on individual aspects of the dynamics, one at a time. Thus, the virtual population analysis (VPA) of Gulland (19659 contains only mortality components, the von Bertalanffy growth curve includes only growth, single-species yield per recruit analysis normally only considers a fixed growth and mortality pattern, although some simple density dependence can also be included (Beverton and Holt, 1957). Similarly, early multispecies models only considered the effects of predation on mortality (MSVPA) as in Helgason and Gislason (1979) or other single effects such as of consumption on growth Magnusson and Palsson (1991).

More comprehensive single species models such as Stock Synthesis (Methot, 19xx) include many of these components at the same time, e.g. a mortality model, and a growth model and a thus selection pattern based on length rather than age can be used.

Recent multispecies models of fish population dynamics such as MULTSPEC (Tjelmeland and Bogstad, 1989) and Bormicon (Stefansson and Palsson, 1995) include not only mortality and growth functions, but the growth functions can be dynamics and will typically depend on the amount consumed. The varous processes which need to be accounted for in these models are described e.g. in Stefansson and Palsson (1998). At a given time step and area, these models typically have as their main internal component the number of fish in an age and length group. Growth models become an issue of how to transfer fish between length groups. Both MULTSPEC and Bormicon include very simple models of these updates.

This paper describes a growth modelling technique which is considerably more flexible and lends itself to statistical estimation and evaluation methods. This particular approach is developed as a part of a new area-disaggregated multispecies model, Gadget.

2. Updating length distributions

Fish population dynamics are modelled in MULTSPEC and Bormicon through forward simulations of fish populations, allowing fish to migrate between areas, die, grow, mature and spawn. The basic unit in these models is the number of fish in a certain model "cell". The fish in a "cell" are in the same age and size group, in the same region and time step. When this basic model formulation is used, the numbers in a "cell" need to be updated during a given time step, so as to reflect all processes being modelled. In addition to growth, these processes include migration, spawning, natural and fishing mortality. Only growth will be considered in this document.

A given amount consumed predicates an average growth for the fish in a given "cell". This growth can be either in weight or length or both, but only length growth will be considered here.

A common approach is to start with a predicted average length increment (Δ) based on consumption and to try to distribute fish in the length class into upper length classes in a reasonable manner. Simple techniques may use only few upper length intervals and use a simple ad-hoc update scheme. The update scheme needs to be evaluated in terms of its ability to provide adequate eventual length distributions. This sets some immediate bounds on the dispersion at each time step, since an overly high or low variance in the length update will quickly result in inadequate final length distributions at age for the oldest ages.

The length update scheme can most easily be implemented through a look-up table, where a discrete set of Δ-values is provided along with the distribution to be used for reallocating the length group when the chosen growth is Δ. This is undesirable for many reasons. Firstly, the setup is completely rigid as there is no built-in parameter to describe possible possible deviations of growth from the specified distribution and hence data on growth may adversely affect parameters in other parts of a complex model only because of incorrect specification of the rigid relationship. Secondly, a simple discrete (rounded) lookup provides a nondifferentiable likelihood function which will result in estimation problems later on.

What is needed is a way to specify a flexible parametric distribution with enough parameters to allow minimal flexibility to track length distributions of an age group, yet with enough parsimony in parameters to allow for the estimability of the parameters involved.

2.1 A formal model for the update

Although a first step might be to attempt to estimate individual probabilities, these would result in far too many parameters. Another approach would be to estimate variance, skewness and kurtosis and go from these to transition probabilities, but there is no trivial transformation between the two.

A flexible distribution such as the 4-parameter inverse lambda distribution could probably be used (Ramberg et al, 1979), but parameter estimation tends to be difficult. Similarly, a binomial distribution (or even a a (truncated) Poisson) can be used, but both are completely rigid, since the value of Δ completely specifies the single free parameter in each of these distributions (assuming the number of permissible length group increases to be fixed).

The beta-binomial distribution can be used as a simple alternative. This approach can be formulated so as to provide a single estimable parameter in addition to the mean, which is specified by Δ.

First consider the binomial distribution which is defined for integers, $x = 0, \ldots, n$ by

$$\binom{n}{x} p^x (1-p)^{n-x} = \frac{\Gamma(n+1)}{\Gamma(x+1)\Gamma(n-x+1)} p^x (1-p)^{n-x}$$

Using this distribution for the issue at hand, for a given n, the other parameter, p, of this distribution, is fully defined since $\mu = np$ and the mean growth is given as the specified Δ, which fixes $p = \Delta/n$. Although this distribution can certainly be used, it is clear that no flexibility is allowed at all and in fact it would be quite unlikely for such a rigid distribution to satisfy the specified requirements of attaining the correct final distribution of length at age.

A common approach to more flexibility is to allow the parameter p itself to come from another distribution, often the beta distribution.

The beta distribution is defined for arbitrary values of $\alpha > 0$ and $\beta > 0$ by

$$f(p) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1}(1-p)^{\beta-1}, \quad 0 \leq p \leq 1 \tag{4}$$

and it is well-known that the mean of this distribution is given by

$$E(p) = \frac{\alpha}{\alpha+\beta} \tag{5}$$

Thus, rather than using a fully specified binomial distribution, more flexibility is obtained by using this combined beta-binomial distribution. This approach results in the following marginal distribution of the length increments:

$$\begin{aligned}
P[X=x] &= \int_{p=0}^{1} P[X=x|p]f(p)dp \\
&= \int_{p=0}^{1} \frac{n!}{x!(n-x)! <} p^x(1-p)^{n-x} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1}(1-p)^{\beta-1} \\
&= \frac{\Gamma(n+1)\Gamma(\alpha+\beta)}{\Gamma(x+1)\Gamma(n-x+1)\Gamma(\alpha)\Gamma(\beta)} \int_{t=0}^{1} p^{x+\alpha-1}(1-p)^{n-x+\beta-1} \\
&= \frac{\Gamma(n+1)\Gamma(\alpha+\beta)}{\Gamma(x+1)\Gamma(n-x+1)\Gamma(\alpha)\Gamma(\beta)} \frac{\Gamma(x+\alpha)\Gamma(n-x+\beta)}{\Gamma(n+\alpha+\beta)} \\
&= \frac{\Gamma(n+1)}{\Gamma(n-x+1)\Gamma(x+1)} \frac{\Gamma(\alpha+\beta)}{\Gamma(n+\alpha+\beta)} \frac{\Gamma(n-x+\beta)}{\Gamma(\beta)} \frac{\Gamma(x+\alpha)}{\Gamma(\alpha)}
\end{aligned}$$

Since for any positive number, y, the relationship $\Gamma(y+1) = y\Gamma(y)$ holds, it also follows that for any integer $x \geq 1$ and $\alpha, \beta > 0$,

$$\frac{\Gamma(x+\alpha)}{\Gamma(\alpha)} = (x-1+\alpha)(x-2+\alpha)(x-3+\alpha)\cdot\ldots\cdot(\alpha+1)\alpha,$$

and

$$\frac{\Gamma(n-x+\beta)}{\Gamma(\beta)} = (n-x-1+\beta)(n-x-2+\beta)(n-x-3+\beta)\cdot\ldots\cdot(\beta+1)\beta,$$

and finally, for $n \geq 1$.

$$\frac{\Gamma(\alpha+\beta)}{\Gamma(n+\alpha+\beta)} = \frac{1}{(n-1+\alpha+\beta)(n-2+\alpha+\beta)(n-3+\alpha+\beta)\cdot\ldots\cdot(1+\alpha+\beta)(\alpha+\beta)}$$

It follows that the above probabilities can be rewritten as

$$\begin{aligned} P[X=x] &= \frac{\{n\cdot(n-1)\ldots\cdot(n-x+1)\}}{x!} \\ &\cdot \frac{(n-x-1+\beta)(n-x-2+\beta)(n-x-3+\beta)\cdot\ldots\cdot(\beta+1)\beta}{(n-1+\alpha+\beta)(n-2+\alpha+\beta)(n-3+\alpha+\beta)\cdot\ldots\cdot(1+\alpha+\beta)(\alpha+\beta)} \\ &\cdot (x-1+\alpha)(x-2+\alpha)(x-3+\alpha)\cdot\ldots\cdot(\alpha+1)\alpha \end{aligned}$$

It should be noted that in the case of growth by length groups within a short time interval, only low values of n and x are needed.

Thus, probabilities can readily be generated from this beta-binomial distribution, given specified values of α, β and n. The last parameter of these, n, will usually be assumed, outside an estimation procedure.

It is also reasonably easy to see that the mean of the beta-binomial distribution is given by $\mu = nE[p] = \frac{n\alpha}{\alpha+\beta}$. If β is taken as a parameter to be estimated, the requirement $\Delta = \mu$ therefore implies $\alpha = \frac{\beta\Delta}{n-\Delta}$.

This approach will therefore be implemented in Gadget by defining a new growth function with a single estimable parameter β, to be set (along with n) to an initial value in a specification file.

3. Model flexibility

Future work includes a close scrutiny of how variations in the β parameter affect the growth update and how this affects the final length distributions, conditional on all other model components.

4. Process error

It is clear that there will always be considerable unexplained variation in growth and it is also clear that this variation is persistent, i.e. it can not be treated as independent random errors (e.g. Millar, 1991).

Future work therefore must also consider the possibility of including process error, e.g. in the form of annual variation in β. A simple form for this is to assume $\beta_y \sim n(\beta, \sigma^2)$ where β is an unknown parameter but β_y is the annual effect in the growth.

5. Evaluation of the growth functions

Future testing of these models must include likelihood functions linking growth or modelled length distributions to data from surveys or commercial catches. In either case, however, the comparison will be confounded due to the well-known intra-haul correlation and overdispersion commonly found in fisheries data (Pennington and Völstad, 1994).

In addition, problems arise from the compound nature of the data sets used in these models: Since the models not only include growth but also other processes which can only be estimated by including other data sources such as abundance indices from surveys, there are many data sets in the full likelihood function to be used in the models. The question therefore arises on how to weight together these components. If probability distributions of the data could be fully specified, maximum likelihood could be used, but the question is particularly pertinent since the individual components are difficult to fully specify in light of the overdispersion mentioned above. In fact it turns out that model results are quite sensitive to the weighting use for the different data sets and therefore it is quite important to develop methods for the estimation of the weighting factors (Stefansson, 1998).

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E.2 Likelihood functions for length distribution

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Work is being undertaken to investigate plausible likelihood components for length distributions. Although a multinomial assumption for these data is the obvious one, this model depends on the assumption of "independent fish", i.e. that each fish is sampled independently of all others.

For the following analysis groundfish survey stations were selected where more than 50 fish had been length measured. From each station 50 fish were selected at random and the proportion of fish of length under 35cm was computed.

If the fish were sampled truly at random, these proportions should appear to come from binomial distributions with well-known variances. If Y denotes the number of fish below 35 cm, then standard assumptions would be that $Y \sim b(n, p)$ where, here, $n = 50$.

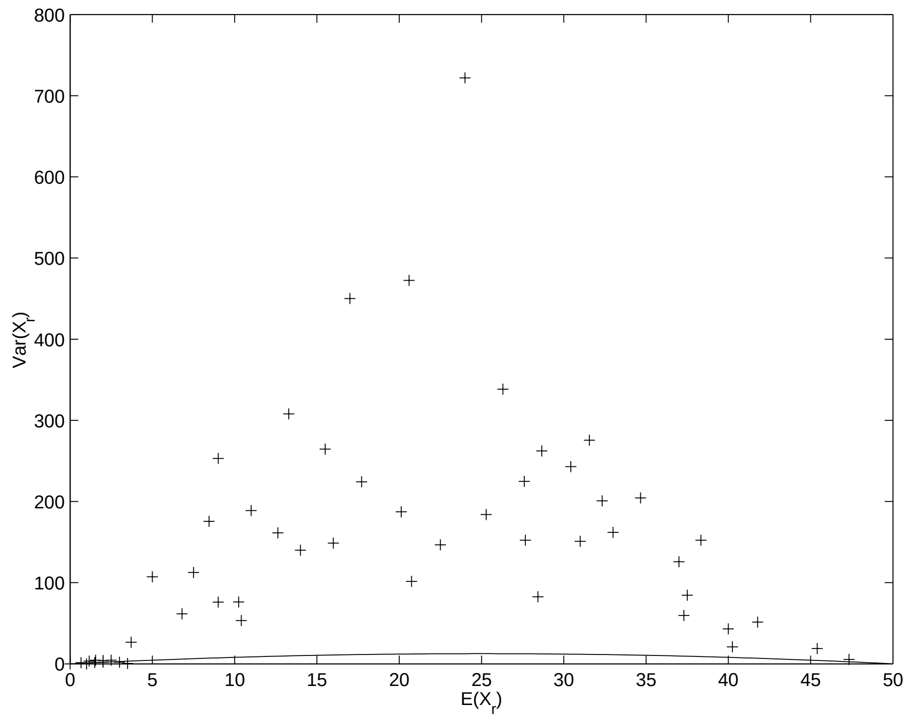

Figure 1: Variance-mean relationship for number of fish below 35 cm.

Taking small geographical areas it is now easy to compute the mean and variance of these proportions or numbers within each area. These data can be compared with the theoretical value of $E[Y] = np$ and $V[Y] = np(1-p)$, i.e. the theoretical mean-variance relationship should be $V[Y] = E[Y](n - E[Y])/n$. An example is seen in 1, where it is clear that the theoretical curve far underestimates the actual variability in the data.

From this it is clear that the common binomial assumptions in GLM and GAM approaches fail quite badly and this may explain some of the reasons why there is an apparent need to use highly complicated models for the mean response (e.g.

Stefansson and Palsson, 1997).

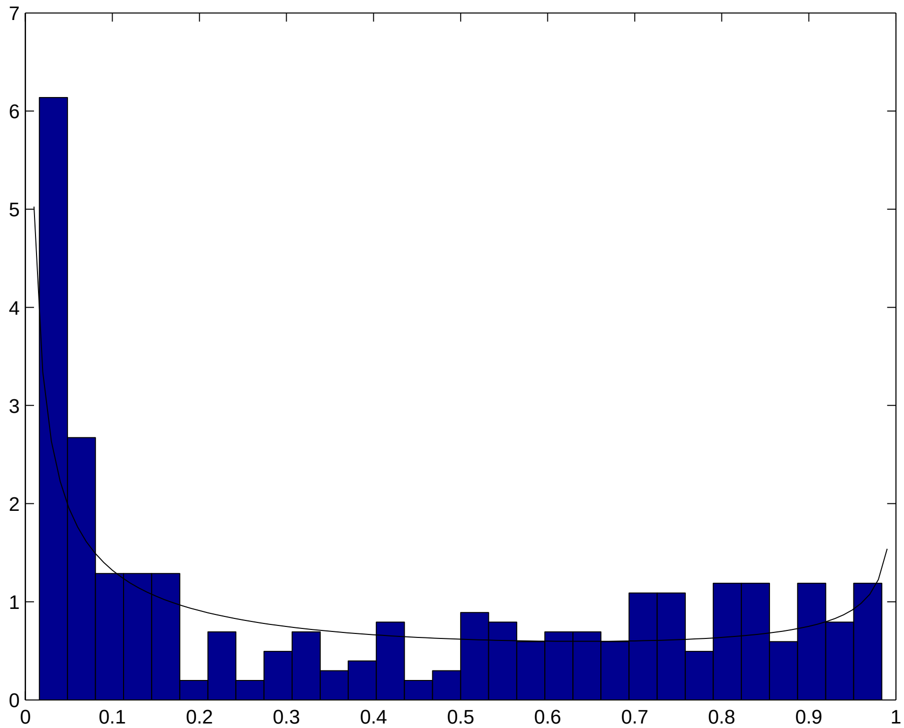

Figure 2: Using the beta-binomial distribution

It is possible that this may be alleviated through the use of the beta-binomial distribution or through the use of an overdispersed binomial distribution (e.g. MacCullagh and Nelder), cf 2.

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F Fleksibest - an age-length structured fish stock assessment model

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Abstract

Fleksibest is an age-length structured population model intended for use in fish stock assessment, primarily on boreal stocks. A main feature is that a self-contained population model is fitted to observations, e.g. commercial catch data and scientific survey data. In Fleksibest, growth, mortality and maturation are modelled by means of parametric models. Recruitment is estimated, no stock-recruitment function is used. Fleksibest has been developed for use in the assessment of the stock of North-East Arctic cod (*Gadus morhua* L.), but it may also be applied to other stocks.

Often age is used as a proxy for length in assessment models. This may be an unsatisfactory solution for many boreal stocks, as large variation in growth rates is typical of stocks in boreal systems. Thus the biological processes in Fleksibest are modelled as functions of length, because the processes are mainly related to length rather than age.

Key words: Cod age-length structured population model

1 Introduction

In fish stock assessment, age-structured population models are often used. The first generation of such models was VPA-based (Beverton and Holt 1957) methods. These 'book-keeping' methods assume that the reported catch numbers at age are exact. They also utilise assumptions about natural mortality and about relationships between abundance indices and stock size.

Later, age structured assessment models sometimes termed 'statistical catch at age analysis' (CAGEAN) (Fournier and Archibald 1982; Deriso, Quinn, and Neal 1985) were developed. The characteristic feature of these models is that a self-contained population model is fitted to the data. This is different from the

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commonly used VPA-based methods, where the stock abundance numbers and fishing mortalities are derived directly from catches at age. In particular, the reported catch numbers at age are not assumed to be exact.

Fleksibest is essentially a length-structured version of the CAGEAN class of models. Length structure is included because most population dynamics processes are related to the size rather than the age of fish. For fish stocks in boreal systems, age is not a good proxy for size. Such stocks experience large inter-annual variation in growth and thus in size at age (Mehl and Sunnanå 1991; Mehl 1991). Figure 1 shows the difference in length growth for some ages of North-East Arctic cod (*Gadus morhua* L.). The difference in growth is seen both as a large variation in length growth from year to year and as a year-to-year variation in the condition factor. An adequate population model for such stocks should thus be length structured and contain a growth model.

In particular, the assumption made in many CAGEAN type models that the fishing pattern at age is constant, is far from reality for many boreal stocks. A length dependent fishing pattern will be a more adequate assumption. Each fleet may have their own length dependent fishing pattern in Fleksibest.

Other features which we have found appropriate to include in Fleksibest when applied to North-East Arctic (NEA) cod, but which should be relevant also for other stocks, are a model for predation mortality due to cannibalism, a length based maturation model and separate population parameters for immature and mature fish.

The present approach was chosen because it offers more flexibility as to formulations of the mortality structure and the relations between stock size and observations. Also, at least in principle it allows for taking the statistical structure in the information into account and transfers that to statistical properties of the results.

In recent years, North-East Arctic cod has been assessed using XSA (Shepherd 1999), which is a model of the VPA type. The plan is to take Fleksibest in use as assessment tool for NEA cod from 2001.

2 Model structure

In the commonly used VPA-based methods (Beverton and Holt 1957; Shepherd 1999; Gavaris 1988), the basis is the equation

$$\frac{1}{N}\frac{dN}{dt} = -Z \tag{1}$$

where N is the population number at time t and Z is the instantaneous mortality rate. For practical purposes, Z is calculated over a time period, often a year. Z is usually divided into fishing mortality, F, and natural mortality, M:

$$Z = F + M \tag{2}$$

Equations (1) and (2) are applied to each cohort separately, both in VPA-based and CAGEAN-type models. It is also the basis for an age-and-length structured model, but in addition, a choice has to be made about how to model the length structure of a cohort.

There are two ways that have been used to represent the length structure of a cohort:

- Describing the length structure by a probability distribution (Deriso and Parma 1988). This puts some restrictions on which functional forms can be used to describe the population dynamics processes.
- Structuring the population by length and age groups, so that the population size at a given point is described by an abundance matrix (number of fish in each age and length group). This approach has been used in several multispecies models for boreal areas: MULTSPEC (Bogstad, Hiis Hauge, and Ulltang 1997); BORMICON (Stefánsson and Pálsson 1997; Stefánsson and Pálsson 1998), as well as for very short-lived species (Skagen and de Sousa 1997).

We chose the second approach in order to draw on our previous experience with age-length structured population models. Fleksibest was therefore developed as a modification and extension of the Icelandic multispecies-multiarea-multifleet simulation model BORMICON. The Fleksibest code is thus modified and extended BORMICON code. The main modification is the change from a multispecies to a single species stock assessment tool.

Fleksibest differs from BORMICON in the way fishery is handled. In accordance with the general CAGEAN approch, Fleksibest explicitly assumes a model for fishing mortality F, while BORMICON generally treats fishery as another predator for which the consumption in tons is calculated.

The advantage of Fleksibest's formulation is that "understocking" never occurs. Understocking occurs when the model calculates a larger biomass consumption of a stock than the stock biomass present. Understocking may occur in all multispecies models which are based on consumption.

In Fleksibest, growth, mortality and maturation are modelled by means of parametric models. In nature, the immature and mature stock may have different growth and mortality and also different selection by fleets and surveys. Thus it was decided to divide the model stock into a mature and an immature part, each part having their own population dynamics. Maturation is related to length through a maturation model, and to age by introducing a minimum maturation age. Accordingly, the immature and the mature stocks are calculated separately, while in traditional models, the spawning stock is usually calculated from the total stock by means of a given (observed or time-series average) proportion of mature fish at age.

Maturation and spawning mortality of Northeast Arctic cod shows a clear difference by sex (Jakobsen and Ajiad 1999). The model allows for dividing the stock by sex, but this has not been done in practice yet.

The annual recruitments (number of fish entring the population at the recruitment age) are model parameters which are estimated. The mortalities are modelled by parametric models. Parametric models for fishing mortalities require that some structure is assumed for the fishing mortality. The assumption in Fleksibest is that the fishing mortality generated by fleet f in year y on fish of length l, $F_f(l, y)$, is the product of selection at length $S_f(l)$ and a year factor $\lambda_f(y)$.

The partial (fleet) fishing mortality is thus a function of length rather than of age. The total fishing mortality is the sum of the partial fishing mortalities. We also relate natural mortality (including cannibalism) to length, which is likely to be most realistic from a biological point of view.

2.1 The operators on matrix form

The basic biological processes are

- Aging H
- Mortality S
- Length growth G
- Maturation B, C and E
- Recruitment R

Due to the complexity of the model, we found it useful to write each of the processes above on matrix form. The capital letters are the matrix name(s) associated with the process. Then we use matrix operators to describe the stock matrix $N(t_{m+1})$ as a function of $N(t_m)$. Note that many of the matrix operators are functions of the time step t_m.

Matrix notation is more common in general theoretical population dynamics, e.g. in connection with stability studies and in stochastic control theory. It is not commonly used in description of assessment models. However, matrix notation will give us a compact and precise mathematical formulation.

In our formulation, the $A \times L$ stock matrix $N(t_m)$ has age as row index and length as column index. The first row is associated with the minimum age (recruitment age) of the stock in the model, and the last row is associated with the maximum age. The first column is associated with the smallest length group in the stock, and the last column is associated with the largest length group. For simplicity, the age range and the length range are supposed to be equal for immature and mature stock.

Since matrix multiplication is not commutative, the operator sequence is important. It is possible to study the difference in matrix norms between the matrix products AB and BA. This will give information about the influence the process sequence will have on the final result.

The connection between $N(t_{m+1})$ and $N(t_m)$ is given as:

Immature stock:

$$N(t_{m+1}) = H(t_m)(N^{(2)}(t_m) - C^{(2)}(t_m)) + R(t_{m+1}) \tag{3}$$

Mature stock:

$$N(t_{m+1}) = H(t_m)(N^{(2)}(t_m) + C^{(2)}(t_m)) \tag{4}$$

Definition of intermediate matrices:

$$N^{(1)}(t_m) = N(t_m)G(t_m) \tag{5}$$

$$N^{(2)}(t_m) = N^{(1)}(t_m)S(t_m) \tag{6}$$

$$C^{(1)}(t_m) = N^{(2)}(t_m)B(t_m) \tag{7}$$

$$C^{(2)}(t_m) = EC^{(1)}(t_m) \tag{8}$$

2.1.1 The structure of the process matrices **Aging**

The aging matrix H for the stock is an $A \times A$-matrix. Aging takes place during the last step in the year, so if $(m \bmod steps) = 0$, $H(t_m)$ is given by (9). Else $H(t_m) = I$, i.e. an identity matrix.

$$H(t_m) = \begin{pmatrix} 0 & 0 & & & \dots & 0 \\ 1 & 0 & & & & 0 \\ 0 & 1 & & & & 0 \\ \vdots & & & \ddots & & \vdots \\ 0 & \dots & & 1 & 0 & 0 \\ 0 & \dots & & 0 & 1 & \xi \end{pmatrix} \tag{9}$$

$$\xi = \begin{cases} 0 & \text{if the last age is a true age} \\ 1 & \text{if the last age is a plus group} \end{cases} \tag{10}$$

The oldest age group may either be a true age group or a plus age group (accumulation group). If it is a plus group, it is a sum of all fish at that age and older.

Mortality

$S(t_m)$ is a diagonal matrix with all diagonal elements in the interval $(0, 1)$. This matrix give *the survival* of the length groups. S has dimensions $L \times L$.

$$s_{ij} = \begin{cases} 0 & \text{if } i \neq j \\ \exp(-Z(l_j, t_m)) & \text{if } i = j \end{cases} \tag{11}$$

$Z(l_j, t_m)$ is defined by Equation (22).

Growth

The average length growth of the fishes in a length group is defined by (39) or (40). The growth matrix gives the distribution of the average growth. The maximum number of length groups a fish can grow in one time step is g, g is defined in the appendix.

The growth matrix $G(t_m)$ is a $L \times L$ band matrix, with non-zero diagonal elements and g superdiagonals.

The growth matrix G below is a sample growth matrix with $g = 2$.

$$G = \begin{pmatrix} g_{11} & g_{12} & g_{13} & 0 & 0 & \dots & 0 \\ 0 & g_{22} & g_{23} & g_{24} & 0 & & 0 \\ \vdots & & & & \ddots & & \vdots \\ 0 & & \dots & & 0 & g_{L-1,L-1} & g_{L-1,L} \\ 0 & & \dots & & 0 & 0 & 1 \end{pmatrix} \tag{12}$$

Note that $\Sigma_{j=i}^{i+g} g_{ij} = 1 \; \forall \; i$, i.e. growth is a conservative process with respect to the number of fish.

The average growth is described further in subsection 2.3.2 and the distribution of the growth in the appendix.

Maturation

The use of E in (8) implements the minimum maturation age, while matrix B defined by (13) implements the length dependency in the maturation function.

The matrix B gives the fraction of a length group that matures during a time step. Maturation takes place once a year. B is a diagonal $L \times L$ matrix. $B(t_m)$ is given by (13) if $(m + q \bmod \mathit{steps}) = 0$, $B(t_m) = \mathbf{0}$ otherwise. q is the number of the time step within a year when maturation occurs, i.e. $1 \leq q \leq \mathit{steps}$.

$$b_{ij} = \begin{cases} 0 & \text{if } \; i \neq j \\ b_i & 0 \leq b_i \leq 1, \quad b_i \text{ defined as a length dependent function} \end{cases} \tag{13}$$

$$E = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ \vdots & & & & \ddots & & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & & \dots & 0 & 1 & 0 & 0 \\ 0 & & \dots & 0 & 0 & 1 & 0 \\ 0 & & \dots & & 0 & 0 & 1 \end{pmatrix} \tag{14}$$

Matrix E is an $A \times A$ matrix, where the p first rows only contains zeros.

$$p = a_m - a_0 \tag{15}$$

a_m is the minimum maturation age, a_0 is the recruitment age.

See subsection 2.3.3 for a further discussion.

Recruitment

Recruitment is supposed to take place once a year, in the first time step. The recruitment matrix $R(t_m)$ is an $A \times L$ matrix and defined as follows when (m mod $steps$) = 1:

$$r_{ij} = \begin{cases} r_j & \text{if } \ i = 1, \ r_j \geq 0 \\ 0 & \text{if } \ i > 1 \end{cases} \tag{16}$$

For all other time steps $R(t_m) = \mathbf{0}$.

2.2 Symbols and definitions

The symbols and definitions used are given below:

- N - number of fish
- W - individual weight of fish
- a - age index
- a_0 - youngest age (recruitment age)
- A - Number of age groups
- l - (continuous) length
- l_i - discrete length, mid point in length group no. i.
- l_{min} - minimum fish length
- l_{max} - maximum fish length
- L - the number of length groups.
- t_m - time step.

- y - year
- f - fleet, $f = 1, 2...., N_f$
- s - survey, $s = 1, 2...., N_s$
- u - stock, immature (imm) or mature (mat)
- m_{max} - the number of time steps in a run
- $m(l_i)$ - the fraction of a length group which becomes mature during a year.

steps is the number of (equally long) time intervals within a year.

$$\Delta t = \frac{12}{steps} \tag{17}$$

$$t_m = y_0 + m\Delta t, m = 1, 2...., m_{max} \tag{18}$$

$$y = y_0 + [\frac{m}{steps}], m = 1, 2...., m_{max} \tag{19}$$

where [ ] denotes the integer part of the argument.

$$\Delta l = \frac{l_{max} - l_{min}}{L} \tag{20}$$

$$l_i = l_{min} + (i - \frac{1}{2})\Delta l \tag{21}$$

For convenience, we assume that the model is started in the first step of the first year.

2.3 Description of processes in population model

The processes which are modelled in the population model are growth, mortality and maturation. The number of recruits is estimated. We must also account for the fact that the fish gets older (aging).

2.3.1 Mortality The total mortality is given as

$$Z(l_i, t_m) = F(l_i, t_m) + M(l_i, t_m) \tag{22}$$

where $F(l_i, t_m)$ is the fishing mortality and $M(l_i, t_m)$ is the natural mortality.

Fishing mortality The total fishing mortality $F(l_i, t_m)$ is the sum over the partial fishing mortalities $F_f(l_i, t_m)$:

$$F(l_i, t_m) = \sum_{f=1}^{N_f} F_f(l_i, t_m) \tag{23}$$

The partial fishing mortality $F_f(l_i, t_m)$ is a product of a time dependent fishing level and a selection curve, both fleet specific:

$$F_f(l_i, t_m) = \xi_f(t_m) S_f(l_i) \tag{24}$$

$$\xi_f(t_m) = \lambda_f(y)\theta_f(t_m) \tag{25}$$

$\lambda_f(y)$ is the annual fishing mortality level for fleet f in year y and is the fishing mortality of fish that is fully recruited to the fishery. $\theta_f(t_m)$ distributes the annual fishing mortality level $\lambda_f(y)$ among the time steps in year y. $\theta_f(t_m)$ is set so that the distribution of the fishing mortality on the time steps in year y is the same as the distribution of the catch in weight on the time steps in year y. This definition of $\theta_f(t_m)$ is chosen to reduce the number of parameters.

$$\theta_f(t_m) = \frac{C_f(t_m)}{\sum_{j=k+1}^{j=k+steps} C_f(t_j)} \tag{26}$$

$k + 1 \leq m \leq k + steps$

$k = (y - 1) * steps.$

$C_f(t_m)$ is the catch by fleet f in weight during time step t_m. It follows that

$$\sum_{j=k+1}^{j=k+steps} \theta_f(t_j) = 1 \quad \forall f \text{ and } \forall k \tag{27}$$

$S_f(l_i)$ is the selectivity of fleet f.

Selectivity functions are used both in survey and catch modelling. In Fleksibest there are many possible selectivity functions, the most frequently used being the logistic function (28) and the modified logistic function (29):

$$S(l) = \frac{1}{1 + \exp(-4\alpha(l - l_{50}))} \tag{28}$$

$$S(l) = \begin{cases} \dfrac{1}{1 + \exp(-4\alpha(l - l_{50}))} & \text{if } l \leq l_{50} \\ \dfrac{1}{1 + \exp(-4\alpha\beta(l - l_{50}))} & \text{if } l > l_{50} \end{cases} \tag{29}$$

α, β and l_{50} are different for each survey and fleet. β in (29) is introduced to give a steeper selection curve when $l > l_{50}$, i.e. $\beta > 1$.

Natural mortality The natural mortality $M(l_i, t_m)$ can be divided into predation mortality M2 and residual natural mortality M1, as it is done in multispecies VPA (Helgason and Gislason 1979; Pope 1979).

The total natural mortality can then be written as

$$M(l_i, t_m) = M1(l_i) + M2(l_i, t_m) \tag{30}$$

In the present implementation for NEA cod, the only predation mortality accounted for is cannibalism.

Cannibalism mortality Cannibalism is modelled as a function of prey length, the biomass of the fishes which are able to eat the prey and the biomass of alternative food (to account for prey switching). It is assumed that cannibalism only takes place on the immature part of the stock and that both immature and mature fishes are predators. The functional form is developed for North-East Arctic cod in particular, and the functions are based on data for this stock (Bogstad and Mehl 1997; Bogstad, Lilly, Mehl, Pálsson, and Stefánsson 1994; ICES 2000).

To calculate the cannibalism predator potential $\Phi(l_i, t_m)$, we calculate the biomass of the immature and mature stock of length $\geq c\, l_i,\ c \geq 1$.

$$M2_{imm}(l_i, t_m) = \frac{\alpha_m * f(l_i)}{\zeta(t_m)} * \Phi(l_i, t_m) \tag{31}$$

$$f(l_i) = \exp(-\beta * l_i{}^{\gamma}) \tag{32}$$

$$\zeta = \eta^{\delta} \tag{33}$$

$$\Phi(l_i, t_m) = \Sigma_{a=1}^{a=A} \Sigma_{u=imm}^{mat} \Sigma_{s=j}^{L} N_u(a, l_s, t_m) W_u(a, l_s, t_m) \psi_u(t_m) \tag{34}$$

$$l_{j-1} < c\, l_i < l_j \tag{35}$$

$$\psi_u(t_m) = \begin{cases} 1 & \text{if the predator stock overlaps with the prey stock} \\ 0 & \text{if the predator stock does not overlap with the prey stock} \end{cases} \tag{36}$$

$\psi_u(t_m)$ is introduced to take care of seasonal variation in overlap.

η is the biomass of alternative food.

α_m, β, γ and δ must be positive numbers.

Residual natural mortality We have chosen a function describing the residual natural mortality which allows for higher natural mortality of small and large fish than of fish of intermediate lengths. This is similar to the assumption made by (Tretyak 1984).

$$M1(l) = \begin{cases} \frac{a_1}{b_1+l'} & l_{min} \leq l < l_1 \\ c & l_1 \leq l \leq l_2 \\ \frac{a_2}{b_2+l'} & l_2 < l \leq l_{max} \end{cases} \tag{37}$$

$$l' = l * (M1(l_{max}) - M1(l_{min})) \tag{38}$$

Note that a_1, a_2, b_1, b_2 must be chosen so that $M1(l)$ is continuous at $l = l_1$ and $l = l_2$.

2.3.2 Growth

The average growth in length of a fish of length l_i in year y is modelled by using one of the growth functions below:

1. von Bertalanffy growth function (von Bertalanffy 1934; von Bertalanffy 1938):

$$\delta l(l_i, t_m) = (L_\infty - l_i) * (1 - \exp(-k(y)\Delta t)) \tag{39}$$

2. Power or linear growth:

$$\delta l(l_i, t_m) = k(y)\Delta t \, l_i^q \quad q \leq 0 \tag{40}$$

The case where $q = 0$ gives linear growth. (40) was used by (Bogstad, Hiis Hauge, and Ulltang 1997) to describe the growth of North-East Arctic cod. The growth of this stock has been shown to be approximately linear before maturation (Jørgensen 1992).

The connection between y and t_m is given by (18)-(19).

The average length increase given by (39) or (40) is then distributed according to a probability function described in the appendix.

For all ages a, the number of fish in length group i after the growth has taken place, is given by

$$N^{(1)}(a, l_i, t_m) = \sum_{r=i-g}^{i} N(a, l_r, t_m) * p(i, r|\delta l(l_r, t_m)) \tag{41}$$

$N^{(1)}$ is defined by (5).

Equation (41) gives the sum of the fishes from the $g+1$ length groups that grow into length group i (including those which remain in length group i). g is the maximum number of length groups a fish can grow in one time step. $p(i, r|\delta l(l_r, t_m))$ is defined by (65).

In order to keep the total number of fishes unchanged, the following condition needs to be satisfied:

$$\sum_{i=r}^{i=r+g} p(i, r|\delta l(l_r, t_m)) = 1 \tag{42}$$

(42) ensures that the fishes that were in length group r at time step t_m, are conserved during the distribution of the average length growth $\delta l(l_i, y)$.

The growth in weight is not modelled explicitly, a weight-length relationship for each time step based on observations from surveys is used as model input:

$$W(l_i, t_m) = w_1(t_m) * l_i^{w_2(t_m)} \tag{43}$$

where $w_1(t_m)$ is the condition factor. $w_2(t_m)$ is typically close to 3.

2.3.3 Maturation

The fraction of the immature fish of length l which becomes mature during a year is assumed to be length-dependent (Marshall, Kjesbu, Yaragina, Solemdal, and Ulltang 1998; Ajiad, Jakobsen, and Nakken 1999) and age dependent. The age dependence is given as a minimum maturation age. The length dependence is given as a logistic function, i.e. the same functional form as the selection curve in (28):

$$m(l) = \frac{1}{1 + \exp(-4\alpha(l - l_{50}))} \tag{44}$$

Thus for all fishes that are old enough to mature, maturation is a purely length dependent process in this modell. In (7)-(8) the matrix E in (8) takes care of the minimum maturation age, while matrix B in (7) implements the length dependence, given by (44). In general, the maturation is also dependent on the weight-length relationship of the fish (Marshall, Kjesbu, Yaragina, Solemdal, and Ulltang 1998), and the model can easily be extended to account for this. When comparing parameter values in the maturation model to parameter values found in the literature, it should be noted that in the literature it is usually the proportion of mature fish which is calculated and not the proportion of the immature fish which becomes mature. The maturation is assumed to take place at a given time step each year.

2.3.4 Recruitment

There is no stock-recruitment function used in this model. The number of recruits in each year is a model parameter, as are the mean length and standard deviation of the mean length of these recruits. Thus, we have assumed a normal distribution of the length for practical purposes.

3 Data available

The data sources used in Fleksibest at the moment are:

- Commercial catch data
- Survey data
- Data on occurrence of prey in predator stomachs

In age-structured models, age-based catch and survey data are used. In Fleksibest, age-length structured data are needed. In both cases, the data do not represent direct observations, they are derived by combining data from different sources. In CAGEAN-type models, the model results are compared to (processed) data on age or on a more aggregated level, e.g. spawning stock biomass estimates. In Fleksibest, the model data are usually compared to (processed) age-length structured data from catches and surveys. The main issue here is that both the CAGEAN and Fleksibest data are processed, so that the statistical properties of the data are unclear or destroyed. The choice of likelihood function may then not be founded on the statistical properties of the data.

Another possible approach is to compare the model results to the direct observations such as catch in biomass, total acoustic abundance, length samples and subsamples of length distributions which are age sampled.

An advantage of the first method is that the existing calculation methods for catch and survey data can be utilised, and the input data will be compatible to those used by existing models. In the second approach, the statistical properties of the data are much more clear, as discussed e.g. by (Deriso and Parma 1988) for commercial catch data. Thus, the objective function can be formulated as a true likelihood function. This approach is also the one taken in BORMICON (Stefánsson and Pálsson 1997; Stefánsson 1998). In the present implementation, we have chosen the first approach, since being consistent with previous models used for assessing this stock has been considered most important. In later versions of the model, we will consider using the second approach.

The description of the data given below refers to the data presently used for parameter estimation in Fleksibest.

3.1 Commercial catch data

Data on total catches in weight are available by year, quarter, fleet and area based on reporting of catch to the national authorities. In addition, data on age and length composition as well as length-weight relationships are available from samples of the catch. These data are used for conversion of the catch in tons to catch in numbers by year, quarter, fleet, age and length, which is used by the Fleksibest model. This is a fairly complicated process with many steps. The representativity of the sampling may be quite variable, and the data on total catch may be in error.

The modelled catches C_{mod} are calculated by means of the catch equation:

$$C_{mod} = \frac{F}{Z} N(1 - \exp(-Z)) \qquad (45)$$

which, when applied to each age group, length group, fleet and time step can be written

$$C_{mod}(f, a, l_i, t_m) = \frac{F_f(l_i, t_m)}{Z(l_i, t_m)} N(a, l_i, t_m)(1 - \exp(-Z(l_i, t_m)) \qquad (46)$$

F_f is defined by (24), and Z is given by (22).

Fleets are assumed to fish on the immature stock, the mature stock, or both.

3.2 Survey data

Survey estimates are generally not considered as measurements of absolute stock abundance, but as relative measures of abundance (indices). One exception to this is the acoustic abundance estimates for Barents Sea capelin (*Mallotus villosus*), which are used as absolute estimates in the stock assessment and management (Gjøsæter 1998). The main reasons why the survey estimates are used as indices are:

- Some of the surveys are limited in their geographical (horisontal) coverage.
- Problems with vertical coverage. Concentrations of fish close to the bottom are effectively sampled by the bottom trawl but underestimated by the acoustics since much of the fish will be situated in the acoustic 'dead zone' 1-2 m up from the bottom. Pelagic concentrations which are clearly off the bottom are, however, effectively sampled by the echo sounder but less available to the bottom trawl; the availability depending on the distance between fish and bottom as well as the size of the fish (Aglen 1996).
- Problems with converting the observations of density to abundance estimates. This may be due to lack of knowledge about the efficiency of the sampling gear (how large proportion of the fish is caught by the trawl), unknown fishing width and height of the trawl, and uncertainty in acoustic target strength.

3.2.1 Relationship between survey data and modelled population

There are many factors such as gear selectivity, fish distribution horisontally and vertically and environmental conditions which may influence the relationship between the survey index and the population number. It is difficult to model each of these factors adequately and so common practice is to assume simple functional relationships.

Fleksibest provides two models for describing the relationship between survey indices and modelled population:

Linear model:

$$I_{mod}(s, a, l_i, t_m) = b_s(l_i) + q_s(t_m) * \tau_s(l_i) * N(a, l_i, t_m) \tag{47}$$

This formulation with negative intercept values (i. e. $b_s(l_i) < 0$) has been shown to give a good fit between abundance indices and stock estimates (Korsbrekke, Mehl, Nakken, and Pennington 2001).

Power model:

$$I_{mod}(s, a, l_i, t_m) = q_s(t_m) * \tau_s(l_i) * N(a, l_i, t_m)^{b_s(l_i)} \tag{48}$$

Often, $q_s(t_m)$ is set to a constant, but $q_s(t_m)$ may also have other forms.

The length selectivity function $\tau_s(l_i)$ is often a logistic function, given by (28), but other functional forms are also available (Stefánsson, Sigurgeirsson, Björnsson, Thiem, and Frøysa 2000).

$$b_s(l_i) = b_1 * \exp(-b_2 * l_i) \tag{49}$$

Usually $b_s(l_i) = b_1$ is used.

A survey is assumed to cover the immature stock, the mature stock, or both.

3.3 Stomach content data

The consumption of small (immature) fish by larger (immature and mature) fish can be calculated from data on stomach content of cod, temperature data and a model for the gastric evacuation rate. How this is done for North-East Arctic cod is described by (Bogstad and Mehl 1997). The consumption is given in kg per time unit (half year) per predator for each predator age group and prey length group.

Fleksibest calculates the consumption D_{mod} based on the catch equation (45), but with $M2$ instead of F, i.e.

$$D_{mod} = \frac{M2}{Z} N(1 - \exp(-Z)) \tag{50}$$

Furthermore, F is assumed to be negligible ($M \gg F$) on the length groups which are subjects to cannibalism. We use the approximation $Z = M$ to avoid to iterate on F.

We then get

$$D_{mod} = \frac{M2}{M} N(1 - \exp(-M)) \tag{51}$$

which can be written as

$$D_{mod}(l_i, t_m) = \sum_{a=1}^{A} \frac{M2_{imm}(l_i, t_m)}{M_{imm}(l_i, t_m)} N_{imm}(a, l_i, t_m)(1 - \exp(-(M_{imm}(l_i, t_m)))) \tag{52}$$

when broken down on length groups.

4 Parameter estimation

4.1 Objective functions

The purpose of a objective function is to compare observed and modelled values. The observed values need not be direct observations, the consumption data are for instance considered as observed values. We have three different data sources; catches, surveys and consumption. There are several surveys and fishing fleets. Each fleet and survey will contribute with one term to the total sum. Thus the total sum will contain contribution from very different sources with a different number of data points. The internal weighting of sources to the total sum is thus important. It is here implicitly assumed that all the data sources are independent, this may not be the case. One example is the bottom trawl and acoustic abundance estimates from the same survey, which are not independent.

Common practise is to derive objective functions as likelihood functions, assuming some distribution of the noise in the data.

The statistical properties of the data are often poorly known, due to the complicated processing that often lies behind the estimates of abundance at age and length. We do not know a priori which (if any) distribution approximates the error structure best. A common assumption is that the noise is log-normally (or sometimes multinomially) distributed. This assumption may give misleading results if it does not hold (Wiens 1999). The problem has been encountered e.g. in the assessment of Norwegian spring-spawning herring (*Clupea harengus*) (ICES 1997; Patterson 1999), where a gamma distribution was found to be the most appropriate. Careful testing is necessary to choose the best likelihood formulation.

4.1.1 Surveys and catches

We have implemented 4 different objective-functions for catch and survey data. We will give the generic forms of the functions. Subscript *obs* indicates "observed" values and subscript *mod* gives the modelled counterpart.

1. A multinomial likelihood function.

$$X_{obs} \ln(X_{mod} + \epsilon) \tag{53}$$

2. A square of log transformed variables.

$$\begin{cases} (\ln X_{obs} - \ln X_{mod})^2 & X_{mod} > \epsilon \ \wedge \ X_{obs} > \epsilon \\ 0 & \text{else} \end{cases} \tag{54}$$

3. A Pearson function.

$$\frac{(X_{obs} - X_{mod})^2}{X_{mod} + \epsilon} \tag{55}$$

4. The likelihood function for a gamma distribution with constant coefficient of variation.

$$\frac{X_{obs}}{X_{mod} + \epsilon} + \ln(X_{mod} + \epsilon) \tag{56}$$

In these formulae it is possible to account for the estimates of different age and length groups having different uncertainty, this has not been done yet. For functions 1,3 and 4 the comparisons will usually be made on cell (age and length) level, while the comparisons using function 2 will be made on a more aggregated level.

Interpretation of the objective functions:

1. Likelihood with multinomial distribution.
2. Likelihood with log normal distribution.
3. A proxy for likelihood ratio with multinomial distribution.
4. Likelihood with gamma distribution with constant CV.

For more details on the formulations see (Fahrmeir and Tutz 1994).

4.1.2 Consumption

The objective function for consumption is defined as follows:

$$\frac{n}{\sigma^2}(X_{obs} - X_{mod})^2 \tag{57}$$

where n is the number of stomachs sampled and σ is the assumed or externally derived standard deviation.

4.2 Total objective function

The total objective function from a fleet or a survey is a sum over time steps. The time span may differ between fleets and surveys. We define the total contribution from a fleet f as a sum over all time steps:

$$L_f = \sum_{r=r_1(f)}^{r_2(f)} \ell_{f,r} \tag{58}$$

We define the total contribution from a survey s as a sum over all time steps:

$$L_s = \sum_{r=r_1(s)}^{r_2(s)} \ell_{s,r} \tag{59}$$

We define the total contribution from the consumption terms as

$$L_{cons} = \sum_{r=r_1}^{r_2} \ell_{cons,r} \tag{60}$$

The total objective function is a weighted sum of the individual components:

$$LTOT = \sum_{f=1}^{N_f} w_f L_f + \sum_{s=1}^{N_s} w_s L_s + w_{cons} L_{cons} \tag{61}$$

where the w_i's are weighting factors which have to be set (externally) in advance. It is a non-trivial problem to determine this weighting, due to scale dependent terms, unknown quality of the data and unknown variances.

4.3 Parameters to be estimated

Fleksibest has a great flexibility on which parameters that can be estimated. Some parameters must be estimated, and a lot of parameters may be estimated.

The following parameters have to be estimated by the model:

- Number at age (immature and mature) at start of first year.
- Annual recruitment (in numbers).
- Annual fishing mortality.

The parameter groups listed below may also be estimated, and in most model runs, some of them will be estimated.

- Mean length at age in initial year, mature and immature fish.
- Standard deviation of length at age in initial year, mature and immature fish.
- Mean length of the recruits in each year.
- Standard deviation of the length of the recruits in each year.
- Growth parameters, i.e. annual growth parameter $k(y)$ in (39) or (40) and variance in (65).
- Maturation parameters.

- Cannibalism parameters.
- Residual natural mortality.
- Selectivity parameters for fleets and surveys.

4.4 Parameter estimation algorithms

Typically, one may want to estimate 150-200 parameters, and this can be quite time-consuming. Three algorithms for parameter estimation are implemented at present.

- Hooke and Jeeves (Hooke and Jeeves 1961)
- simulated annealing (Kirkpatrick, Gelatt, and Vecchi 1983)
- bfgs (Quasi-Newton method) (Luenberger 1984)

In order to use a gradient method the objective function must be differentiable, which is not the case with the current implementation of growth.

5 Results

We here present some results from a sample run with Fleksibest. It is the run used in the alternative assessment at the 2000 meeting of the AFWG, assessing NEA cod (ICES 2001). All results are compared to the XSA run, which is the official assessment of NEA cod. The main results are presented in Figs 2-5.

The main feature when comparing Fleksibest and XSA, is that Fleksibest seems to give a more dynamic stock development than XSA gives. This is seen from Fig 2. Fleksibest's result is in accordance with the surveys, which indicate a more dynamic stock development than the XSA assessments normally do (Korsbrekke, Mehl, Nakken, and Pennington 2001). Fleksibest gives a higher spawning stock biomass (SSB) over the whole period (except for the first and the last year), and the peak at the beginning of the 1990's is both higher and longer in time. Fleksibest gives a steeper decrease in SSB over the last years, this is in accordance with the results from the acoustic Lofoten survey on the spawning grounds.

Figure 3 shows that the reference fishing mortality F_{5-10} is lower for Fleksibest than XSA over the whole period. This is reasonable, as Fleksibest estimates higher stock size than XSA does.

The recruitment in Fig 4 shows the same general trends for both methods. Most of the time period Fleksibest indicates a higher recruitment than XSA, but over the last year, XSA has the highest recruitment.

Figure 5 shows estimated catch in tons from Fleksibest and the official catches in tons. The figure shows that Fleksibest systematically estimates larger catches in tons than the official catches. It is worth to note that Fleksibest uses catch in numbers (equation (46)) in the likelihood formulations, so the main emphasis is put on making catch in number fitting. Some of the deviance may thus come from the weight at length used to calculate the catches in tons.

The conclusion is that Fleksibest and XSA have the same large, general trends, but Fleksibest is closer to the trends in the surveys.

6 Discussion and further work

In this paper, we have described the mathematical formulation of the Fleksibest model and the motivation for developing it. It is indicated why such an age-length structured parametric model is particularly suitable for assessing boreal fish stocks (e. g. North-East Arctic cod). A model of this kind also makes prediction easier and more transparent. In the parametric formulations, it is easy to systematically change a group of parameters at time, and then see the influence of those parameters. It is also easy to use earlier environmental conditions in predictions, by using the parameters for growth e.g. associated with the specified conditions.

The model will now be systematically tested using data for NEA cod. It will also be taken in use in the assessment made by ICES. Future work will focus on:

- Testing alternative formulations of the biological processes, e.g. length growth.
- Testing various likelihood functions and weighting of data sources.
- Describing how uncertainty in the model results are connected to uncertainty in the data and uncertainty in the model formulations.
- Making parameter estimation more effective and robust.
- Model accuracy vs. model complexity.
- Investigate parameter correlations.

The results of these investigations will be reported in forthcoming papers.

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Growth distribution

When the mean growth has been calculated the length distribution of each age group must be updated according to the calculated growth.

A certain proportion of the fishes do not grow, some proportion grows one length group, some proportion two length groups, etc. The maximum number of length groups a fish is allowed to grow in a time step is denoted g. The proportions are selected so that the following three equations are satisfied:

$$\sum_{i=r}^{i=r+g} p(i,r|\delta l(l_r,t_m)) = 1 \tag{62}$$

$$\sum_{i=r}^{i=r+g} (i-r)p(i,r|\delta l(l_r,t_m)) = \mu_r \tag{63}$$

$$\sum_{i=r}^{i=r+g} (i-r-\mu_r)^2 p(i,r|\delta l(l_r,t_m) = \sigma_r^2 \tag{64}$$

$$p(i,r|\delta l(l_r,t_m)) = \begin{cases} 0 & r < i-g \\ h(\mu_r,\sigma_r^2,i-r) & i-g \le r \le i \\ 0 & r > i \end{cases} \tag{65}$$

where

$$\mu_r = \frac{\delta l(l_r,t_m)}{\Delta l} \tag{66}$$

is the average length growth of length group r and σ_r^2 is the variance. $h(\mu_r,\sigma_r^2,i-r)$ is calculated so that $p(i,r|\delta l(l_r,t_m))$ satisfies (62)-(64).

A typical value of g is 4 or 5. These formulas must be adjusted if $r+g > L$. Here μ_r is the calculated average growth (see subsection 2.3.2) and σ_r^2 the variance of the spread, calculated from $\sigma_r^2 = k_0 + k_1\mu_r$. k_0 and k_1 are constants that are prespecified or estimated and control the spreading of the length distribution.

Often all three equations can not be solved exactly. Then (62) is solved exactly and much more weight put on approximating (63) than (64). In summary this means that priority is put on not losing fish (or gaining), then to get the average growth (in length) correct and finally to get the dispersion correct. In other cases there might be more than one combination satisfying the equation exactly. In those cases the solution having the fewest numbers of extrema is chosen to get as smooth a solution as possible.

The proportions are selected from a table that has been generated by solving the preceding equations for different values of μ_r and σ_r. σ_r in the table is generated on an interval of 0.05 length groups and μ_r on an interval of 0.01 length groups. A 4-point interpolation is used if the calculated values of μ_r and σ_r lie between table values.

The method described has one major problem, relatively small changes in the parameters μ_r and σ_r^2 can sometimes lead to relatively large changes in the proportions, by jumping from one solution fulfilling (64) to another. This becomes a serious problem in optimizing algorithms using the gradient so another "parametric" solution has been developed using the beta-binomial distribution to calculate the probabilities. One of the parameters in the beta distribution is then estimated instead of k_0 and/or k_1.

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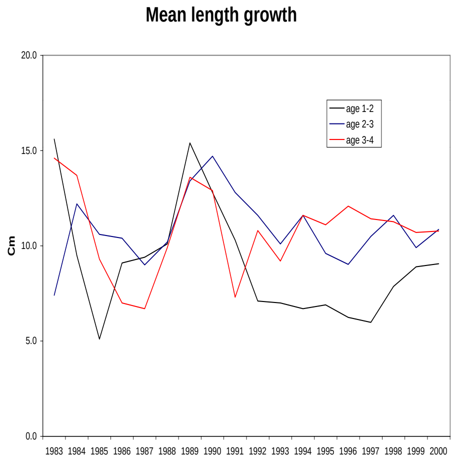


Figure 1: The mean length growth of North-East Arctic cod. The growth is calculated as the increase in the average length at age of the cohorts.

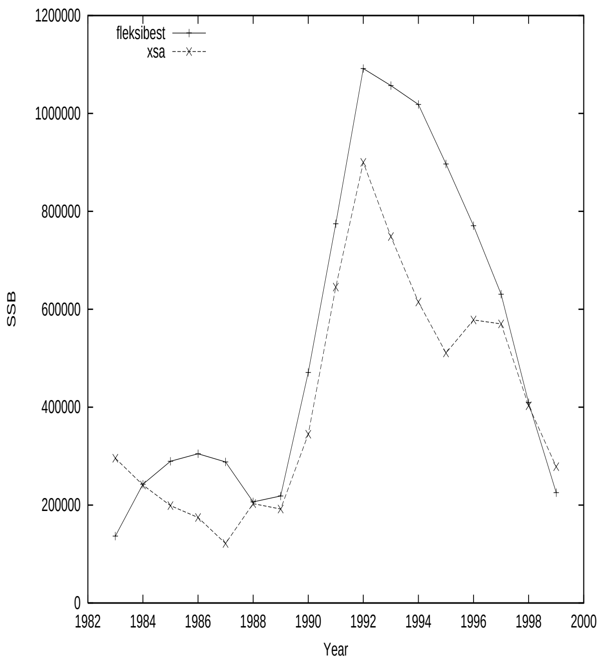


Figure 2: The spawning stock biomass (in tons) of NEA cod, estimated by XSA and Fleksibest. Note that XSA only estimates the total stock, and then calculates SSB from maturity ogives (fraction mature) at age, while SSB in Fleksibest is the biomass of the mature stock estimated separately.

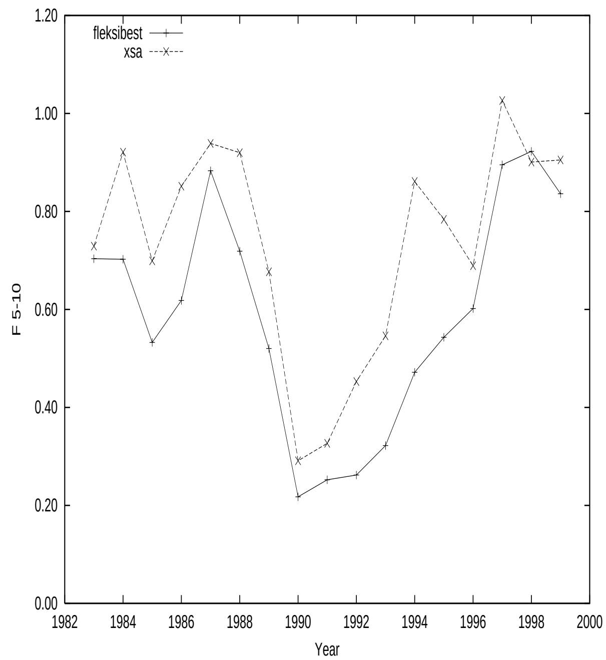


Figure 3: Reference fishing mortality. The reference fishing mortality F_{5-10} is an unweighted arithmetic mean of fishing mortalities of the age groups 5 to 10, used for management purposes.

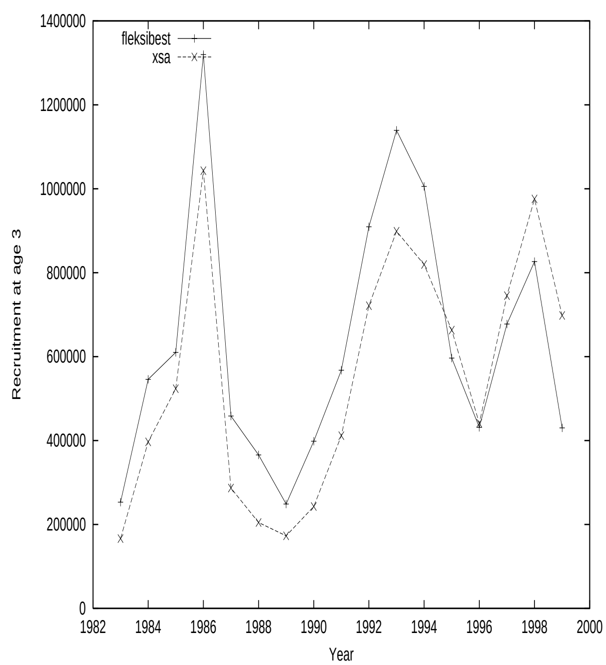


Figure 4: Recruits at age 3 (in thousands) estimated by Fleksibest and XSA.

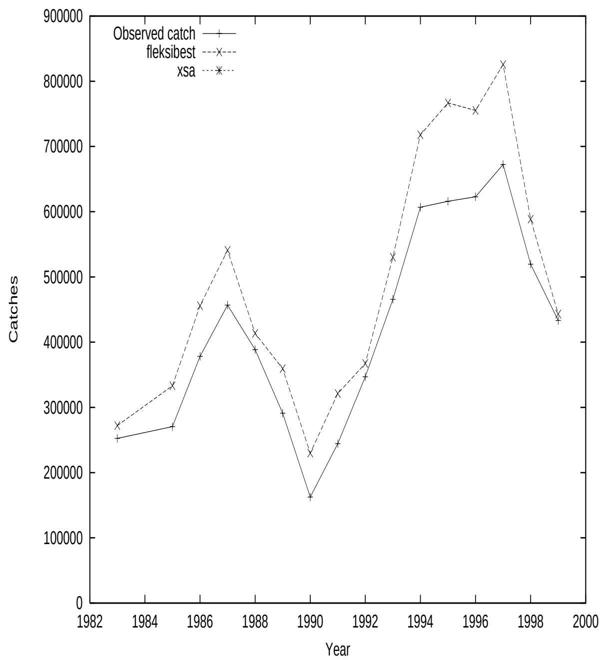


Figure 5: Estimated and reported catches in tons. Fleksibest estimates catch in number according to (46), and calculates catch in tons by multiplying with weight at length. XSA uses the reported catches in number at age for the 'book-keeping'.

G Estimation Procedures

G.1 Estimation of weights for likelihood components

Gunnar Stefánsson

1. Introduction

It has been demonstrated that when several data sets and different likelihood components are used in fisheries models, several estimation issues arise.

A technique for overcoming this problem has been proposed earlier (Stefansson, 1998) and tested on certain data sets but not evaluated quantitatively. The method is based on iteratively putting heavy weights on individual data components in order to estimate the minimum value of each likelihood component.

This document proposes a methods for formal evaluation of the method.

2. A technique for estimation of weights

In cases where only a part of the full data set needs to be used to make parameters estimable, it is in principle possible to perform least squares estimation based on each part separately. This method can in principle give unbiased estimates of the variance associated with each data set and therefore an estimate of the appropriate weighting factors.

Even in the more general case, one can speculate that putting very high weight on a component of the data and then estimate parameters will tend to give an approximately unbiased estimate of the variances. Including the “other” components with a very low relative weight should in principle only stabilise the parameter estimates but have little effect on the estimate of the weighting factor in question.

3. A theoretical example

In order to evaluate the behaviour of the estimation procedure, consider the following simple linear model:

$$Y_{ij} \sim n(\alpha_i + \beta x_{ij}, \sigma_i^2), \quad j = 1, \ldots, n_i \;\; i = 1, 2, \tag{1}$$

where $\alpha_i,\ i_1, 2$ and β are the unknown regression parameters, $\sigma_i,\ i = 1, 2$ are the unknown and different variances and x_{ij} are regression constants.

The following approaches to estimation will be used and compared:

- Maximum likelihood estimation of all parameters including σ_i. Although this will be the best model in this particular case, the general case does not follow, since the likelihood function is usually not fully specifiable for fisheries models.

- Separate maximum likelihood estimation of σ_i under the assumption that $\sigma_i \to 0$, followed by parameter estimation using these variance estimates as inverse weighting factors.
- Maximum likelihood estimation of all parameters except σ_i under the assumption $\sigma_1 = \sigma_2$ but with different true variances.

Parameters in each of these models will be estimated and the performance of the estimators compared analytically and numerically.

Results from these analyses will indicate whether conclusions can be drawn on the applicability of the estimation method in the specific case and thus indicate directions for future research.

4. The MLE

Rewriting the model in terms of data and in matrix form yields:

$$\mathbf{y} = \mathbf{X}\theta + \mathbf{e}$$

where the X-matrix is

$$\mathbf{X} = \begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & 1 \\ \vdots & \vdots & \vdots \\ 1 & 0 & 1 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \\ \vdots & \vdots & \vdots \\ 0 & 1 & 1 \end{bmatrix}, \tag{2}$$

the measurements have been collected into a vector,

$$\mathbf{y} = \begin{bmatrix} y_{11} \\ y_{12} \\ \vdots \\ y_{1n_1} \\ y_{21} \\ y_{22} \\ \vdots \\ y_{2n_2} \end{bmatrix} \tag{3}$$

and $\mathbf{e}$ denotes the usual (numerical) error term. The parameter vector is given by $\theta = (\alpha_1, \alpha_2, \beta)'$.

If it can be assumed that $\sigma_1 = \sigma_2$ (not the case here), then the maximum likelihood estimator for the parameter vector is $\hat{\theta} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{y}$. In the current setting, however, σ_1 and σ_2 are not only unequal but also unknown.

The likelihood function in this case becomes

$$L = \left(\frac{1}{\sqrt{2\pi\sigma - 1}}\right)^{n_1} e^{-\frac{\sum_{j=1}^{n_1}\left(y_{1j}-\alpha_1-\beta x_{1j}\right)^2}{2\sigma_1^2}} \left(\frac{1}{\sqrt{2\pi\sigma - 2}}\right)^{n_2} e^{-\frac{\sum_{j=1}^{n_2}\left(y_{2j}-\alpha_2-\beta x_{2j}\right)^2}{2\sigma_2^2}}.$$

It is well known that whatever the estimates of the regression parameters, the maximum likelihood estimates of the variances are obtained with

$$\hat{\sigma}_i^2 = \frac{\sum_{j=1}^{n_i}\left(y_{ij} - \hat{\alpha}_i - \hat{\beta}x_{ij}\right)^2}{n}, \text{ for } \quad i = 1, 2.$$

Similarly it is easy to ascertain that the MLE, $\hat{\alpha}_i$, of α_i only depends on data set i and is therefore trivial, given the estimate $\hat{\beta}$ of β:

$$\hat{\alpha}_i = \bar{y}_{i.} - \hat{\beta}\bar{x}_{i.}, \text{ for } \quad i = 1, 2.$$

A bit of algebra also quickly shows that inserting these equations into the formula for the likelihood function, taking negative logs and dismissing constants indicates that the MLE for β is obtained by minimising:

$$l(\hat{\beta}) = \sum_{i=1}^{2} \ln\left\{\sum_{j=1}^{n_i}\left((y_{ij} - \bar{y}_{i.}) - \beta\left(x_{ij} - \bar{x}_{i.}\right)\right)^2\right\}.$$

Differentiating the equation gives the obvious extension to the normal equations, since the derivative of the logs will give $\hat{\sigma}^2$ as the inverse weighting factors, but these weighting factors now are functions of $\hat{\beta}$, as is to be expected. Although for only two groups of measurements, the resulting equations can be written as roots to a cubic equation and therefore in principle be solved, the approach here will mainly be to compare results numerically.

References:

Gunnar Stefánsson (1998:). Comparing different information sources in a multispecies context. Í: F. Funk [et al.] (ritstj.): Fishery Stock Assessment Models : Proceedings of the international symposium; Anchorage 1997. 15th Lowell Wakefield Fisheries Sympo

G.2 Sensitivity analyses

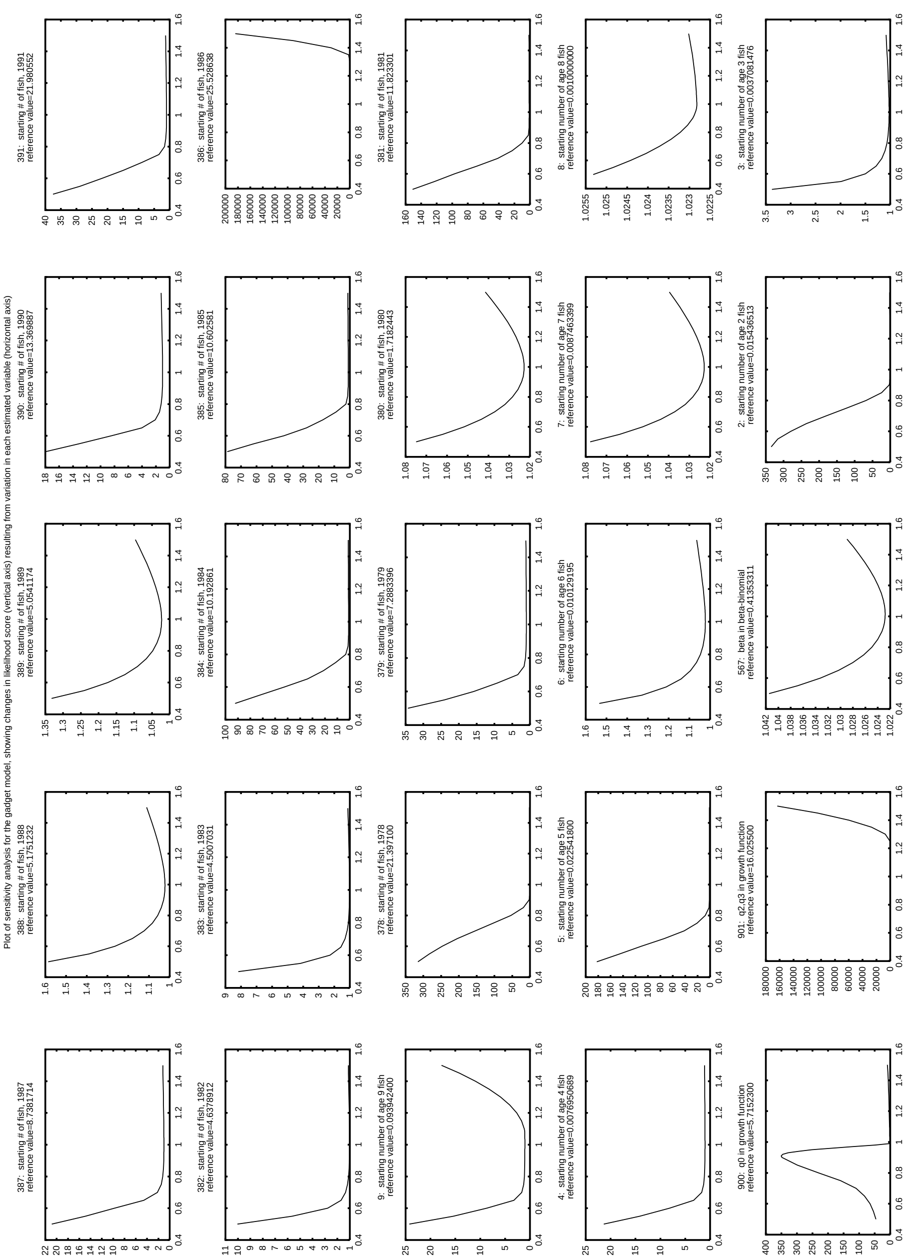
Daniel Howell

Workpackages 2 and 4 require the development of specific models to incorporate into Gadget. Workpackage 3 requires the investigation of different modelling approaches within Gadget. Workpackage 5 requires the development of specific case study mdoels. In each case it is important to be able to readily compare different possible model formulations against both the real-world data and other possible model formulations. In order to facilitate this a number of different diagnostics have been investigated in order to identify those suitable for use in model building and testing. These tools will be of use in building specific models, and in a more general assessment of the success of different model components.

The use of likelihood scores and likelihood components as a tool in model building have been investigated. The likelihood score measures the numerical match between the model results and the data set(s) supplied to the model during optimisation. For a single data set a series of different models were constructed with different parameters to be estimated and the results compared using the overall likelihood scores and individual likelihood components. This confirmed that the overall likelihood score can be successfully used to determine which estimated variables gave the greatest increase in the fit between the model and the real world. Furthermore an examination of the individual likelihood components can identify where the greatest improvement has occurred within the model, and thus lead to identification of which areas remain to be addressed.

Software has been developed to conduct automated sensitivity analysis of specific model formulations. The number of estimated variables within the Gadget model is potentially very large, and a thorough sensitivity test can be a large undertaking. By automating this process comparisons between models can be made quickly and easily. Among other things this can identify redundant variables and highlights those variables of maximum sensitivity within the model. It also identifies variables where variation can lead to multiple local minima in the likelihood score, and thus where care is needed in the selection of initial values. It is also intended to use this software as an aid to compare different model formulations.

An example of the output of these programs is presented below, showing the response in the likelihood value of varying individual model variables by up to 50% around the optimised solution.


Plot of sensitivity analysis for the gadget model, showing changes in likelihood score (vertical axis) resulting from variation in each estimated variable (horizontal axis)
391: starting # of fish, 1991
reference value=21.980552
390: starting # of fish, 1990
reference value=13.369887
389: starting # of fish, 1989
reference value=5.0541174
388: starting # of fish, 1988
reference value=5.1751232
387: starting # of fish, 1987
reference value=8.7381714
386: starting # of fish, 1986
reference value=25.528638
385: starting # of fish, 1985
reference value=10.602581
384: starting # of fish, 1984
reference value=10.192861
383: starting # of fish, 1983
reference value=4.5007031
382: starting # of fish, 1982
reference value=4.6378912
381: starting # of fish, 1981
reference value=11.823301
380: starting # of fish, 1980
reference value=1.7182443
379: starting # of fish, 1979
reference value=7.2883396
378: starting # of fish, 1978
reference value=21.397100
9: starting number of age 9 fish
reference value=0.093942400
8: starting number of age 8 fish
reference value=0.0010000000
7: starting number of age 7 fish
reference value=0.0087463399
6: starting number of age 6 fish
reference value=0.010129195
5: starting number of age 5 fish
reference value=0.022541800
4: starting number of age 4 fish
reference value=0.0076950689
3: starting number of age 3 fish
reference value=0.0037081476
2: starting number of age 2 fish
reference value=0.015436513
567: beta in beta-binomial
reference value=0.41353311
901: q2,q3 in growth function
reference value=16.025500
900: q0 in growth function
reference value=5.7152300

DRAFT. February 2001

DEVELOPMENT OF STRUCTURALLY DETAILED STATISTICALLY TESTABLE MODELS OF MARINE POPULATIONS

Contract No: QLK-CT 1999-01609

FORMULATION OF A STOCHASTIC MULTISPECIES MODEL

PETER LEWY

D. 21.2. 2001

Development of stochastic multi-species models

The model developed is supposed to include a historical part, "VPA" and a prediction part. The model will be based on whole are. Migration within this area will not be considered. It should further be possible to extend the model to include growth.

If migration should be included it may done within the frame of a biomass dynamic model.

Specification of the model requires specification of

1. The differential equation models, dN/dt = -Z*N, dC/dt = F*N etc.
2. The likelihood function given the observations, i. e. catch-at-age and relative stomach contents , which are assumed independent. In this continuous formulation of stock and catch changes the likelihood function only indirectly includes the parameters. These is included through the expected values of observations obtained by integration of the differential equations.
3. The model will be implemented as modules such that separate processes will be clearly separated and exchangeable. The following modules be included:

- Data input/database module
- A Module for definition of differential equations and specification of parameterisation.
- Modules for predation and growth models.
- A module for definition of the likelihood function, where the probability models of observations are defined.
- An algorithm module for solving ordinary differential equations.

- A module to minimise the likelihood function.
- A module to calculate the Hessian matrix and the variance/covariance of parameters.
- An output module enabling graphical and other presentations.

The prediction model may be fleet based and include technical interactions, i. e. that the catch composition by species and age for each fleet is accounted for by the model.

Notation s denotes the species
a denotes the age
t denotes the time
C denotes observed catch in numbers
$\hat{C}$ denotes expected catch in numbers
N denotes the stock numbers in the sea
Z denotes total mortality rate
F denotes fishing mortality rate
$M1$ denotes natural mortality excluding predation
$M2$ denotes predation mortality
$SUIT(prey, a, pred, b, t)$ denotes suitability parameter for given prey/age and predator/age species
$\eta(pred, b)$ denotes the "mean" in the food preference function
$\sigma^2(pred, b)$ denotes the "variance" in the food preference function
$\rho(prey, pred), \rho_1(prey)and\rho_2(pred)$ denote vulnerability parameters
$STOM(prey, a, pred, b, t)$ denotes the average weight of prey $(prey, a)$ in the stomach of predator $(pred, b)$ to time t/ average total weight of the stomach contents of predator $(pred, b)$.

Specification of the likelihood function

The differential equations for stock and catch changes are the standard models:

$$l\frac{\partial N(s,a,t)}{\partial t} = -Z(s,a,t)N(s,a,t) \tag{1}$$

new

$$new\frac{\partial C(s,a,t)}{\partial t} = F(s,a,t)N(s,a,t) \tag{2}$$

new

Total mortality, $Z(s, a, t)$, is as usual defined as

$$Z(s,a,t) = F(s,a,t) + M1(s,a,t) + M2(s,a,t)$$

$$M2(prey,a,t) = \sum_{pred,b} \frac{\bar{N}(pred,b,t)Food(pred,b,t)SUIT(prey,a,pred,b,t)}{AVAIL(pred,b,t)}$$

and

$$\begin{aligned} &AVAIL(pred,b,t) = \\ &\quad \sum_{prey,a} \bar{N}(prey,a,t)w((prey,a,t)SUIT(prey,a,pred,b,t) + \\ &\quad + OTHERFOOD(pred,b,t)SUIT(OF,pred,b,t) \end{aligned}$$

Suitability is modelled as suggested by Andersen and Ursin (1977):

$$SUIT(prey,a,pred,b,t) = \rho(prey,pred)\exp(-\frac{(\ln\frac{w(pred,b,t)}{w(prey,a,t)} - \eta(pred,b))^2}{2\sigma^2(pred,b)})$$

The vulnerability parameter, ρ, may be simplified assuming that

$\rho(prey,pred) = \rho(prey)\rho(pred)$

The observations are catch-in numbers by species, age, year and quarter and relative stomach content s of predators included by predator/age, prey/age, quarter and year.

Fishing mortality is assumed to be multiplicative:

$F(s,a,t) = F(s,a)F(s,t)$

Assuming that the catches are log normal distributed the part of the likelihood function associated with the catches, LC, is

$$L_C = \prod_{s,a,t} \frac{1}{\sigma(s)\sqrt{2\pi}}(\exp(-\ln(C(s,a,t)) - \ln(\hat{C}(s,a,t)))^2/(2\sigma^2(s)))$$

where the expected catches, $\hat{C}$, obtained by integration of equation (1) and (2) depends on the stock and mortality parameters.

The likelihood for the stomach contents observations can be expressed as follows:

The relative stomach contents, $STOM(prey,a,pred,b,t)$ is assumed to be a stochastic variable subject to sampling and process variations. The distribution of the stomach content observations, $STOM(prey,a,pred,b,y,q)$, may be simulated by Monte Carlo and the variance/covariance matrix be calculated. For the North Sea the ICES Database based on data collected in the Stomach Sampling projects in 1981 and 1991 will be used. A simple approach to obtain a likelihood function is to assume that the vector $(STOM(prey,a,pred,b,y,t),prey,a)$ is multivariate lognormal distributed with log mean (following the formulation of ICES' s MSVPA)

$$E(\ln(STOM(prey,a,pred,b,t))) = \ln\left(\frac{\bar{N}(prey,a,t)w(prey,a,t)SUIT(prey,a,pred,b,t)}{\sum\limits_{prey,a} \bar{N}(prey,a,t)w(prey,a,t)SUIT(prey,a,pred,b,t)}\right)$$

and using the variance/covariance, $D(pred,b,y,t)$, simulated.

The likelihood function, L_{STOM}, for stomach content observations then becomes:

$$L_{STOM} \cong \prod_{pred,b,y,q} |D^{-1}(pred,b,t)| \exp(-0.5RES'(pred,b,t)D(pred,b,t)RES(pred,b,t)$$

where

$$RES(pred,b,t) = STOM(pred,b,t) - E(STOM(pred,b,t)$$

$$STOM(pred,b,t) = \begin{pmatrix} STOM(prey1,a1,pred,b,t) \\ . \\ . \\ STOM(prey\text{n},a\text{n},pred,b,t) \end{pmatrix}$$

$$E(STOM(pred,b,t)) = \begin{pmatrix} E(STOM(prey1,a1,pred,b,t)) \\ . \\ . \\ E(STOM(prey\text{n},a\text{n},pred,b,t)) \end{pmatrix}$$

The likelihood, L, then becomes

$L = L_C * L_{STOM}$

The parameters in the model are:

$M1(s,a)$
$F(s,a,t)$
$F(s,y,t)$
$\rho(s)$

$\eta(pred, b)$
$\sigma(pred, b)$
$N(s, a, t)$

Regarding the stock numbers initial stock size may be treated as parameters while the remaining may be considered as deterministic functions of initial stock size and mortality parameters.

References

Andersen, K. P., and Ursin, E. 1977. A Multispecies Extension to the Beverton and Holt Theory of Fishing, with account of Phosphorus Circulation and Primary Production. Meddr. Danm. Fisk.- og Havunders. **7** 319-435.

H MSVPA for two areas the North Sea

Morten Vinther
DIFRES
February 2001

Introduction:

Protected areas, with no or a limited human activity, are a widely used management measure for protection of marine resources (ref). Stock assessments of the fish in the affected sub-areas are essential in the evaluation of a potential effect of local fishing effort reduction or closed areas. However, such assessments which include area dependent moralities and migration (refs) are not trivial and are in addition very data demanding. In the beginning of the nineties, a lot of effort was used to sample spatially disaggregated catch data (Lewy et al. 1992,) and to evaluate the effect of various local management measures for the North Sea (Anon. 1992) These scenarios had not included the effect of species interaction. Later on, focus has changed from improvement of exploitation pattern of fish stocks to a more ecosystem approach (reference punkter, tobis, ref) which makes the inclusion of species interaction in the model even more important.

Multi Species Virtual Population Analyses (MSVPA) (Helgason and Gislason 1979; Pope 1979; Sparre 1980; Gislason & Sparre, 1987) extends the single species virtual population analyses (VPA) into a multi species version where mortality caused by inter- and intra species predation is estimated. MSVPA implemented for the North Sea is probably one of the most investigated multispecies models (see i.e. ICES, 1997) and has a very comprehensive database of stomach contents data (Daan, 1989; ICES, 1997). Spatial disaggregated VPA including migration is technically impossible (Gislason and Sparre, 1994) and a more simple approach must be applied. In this paper, the traditional MSVPA output is combined with stock distribution data, spatial disaggregated catch and stomach contents data to estimate local food suitability coefficients and fishing mortalities. These values are then used in a multispecies catch projection for evaluation of local area management measures. A hypothetical local area effort reduction in the North Sea stock has been chosen as an example and the effects are estimated using both the traditionally one-area method and this new method.

(Another paper: The estimated local food suitabilities are compared)

Methods and material

Spatially disaggregated assessment model

The method for assessment of sub-areas is straightforward and based on the MSVPA algorithm. Gislason and Sparre (1987) give a formal description of MSVPA and only a few details are given here. MSVPA operates by quarter of the year as time step and includes the following variable given by year and quarter.

Input to MSVPA includes the variables (not the complete list):

- $C_{s,a}$ Catch numbers by species (s) and age (a):
- $F_{s,a}$ Terminal fishing mortality
- $M1_{s,a}$ Residual natural mortality
- $R_{s,a}$ Food ration per predator
- $W_{j,a,i,b}$ Mean weight of prey (i), age (b) in the stomach of predator (j), age (a)
- $S_{j,a,i,b}$ Relative stomach contents weight

Output from the MSVPA includes:

- $M_{2s,a}$ Predation mortality
- $F_{s,a}$ Fishing mortality
- $Z_{s,a}$ Total Mortality
- $N_{s,a}$ Stock numbers
- $U_{j,a,i,b}$ Food suitability coefficient (year independent)

Stock assessment for sub-areas (r) requires in addition, the following data for at least one year:

- $DIST_{s,a,r}$ Stock distribution (relative)
- $S_{j,a,i,b,r}$ Relative stomach contents weight
- $C_{s,a,r}$ Catch numbers

The method for the proposed local assessment is first to perform a MSVPA for the total area. The result includes stock numbers and mortality rates for the whole areas. To do the local area assessment, stock numbers are then distributed on sub-areas in accordance with the assumed known stock distribution ($\overline{N}_{s,a,r} = \overline{N}_{s,a} * DIST_{s,a,r}$). When the local stock numbers are estimated, local food suitability coefficients can be calculated from the local stomach contents in accordance to the definition of suitability (Gislason and Sparre, 1987).

$$U_{i,a,j,b,r} = \frac{\frac{S_{i,a,j,b,r}}{\overline{N}_{i,a,r} * W_{i,a,j,b}}}{\sum_{k,d} \frac{S_{k,d,j,b,r}}{\overline{N}_{k,d,r} * W_{k,d,j,b}}}$$

Index k and d means all preys species and all prey ages respectively.

The local predation mortality can then be calculated from the definition (Gislason and Sparre,1987) as:

$$M2_{i,a,r} = \sum_{j,b,r} \overline{N}_{j,b,r} * R_{j,b} * \frac{U_{i,a,j,b,r}}{\sum_{k,d,r} \overline{N}_{k,d,r} * W_{k,d,j,b} * U_{k,d,j,b,r}} \qquad (1)$$

and finally local fishing mortalities can be calculated from local catches and mean local stock numbers: $F_{s,a,r} = \frac{C_{s,a,r}}{\overline{N}_{s,a,r}}$.

The estimated stock numbers, fishing and total mortalities for the local area should be used in the validation process of method and local area data. Moreover, the estimated local food suitability coefficient can be used in multispecies scenarios to evaluate the effect of protected areas.

MSVPA is an analysis of historical data, but the concepts concerning species interaction can be used in prediction mode as well. The forecast model, MSFOR (Gislason and Sparre,1987) predicts future catches and stock sizes from input fishing mortalities and initial stock sizes. The predation mortality is estimated as given in (1) using the MSVPA estimated food suitability values.

Like MSVPA, MSFOR is originally designed for one area only. To handle more areas, it is assumed that the stock numbers estimated independently for each sub-area redistributed at the end of each quarter in accordance to the historically observed distribution data.

The MSVPA and MSFOR algorithm, including local areas have been implemented as part of the so-called 4M package (Vinther et al, 2000) which is and updated and extended version of MSVPA and MSFOR programs.

Spatially disaggregated data

The required data for assessment by sub-areas comprise stock distribution data, catch data and stomach contents data. MSVPA operates by quarter and the spatial disaggregated data must be given by quarter as well. The year 1991 was the exception where all the types of data were available. The ICES, International Bottom Trawl Survey (IBTS) supplied stock distribution data; the STCF data base (Lewy et al, 1992) gave catch catches and the ICES stomach sampling program (ICES, 1997) supplied stomach contents data. For all data set, information is given by quarter and ICES rectangles (10x 0.50 . However , the stratification for sampling of age-length keys has in most cases been the so-called ICES roundfish areas, such that the actual minimum sub-area becomes one of the totally seven roundfish area in the North Sea.

Stock distribution data

The IBTS was initiated in 1991 as a quarterly trawl survey for the North Sea. More than 1300 hauls were conducted in 1991, with 287 hauls in the fourth quarter as the lowest quarterly effort. Description of the survey method can be found in ICES (1996) and a detailed description of the result for 1991 is given in ICES, 1998/D:8. IBTS data for stock distribution consist of the mean CPUE per ICES rectangle by species and age. The proportion of the stock in a sub-area was calculated as the arithmetic mean of the average rectangle CPUE. No attempt was made to correct for varying rectangle area or rectangles without hauls. Catches of older fish were sporadic, and for each species a plus group was defined, which was assumed to represent the distribution of older fish.

Sandeel are caught in a very low number at the IBTS survey and the spatially distribution of commercial catches) was assumed to represent the stock distribution. Fishery for sandeel takes mainly place in the second quarter. Third quarter has a rather limited effort while the fishery is almost non-existing for the rest of the year. The assessment (ICES, 2001) give catches by half-year for the Northern and southern North Sea. Caused the distinct season fishery the catch distribution for the first half-year of 1991 was used as stock distribution key for all quarters.

Catch distribution data
The STCF data base contains quarterly catch at age data for each of the ICES rectangles in the North Sea in 1991. These data were used as a spatially distribution key to spilt the MSVPA catches on sub-areas

Stomach contents data
Input to the MSVPA is average relative stomach content (weight) of a prey, and the mean (fresh) weight of the prey. Data are given by year, quarter, predator, predator age, prey and prey age. MSVPA operates for the entire North Sea and stomach data reflect average stomach contents for the total population in the whole model area. This section describes the compilation of data to transform stomach data from the individual sample to the average stomach data at population level for one ore more sub-areas. The methods follows the technique given in *Anon.*, 1997 (ICES Coop. Res. Rep. No. 219), however, the description here is supplemented by formulas for the actually data transformations done. Moreover, descriptions on what to do in cases of incomplete data are given. (det følgende er skrevet så jeg selv kan huske hvad jeg gjorde)

Individual sample information:

Observed stomach contents data include the information shown in the following data hierarchy:

Haul information (h)
- Quarter of the year (q)
- ICES Roundfish area (r)
- ICES rectangle (sq)
    Predator (c)
        Predator length class (cl)
        - CPUE , $(CPUE)$
        Sample no (s)
        - number of feeding (valid) stomachs, $(NFEED)$
        - number of feeding, but regurgitated stomachs, $(NRGUR)$
        - number of stomachs with skeletal remains only, $(NSKEL)$
        - number of empty stomach, $(NEMPT)$

- total number of stomachs, ($NTOT$)
- Total stomach contents of valid stomachs ($WTOT$)

  Prey species (p)

  Prey length class (pl)

  -Stomach contents weight (W)

  -Number of preys

Only stomach contents from the feeding, non-regurgitated, stomachs were sampled. It is assumed that the regurgitated stomachs had a similar stomach content as the (valid) feeding fish and the average stomach contents for a predator length group in haul (potentially including one or more samples) were calculated applying the following relationship:

$$\overline{W}_{h,c,cl,p,pl} = \frac{\sum_s W_{s,h,c,cl,p,pl}}{\sum_s NFEED_{h,s}} \times \frac{(\sum_s NFEED_{h,s} + \sum_s NRGUR_{h,s})}{\sum_s NTOT_{h,s}}$$

(Niels Daan korrigerer på lignende måde også for NSKEL i ICES RAP 219, side 5, men i opgangnings programmet er NSKEL ikke med som korrektion. Det er uklart om Maveindholdet fra NSKELR faktisk er med i det oparbejdede maveindhold. Niels Daan snyder- hvis en sample kun har NSKELR maver regnes den som en NFEED mave. Den praktiske betydning for MSVPA data er dog ubetydelig.

Average stomach contents per roundfish area

ICES rectangles are used as strata in the calculation of average stomach content per ICES roundfish area. If more than one sample are taken from a rectangle, the average stomach content for a predator length class is calculated as a weighted mean, using the number of stomachs sampled as weighting factor.

$$\overline{W}_{sq,c,cl,p,pl} = \frac{\sum_s \overline{W}_{sq,s,c,cl,p,pl} NTOT_{sq,s,c,cl}}{\sum_s NTOT_{sq,s,c,cl}}$$

The average stomach content of a given predator and length class in a roundfish area are calculated as a weighted mean of the average stomach content per square weighted by the average (square root of) CPUE for the square.

$$\overline{W}_{r,c,cl,p,pl} = \frac{\sum_{sq} \overline{W}_{sq,c,cl,p,pl} \sqrt{\overline{CPUE}_{r,sq,c,cl}}}{\sum_{sq} \sqrt{\overline{CPUE}_{r,sq,c,cl}}}$$

Average square CPUE is the arithmetic mean of the observed CPUEs within a square.

Species and size redistribution of preys

In a few cases a prey item has been identified to species level but the length is not recorded. These items are redistributed on length groups proportionally to the observed length distribution within the species; first within the square and in cases of no “match” within the roundfish area.

A prey item can be partly digested such that species identification is impracticable. However, these items are often identified to a higher taxon (e.i. Gadidae). Such partly identified items belonging to the families (f) Gadidae, Clupeidae, Pleuronectidae and Soleidae were allocated proportionally to the species identified within the family. If a prey item had been assigned to a particular length class the redistribution was made over all family members in this length class. If the prey item was well digested and the length class is unknown, the redistribution was made over all identified family members and size classes. The redistribution was made within a predator size class and was first done using redistribution “keys” from the same ICES rectangle. If there was no key to a particular prey item, the redistribution was made using a redistribution key calculated for the entire roundfish area. In cases with no matches on roundfish level either, the prey item was classified as unknown. The manipulations can be summarised as follows:

1) Redistribute identified species without length using a species-length key by rectangle
2) Redistribute "unmatched" preys from 1) using a species-length key by roundfish area.
3) Classify unmatched remains from 2 as unknown species
4) Redistribute "family members" with length information using a familylenght -species key by rectangle
5) Redistribute unmatched preys from 4) using a key familylength-species by roundfish area
6) Redistribute family members without length information using a family-species key by rectangle
7) Redistribute unmatched preys from 6) using a family-species key by roundfish area
8) Classify unmatched remains from 5) and 7) as “Other food”

Prey items not identified to the mentioned families were not redistributed. That means that prey in the category “Unidentified fish” are not allocated to species and classified as unknown (Other food).

Age length transformations

All stomach contents observations are done by length classes of predator and preys and must be transformed to age before used in MSVPA. For each roundfish area, there exist a age-length-key (ALK) which gives the proportion of an age class within the length class.

For most species the ALK is constructed from the IBTS CPUE data. First, the average CPUE of a length class is calculated for each ICES rectangle as a simple mean of the available haul's CPUE. The average CPUE per length class within a roundfish area is then calculated as the arithmetic mean of average CPUE per rectangle. The age distribution within combinations of roundfish area and length class is found from otoliths randomly sampled in strata.

To calculate the mean stomach content of a given predator age group (ca) within a roundfish area the following was done:

$$\overline{W}_{c,ca,p,pl} = \sum_{ca} \frac{ALK_{c,ca,cl}\overline{W}_{c,cl,p,pl}}{\sum_{cl} ALK_{c,ca,cl}}$$

Niels Daan fravaelger implicit i nogle tilfaelde data fra et rundfiskeområde ved at undlade at give en ALK, Således benyttes der kun sej-maver fra rundfiskeområde 1. For makrel skifter de benyttede områder mellem kvartaler- det er noget med west og nordsømakrel, men det er ikke helt klart hvad der bestemmer valget af områder.

The age distribution of preys was calculated in a similar way as for the predator ages.

$$\overline{W}_{c,ca,p,pa} = \sum_{pl} \frac{ALK_{p,pa,pl}\overline{W}_{c,ca,p,pl}}{\sum_{pa} ALK_{p,pa,pl}}$$

First the ALK by roundfish area was applied if such exist. If there were no ALK for a particularly prey in the roundfish area, an ALK calculated for the total North Sea was used.

For partly digested prey remains (Wrem) without length information, it was assumed that they have had an age and age distribution similar to just estimated age-distribution.

$$\overline{Wnew}_{c,ca,p,pa} = \frac{\overline{Wrem}_{c,ca,p}\overline{W}_{c,ca,p,pa}}{\sum_{pa} \overline{W}_{c,ca,p,pa}}$$

Calculation of average North Sea stomach contents

Average stomach contents of a predator for a combination of roundfish areas are calculated as the mean of the roundfish's average value, weighted by the predator abundance and spatial extent of the of the roundfish area. FORMEL MANGLER

MSVPA and MSFOR data and setup

Table 1 gives the setup of MSVPA with respect to species and stomach contents data. Species where stomachs have been sampled are in the model considered

Table 1: Input data and setup for the North Sea MSVPA

VPA Species	Age groups	No. of stomachs sampled, 1991
Cod	0-11	9700
Haddock	0-10	12883
Saithe	0-10	3020
Mackerel ("Other predator" group)	0-15	5456
Whiting	0-8	38413
Herring	0-9	
Norway pout	0-3	
Sandeel	0-4	
Plaice	0-15	
Sole	0-15	

as predators on all species in the model. Stomach data were sampled in 1991. Compared to the so-called key run, defined at the WG (ICES 1997), stomach data from other years, mainly 1981, were left out of the model. The key run includes a group of other predators like "sea birds", grey gurnards and raja radiata with an assumed known biomass, and an observed or derived stomach contents. Predation from this group induce a mortality on the VPA species, but due to problems with the division of stomach contents data on sub-areas, this group was left out of the MSVPA. The catch numbers were extended to year 1998, compared to 1995 used in the key-run.

In VPA and MSVPA fishing mortality values for the oldest age and for all ages the last year must be given as input. These "terminal F" values were estimated in a so-called multispecies tuning (Vinther 2001) which is a technique where the tuning algorithms applied in the ICES stock assessment uses the multispecies natural mortality rates. The resulting terminal Fs from tuning are then used in MSVPA for production of a new set of natural mortality values. This exchange of terminal F and natural mortalities is continued until equilibrium.

Results

Discussion

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I Biological Reference Points for Fish Stocks in a Multispecies Context

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Biological reference points (BRPs) are widely used to define safe levels of harvesting for marine fish populations. Most BRPs are either minimum acceptable biomass levels or maximum fishing mortality rates. The values of BRPs are determined from historical abundance data and the life-history parameters of the fish species. However, when the life-history parameters change over time, the BRPs become moving targets. In particular, the natural mortality rate of prey species depends on predator levels; conversely, predator growth rates depend on prey availability. We tested a suite of BRPs for their robustness to observed changes in natural mortality and growth rates. We used the relatively simple Baltic Sea fish community for this sensitivity test, with cod as predator and sprat and herring as prey. In general, the BRPs were much more sensitive to the changes in natural mortality rates than to growth variation. For a prey species such as sprat, the fishing mortality reference level must be conditioned on the level of predation mortality, as estimated with a multispecies model. For a predator species, a conservative level of fishing mortality can be identified that will prevent growth overfishing and ensure stock replacement. However, for a cannibalistic species such as cod, BRPs also depend on the degree of cannibalism, as influenced by the abundance of alternative prey. These first-order multispecies interactions should be considered when defining BRPs for medium-term (5-10 yr) management decisions.

8 December 2000

Biological reference points (BRPs) are benchmarks against which the actual status of a fish stock can be measured. Commonly used BRPs are defined as either maximum or target fishing mortality rates or minimum stock biomass levels (Table 1). Three groups of fishing mortality reference levels can be defined, based on (i) a stock-production or dynamic pool model, (ii) yield-per-recruit analysis, or (iii) spawning stock biomass per recruit combined with stock-recruitment data. Biomass-based reference points are less numerous and, until recently, have been less widely used in fisheries management. Most of the commonly used BRPs are limits or thresholds, not targets. During the past decade the emphasis in fisheries management has shifted from optimizing yield toward conserving fish stocks, by preventing overfishing (Caddy and Mahon 1995). The definition and widespread use of BRPs has greatly benefited fisheries management, especially in North America and Europe. For each managed fish stock, the fishing mortality and biomass based BRPs can be combined as a "control law" to specify fishing mortality rates as a function of stock biomass (Rosenberg et al. 1994, Caddy and Mahon 1995, NRC 1998). In the US, the formal definition of overfishing reference levels has been instrumental for recognizing and reversing overfishing. Once fishing mortality thresholds are established, stock assessments can determine whether a stock is overfished or not and appropriate action can be taken. Establishing appropriate rebuilding schedules for overfished stocks involves, not only the specification of biomass targets, but also the pragmatic difficulties in regulating fisheries. Biological reference points are calculated from the demographic parameters and historical abundance data of a fish stock. For data-poor stocks, BRPs may be based on analogy with a similar species for which more complete data exist (Rosenberg et al. 1994). BRPs may be updated as needed, but they are intended as fixed benchmarks against which changes in fishing mortality or fluctuations in stock abundance can be measured. As long as the demographic parameters of a fish stock remain constant or fluctuate within narrow bounds, the corresponding BRPs also remain constant. However if there are systematic shifts in demographic parameters due to changes in the fish community structure or other environmental shifts, the BRPs become moving targets. If the reference level itself must be adjusted to prevailing environmental conditions, it becomes less useful as a benchmark to define overfishing. In this paper, we investigate the sensitivity of commonly used BRPs (Table 1) to trophic interactions in fish communities. Predation is known to be an important process in structuring fish communities (Bax 1998) and the effects may be both top-down and bottom-up. In the North Sea and on Georges Bank there are high levels of predation mortality on pre-recruit fish (Pope 1991, Tsou and Collie 2000); hence, the natural mortality rates of prey species vary with the abundance of their predators. Conversely, the growth rates of many fish species are variable and may partly depend on prey abundance (Collie 2000). For example, the growth rate of Icelandic cod is positively related to the abundance of capelin, its principal prey species (Stefánsson et al. 1998). How do these trophic interactions affect the calculation of BRPs? The UN Law of the Sea Convention specifies that the potential effects on species associated with or dependent upon harvested species should be considered. For example, catch limits for capelin off Newfoundland and Norway are conditioned on consumption of capelin by cod (Caddy and Mahon 1995). However BRPs that recognize species interactions have not been routinely calculated or applied. In the ICES community there has been considerable work on estimating predation mortality rates, but much less on translating these estimates into reference levels for management. The ICES Multispecies Assessment Working Group examined the consequences of ignoring species interactions in calculating BRPs (ICES 1997a). Extending this exercise, Gislason (1999) compared single and multispecies reference levels for Baltic Sea fish stocks. The general question is whether BRPs can be identified which are robust to species interactions or whether they must be conditioned on the prevailing levels of prey and predator populations. We chose the Baltic Sea fish community for this study because it is relatively simple and the species interactions are well understood (Sparholt 1996, Gislason 1999). The fish biomass is dominated by one predator (cod, *Gadus morhua*) and two prey species (herring, *Clupea harengus*, and sprat, *Sprattus sprattus*). There have been large shifts in the community structure of the Baltic Sea during the past twenty years (Fig. 1). Cod biomass declined due to high exploitation and unfavorable spawning conditions. Predation mortality on sprat declined and sprat biomass increased. Our objective in this paper is to test the sensitivity of conventional single-species BRPs to the changes in life-history parameters that have been observed in the Baltic Sea.

Methods

For consistency, all the life-history and abundance data were extracted from Gislason's (1999) multispecies model with variable cod growth. A suite of biological reference points (Table 1) was estimated for cod and sprat under three different scenarios. The scenarios were chosen to represent different configurations of community structure in the Baltic Sea. One scenario represents conditions around 1980 when cod abundance was high and sprat abundance was low. With high cod abundance, the rate of cannibalism and predation on sprat was high. The opposite conditions prevailed in 1992 with low cod abundance and high sprat abundance. The intermediate, or average scenario, represents the community structure in the mid 1980s. The BRPs were calculated as if the community were in equilibrium at that configuration such that the prevailing conditions would persist for at least one generation (5-10 years). The purpose of this exercise was to determine which of the observed species interactions have the biggest effect on the calculation of BRPs. To do so, we examined each process in turn while holding all other life-history parameters constant. We also investigated the consequences of ignoring the variable life-history parameters. Each BRP is defined based on the level of some criterion (e.g. yield per recruit, MSY, etc.). If the BRPs for the average conditions in the Baltic Sea were adopted how much would it change the levels of criteria on which the BRPs are defined? What is the penalty for being naïve and ignoring the changes in demographic parameters? The changes in these criteria were calculated relative to correctly adjusting the BRPs for changes in the life-history parameters.

Case 1: Food-dependent growth of cod

In this case we were interested in the effect of prey availability on cod growth rates. Cod weight at age was modeled according to Eq. 2 of Gislason (1999). The ratio of available food to the mean level was set to 0.8, 1.0, and 1.2. Splus functions were written to calculate spawning stock biomass (SSB) per recruit and yield per recruit (YPR). For consistency with the stock-recruitment data these functions calculate SSB at the start of the year. In the variable-growth case, maturity is a function of weight (Gislason 1999, Eq. 8) and recruitment to the fishery is a logistic function of body length. A stock-recruitment relationship is required to estimate several of the BRPs. The cod abundance data from Gislason (1999) cover the years 1977 through 1996. An environment-dependent Ricker model was used:

$$R = S \exp(a - bS + cV) \tag{1}$$

where R is the number of recruits in millions, S is spawning-stock biomass in thousand tons and V is the deviation from the mean reproductive volume in km^3. Cod spawns in the deep basins in the Baltic Sea; and the reproductive volume is the volume of water in these basins where salinity (>11 psu), oxygen (>2 ml^{-l}), and temperature conditions (>1.5^{o}C) permit the successful development of cod eggs (MacKenzie et al. 2000). Previous studies have shown cod recruitment to be positively related to the reproductive volume. For each spawning basin we averaged the seasonal spawning volume measurements during the three-month period of cod spawning. The spawning period was taken to be April-June prior to 1990, May-July from 1990-1992, and June-August from 1993-1997 (Wieland and Horbowa 1996). Spawning volumes from the different basins were summed. The resulting time series of V updates that of Sparholt (1996) and the two are highly correlated (r^2=0.98). In this case the stock-recruitment model was fit for age 2 recruits to isolate the variability in growth rates from changes in pre-recruit mortality, which mainly occurs before age 2. Recruitment estimates for ages 0 and 1 are more uncertain because they must be back-calculated with estimated predation rates.

Case 2: predator-dependent mortality of sprat

Sprat was chosen as a prey species with variable natural mortality rate. Again, a suite of biological reference points was estimated for the three different scenarios. In this case we were interested in the effect of variable predation mortality rates. Sprat is an important prey species of cod and the natural mortality rate has varied considerably in relation to the ratio of cod-to-sprat biomass (Gislason 1999). Natural mortality was modeled as if cod predation were a fishing fleet with a fixed age effect and a variable year effect scaled to the natural mortality rate of the oldest ages (7-9). We used three levels of natural mortality corresponding to the predation levels in 1980 (high), 1985 (medium), and 1992 (low). The Splus functions were modified to calculate SSB per recruit and YPR for different levels of natural mortality. We also calculated total production per recruit as the sum of age-specific mortalities. This function was then used to identify the mortality level resulting in maximum biological production (cf. Caddy and Mahon 1995). A Ricker stock-recruitment model was fit to the estimates of SSB and age-0 recruitment from Gislason (1999).

Case 3: Cannibalism of cod

Cannibalism is known to be an important self-regulatory mechanism for Baltic cod (Sparholt 1995, 1996, Neuenfeldt and Köster 2000). The magnitude of this predation mortality depends primarily on the abundance of the older, cannibalistic cod (Eq. 6 in Gislason 1999) and secondarily on the abundance of the alternative prey species, herring and sprat. Predation mortality was therefore made proportional to SSB at the start of the year. The age dependency of cannibalism was taken from the multispecies model of Gislason (1999); cannibalism was highest for age-0 cod and decreased by a power of 7 for the older ages. We investigated three scenarios regarding the magnitude of the proportionality constant (m) between mortality and SSB. The low cannibalism scenario (m=1.5) represents conditions around 1992 when sprat biomass was high. The high cannibalism scenario (m=3.5) represents conditions around 1980 when sprat biomass was low; the intermediate case (m=2.5) represents average conditions. With predation proportional to SSB, SSB becomes both an argument and the result of the SSB-per-recruit function. A root finder was therefore used to solve for the equilibrium level of SSB. In the cannibalism case, SSB per recruit depends on the level of recruitment; hence many of the standard BRPs are not meaningful. It was possible to calculate equilibrium yield and reference levels corresponding to maximum sustainable yield. The stock-recruitment relationship for age-0 cod was standardized for the mean reproductive volume between 1977 and 1996. Parameter b in Eq. 1 was fixed at 0 because density-dependent mortality is assumed to occur after age 0. The YPR function was modified to calculate yield for a given level of SSB and the corresponding equilibrium recruitment.

Results

Case 1: Prey-dependent growth rate of cod

The growth trajectories of cod with different levels of available food approximate the low weight at age observed in 1980, average weight at age, and the higher weight at age observed in 1992, respectively (Fig. 2A). The fitted stock-recruitment model was:

$$R = S\exp(-0.197 - 0.0028S + 0.0021V) \qquad (2)$$

The density-dependent parameter (b) was of the expected sign but not significantly different than 0 (p=0.67). The effect of spawning volume was positive and significant (p=0.014). Model fit was good in that the residuals were normally distributed. There was one positive outlier (1979) and two negative outliers (1983, 1994). This model was used to adjust the stock-recruitment data to the average spawning volume from 1977 to 1996 (198 km^3). This adjustment reduced the scatter in the stock-recruitment data (Fig. 2B) except for the outlier years. There is little curvature of the stock-recruitment curve over the range of observed stock sizes, and hence, little evidence of density dependence. Cod yield per recruit and spawning stock biomass per recruit both depended on the growth rates and hence food availability (Fig. 3). Despite a relatively large difference in the maximum yield per recruit, the difference in $F_{0.1}$ reference levels between growth scenarios was much smaller (Fig. 3A). The fishing mortality rate corresponding to the median recruits per spawner (F_{med}) was also relatively insensitive to the different growth trajectories (Fig. 3B). For example, if F_{med} for the average growth conditions were applied in the slow growth scenario, 32% of the R/S observations would be above the replacement line instead of 50%. Of the BRPs expressed as fishing mortality rates (F), those based on MSY, YPR, and SSB per recruit were lower and of the same order as natural mortality (M). The absolute values of yield, YPR, SSB per recruit were sensitive to growth changes, but the BRPs based on these criteria were quite insensitive (Fig. 4). If these BRPs were adopted, the penalty for ignoring variable growth would be minor. The BRPs based on replacement of SSB were considerably higher, partly because the observed R/S have been quite high (Fig. 2B). These F levels were more sensitive to changes in growth; when growth changes, the BRP would need to be adjusted to maintain the same percent of years with replacement. The consequence of not changing the BRP would be detrimental in the slow growth scenario. F_{loss} appeared to be a good approximation of F_{crash} and was only slightly higher than F_{med}. Either one of these three would be a suitable limit reference point, provided that it accounted for changes in growth rate. Of the BRPs expressed as biomass levels, those based on the stock-recruitment model all gave BRPs that were larger than SSB observed during the period of study (Table 2). This is due to the lack of data at larger SSB and the lack of curvature in the stock-recruitment curve. The SSB corresponding to the intersection of $R/S_{90\%}$ and $R_{90\%}$ was considerably higher than B_{loss} or B_{pa} and may be more appropriate as a target than a limit reference point. Though the level of B_{msy} seemed unrealistically high, the corresponding F_{msy} may still be useful because it is based on the slope of the stock-recruitment curve, which is fairly well defined in this case. In summary, to prevent overfishing of a predator species with variable growth rate, it appears sufficient to prevent growth overfishing. This condition, of itself, is quite stringent and, provided that the environmental conditions affecting the survival of eggs and larvae were favorable, did not change this condition, of itself, is quite stringent and would ensure that a species with a high reproductive rate, such as Baltic Sea cod, would replace its SSB on average.

Case 2: Predator-dependent natural mortality rate of sprat

Biological production of Baltic Sea sprat would be maximized at intermediate levels of natural mortality (Fig. 5A). This result implies that sprat predators (i.e. cod) may already be consuming sprat at the level of maximum biological production. At the highest levels of observed predation mortality there was no surplus production for a sprat fishery. The stock-recruitment model fit for age-0 sprat was statistically significant and biologically realistic (Fig. 5B). Sprat yield per recruit and spawning stock biomass per recruit were extremely sensitive to the observed variation in predation mortality (Fig. 6). The high mortality and rapid growth of sprat combine to give YPR curves that are essentially flat topped (Fig. 6B). Hence BRPs based on YPR are inappropriate for prey species such as sprat. Reference levels based on stock replacement are also very sensitive to the predation mortality rate. For example, F_{med} was undefined for the high predation scenario because the observed R/S points would be insufficient to replace the SSB 50% of the time at this level of mortality (Fig. 6B). The BRPs were extremely sensitive to the range of natural mortality rate from 0.36 to 0.95 (Fig. 7). Under the high mortality scenario the sprat stock would not be able to replace itself. According to the stock-recruitment data, recruitment would be sufficient to replace the SSB in only 17% of years with 0 fishing mortality on sprat. In the high mortality scenario, only F_{high} is a feasible overfishing limit. The BRPs expressed as fishing mortality rates can be grouped into those that increase with M and those that decrease with increasing M. To ensure replacement of the stock, the total mortality should be kept relatively constant. Hence BRPs that increase with M ($F_{40\%}$, $F_{0.1}$, F_{max}) are inappropriate for sprat. The BRPs based on stock production or stock recruitment compensate for changes in natural mortality. Of these F-based BRPs, F_{msy} and F_{med} could be considered as targets, whereas F_{crash} and F_{high} are clearly overfishing limits. The BRPs expressed as biomass levels appear to be fairly conservative (Table 2). The BRPs that are based on the dynamic-pool model are sensitive to the natural mortality rate. As with cod, the SSB corresponding to the intersection of $R/S_{90\%}$ and $R_{90\%}$ is considerably higher than B_{loss} or B_{pa} and may be more appropriate as a target than a limit reference point. In summary, the BRPs for a prey species such as sprat are very sensitive to the level of natural mortality. The consequences of assuming a constant medium natural mortality rate would be severe. As the natural mortality rate changes, the BRPs should be adjusted to keep the total mortality constant. BRPs based on stock replacement and sustainability seemed to perform best for the prey species. Whichever BRP is used, a multispecies model is needed to adjust it to the actual level of predation mortality.

Case 3: Cannibalism of cod

Many of the standard single-species BRPs could not be calculated in the case of variable cannibalism because YPR and SSB per recruit depend on the level of recruitment. As recruitment increases, the level of SSB per recruit declines due to higher mortality. Thus there is a diminishing return of higher recruitment. The levels of YPR and SSB per recruit can only be defined for given levels of recruitment, which diminishes their usefulness as general BRPs. It was possible to calculate replacement lines for a range of fishing mortality rates (Fig. 8A). Without cannibalism, the replacement lines are straight (e.g. Figs. 2B, 5B); with cannibalism, the replacement lines bend upwards with the degree of curvature proportional to m. The replacement lines were superimposed on the observed stock-recruitment data. The stock-recruitment curve divides the data into a set of high R/S levels from 1977 to 1985 followed by low levels from 1986 to 1996. To approximate BRPs for the three levels of cannibalism, we calculated the percentage of points that fell above the replacement lines for different levels of fishing mortality. For intermediate levels of cannibalism, $F_{med} \sim 0.6$ and $F_{low} \sim 0.4$. While only approximate, these BRPs are of the same magnitude as those obtained in the variable-growth case (Fig. 4). The replacement percentiles were very sensitive to the level of cannibalism mortality. In the low cannibalism scenario F_{med} would increase to 1.0 and F_{low} to 0.6. Conversely, in the high cannibalism scenario, F_{med} would be below 0.4. The replacement percentiles were also sensitive to the high R/S values in the early years; the BRPs would be lower if based only on the more recent years. The intersection between the stock-recruitment curve and the replacement line defines the equilibrium recruitment and SSB (Fig. 8A). Equilibrium yield relationships for three levels of the cannibalism multiplier (m) were calculated by solving for the equilibrium fishing mortality across a range of SSB. Equilibrium yield and B_{msy} decreased with increasing m (Fig. 8B) but F_{msy} (0.68) was independent of the degree of cannibalism mortality. The F_{msy} estimate depends on the slope of the stock-recruitment relationship (a in Eq. 1), not on the magnitude of cannibalism. Hence F_{msy} may be a robust reference point provided that it can be reliably estimated. This F_{msy} estimate of 0.68 is considerably higher than the value estimated in Case 1, starting with age-2 recruits.

Discussion

This study illustrates the sensitivity of the commonly used biological reference points to changes in demographic parameters. The BRPs for cod were relatively insensitive to the observed changes in growth rates (Figs. 3 and 4). In particular, the BRPs based on per-recruit calculations ($F_{0.1}$ and $F_{40\%}$) were lower than the other BRPs and quite insensitive to the observed changes in growth rate. This result suggests that it is possible to select a conservative fishing mortality rate that will ensure stock replacement without foregoing potential harvest. In their review of 117 definitions of overfishing for U.S. fish stocks, Rosenberg et al. (1994) also noticed that reference levels to prevent growth overfishing (e.g. $F_{0.1}$) would, in most cases, also prevent recruitment overfishing. This insensitivity of BRPs to changes in growth rates occurs because the per-recruit calculations were started at age 2, which corresponds to the age of entry to the fishery but is after most predation mortality has occurred. This conclusion could be altered by changes in pre-recruit mortality, as discussed below. Biological reference points for sprat were very sensitive to the level of predation mortality (Figs. 6 and 7). In the case of a small forage fish such as sprat, BRPs based on pre-recruit calculations are not useful because sprat grow quickly before recruiting to the fishery; hence even unrealistically high levels of fishing mortality could not substantially reduce the yield or SSB. The BRPs based on stock-production or stock-recruitment relationships would be adjusted downwards as predation mortality increased (Fig. 7). BRPs such as F_{med} and F_{msy} are conservative in the sense that replacement of the spawning stock would be ensured by preventing recruitment overfishing. However, major adjustments would be required in response to the prevailing level of predation mortality. For example, at low levels of predation mortality, F_{msy} = 1.6 whereas at the high level of predation mortality, a sprat fishery would be barely sustainable. Hence the BRPs for forage species become moving targets that need to be redefined according to the prevailing level of predation mortality as estimated with a multispecies model. Cannibalism is common among marine fish (Bogstad et al. 1994) and can be considered as a special case of predation mortality. If the rate of mortality due to cannibalism is constant, it can be subsumed in the stock-recruitment relationship and the standard single-species BRPs can be used. Alternatively, if the degree of cannibalism depends on the abundance of alternative prey, a multispecies model is required and the BRPs may need to be adjusted to ensure stock replacement. A subset of the BRPs was estimable (e.g. F_{med}) and this was sensitive to the level of natural mortality, in this case due to cannibalism. As might be expected, the higher the cannibalism mortality, the lower the fishing mortality to ensure stock replacement. The level of F_{med} from the intermediate cannibalism scenario (0.6) is consistent with the estimate from the intermediate growth scenario ($F_{med} \approx 0.7$) but the BRPs are more sensitive to changes in cannibalism mortality than to changes in growth rate. The BRPs based on YPR and SSB per recruit of age-2 cod (Fig. 4) are more conservative and would appear to ensure stock replacement even in the high cannibalism scenario. Which, if any, of the single-species biological reference points are useful in a multispecies context? The BRPs based on stock-recruitment data (F_{high}, F_{med}, F_{low}), or a stock-recruitment relationship (F_{loss}, F_{msy}) would be adjusted in a conservative direction in response to changes in the demographic parameters. The reference levels of fishing mortality would decrease with lower growth rates (Fig. 4) and decrease with high predation rates (Fig. 7). Despite its checkered history (Larkin 1977), F_{msy} emerged as a robust BRP that was always estimable and moved in a conservative direction with changes in the demographic parameters. In the U.S. F_{msy} is now the default overfishing definition (USDOC 1996) but for some species it may be appropriate as a target fishing mortality rate. F_{med} and F_{loss} are appropriate as overfishing thresholds that would also be adjusted in a conservative direction in response to changing demographic parameters. F_{loss} is a conservative estimator of F_{crash} (ICES 1997b) in that if F_{loss} is not exceeded there would be little risk of stock collapse. In contrast, the BRPs based only on per recruit calculations ($F_{0.1}$ and $F_{40\%}$) would be adjusted in a risky direction with changes in growth (Fig. 4) or mortality rates (Fig. 7). While the target fishing mortality rate, F0.1, is no longer widely used, the overfishing definitions for many U.S. fish stocks are based on $F_{x\%}$, where x is some percentage (e.g. 40) of the SSB with no fishing (Rosenberg et al. 1994). Comparing among species, it is well known that short-lived, fast growing species have higher $F_{40\%}$ levels than long-lived, slow-growing species. However, it would be risky and inappropriate to use the formula for calculating $F_{40\%}$ to adjust the BRP of a given species in response to changes in growth or mortality rates. Particularly for prey species, it can also be risky to maintain the $F_{40\%}$ for average conditions when the demographic parameters change. Hence, alternatives to $F_{x\%}$ need to be found for forage fish species. The use of $F_{x\%}$ as an overfishing definition was advocated because of the high variability in many stock-recruitment relationships. However, the choice of the appropriate percentile can only be made with reference to the stock-recruitment data. By identifying the desired replacement lines from the stock-recruitment data (e.g. Figs 2B, 5B) and calculating the corresponding fishing mortality rate, BRPs can be identified that are more robust to the changes in demographic parameters. Graphically this means moving from Fig. 2B to 3B, not the opposite. To what extent can our results from the Baltic Sea be generalized to other fish communities? The magnitude of change in the estimated BRPs was roughly proportional to changes in the underlying demographic parameters. The variability of the growth and mortality rates can be compared by expressing the range as a percentage above and below the midpoint or mean value of the parameter. In our Baltic Sea study, the weight of age-9 cod varied by $\pm 20\%$ of the medium growth value, whereas the predation mortality of sprat varied by $\pm 50\%$. Hence the BRPs for cod were less variable than for sprat. A brief survey of demographic parameters in other well-studied fish communities confirms that predation mortality rates are more variable than growth rates. The weight at age of Arcto-Norwegian cod varied by $\pm 25\%$ between 1984 and 1988 (Mehl and Sunnanå 1991). Weight at age of Icelandic cod varied by $\pm 25\%$ at age 4 and $\pm 28\%$ at age 5 (Stefánsson et al. 1998). In both populations, cod growth was linked to prey abundance. The predation mortality of age-1 haddock varied by ±33% in the North Sea (Pope 1991) and by ±90% on Georges Bank (Tsou and Collie 2000). Predation mortality on age-1 herring, an important forage species on Georges Bank, varied by ±65% (Tsou and Collie 2000). Predation mortality of age-1 pollock varied by ±40% in the Gulf of Alaska (Hollowed et al. 2000a) and by ±57% in the eastern Bering Sea (Livingston and Methot 1998). The predation mortalities were estimated with multispecies virtual population analysis (MSVPA) or a similar age-structured multispecies model and may therefore have more estimation error than weight at age, which can be measured directly from catches. Another reason that predation mortality rates are more variable than predator growth rates is that most of the piscivorous fish are harvested and are therefore subject to fishing induced fluctuations in abundance. In contrast, growth rates are buffered because the predators can generally switch to alternative prey species that are unharvested (e.g. invertebrates) and thus subject to only natural fluctuations. The higher variability in predation mortality than in growth rates suggests that it is much more important to account for predation mortality than food-limited growth in multispecies models such as MSVPA, which has traditionally assumed predator ration and growth rates to be independent of prey abundance. More recent multispecies models (e.g. Gislason 1999) also incorporate food limitation but it may be possible to identify BRPs for predator species that are robust to changes in predator growth rates of the magnitude observed in exploited fish communities. In contrast, predation mortality rates clearly need to be tracked with multispecies models and the BRPs for forage species adjusted accordingly. How can multispecies advice be used in practical decision making? It is well recognized that multispecies considerations are most useful for medium and long-term decisions (Hollowed et al. 2000b). The demographic parameters that underlie biological reference points change on the time scale of fish generation times (5-10 yr). For medium-term advice it may suffice to consider only one-way trophic interactions between harvested species and to categorize each species as a predator or prey. Predator reference levels then can be conditioned on the prevailing prey abundance and vice versa. This simplification of food webs is convenient because it means that predators can be added to single-species stock assessments without needing to consider the longer-term feedback between the prey and predator populations (e.g. Livingston and Methot 1998, Hollowed et al. 2000a). For prey populations, the guiding principle is to maintain the total mortality (Z) below a threshold level. This objective can be achieved by conditioning the fishing mortality reference level on predator abundance, but it would defeat the intention of having BRPs remain constant in time. However, if the prey BRP can be expressed as a total mortality rate (e.g. Z_{mbp}) a formula could be used to specify prey harvest levels in a future year t

$$TAC_t = Z_{mbp}\bar{B}_t - PC_t \qquad (3)$$

where TAC is the Total Allowable Catch of the prey species, B is the projected mean prey biomass and PC is the biomass of prey consumed by predators as projected with a multispecies model. In the sprat example, $Z_{mbp} = 0.51$ for the sprat ages that are fully vulnerable to cod predation (Fig. 5A). If Eq. 3 were adopted, the sprat TAC would be zero during periods of high cod abundance and hence high predation mortality. Longer-term management strategies span several or many fish generations and must therefore incorporate all the feedback loops between prey and predator species (Gislason 1999). Besides the requirement to prevent overfishing, long-term strategies involve explicit trade-offs between harvesting prey and predator populations. If revenue maximization is the objective, a common outcome is not to harvest the less-valuable prey species so as to maximize the yield of the more valuable predator (Gislason 1999). A longer-term perspective also requires a broader view of food web dynamics. In this case we must recognize that fish species are preyed on as juveniles and become predators as adults. In this study we assumed that the underlying stock-recruitment relationships were constant (sprat) or depended only on abiotic factors (e.g. reproductive volume) and not on the abundance of other species. However, sprat have been found to prey on cod eggs (Köster and Möllman 2000), an interaction which could potentially affect the cod stock-recruitment relationship (Sparholt 1996). To investigate this possibility we estimated the biomass of age 1+ sprat and added it as an additional term to the environment-dependent stock recruitment model (Eq. 1). The sprat coefficient was negative as expected but insignificant (p=0.215). The addition of sprat gave more curvature to the stock-recruitment curve without significantly decreasing the scatter in the stock-recruitment points. In summary, management strategies should incorporate important predator-prey interactions, but increased complexity may preclude the use of traditional biological reference points. For providing medium-term management advice, it may be pragmatic to deliberately simplify multispecies models so that their results can be incorporated into fishery management frameworks.

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Table 1. Commonly used biological reference points. Detailed definitions and references for each reference point are given in Caddy and Mahon (1995).

Reference point	Theoretical basis	Data needs	Target or Limit?
	Reference points based on production models		
F_{msy}	Fishing mortality (F) for maximum sustainable yield	surplus-production model or dynamic pool model	limit
F_{crash}	Fishing mortality for stock extinction	surplus-production model or dynamic pool model	limit
Z_{mpb}	Total mortality rate for maximum biological production	catch per unit effort and total mortality	target
	Reference points based on yield per recruit		
F_{max}	maximum yield per recruit (YPR)	natural mortality and growth data	limit
$F_{0.1}$	slope of YPR curve is 0.1 slope of YPR curve at the origin	natural mortality and growth data	target
	Reference points based on spawning stock biomass per recruit		
$F_{40\%}$	F for 40% of spawning biomass per recruit (SPR) when F=0	natural mortality and growth data	limit
Flow	Fishing mortality giving 90% of years with stock replacement	stock-recruitment data and SPR	target
F_{med}	Fishing mortality giving 50% of years with stock replacement	stock-recruitment data and SPR	limit
F_{high}	Fishing mortality giving 10% of years with stock replacement	stock-recruitment data and SPR	limit
F_{loss}	Fishing mortality for replacement of lowest observed stock size	stock-recruitment model and SPR	limit
	Biomass-based biological reference points		
B_{loss}	Lowest observed stock size	spawning stock biomass	limit
B_{pa}	Biomass below which probability of reduced recruitment is increased	stock-recruitment data	limit
$B_{90\%R,90\%R/S}$	B corresponding to intersection of 90% of R/S and 90% of R	stock-recruitment data	limit
B_{msy}	Biomass for maximum sustainable yield	surplus-production model or dynamic pool model	limit
$B_{50\%R}$	Biomass at which R is one half of its maximum level	stock-recruitment model	limit
$B_{20\%}$	Biomass corresponding to 20% of Biomass when F=0	surplus-production model or dynamic pool model	limit

Reference point	Food available to cod			Predation mortality on sprat		
	Low	Medium	High	Low	Medium	High
B_{loss}	188	188	188	324	324	324
B_{pa}	240	240	240	275	275	275
$B_{90\%R,90\%R/S}$	445	445	445	586	586	586
$B_{50\%R}$	832	832	832	217	217	217
B_{msy}	3176	3535	3756	755	401	29
$B_{20\%}$	1454	1636	1781	405	180	12

Table 2. Biomass-based biological reference points for Baltic Sea cod with a variable growth rate and for sprat with a variable mortality rate. The units of spawning stock biomass are thousand tons.

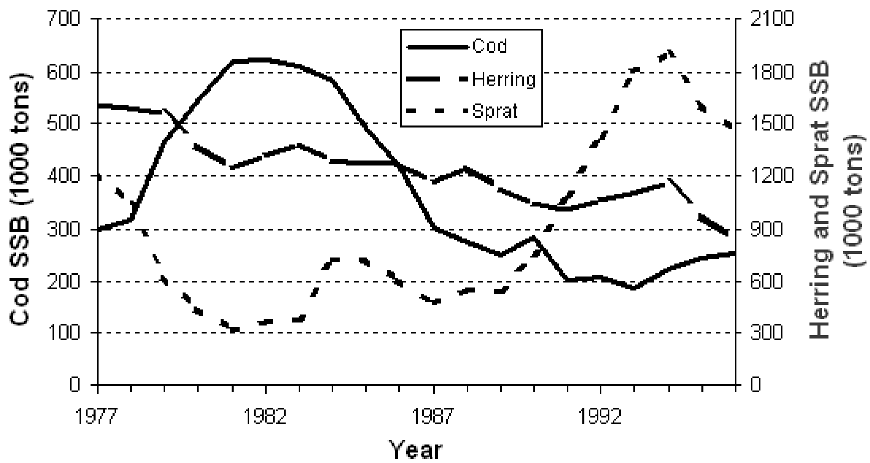

Figure 1: Fig. 1. Spawning stock biomass of cod, herring, and sprat in the Baltic Sea (data from Gislason 1999)

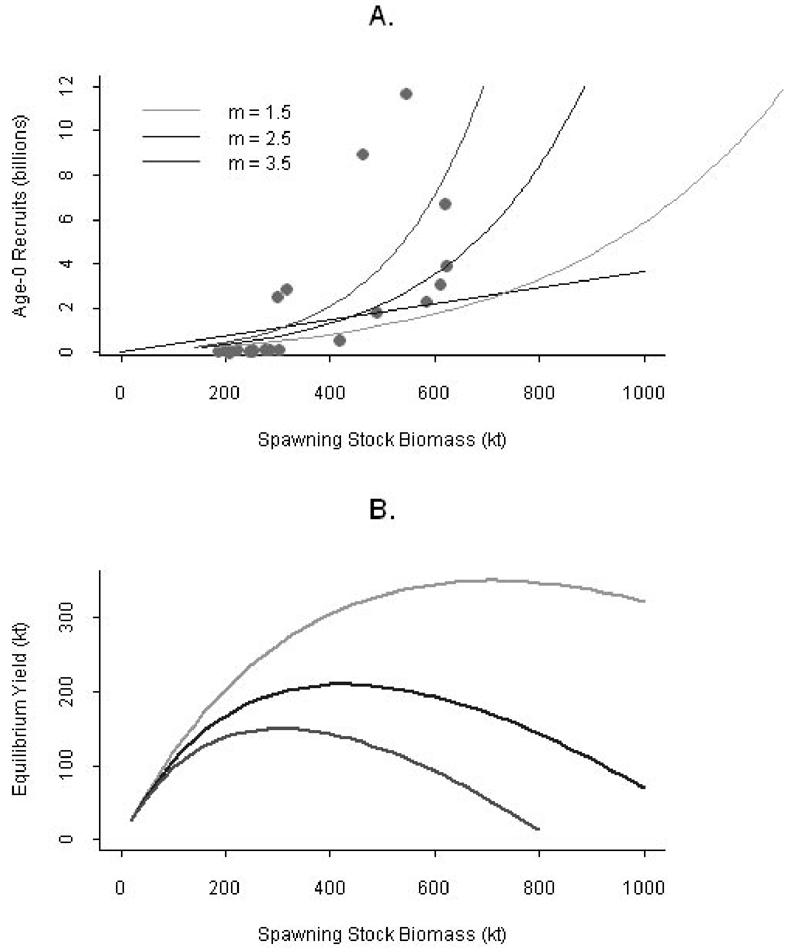

Figure 2: Fig. 8. A. Stock-recruitment data (points) and fitted relationship (straight dotted line) for age-0 cod. The curved lines are replacement curves for three levels of cannibalism mortality. The three levels of m correspond to age-0 predation mortalities of approximately 0.6, 1.4, and 2.2. B. Equilibrium growth curves for three levels of cannibalism mortality as identified in A.

Figure Captions

Fig. 2. A. Mean weight at age of cod with three levels of food availability. The growth increments were calculated according to Eq. 2 of Gislason (1999). B. Cod stock-recruitment data (points) and fitted curve (solid line) adjusted to the mean reproductive volume. Outliers are identified by their brood year. Broken lines are replacement lines corresponding to the given percentiles of the stock-recruitment data.

Fig. 3. A. Cod yield-per-recruit curves for three levels of food availability. Arrows indicate the $F_{0.1}$ reference level. B. Spawning stock biomass per recruit for three levels of food availability. The intersections between the SSB per recruit curves and the 50% replacement line define the F_{med} replacement levels.

Fig. 4. Cod biological reference points for three levels of food availability.

Fig. 5. Total production of sprat as a function of natural mortality. The rug plot shows annual values of natural mortality for the years 1977 to 1996 estimated by Gislason (1999) with a multispecies model. The vertical lines indicate the three levels of natural mortality used in our sensitivity analysis. B. Sprat stock-recruitment data (points) and fitted Ricker curve (solid line). The broken lines are replacement lines for the given percentiles of the stock-recruitment data.

Fig. 6. Sprat yield-per-recruit curves for three levels of predation mortality. Arrows indicate the $F_{0.1}$ levels. B. Spawning stock biomass per recruit for three levels of predation mortality. The arrows indicate the F_{med} levels.

Fig. 7. Sprat biological reference points for three levels of predation mortality.

J The effects of exploitation and environmental change on the trophic structure of the Celtic Sea fish community

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The effects of exploitation and environmental change on the trophic structure of the Celtic Sea fish community

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Abstract
Fishing has profound impacts on the structure of multispecies communities, leading to decreases in the mean size and age of individuals and shifts in patterns of diversity and abundance. These changes in multispecies communities are often reflected in fisheries landings. According to FAO landing statistics and gut-contents data, the mean trophic level of catches in the eastern Atlantic has declined over the past 50 years. However the basis for this decline has been questioned, particularly with respect to the taxonomic and geographic resolution of the FAO data used and the methodology for assigning trophic levels to species. In the present paper we explore in greater detail changes which have occurred in the trophic level of Celtic Sea (ICES divisions VII j-k) fishery landings and survey data, using trophic level estimates derived from stable isotope analysis.
There has been a significant decline in the mean trophic level of fish caught during government surveys since 1982 and in international fishery landing statistics since 1946. This has coincided with dramatic changes in survey and catch composition, with a move away from large piscivorous fishes (e.g. gadoids and small sharks) towards smaller pelagic species (e.g. mackerel, horse mackerel, blue whiting, *Capros aper*) which feed at a lower trophic level. The implication is that there have been substantial changes in the structure of the ecosystem underlying Celtic Sea fisheries and not simply a change in fishery preferences. In the early 1970s there was a great expansion of pelagic and industrial fisheries in the Celtic Sea, and overall fishery catches have continued to increase over the last 50 years. Because the expanding pelagic fisheries have flooded the market with low trophic level species, the absolute and relative market prices of these fish have declined since 1979, whilst the increasing scarcity of high trophic level species such as hake, cod, haddock and monkfish has forced prices of these species up.
The long-term trends we have observed in fish communities and consequently fisheries, are probably a result of diminished spawning-stock biomasses in many

target species as a result of intensive fishing, but also climate changes which occurred since the late 1960s.

Introduction

The Celtic Sea comprises the International Council for the Exploration of the Sea (ICES) statistical divisions VII f-j, and is mainly fished by France, Ireland, the United Kingdom, Spain and Belgium. Generally speaking the Celtic Sea is not as productive in terms of fish as is the North Sea (Lee & Ramster, 1981) but nevertheless supports many important and valuable fisheries (Warnes & Jones, 1995). This is particularly so in terms of Hake, Megrim and Horse Mackerel which represent 38, 32 and 22% respectively of UK landings for these species (MAFF, 1999).

The fisheries of the Celtic Sea are operated by several distinct fleets (métiers), characterised by different gears and different target species (Marchal & Horwood 1996; Laurec, et al. 1991). French vessels are primarily trawlers targeting Nephrops, cod, whiting and hake. The UK fisheries are more diverse consisting of otter trawlers, beam trawlers and gill netters, many of which operate in comparatively shallow waters. Spanish (including Spanish-Irish and Spanish-UK) vessels largely operate long-lines at the edge of the Celtic Shelf. Irish vessels consist of otter trawlers targeting Nephrops or finfish and sometimes switching to pelagic fishing (herring and sprat), whilst the Belgian fleet consists largely of beam-trawlers harvesting flatfish (Marchal, 1996). In addition Norway and the Faroes take substantial quantities of blue whiting. ICES record some 67 finfish species in their fisheries landings for the Celtic Sea, and in recent years the importance and magnitude of fisheries in this region have greatly increased. This expansion has prompted some concern about the present and future state of Celtic Sea fish stocks (e.g. Horwood 1993), the scale of fishery discards/by-catch (Morizur et al. 1999; Perez et al. 1996; Destanque 1981) and possible implications for the ecosystem as a whole.

According to Pauly et al. (1998a), the mean trophic level (TL) of Northeast Atlantic (FAO area 27) fishery catches have declined significantly since the late 1950s. This decline reflects a gradual transition in landings from long-lived, high trophic level piscivorous fish toward short-lived, low trophic level invertebrates and planktivorous pelagic fish (Pauly et al. 1998a, Pauly et al., 2000a). These findings attracted much interest in the scientific and popular literature alike, although the approach was also criticised on methodological grounds by Caddy et al. (1998). The data used by Pauly et al. (1998a), consisted of aggregated landing statistics from the UN Food and Agriculture Organisation (FAO) together with approximate trophic levels for individual species (or groups of species) derived from ecosystem models. The objections raised by Caddy et al. (1998) (and responded to by (Pauly et al. 1998b; Pauly & Palomares 2000) largely focussed on (i) problems associated with the trophic levels assigned to individual species, and (ii) problems associated with the FAO fishery data used.

The fishing data used by Pauly *et al.* (1998a), covered the whole of the Northeast Atlantic, despite there being significant and substantial differences in the fisheries and fleets which operate in this region (e.g. MAFF, 1999). The FAO data for the Northeast Atlantic are derived from the assessments of ICES, who collate data on a much more detailed basis than did Pauly *et al.* (1998), dividing the region into 15 distinct sub-areas. The ICES statistical sub-area VII is itself split into 10 divisions of which the Celtic Sea encompasses only four, VII f,g,h,j (although VIIk is sometimes also included). The large-scale geographical aggregation of the data used by Pauly *et al.* (1998a) makes it difficult to examine which species and which fleets are most responsible for the observed changes in mean trophic level, consequently there is a need for more detailed 'local' studies. Another potential problem is the general lack of 'taxonomic resolution' in the FAO landing data, and in many cases the 'species' considered by Pauly *et al.* (1998a) were grouped at least in terms of their allocated trophic level, into coarse ISSCAAP (International Standard Statistical Classification of Aquatic Animals and Plants) categories. The excessive lumping together of species may affect the apparent properties of foodwebs (Goldwasser & Roughgarden, 1997), a point raised by Caddy *et al.* (1998) and re-examined by Pauly & Palomares (2000). ICES landing data are generally more detailed taxonomically as well as geographically. Caddy *et al.* (1998) suggested however, that fishery landing data in general are not good ecosystem indicators, since they may reflect changes in fishing technology/strategies, customer preferences or the prices of other (non fish) sources of protein, rather than changes in the underlying ecosystem. One way to address this difficult issue is to examine fishery-independent scientific trawl surveys, and Christensen (1998) has demonstrated that apparent declines in trophic level of the ecosystem may be even more marked in survey data than in fishery landing data from the same region, reflecting massive underlying changes in ecosystem structure. Ground-fish survey data are available for the Celtic Sea from the UK Ministry of Agriculture, Fisheries and Food, covering the years 1982-2000 (Warnes & Jones 1995).

The trophic level estimates used by Pauly *et al.* (1998a) were obtained from 60 published mass-balance models, which apparently covered all major ecosystem types. However those utilised for the North East Atlantic come almost exclusively from the North Sea Model of Christensen (1995), which divides all fish species into 15 groups including 'other predatory fish' and 'other prey fish'. Furthermore, the trophic levels obtained from the mass-balance model of Christensen (1995) were based on gut contents analyses, which are known to have a number of limitations (Deb 1997; Polunin & Pinnegar, in press); for example they tend to provide mere snapshots of diets at particular points in time and space. Moreover they also neglect certain dietary materials such as gelatinous plankton, microorganisms and detritus, that may nevertheless be very important. For calculating the trophic level of top-predators, gut contents analysis may be particularly unsuitable due to intermittent feeding and the frequent regurgitation of food upon capture (Bowman, 1986).

Stable isotopes of nitrogen have been widely used as an independent and objective means of establishing trophic level in aquatic organisms (e.g Vander Zanden *et al.* 1997; Post *et al.* 2000; Cabana & Rasmussen 1996). This relies on the general observation that with every trophic level, there is bioaccumulation of the

heavier isotope ^{15}N (Minagawa & Wada, 1984). Trophic level estimates resulting from stable isotope analysis (SIA) largely corroborate trophic level data derived from steady-state modelling (Kline & Pauly 1998; Pinnegar 2000) and/or gut contents analysis (Vander Zanden *et al.*, 1997). They also offer many advantages in that isotopes in tissues are integrated from prey over a long period of time, more than a year in many fish species (Hesslein *et al.* 1993) and thus they are much less subject to seasonal bias. Isotopes in tissues of a consumer are derived from the materials that are assimilated and not merely ingested. Collection of tissues from fish species in the Celtic Sea, for stable isotope analysis, would make it possible to re-examine and dissect the relationship proposed by Pauly *et al.* (1998) using completely independently derived trophic level estimates.
To date there has been very little interest in the relative price distribution of fishery species on a long-term basis. There is some evidence that as species become scarcer, their average market price increases (e.g. Murawski & Serchuk 1989; OECD 1997), i.e. that in some instances consumers are fairly insensitive to changes in price and will continue to purchase the product even if prices increase greatly. However, it is generally expected that where a diverse portfolio of harvestable resources exist, consumers may switch to a substitute product, depending on the availability and price of the alternatives and the income of the consumer, thus leading to a relative increase in the price of other species in the portfolio (cross-price elasticity) (Lawson, 1984). Sumaila (1998) suggested that markets are good at giving value to previously undesirable fish species when target species becomes scarce. It was demonstrated that on a world-wide basis, between the years 1952 and 1994, the average price of low trophic level species increased relative to the price of high trophic level species (Sumaila, 1998). However, the approach taken by Sumaila (1998) to aggregate prices and species into ISSCAAP categories is potentially problematic, since prices even for individual species may vary greatly on country, regional and local scales depending on local consumer preferences (Taylor, 1960). Consequently this approach is more appropriate where time-series of market prices exist on a local scale.
The main objective of the present study is to use three independent sets of time-series data to look for long-term fishery induced changes in Celtic Sea fish communities. Specifically: (i) to test for any changes in the mean trophic level of survey and fishery landings data using stable isotope derived estimates of trophic level, and (ii) to examine whether such changes are also evident in the relative market price distribution of fish species. We aim to test the null-hypothesis that the expansion of fishing in the Celtic Sea has had no discernible impact on the fish communities of this region.

Methods

Stable Isotope Measurements

Individual species were sampled in the Celtic Sea from the research vessel '*Cirolana'* and using the standard bottom trawl gear utilised for annual ground-fish surveys. This gear consisted of a modified Portuguese High-Headline Trawl, which was fitted with 14 inch rubber bobbins on the ground-rope, and a bunt tickler chain (Warnes & Jones, 1995). The codend was fitted with a small-meshed liner

(nominal diagonal stretched mesh size 20mm) and tows of 30 minutes duration were made at a speed of approximately 4 knots. Sixty-one standard survey stations were fished (Figure 1) during February and March 2000. Where possible, three fish of each species, were selected from the survey hauls, and these animals were dissected aboard ship to obtain tissue samples for nitrogen stable isotope analysis. Approximately 2g of white muscle was dissected from the dorsal musculature of each fish (Pinnegar & Polunin, 1999), placed in a vial and immediately frozen at -30°C. On return to the laboratory, the frozen tissue was freeze-dried and ground to a fine powder (particles <60μm). This was thoroughly mixed and a 1mg sample was weighed into a tin capsule for stable isotope analysis.
The ^{15}N composition of the samples was determined using continuous-flow isotope ratio mass spectrometry (CF-IRMS). The weighed samples were oxidised and the resulting N_2 passed to a single inlet, duel collector mass spectrometer (Automated Nitrogen Carbon Analysis (ANCA) SL 20-20 system at the Biochemical Mass Spectrometry Unit, University of Newcastle. Two samples of an internal reference material (homogenized cod white muscle) were analysed after every six tissue samples in order to calibrate the system and compensate for drift with time. The conventional delta notation was used to express stable isotope ratios and these were reported (in ‰) relative to an international standard (atmospheric nitrogen) and defined by the equation:

$$\delta^{15}N = \left(\frac{R_{sample}}{R_{s\tan dard}}\right) \times 1000 \qquad \text{[Equation 1]}$$

where R is the ratio ^{15}N:^{14}N. Experimental precision (based on the standard deviation of replicates of the internal standard) was 0.1‰.

Trophic Level Estimates

Stable isotope based estimates of trophic level were calculated assuming a constant per trophic level fractionation of 3.4‰(Minagawa & Wada, 1984). As a reference material, Celtic Sea scallops *Pecten maximus* (n=6) were utilised. These were collected during a beam trawl survey of benthos, aboard the research vessel '*Corystes*' during xxxxx 2000. Scallops of similar size were chosen (11.37 ± 0.06 cm) and the δ^{15}N of their adductor muscle determined. The value obtained (7.21 ± 0.18 ‰) was then utilised via equation 2:

$$TL_{Ni} = \left(\frac{(\delta^{15}N_i - \delta^{15}N_{ref})}{3.4}\right) + 2 \qquad \text{[Equation 2]}$$

where TL_{Ni} is the trophic level of species *i,* $\delta^{15}N_i$ is the mean δ^{15}N of species *i,* and $\delta^{15}N_{ref}$ is the mean δ^{15}N of the scallops, which were assumed to be herbivorous/detritivorous and consequently to be at trophic level 2.

Groundfish Survey Data

Demersal fish populations have been monitored in the Celtic Sea, by the UK Ministry of Agriculture, Fisheries & Food (now the Centre for Environment, Fisheries & Aquaculture Science) since 1981 (Warnes & Jones, 1995). The purpose of the survey was originally to investigate the distribution and biology of mackerel, but subsequently with an increasing need for fishery independent data on western stocks, the objectives were widened to include the biology, distribution and abundance of all species which could be sampled representatively by bottom trawl. From 1982 onwards, catch numbers, weight and length compositions were recorded routinely – thus giving a time-series of 18 years. The area of coverage extends from 47º 30' N to 52º 30'N and from 3º W to 12º W, and includes ICES Divisions VII f,g,h,j and the northern part of VIIe (figure 1). In the earlier years two surveys were normally carried out each year, one in the spring (March/April) and one in winter (December). However from 1989 onwards, only the spring survey has been undertaken, and thus only data for the spring surveys were utilised in the present analysis. No spring survey data were available for 1983.

Nominal International Fishery Landings

Nominal catches of fish and shellfish are officially submitted to ICES by each of the 19 member countries on an annual basis. ICES has published these data in *Bulletin Statistique des Pêches Maritimes* from 1903 to 1987 and from 1988 onwards in *ICES Fisheries Statistics.* In the present analysis we have used aggregated data from ICES divisions VII j-k (figure 1). Data for the period 1946-1972 were obtained directly from the yearly issues of *Bulletin Statistique*, data from 1972-1998, were downloaded from the ICES website www.ices.dk. Catches were expressed in tonnes live weight equivalent (excluding discards) throughout. The introduction to each issue of *Bulletin Statistique* should be consulted with reference to the potential limitations of the annual data-sets, although notable discrepancies over the time series include the occasional aggregation of Common Dab (*Limanda limanda*) and Lemon Sole (*Microstomus kitt*) in French reports and the separation of blue-whiting (*Micromesistius poutassou*) from non-specified gadoids in 1975.

In theory, it would be expected that if the trophic level at which a fishery operates is lowered one step, then catches should increase by approximately a factor of 10; this is in accordance with the finding that the average transfer efficiency between trophic levels in marine systems is ~10% (Pauly & Christensen, 1995). To study this effect (Pauly *et al.*, 2000b) introduced the 'fishing-in-balance' (FIB) index; which is derived from:

$$FIB = \log\left(Y_i \cdot (1/TE)^{TE_i}\right) - \log\left(Y_0 \cdot (1/TE)^{TL_0}\right) \qquad \text{[Equation 3]}$$

where Y is the catch, TL is the trophic level of the catch, TE is the mean energy-transfer efficiency between trophic levels (assumed to be 10%), and 0 refers to the first year in the series (which is used as a baseline). If catches increase tenfold for every full trophic level decline, the FIB index will remain constant and fishing can be deemed 'in balance'.

Relative Price Index (RPI)

Total fishery landings by English, Welsh and Northern Ireland vessels and the value of catches, plus those of foreign vessels landing fish in England, Wales and Northern Ireland are recorded by the Centre for Environment, Fisheries and Aquaculture Sciences (formerly MAFF). In the present paper we used a database of catch (in tonnes) and value (in 1000s UK £) from ICES regions VII f-k, to estimate the average price of individual fish species (in £/tonne) from the Celtic

Sea between 1979 and 2000. 26 fish species (table 1) were selected, for which there existed a complete time series of price estimates spanning 1979-2000 with no gaps. Linear regressions across all 26 species were performed on an annual basis, between the prices and assigned trophic levels, and the slope of the regression (b) used as the relative-price-index (RPI) for that particular year. The expectation is that if the RPI decreases, then the prices of lower trophic level species have increased relative to higher trophic level species (*sensu* Sumaila 1998). If the RPI increases, then it infers that the top predators have increased in value relative to the low trophic level species, and if RPI remains constant then the relationship in terms of prices between low and high trophic level species has remained virtually the same, although the actual values may have increased due to inflation.

Statistical Analysis

To test for significant long-term trends in time series data, nonparametric Man-Kendall tests were performed (Gilbert, 1987). Where a significant linear trend was indicated, the true slope (change per unit time) was estimated using the nonparametric procedure developed by Sen (1968), which is not greatly affected by gross data errors or outliers and can be computed when data for individual years (e.g. 1983 in Celtic Sea survey data) are missing (Gilbert, 1987). Differences were judged significant when $p < 0.05$.

Results

Nitrogen stable isotope compositions were gathered for 48 fish species, which together represented 54.4% of the species richness and 99.7 % of the biomass in the year 2000 groundfish survey. δ^{15}N values ranged from 10.2‰ in *Gadiculus argentius* to 17.2‰ in *Merlangius merlangius*, and trophic level ranged from 2.88 to 4.94. The mean trophic level of all fish combined was 3.86 ± 0.07 (SE).

Survey Data

Using stable isotope derived trophic level estimates and groundfish survey data for the period 1982-2000, it was possible to demonstrate that there has been a significant decline in the mean trophic level of the fish caught (Man-Kendall $Z = -2.01$, $p = 0.04$), over the course of the 18 year time-series (Fig. 2a). Sen's nonparametric estimator of slope indicated that for each year of the time-series the trophic level has declined by around 0.04. These trends have coincided with dramatic changes in the composition of the survey, and in particular, there have been major declines in the proportion of the catch represented by gadoids and elasmobranchs (high trophic level species) (Fig. 2b). In recent years the proportion of the survey represented by the horse mackerel *Trachurus trachurus* (TL 3.94) has also declined whilst the relative contribution made by mackerel *Scomber scomber* (TL 3.61) has increased (Fig. 2b). Similarly the proportion of the survey represented by 'seabasses, redfishes and congers' (ISSCAAP group 33) had increased over the course of the time series, and this is largely attributable to increased catches of the boarfish *Capros aper* (Fig. 2c), which feeds at a low trophic level (TL 2.94). Among the other 'seabasses, redfishes and congers', the proportion of the catch represented by anglerfishes (*Lophius* spp.), which feed at a high trophic level (*L. piscatorius* TL 4.09) has declined markedly over the course of the time-series, from 22.8% of the groups biomass in 1986 to only 0.7% in 2000 (Fig. 2c). It would appear that until 1988 the mean trophic level of the groundfish survey was relatively stable (Fig. 2a), but in subsequent years this has been much more variable, largely due to variation in mackerel and horse-mackerel stocks, with very low catches of these species in 1993-1995.

Landings Data

Using stable isotope derived trophic level estimates and international fishery landing data collated by ICES for the period 1946-1998, it was clear that there has been a significant decline in the mean trophic level of the fish landed (Man-Kendall Z = -3.25, p = 0.01), over the course of the 53 year time-series (Fig. 3a). Sen's nonparametric estimator of slope indicated that for each year of the time-series the trophic level declined by around 0.03. However, for the period 1982-1998 (the years covered by the groundfish survey data), there was no significant overall trends in the mean trophic level of landings (Man-Kendall Z = 0.48, p = 0.63), and particularly low TL values were indicated for 1987 and 1988 (Fig. 3a). There was a significant correlation (Pearson r = 0.52, $p < 0.01$) between mean trophic level and the total international catches (in tonnes), such that when catches were high, mean trophic level was low. When mean trophic level was plotted against total catch (Fig. 3b) it became apparent that between 1946 and 1968 mean trophic level and catch varied relatively little from year to year (TL 3.86-4.01, catch 5,1235-201,494 tonnes). However, from 1969-1976 catches increased greatly (upto 489,776 tonnes in 1976), and this was accompanied by a decline in the mean trophic level of the fish landed (TL 3.78 in 1976). Between 1976 and 1977 catches declined dramatically (to only 155,131 tonnes) and this coincided with a slight increase in the mean trophic level until 1985-1988, when catch began to increase again and trophic level declined (to TL 3.65, catch 304,792 tonnes). In subsequent years (1989-1998) catches have varied comparatively little from year to year (232,501 – 364,942 tonnes), whilst the mean trophic level of the fish landed has ranged from 3.80 to 3.91 (Fig 3b).
The trends we observed in fishery landings coincide with marked changes in the composition of fishery catches in the Celtic Sea (Fig. 4a), notably a decline in the proportion of the catch represented by high trophic level groups such as the gadoids (78.1% of the catch in 1946, 13.9% in 1998) and elasmobranchs (7.5% of the catch in 1946, 3.3% in 1998). Up until 1967, reported landings of horse-mackerel *Trachurus tracurus* were very low representing only 0.03% in 1946, however in subsequent years this fishery has greatly expanded and horse-mackerel represented 50.4% of total landings in 1998. Similarly the fishery for mackerel *Scomber scomber* was very small in the early years of the time-series (6.6% in 1946) but expanded throughout the 1960s and 1970s, however the proportion of the catch represented by mackerel reached its peak in 1976 and the importance of this fish has subsequently been surpassed by that of horse-mackerel (Fig 4a). The proportion of the catch represented by flatfishes (ISSCAAP group 31) and 'seabreams, redfishes and congers' (ISSCAAP group 33) has remained relatively unchanged over course of the whole time-series, however the contribution of clupeoids and anchovies (ISSCAAP group 35) has exhibited occasional peaks, notably in 1958-1959, 1926-1964 and 1966-1970. Between 1984 and 1990, the proporti-

on of the catch represented by gadoids (ISSCAAP group 32) made somewhat of a recovery and this was largely due to increased catches of the low trophic level (TL 3.14) species *Micromesistius poutassou*. This peak in blue-whiting catches, corresponded with the marked anomaly observed in the mean trophic level data (Fig. 3a). In subsequent years the proportion of the landings represented by gadoids continued to decline (Fig 4a), and among the gadoids, high trophic level species such has hake *Merlucccius merluccius* (TL 3.85) have come to represent much less of the fishery in recent years.

Overall, between 1946 and 1998, there was a significant increase (Man-Kendall $Z = 7.48$, $p < 0.0001$) in fishery landings from the Celtic Sea (Fig 4b), and in general catches of most fish groups increased in absolute terms including gadoids, flatfish, mackerel and especially horse-mackerel. Particularly high catches of mackerel and horse-mackerel were taken in 1976. When total catch and mean trophic level were used to calculate the 'fishing-in-balance' (FIB) index, a clear and strongly significant increase became apparent over the course of the 53 year time series (Man-Kendall $Z = 4.32$, $p < 0.0001$) (Fig. 4c).

Relative Price Index (RPI)

We observed a strongly significant increase (Kan-Kendall $Z = 3.16$, $p = 0.016$) in the 'relative-price-index' over the course of the 22 year time series (1979 - 2000) indicating that high trophic level species have become relatively more valuable in relation to species feeding at lower trophic levels (Fig. 5). Sen's nonparametric estimator of slope indicated that for each year of the time-series the RPI increased by around 0.03. From 1979 until 1984 the RPI changed very little from year to year, however From 1984 onwards the relative distribution of prices began to change markedly, and in 1985 the prices of many low trophic level species e.g. horse-mackerel, gurnards, megrim, herring and mackerel had declined in absolute terms (by 92, 38, 34, 23 and 12% respectively) in relation prices in the previous year. Prices of many high trophic level species were much higher in 1985 compared to 1984, e.g. saithe, red mullet, whiting, tope, dory, ling and cod which increased by 51, 30, 23, 22, 16 and 12% respectively.

Discussion

In general the 48 stable isotope-derived trophic level estimates we present (appendix 1) are similar to those given by Christensen (1995), but in many cases were quite different to the values used by Pauly et al. (1998). This was largely due to the wide usage of default values by Pauly et al. (1998) to represent whole groups of species. For example, if we consider the same 48 species for which we have isotope derived trophic level estimates (appendix 1),18 were allocated a trophic level of 3.5 ± 0.26 by Pauly *et al.* (1998), the default for 'demersal percomorphs', five were given the default value for 'gadiformes' (3.8 ± 0.25), 2 were given the default for 'clupeiformes' (2.8 ± 0.27) and 2 were given the default for 'elasmobranchs' (3.6 ± 0.24), with the defaults obtained from Pauly & Christensen (1995). Indeed, of the trophic level estimates utilised by Pauly et al (1998), only 17 out of the 48 species were allocated non-default trophic level estimates, 14 of which came from Christensen (1995) and none of which were based on data from the Celtic Sea. We have provided species-specific and geographically relevant trophic level estimates for 99.7% of the Celtic Sea fish community (based on the 2000 survey data), and as such the long-term trends we observe should be less speculative than those of Pauly *et al.* (1998) which were based on somewhat spurious trophic level estimates.

The decline in mean trophic level we have observed in Celtic Sea survey data and fishery landings, agree with the supposition of Pauly *et al.* (1998) that there have been major changes in the fish communities of the northeast Atlantic generally over the past 50 years. The decline we observed in the survey data (0.04 TL/ year), was slightly stronger than the decline we observed in the landings data (0.03 TL/ year), and in both cases this decline was more marked than that given in Pauly et al. (1998) for the NE Atlantic as a whole ($\sim$ 0.02 TL / year). The fact that we found a significant decline in the fishery-independent survey data over the past 19 years, when there was no apparent trend in the landing data over this same period, suggests that the changes occurring in the underlying ecosystem may be stronger than any changes observable in fisheries landings. Some species which have become particularly common in trawl surveys in recent years e.g. *Capros aper* are not commercially very important, thus major changes which have occurred in the fish community may not necessarily be picked up by analysis of fisheries landing data. On the other hand fisheries landing data may reflect political changes as well as biological changes, for example after 1977 Eastern Bloc

fleets were excluded from fishing within EC waters, greatly reducing the number of blue-whiting (*Micromesistius poutassou*) mackerel (*Scomber scomber*) and horse-mackerel (*Trachurus trachurus*) removed from the Celtic Sea (Eaton, 1983). This event affected total catches (Fig. 4b), the relative composition of landings (Fig. 4a), and consequently was responsible for some of the variability in the mean trophic level of fishery landings (Fig. 3a). Initially the EC fleets did not have the capacity to replace the fishing effort exerted by the Eastern Bloc countries; but since then this catching power has been replaced by British, Dutch, German and Irish vessels (Lockwood & Shepherd, 1984).

In general, it would appear that total fisheries catches from the Celtic Sea have continued to increase over the past 50 years, suggesting that new fisheries are still being developed. This is unlike elsewhere in the northeast Atlantic where most stocks have been exploited for a considerable period of time, e.g. the North Sea. After the second world-war Celtic Sea fisheries targeted mainly gadoids, but throughout the 1960s and 1970s new fisheries opened up, which targeted more pelagic species. Mackerel stocks were exploited at la low level before World-War II, and from 1946 to 1965 the landings from this stock increased only slightly, however in the mid 1960s a major winter fishery began adjacent to the Cornish peninsula, initially operated by the USSR (Lockwood & Shepherd, 1984). The fishery for horse-mackerel (scad) developed as a potential alternative to mackerel in the late 1960s (Lockwood & Johnson, 1977), again largely operated by the USSR, with small catches by UK, French, Norwegian, Spanish and Portuguese vessels. With the exclusion of the Eastern Bloc countries, the dominant fleet became that of the Netherlands, whose catch of horse-mackerel rose from 2000t in 1977 to more than 40,000t in 1981 (Eaton, 1983). Prior to 1974, there was very little fishing by any country on blue-whiting *Micromesistius poutassou*, however in the late 1970s industrial fisheries developed, largely for use as fish-meal and operated by Norwegian vessels (Pawson, 1979).

The observation that the 'fishing-in-balance' index continued to increase over the 53 year time series from 1946 to 1998 (Fig. 3c), confirms that fisheries were expanding to stocks previously not or only lightly exploited, and that the rate of increase in overall catches was more than enough to counter the observed decline in the trophic level of the system (Pauly *et al.*, 2000b). Christensen (2000) observed that for the NE Atlantic as a whole the FIB index continued to increase up until 1976 but has subsequently declined, indicating that the decrease in TL is no longer being matched by a corresponding increase in catches. We predict that this is likely to occur in the Celtic Sea, once total catches have reached a peak.

Almost all of the new fisheries which have developed over the last 30 years or so, have targeted low trophic level species which feed mainly on zooplankton (Sorbe 1980; Ben-Salem 1988; Mehl & Westgård 1983). This is in contrast to the post-war fisheries which targeted high trophic level species, e.g. cod, hake, haddock and small sharks. Indeed, many of these predatory fishes feed primarily on those species which are now being harvested by the fishery (Du Buit 1982; Olaso *et al.* 1996; Velasco & Olaso 1998), which implies that many modern fleets are operating a full trophic level lower than their post-war counterparts. Even the non-exploited species *Capros aper,* which has become much more common in recent trawl surveys, is a zooplanktivorous species (Macpherson, 1979, 1981), inferring that it is the ecosystem as a whole which has switched to lower average trophic level and not simply fishing preferences.

Environmental influences

Although the trends we have observed are consistent with the 'fishing-down-foodwebs' concept as proposed by Pauly *et al.* (1998), it is possible that the changes in fish communities we have described, might actually be the result of long-term changes in climate. Southward *et al.* (1988) showed that the abundance of some species (herring and pilchard) occurring off the southwest of England (Celtic Sea, Bristol and English Channel), closely correspond with fluctuations in water temperature. Pilchard are generally more abundant and extend further to the east when climate is warmer whilst herrings are generally more abundant in cooler times. This pattern has apparently been occurring for at least 400 years, and major changes were noted in the late 1960s as waters cooled and spawning of pilchard was inhibited. During this time mackerel, another coldwater arctic-boreal species, started to become very abundant, and with these environmental changes came the development of the new pelagic fisheries (Southward *et al.* 1988; Lockwood & Shepherd 1984). Changes in the distribution of other Celtic Sea fish species have been observed to coincide with cold periods (e.g. Coombs 1975; Cushing 1982), including declines in hake, horse-mackerel, monkfish, red mullet, conger and Pollock which are considered warm-water species (Cushing 1982), and increases in cod, ling, plaice, dogfish and lemon sole which are considered cold-water species. *Capros aper* is a species with a southerly distribution, and yet greater numbers have been observed to occur during cold periods (Cushing, 1982).

In recent years, waters of the Celtic Sea and NE Atlantic generally, have begun to warm again, and this has coincided with declines in the survey biomass of many cold-water species including cod and haddock. O'Brien *et al.* (2000) showed that it is a combination of diminished stocks because of overfishing and these adverse warm conditions which may be responsible for the recent near-collapse of cod stocks in the North Sea. Intensive fishing often results in high exploitation on young fish, such that few individuals survive to reach sexual maturity (O'Brien *et al.*, 2000). A combination of low spawning-stock biomasses and climate changes are likely to be the driving forces behind the overall long-term declines we have observed in the mean trophic level of Celtic Sea fish communities.

Markets and Prices

Market prices carry information about consumer preferences and the ability of suppliers (fishermen) to provide the desired product, i.e. the availability of target species in the environment (Lawson 1984; Ludicello *et al.* 1999). If consumers want more of a product than is being offered, they tend to bid up the market price to bring forth additional supply; if suppliers want to move more of their products, they typically must reduce their prices. The evidence from our 22 year time series of market prices for 26 Celtic Sea species, is that high-trophic level species have become relatively more expensive in comparison with low trophic level species. This is because the expanding pelagic fisheries have flooded the market with low trophic level fish species, forcing prices of these fish down (e.g. by 92% in horse-mackerel between 1984 and 1985), whilst many high trophic level fish, e.g. hake, cod, haddock, monkfish and small sharks have become scarce (supply has declined but demand remains high). Similar trends have been observed on a world-wide basis and as a group the price of cod, hake and haddock rose from $700 per ton in 1989 to $1,060 per ton in 1994, reflecting declines in the abundance of these groundfishes generally (Ludicello *et al.* 1999; OECD, 1997). Sumaila (1998) suggested however, that low trophic level species have become more valuable in relation to high TL species over the past 50 years, which would result in a declining RPI. This is in contrast with our findings for the Celtic Sea and those of OECD (1997), and would imply that as prices for high TL species have increased there has been a switch to lower trophic level substitutes, what is known in economic theory as cross-price elasticity. Although we have found little evidence for this in the Celtic Sea, the fact that the mean trophic level of fishery landings have declined, suggests some substitution, whilst increases in the price of previously less desirable species such as saithe, relative to other gadoids, suggests some cross-price elasticity within ISSCAAP groups.

Conclusions

There have been clear and significant changes in the structure and composition of fish communities and fishery landings in the Celtic Sea over the past 50 years, which have coincided with a period of considerable fishery expansion. Whether or not the increased intensity of fishing has been responsible for these community changes or whether shifts in underlying environmental factors have been responsible, and consequently led to secondary changes in fishing practises remains unclear. However, the response of markets as been marked, with a switch away from high trophic level, high price species to low trophic level, low price species. The Celtic Sea is unusual among NE Atlantic seas in that its major fisheries have developed relatively recently, at a time when good fishery monitoring and survey programmes were in place. As a consequence the Celtic Sea offers an ideal situation to study the indirect effects of intensive fishing and the interactions which exist between the many fleets and gears which operate in the NE Atlantic (e.g. Marchal & Horwood 1996; Laurec *et al.* 1991).

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Figure 2


b)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of survey biomass
1984
1986
1988
1990
1992
1994
1996
1998
2000
Survey Year
ISSCAAP Group
Sharks and rays
Mackerels
Herrings & anchovies
Horse mackerel
Basses etc.
Cods & hakes
Flatfishes

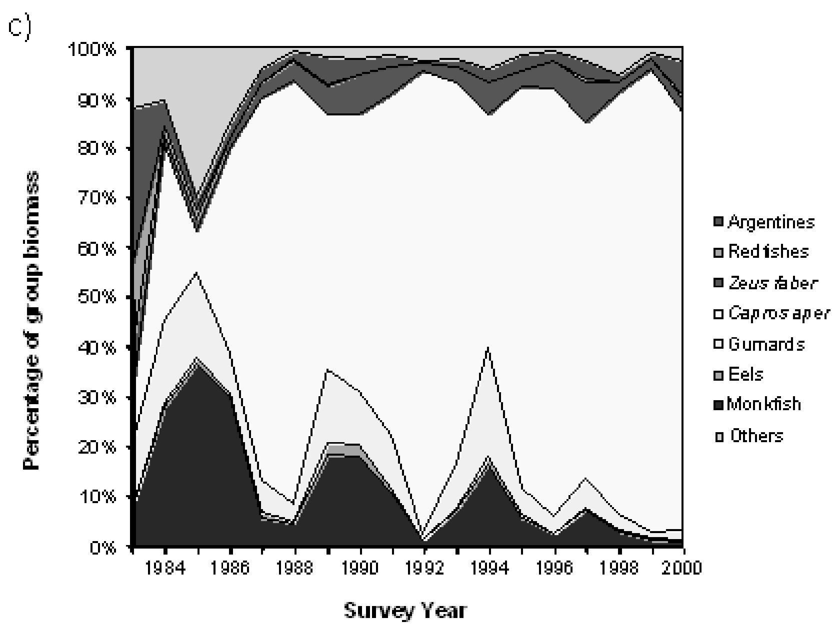

c)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of group biomass
1984
1986
1988
1990
1992
1994
1996
1998
2000
Survey Year
Argentines
Redfishes
Zeus faber
Capros aper
Gurnards
Eels
Monkfish
Others

Figure 3

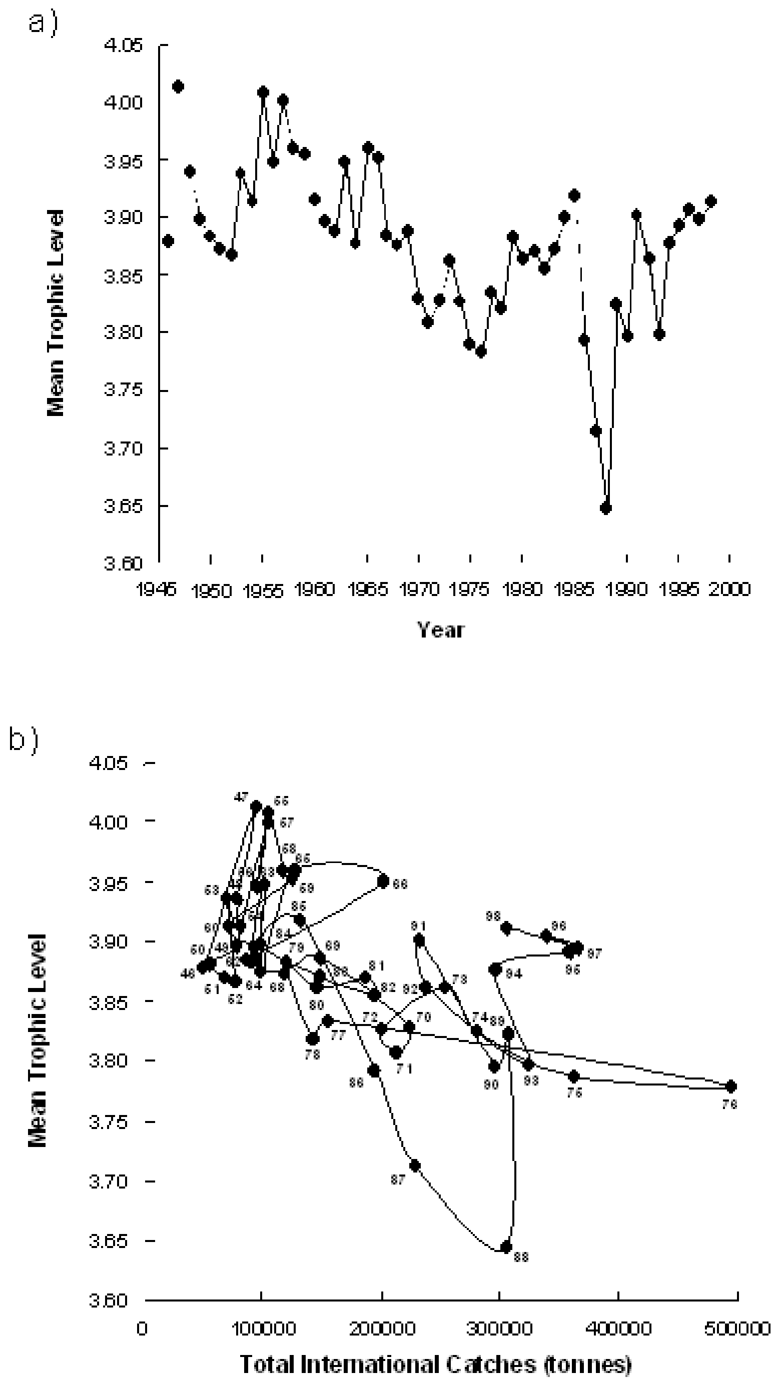

a)
Mean Trophic Level
4.05
4.00
3.95
3.90
3.85
3.80
3.75
3.70
3.65
3.60
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
b)
Mean Trophic Level
4.05
4.00
3.95
3.90
3.85
3.80
3.75
3.70
3.65
3.60
0
100000
200000
300000
400000
500000
Total International Catches (tonnes)

Figure 4

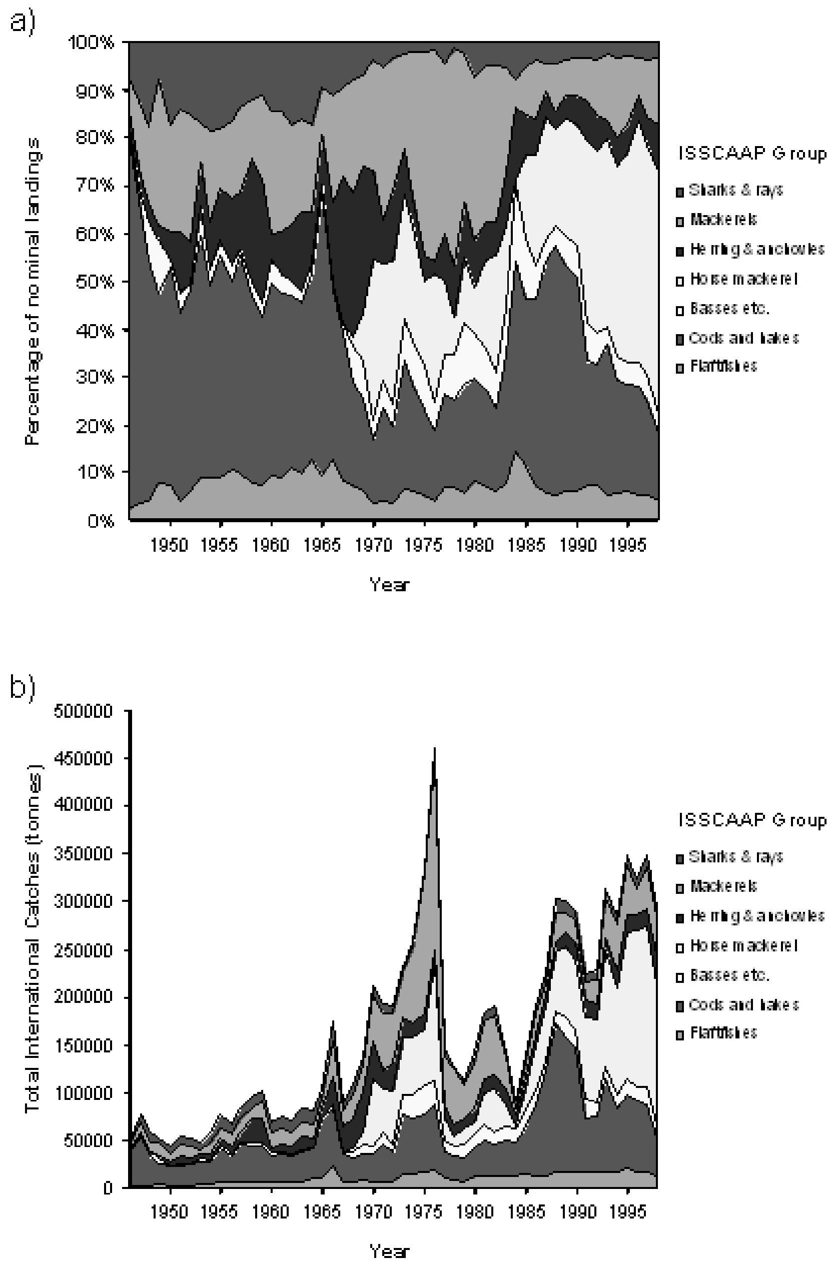
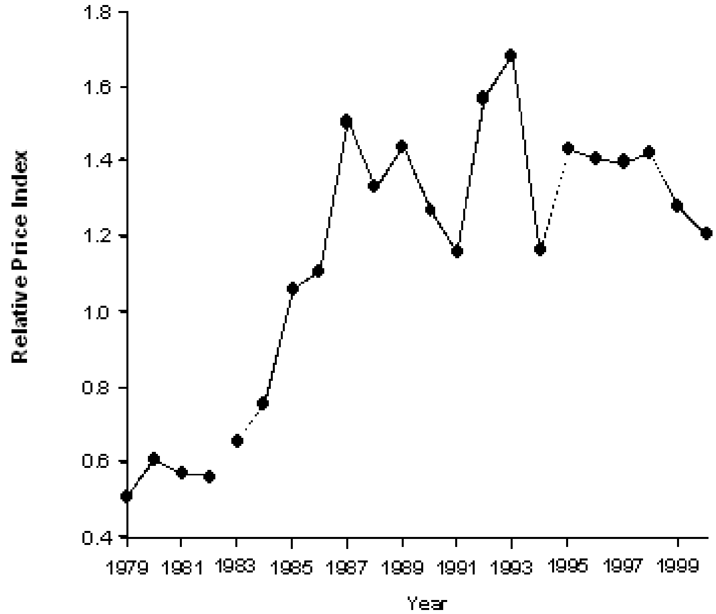

a)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of nominal landings
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Year
ISSCAAP Group
Sharks & rays
Mackerels
Herring & anchovies
Horse mackerel
Basses etc.
Cods and hakes
Flatfishes
b)
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
Total International Catches (tonnes)
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995
Year
ISSCAAP Group
Sharks & rays
Mackerels
Herring & anchovies
Horse mackerel
Basses etc.
Cods and hakes
Flatfishes

Figure 5



1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
Relative Price Index
1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year

K Minutes of dst^2 meeting, Madrid, 4-5 February, 2000.

Introduction

The first dst^2 meeting was held at ICCAT headquarters in Madrid, 4-5 February, 2000 and was attended by participants from MRI (Iceland, 4 participants), IMR (Norway, 2), SCUI (Iceland, 1), DIFRES (Denmark, 4), FRS (Scotland, 3), CEFAS (England, 2) and IFREMER (France, 1), as listed in Appendix 1.

The purpose of the first meeting was to bring all participants up to date on prior activities in the fields of data warehouse (DW) technology, available implementations of Gadget (or, rather, its precursor, Bormicon, and the subsequent Fleksibest) and schedule work until the first true plenary meeting of dst^2, scheduled for summer, 2000.

Data warehouse

The data requirements for the current and immediate implementations were introduced and implications in terms of data base requirements were discussed. It was noted that although Gadget will in principle be able to run with minimal data requirements, this basically involves reducing the model to a stock-production model and not much is gained in this case. Gains from using the dst^2 approach first become apparent when more complex implementations are considered, either through cannibalism, food-supply-limited growth, spatial variation and migration or predator-induced mortality, not to mention formal statistical approaches to estimating these effects. Requirements for such models far exceed the data requirements for any current assessment models and therefore also require alternative approaches to data storage and access.

Portability was considered extremely important and institutes indicated a desire to be able to run the model and data warehouse at each location. It was therefore agreed that the only realistic approach to implementing the data warehouse was for a single partner to develop an instance of the warehouse and that a single entry format would be defined.

It was decided that this format would be in the form of ASCII files (flat files). The groups set up an initial layout but deferred final definitions of file formats until the summer dst^2 meeting, with considerable work planned in-between meetings.

It was clear that the simpler database entries, such as commercial or survey samples for ages, weights and lengths could be implemented within the near future (i.e. during the year 2000), but it would be considerably more difficult to implement the database for acoustics data and stomach contents. These latter data bases were therefore deferred along with hydrographic and zooplankton data bases.

Aggregation levels

The group agreed that within the data warehouse the data should be as disaggregated as possible, but not to the level of individual fish. This indicates a need to define minimal spatial and temporal resolutions which will suffice to keep the warehouse a manageable size but also to enable views at any levels considered of practical use for Gadget.

Programming approach

The meeting agreed that Bormicon would be used as the basis for Gadget. This should not restrict the directions of development, but used so as to provide a fixed base from which approaches can be developed.

Bormicon has been developed in C++ which will therefore become the programming language for Gadget. Although Java might in many ways be more applicable in terms of portability, performance would suffer and the existing 16000+ lines of Bormicon code can be used by sticking to C++.

Immediate development areas

One major problem at present is the amount of computer time required to estimate parameters in the large multispecies, spatially resolved models. These estimation times can easily run into several weeks given current computer power.

Work in Iceland on parallel processing indicates that the use of computer networks may alleviate these issues substantially.

Case studies

Some case studies of Gadget precursors were presented, from single species data-poor situations (redfish in ICES Div Va), through single-species with cannibalism (Barents sea cod) to a multispecies version (cod-capelin-shrimp in Va).

It was clear from these presentations that although these programs had been used in several instances, there were several aspects which were not understood and several areas in which considerable further development is needed.

Some parts of current models are completely ad-hoc and need to be developed from scratch. This particularly applies to growth and migration.

Interface issues

Some user-interface issues came up during this meeting. DIFRES indicated how a browser could be used as a user interface for the data warehouse. This was considered a useful aspect, but it was pointed out that the most important aspect of the data warehouse, within the current context, was to feed data into Gadget.

It is not at all clear what would be the best way to do this, since there are not only requirements to run Gadget within an institute, but also to run Gadget on other machines which may or may not have direct access into an institute's central database or data warehouse.

In this case it seems clear that although an interactive model where Gadget can read directly from the data warehouse, as indicated by choices which the user makes in a browser, would be ideal in some situations, there are other situations where this is not applicable and a batch-like approach is more suitable.

Similar issues come up when considering whether the data warehouse should eventually be linked directly to the institutional databases. In some cases this would be ideal but there are several drawbacks. One very practical drawback is performance of such links, and another is portability: If the links are severed, then the data warehouse can be made completely portable and carried along e.g. on laptops or CD-Rom.

Ownership and access concerns

Ownership concerns include questions such as where the physical data warehouse(s) are supposed to reside.

Access concerns include various policy decisions at the different institutes. For example some institutes will not give other institutes access to their raw data, possibly not even at the aggregate form used by the data warehouse. Further, some institutes can not link their in-house machines to the Internet and hence can not access a central data warehouse server, no matter how well that server is set up. Such institutes might, however, be able to export their own data by doing so through a nearby university.

It was agreed that the only way forward on this issue was to initially implement a data warehouse at each institute, but with uniform interfaces for loading and extracting data as well as a uniform definition of all tables in the data warehouse.

Technical details of data warehouse

In addition to DIFRES' XML-based presentation, SCUI presented a completely different CORBA-based approach. It was clear that there were some benefits to each approach. The DIFRES approach emphasized the GUI aspects of the issue, whereas the SCUI approach emphasized some technical aspects not handled by DIFRES.

After considerable discussion, the meeting agreed on a plan of action concerning how to approach the data warehouse design and implementation, as drafted in Fig. 1. The plan is designed to pick up and combine the best of the two approaches,

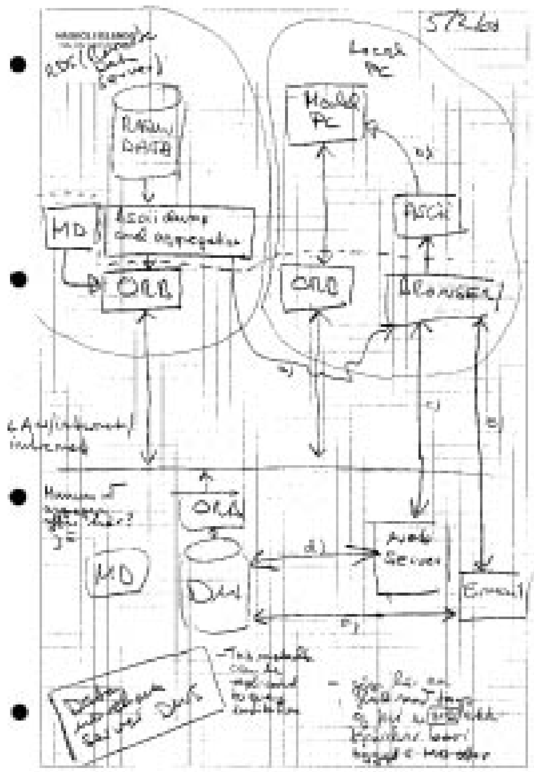


Figure 1: Data warehouse

yet avoiding potential pitfalls which are abundant.

Participants

Scotland	John Simmonds
	Mike Heath
	Ken Patterson
England	Carl O'Brien
	Chris Darby
Denmark	Peter Lewy
	Marc Cromme
	Steen Silberg
	Leif Thomsen
Iceland	Gunnar Stefansson
	Lorna Taylor
	Hoskuldur Bjornsson
	Kjartan Kjartansson
	Helgi Thorbergsson
Norway	Bjarte Bogstad
	Dankert Skagen
France	Verena Trenkel
ICCAT	Victor Restrepo

L Project Meeting, Nantes, June 2000

L.1 Minutes

The first full meeting of dst2 took place in Nantes, France, 27-29 June. Due to an air traffic controller strike some participants were unable to attend during the first day of the meeting.

The meeting was concentrated around two topics:

* Status of all workpackages
* Definition of ASCII tables to be used as data for entering into the data warehouse(s)

It was decided at the Madrid meeting that intermediate ASCII tables should be generated for each case study in order to provide a step which all partners could set up. This will free the DW group to concentrate on a single input format. It is important to define appropriately the type of data (in particular the spatio-temporal scales) to be included in the DW and group members found it convenient to do this in terms of concrete ASCII tables.

These minutes contain the conclusions from the meeting with detail included in appendices

Status of workpackages

It was decided that the various intermediate descriptions of workpackage status will eventually become the annual report structure from the project.

Subgroups were set up for some of these workpackages. The workgroups met between sessions and reported back to the plenum.

WP 1.1 Data entry, validation, raw data description.
No deliverables yet required. Work is in progress.

WP 1.2 Design of data warehouse.
DIFRES require a full description of the input data for them to proceed further. Data will be input into the DW from ASCII files and the ASCII file structure should be defined as soon as possible. Several prototype files were designed and adopted during the meeting (see Appendix L.6) and prototype ASCII input datasets should be available soon from several partners.

Work-groups were set up to define the DW content, functionality and interface.

WP 1.3 Summarise data for DW (aggregation methods).
Initially we will sum and average data for aggregation in the DW. In the future we will have to do better than this although in some instances simple aggregation methods may be sufficient. A point to note is that we need to keep a trace of aggregation methods which should be recorded in the database and retain a measure of the variance of the data which went into each average whenever

possible.

The EU project FINE (involving Carl, Lorna and Dominique) may produce some relevant results on the topic of summarising data

WP 1.4 Extraction programs to generate ASCII files.
It was argued that we are doing the job the wrong way around by defining ASCII files before building the DW. But - the ASCII files we have been trying to define are only regarded as prototypes to allow everyone to get started without having to wait for a DW to be implemented.

WP 1.5 Design of DW views and structures
DIFRES are to write prototypes of the DW. Prototype 1 will have no web or GUI interface. No discussions took place on the second prototype.

DIFRES called for more interaction with other partners. This will involve Leif going to Iceland and the establishment of subgroups.

WP 1.6 Setting up the data warehouse

WP 1.7 Interface to GADGET
Work has to start now as this task is quite complex. Complete functionality is not essential for the prototype.

WP 2.1 Migration and drift
IMR are heavily committed to this WP. An alternative migration model is under development at IMR (including Sigurd Tjermeland) based on gravity centres and diffusion. Herring migration and larval survival are being related to condition, temperature and drift. The main effort is scheduled for the last half of 2000/start 2001.

SCUI are also involved in this workpackage, no activity yet but they will start in the autumn.

WP 2.2 Spawning and Recruitment
It is known that it is at least possible to include spatially variable mortality and thus force data from a larval-drift model to conform to survey indices, in order to close the life-history loop.

At IMR survival and growth of life stages are being investigated for NEA cod based on survey abundance indices and environmental data. NE Arctic cod is the main emphasis of work by IMR as the Barents Sea was originally in the proposal and results in terms of modelling should be generic. This work includes the density dependence of growth of young cod and links between maturation, fecundity, condition, liver index and capelin biomass.

MRI not started but there will also be some work on Icelandic cod from MRI and Norwegian herring from IMR. What about other species - eg those in the Celtic Sea?

The link between this WP and the assembly of hydrodynamic data in WP 1 is not explicit. The link to environmental data is less straightforward although important and the North Sea herring case study will incorporate this.

WP 2.3 Growth maturation and fecundity
IMR are working on a bioenergetic model for NEA cod based on capelin consumption and temperature (including confidence limits on growth predictions). To use this, however, we will also need to simulate the dynamics of the prey abundance, which will be very difficult and the selection pattern of consumption of the prey. Some work going on is the density dependence of growth in juvenile cod. There is also work on relationships between maturation and realised fecundity and condition indices (Tara Marshall).

MRI have been working on ways of parameterising the variability in growth. Growth of a particular age and length cell is according to a distribution (eg growth of X cm distributed about a specific parametric model). The aim to include more flexibility/choice of distribution and a paper describing the first such growth model (employing the beta-binomial distribution) has been distributed to the group.

WP 2.4 Internal model types including process errors
A subgroup was formed to discuss state-space models. The primary aim of which is to rewrite Gadget formulae without using flow-charts, partly in order to obtain a time-series orientated model formulation.

There was a subgroup discussion on how to write down the mathematical formulation of the model as the definitive definition of what is going on. It was accepted that this is very important and must the done. Due Q3.

IMR have written some current functions in matrix form and think it would be helpful to do so before programming as the process became clearer and to program afterwards would be easier. IMR described a draft paper with such a description. IMR and IFREMER will work together on state-space models.

There will potentially be some Bayesian analysis in the WP.

WP 3.1 Estimation procedures (based on likelihood functions).
MRI have done some work on this WP, and will hire someone to work on goodness of fit tests (starting Sept). The current method is to use a multinomial formulation which is inappropriate as the fit is highly overdispersed.

WP 3.2 Programming estimation
MRI will spend a lot of time on this. The current code uses 3 different algorithms for minimisation using parallel processing on a network of computers which seems to work. Version 0 of Gadget (which is known to work under Solaris and Linux) is available for installation at each site.

Inconsistencies in programming have led to the situation that not all new Norwegian changes have been inserted. IMR and MRI will cooperate on a single version.

It was noted that automatic differentiation could probably be used in Gadget but no implementation has yet been attempted.

WP 4.1 Feeding and consumption

UiB will develop a multispecies model of cod - capelin - herring migrations as an individual based model (IBM). The model will use an adaptive random walk approach to determine the optimum movement strategy for the fish - this will be done outside of Gadget but there will be feedback into the other WP's , see Appendix L.3. The approach includes habitat selection and ecological fitness maximisation to select the best movement strategy to move stocks.

SCUI and UiB will cooperate in this area. IMR will also work in conjunction with UiB on comparisons of the final model with available data.

Contributions from DIFRES will include cdf's of stomach content data and IMR also work on DB of stomach content data.

WP 4.2 Spatio-temporal scales
University of Iceland - results from this WP feedback to the spatial scales which need to be built into the ASCII files and the DW. This is an important topic - we need to return to this later and pick up on it again.

WP 4.3 Reference points
There is a need to think about what reference points mean in the context of multispecies systems. This is work in progress by Henrik Gislason and Peter Lewy (DIFRES). Due Q12.

WP 5.1 Icelandic case study.
A haddock case study is already in existence and documented. There are other single species assessments with Gadget for Icelandic stocks and one first draft 3-species assessment.

WP 5.2 Barents Sea
This WP is not formally included in the project as a deliverable, but work is still going ahead, and many of the earlier WP's relate to investigations in the Barents Sea. The individuals concerned flagged up various concerns regarding coding standards and exchange of software - relating to the IMR usage and modification for the Barents Sea ecosystem. This will possibly be implemented as multispecies model, although single-species at the moment.

WP 5.3 Celtic Sea
Irish Sea will be added to this case study, and will include 9 species rather than 6. The ability to incorporate 9 species needs to be assessed as there may not be enough data for all.

Classifying vessels into fleets/metier in this area is difficult as vessels use several gears in single trip and change metier during the year. Some vessels area also involved in as many as 6 different fishing activities.

IFREMER are currently exploring the usefulness of a complex model by feeding it into management model to explore management strategies, this enables the impact of spatial and seasonal management strategies to be assessed.

An example of a use of this model in the Celtic Sea is for whiting. Immature/mature whiting are predominately in different locations and the fishing target zone for whiting is the area with mature whiting. The target zone for nephrops fishing overlaps with both whiting zones which results in the nephrops fishery catching a high bycatch of immature whiting. Use of this model provides information on the impact of restrictions on nephrops fishing in the immature whiting zone. Zones may be dependent on life cycles, fishing pattern and management.

WP 5.4 North Sea herring
Assembly of the necessary data is underway. It is necessary to find data on the diet of herring and the plan is to include zooplankton data as spatio-temporal values with no feedback from consumption by the herring. Larval data is important for this case study which will be a complex single species model.

Data warehouse

The following describes the discussion and conclusions reached at the meeting. Further detail on specific topics is given in Appendices L.5 and L.6

General issues concerning availability and structure of data

For all the tables mandatory columns need to be defined.

The same access permissions should be available for all partners. To maintain levels of access permission would involve more work. The aim is not to include individual data in the DW and if partners require to use it then they have access to their own databases.

Spatio-temporal scales

Spatial and temporal categories were defined.

There are to be 4 hierarchical levels of space, named in descending order: region, division, subdivision and grid cell. Region is defined as being Iceland, North Sea etc; Division as being a coarse sub-set of a region (eg. Northwest North sea); and Subdivisions (eg. Statistical square). A grid cell should be small enough so that no further level of spatial resolution will be needed.

Accessing the original databases should be kept to a minimum after the initial data extraction, therefore the initial aggregation level should be as fine as possible.

The model currently operates on monthly time-steps, but with a facility for subtimesteps if required. We discussed at length what should be the basic time unit for holding environmental data. Year and month are essential. We will devise a coding system to define finer time steps, so that data of different resolutions can be held in the same file.

Time steps will be defined as year, quarter, month. (Some data only available by year or quarter.)

Catch, landings and logbook data

Logbook requirements vary by nation and vessel size. There are also differences in definitions and understanding of the terms fleet and metier.

Data are a mixture of different types. Some are direct observations of landings from port officials or log-books. In other cases the data required are derived from subsampling of the fleet - eg by placing observers on a small sub-set of vessels.

Fleet structure differs in different areas (ie a vessel may be a member of a different metier in a different area) so individual vessels will need to be able to be grouped flexibly. This should not (and in most cases cannot) involve data on individual vessels being available.

2 structural levels of vessel/gear by having subclasses should be sufficient. Other indicators such as target species and area will provide information in order to reclassify fleet/metier. Changes in legal mesh sizes etc can also be a proxy for gear type and reduce the number of gear codes.

French and UK vessels land fish sorted by length so sampling is stratified by market size category - this means that the weight landed of each size category must also be known and the number at length is scaled to the total catch. The data must then be stored in the DW by market size category which requires an extra column. Sampling by Iceland is random.

Location information available varies by nation and for French vessels is large scale, other nations have satellite monitoring but this does not necessarily indicate where the fishing took place.

It was concluded that the data required for this table should be massaged to the Subdivision level from the original observations as necessary, but a flag included to indicate the degree of massaging that has been done. ie the DW will include modelled data.

Although IFREMER log books and landings data are in standard databases, the format of the sampling data is species (chief scientist) dependent.

Data available on very fine scales

Currently the model works in "timesteps" (usually 12 months within a year) of equal length and some daily components are multiplied by 30. BUT the input data are aggregated by calendar months. The question then arises that if subtimesteps (eg taken to represent weeks) are stored within the database how should they be defined (when derived from observed values)? By quarter of a month? The model itself allows the use of subtimesteps and this may be the easiest method to implement processes which operate on very fine timescales such as larvae.

Environmental data should be stored by spatial area and timestep, for those data available on a finer scale such as temperature, the question is how fine should the scale be? Within the DW finer scale data could be aggregated afterwards with a user specified interpolation method. In general, however, data in the DW should be aggregated and if people want to look at their case studies in more detail they have the data anyway.

For larval growth very fine scale temperature data are required as the important time of year for them coincides with a period of rapid temperature change. Interpolating temperature within the model rather than including temperature on timesteps of less than one month is an option and interpolation within GADGET would free ASCII files from timestep dependence.

Should timesteps be fixed or variable? And how should timestep length be defined?

At present, GADGET can run with variable timesteps and in subtimesteps (by applying an integration technique). GADGET currently operates on monthly time-steps (with a sub-timestep facility). We discussed at length what should be the basic time unit for holding environmental data. Year and month are essential. For timesteps of less than one month it was decided to devise a coding system so that data of different resolutions can be held in the same file.

Topographic data

In addition to data sets mentioned at the Madrid meeting, it was decided that there is a need for various topographic data.

These data would be stored within a separate ASCII file and would be constant over time. The table would describe:

Region, division, subdivision, grid node, mean depth, median depth, dominant substrate type, optional (tidal parameters, eg amplitude).

Various environmental data

Movement of passive life stages will be defined by matrices describing water mass transfer, representing the fraction of mass transfered between compartments within timesteps by water movement. These matrices will describe changes in depth along with changes in spatial location.

The matrices of exchange coefficients will be derived from a particle tracking model (separate from GADGET) (cf Mike and herring larvae). Use of these data should be optional by species and age and there should be a species link to these tables. The exchange coefficients will be based on water movement as described by a Hamburg Uni. hydrodynamic model. This is available for the North Sea and should also cover the Celtic Sea (it extends to 48 degrees.)

Temperature will be available by mean, variance, max, min. These could be derived either from observed values or by using a model to generate a gradient. Use of a model could be a user option.

A potential problem is how to store finite data of temperature gradients. For some processes temperature gradients are influential but it is questionable whether this should be part of the DW. It was decided that if fine scale information on temperature is required then the smallest area (grid node) should be appropriately defined and that the DW/GADGET should consider temperature by grid node alone.

Temperature and salinity will be stored by depth strata (linking with Table 3), with the surface and bottom measurements as separate strata.

Although water transport/exchange controls the transport of passive life stages (and discussions were based around this application in GADGET) it can also influence migration patterns of older life stages.

Biological sampling data

A table which lists the number of fish sampled for otoliths is needed. The details are needed to set the 'uncertainty' in the data. There will be some problems for data where collection protocols involve stratified collections of otoliths.

We had a complicated discussion of these tables which was inconclusive. We need to focus on those data and tables that are actually needed for the modelling, and those which contain useful information which will not actually be accessed directly by the model.

General software and DW design issues

It was noted that public domain software is usually preferable and in addition to various Unix-derivatives at MRI, IMR and FLA, IFREMER and CEFAS will have Linux.

There are several open source database programs available, including PostgreSQL. IFREMER will investigate these for comparisons, but at the moment, PostgreSQL seems like the most appropriate for the DW.

It was also noted that by using PostgreSQL, features concerning aggregations which are available in commercial packages will be lost. This will lead to a greater programming cost.

The group discussed aggregation methods and levels in time and space.

The architecture has been agreed upon. No central database but 3 local databases. All DB's accessible by all partners. No facilities to replicate data - if required a local copy would have to be made. The server platform will be Linux (most likely with PostgreSQL only) but with client software developed and tested on Linux and Windows2000. If other operating systems are required users will have to do it themselves. MRI will probably import it into Solaris too.

Report from DW discussion group (see Appendix L.5). - A document was presented by Leif. There followed some discussion about volumes of data and hardware platforms.

The working environment

CEFAS have machines specifically for Internet access which are not connected to the local network so they are able to provide a site for accessible data and can access data. Aberdeen have no Internet access except through Aberdeen University.

ASCII tables

The meeting pulled together most of the data requirements into a description of ASCII tables to hold these data.

Definition of fleet should be based on 2 columns:
Gear and subgear. So that eg shape and mesh are combined in one column.

Column for sampling type (harbour, sea) and the sampling institute. Tables should also be available to describe the gear specifications.

The IT group (DIFRES) will decide how to index the data. Indices described in the ASCII files are only indicative of the information needed but the implementation is a later decision.

An elaborate description of the tables is given in Appendix L.6.

User interfaces

A GUI interface would make database access more user friendly (e.g. knowledge of the database structure would not be required.) This is not necessary for GADGET but would be advantageous in the modelling work and useful in general. XML or JAVA would enable this and would be a extra layer rather than affect the way the DW is structured.

If CORBA is going to be used work should start now. The link into the DW should be either CORBA or command line.

Timing

Agreed deadlines for DW components are based on the requirement of having an example dataset by the end of August, and for a prototype DW by end of December 2000.

Deadlines are:

- August 31st for ASCII examples.

- Complete input specification: 4th September
- 1st October: Specification of all Gadget input tables.
- November: Prototype data set for Celtic Sea
- Prototype DW by December 31st
- Environmental data to be provided by Aberdeen by November.

Aggregation techniques

For the DW to be developed the functional relationships must be defined.

eg temperature = fn(space,time,depth) where space, time and depth are *dimensions*, and temperature is a *measure*.

DIFRES also require the hierarchical division of space to be defined as they must know the structure and the number of levels in the hierarchy in order to create the necessary amount of space in the DW. As it is a hierarchy, the borders of the subdimensions MUST coincide with the borders of the dimensions - as for time with year, quarter, month.

Aggregation will occur up the tree hierarchy and the method of aggregation must be explicit eg whether min, max, mean, sum, count, std etc but the method of aggregation (by level or method) could be interactive.

With such a structure, it would be possible to store data only at the finest level at which it is available although this would involve more work with public domain rather than commercial software.

Predefined tables of aggregation levels and methods should be included in the DW.

Alessandro - can we use GIS to do all this? Marc - no, because there are too many dimensions for GIS.

The hierarchical spatial structure causes BIG PROBLEMS for the UK partners as the otolith geostrata for eg herring and groundfish are different in the North Sea. The DW sub-group must deal with this as a matter of urgency. The problem is that IF statements are complex to deal with in SQL.

General software issues w.r.t. Gadget

Exchange and storage of software

Exchange of software was discussed and some standards were agreed upon in principle, although a few issues still need to be resolved. A standardisation procedure for exchange of versions and updates is needed. This is a problem within the institutes as well as between institutes. Maintenance, documentation and sufficient testing are essential. In particular a proposal for a coding standard is given in Appendix L.7.

There are two problems - one within institutes regarding version control and documentation, the other concerning code exchange between institutes.

A patch mechanism commonly used for distributing software on the Internet was described, but this may not deal with the type of development process we are dealing with in this project.

It was proposed that we instigate a set of rules and protocols for developing new versions of aspects of the model, and a coordinator for accepting and issuing periodic version releases.

Documentation

Documentation and user manuals need to be updated rigorously and regularly with each release version.

If we want our model(s) to be accepted in the wider community then we will eventually have to provide some helpdesk facility.

The software products of the project should include not only the model code, but also any post-processing and visualisation tools, whichever systems they are written in. Scripts currently available to plot and analyse the data include Unix/Splus scripts at MRI and Unix/SAS scripts at IMR.

Scripts

Scripts should be developed to generate the GADGET input files from the DW as currently they tedious and time consuming to compile.

Recommendations for improvement to current code

To aid ease of reading, many of the parameter switches could be recast as alphanumerics rather than simply numerics.

Do we need some overall conventions for variable names, indentations etc.? The current main programmers will meet and write down a convention for general usage.

Quality control

For quality control of versions the model should be run on a collection of standard datasets and on different platforms as a set of test criteria prior to acceptance in a new version release. It was also suggested that testing be done by someone other than the programmer of the changes and the tester should sign the new version.

In addition to the established haddock data set, further test datasets upon which all changes should be tested need to be established.

Updates

Frequent updates are required, with a new version number for every change. In ERSEM all versions were distributed by the coordinator and the coordinator administered all updates. The most recent update could be stored on an ftp site.

It was noted that different institutes are and will be working on different areas and make changes independently and simultaneously - MRI, IMR, DFS, SCUI and possibly IFREMER will want to make changes to the source code. Simultaneous changes may not be compatible and although older versions will still work it would be time consuming to check.

In addition to updating the central program repository, changes to code should be announced to programmers and users through e-mail.

Concurrent version system (CVS), which is public domain, enables automating and steering of the code. A copy of the institute standard version may need to be outwith the firewall. IMR are using CVS locally and will investigate use across institutes. One solution to the firewall problem is to use email with a subject line command and the program as body of message.

Documentation is within the code, but the users manual should be rewritten.

Training

People should be able to get help and training to use GADGET.

Subgroups and tasks for the very near future

Technical DW group: Leif in charge.

DW user subgroup: Alessandro in charge.

Their tasks include defining descriptions of views and how to implement aggregations (including user defined aggregation levels) within the DW.

Planned meetings:

- Plenary meeting, June 2001 in Bergen or Reykjavik.
- Leif to go to Iceland

- Helgi (will be in Denmark in July)
- Alessandro to come to Iceland in August
- Kristin, Morten and Bjarte (more?) to come to Iceland in November
- Carl and Verena to meet in November (where?)

L.2 List of participants

Morten Nygård Åsnes
Höskuldur Björnsson
Bjarte Bogstad
Marc Cromme
Steve Warnes
Kristin Frøysa
Alessandro Gimona
Mike Heath
Simon Hubbard
Geir Huse
Sigfús Jóhannesson
Geir Odd Johansen
Kristjana Ýr Jónsdóttir
Clive Kelman
Kjartan Kjartansson
Kjartan G Magnússon
Carl M. OBrien
Dominique Pelletier
Dankert Skagen
Aril Slotte
Gunnar Stefánsson
Lorna Taylor
Leif Thomsen
Verena Trenkel
Øyvind Ulltang

L.3 Workpackage 4.1 detailed definition.

DST2: Workpackage 4.1 Feeding/Consumption

The objective of this workpackage is to develop a multi-species spatially explicit feeding/consumption model based on habitat and diet selection with an evolutionary fitness basis. The model predictions will be compared with observations of cod, capelin and herring distributions and estimated consumption based on data from the Institute of Marine Research (Norway).

The workpackage shall produce the following deliverables:

4.1.1 Age and size dependent growth of and predation mortality of cod herring and capelin in the Barents Sea.

4.1.2 Spatial distribution of cod, herring and capelin in the Barents Sea.

4.1.3 Estimates of cod's consumption of herring and capelin related to prey density, stock overlap and physical factors.

It is intended that these deliverables shall be produced through the combined use of model predictions and observations, and the output format of the deliverables will be made suitable for Gadget.

Spatial modelling

The modelling concept will be individual-based where each individual can be specified in terms of a range of state variables such as age, size, and spatial position. In addition to these features we will equip individuals with different strategies, features that are a result of adaptations over evolutionary time such as movement behaviour, energy allocation, and size at reproduction. This allows the important link between fish ecology and fisheries assessment to be provided. The model concept works by specifying environmental features important to the growth, survival and hence Darwinian fitness of the fish (Huse and Giske 1998; Giske et al. 1998). By adapting the strategies over many generations using a genetic algorithm in this environment, one tend to end up with a well-adapted population. The spatial distribution of the modelled population may thus be compared with the observed distribution. Similarly other characteristics of the fish, such as stomach content can be extracted at any time and compared with observations taken from the IMR database in the current study. The consumption by cod can be used to estimate the predation mortality of capelin and herring. This could be done using the modelled consumption data, which simulates continuous removal of the prey. Such data can thus be aggregated to the desired level since the model will operate on daily time steps. Predation mortality of herring and capelin can also be estimated by scaling the observed data to the entire overlap area between the species as gathered from the modelled distributions. The procedure for moving fish about in the simulated environment is adapted random walk (ARW, Figure 1, Huse submitted). This is a concept based on adapting the threshold probabilities for movement in each dimension using a genetic algorithm. In addition to being adapted, the threshold values may be estimated from data or simply provided as "common sense" directions provided by the modeller. This makes the concept very easy to port to other systems and allows a common way to implement migration between areas. Alternatively one may use neural networks to perform the individual movement, but this technique is less portable and less intuitive in its functioning.

Figure 1. The adapted random walk concept. Movement in the two dimensions X and Y is determined by drawing random numbers and comparing them with the threshold values Tl and Tu. If the values are below the Tl then the position value is reduced by one. Similarly if the random value is above Tu then the position value is increased. If the random value is between Tu and Tl then current position is maintained.

Stomach data

The stomach data from the Barents Sea are sampled on regular basis (various seasons each year) since 1984, covering the distribution range in the Barents Sea of the three species in question (Mehl 1989; Mehl & Yaragina 1992). The data are from individual fish, and represent extensive time series of field observations on interactions between cod and its prey in this area. They are available from the stomach content database of partner 2 (IMR). Methods for calculating consumption rate based on observed food intake for individual fish combined with information on individual fish size and ambient temperature will be developed. Weight decrease during digestion, as a function of prey type, prey size, predator size and temperature will be used to estimate the time since each individual prey were ingested. In these calculations only prey individuals with recorded length will be included. In this way problems with redistribution of highly digested prey will be omitted. Observations and results from studies on stomach evacuation in cod will be used. The results of these calculations will be in the form of predation rates in number of prey items per time unit. This measure can be integrated according to several levels of aggregation in time and space. Actual consumption in biomass can be calculated by two alternative methods. One is based on a combination of the estimated predation rates with observed growth and models of bioenergetics. Another method is to combine the predation rates with estimates of total consumption of cod. Comparing model predictions with the independent information in the stomach database will be done to test the IBM model. The generality of the model can be tested by comparing output of consumption by cod from the model within the periods and areas covered by the stomach database. In this way the performance of the model can be tested under different environmental and ecological settings.

Input data requirements

The migration model will be forced both by biological and physical input data. The most important physical data will be temperature and current fields from ocean circulation models (Ådlandsvik and Engedahl 1991). Such data will be needed for the entire 16 year period of the stomach database. Access to CTD-data from the databases at IMR is crucial to estimate digestion of prey on the level of individual fish. The ability to test the model output of spatial distribution of the species in concern, depends on access to detailed data from all surveys in the Barents Sea. This includes both data on size- and species distribution from trawl hauls, as well as acoustic data. Acoustic data are stored at IMR, but are in most cases judged only with respect to the main target species of the survey from which they originate. It would be of great value to this workpackage to get access to judged acoustic data on the three species outside the periods of their main surveys.

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Figure 1: The adapted random walk concept. Movement in the two dimensions X and Y is determined by drawing random numbers and comparing them with the threshold values Tl and Tu. If the values are below the Tl then the position value is reduced by one. Similarly if the random value is above Tu then the position value is increased. If the random value is between Tu and Tl then current position is maintained. (Gantt chart)

L.4 Status of DW development for North Sea herring (WP 1 and 5)

Data sets relevant to the Gadget Project.

The building of the Herring database is ongoing.

Several Herring data sets have been acquired and many of these are ready to be transferred into a relational database. The process of retrieving raw data sets, from which square based ones where derived, is underway. These data will also be stored in a relational database.

IBTS length frequency and age by station, Acoustic survey numbers and biomass and market data are ready for transfer.

Negotiations are in progress with partners for the acquisition of further data.

Table 1 shows the status, resolution and format of the relevant data sets.

Table 1:

Data Set	**Years**	**Spatial Resolution**	**Acquisition Status**	**Present Format**
IBTS Herring length frequency by station	1983–1996	ICES Square (1), Station (2)	(1) Acquired (2) Underway	Excel file
IBTS Herring age by station based on area keys	1983–1996	Station and ICES Square	Acquired	Excel file
Acoustic survey Biomass/Numbers estimates from echosounders	1984–1999	ICES square (1) Raw data (2)	(1)Acquired (2) Underway	Excel file
Acoustic survey Biomass/Numbers estimates from echosounders Trawl stations for biological data, Scotland, Norway, Denmark, Netherlands	As available	ICES square &/or raw data	Negotiation in progress	
Maturity Ogive	1984–1999		Underway	
Tagging data	1956–1988	point	Acquired (some further processing underway)	ASCII file
Market data for Scotland and Partners	1985–1996	ICES square	Scottish data acquired, negotiation underway with partners	Excel file
Predation: Cod and Whiting stomach content			Underway	
Temperature, Salinity	1991–1997	point	Acquired	Excel file

L.5 Minutes from subgroup meetings on DW

DST2 Data warehouse.
Nantes meeting. June 27-29 2000.
Data warehouse (WP1). Summary on database discussions.

1. Specifications of the databases

   User database specification group:
   * Alessandro Gimona, FRS, Aberdeen, Scottish herring. Head of group.
   * Kristin Guldbrandsen Frøysa, IMR, Bergen, Responsible for Gadget input specification.
   * Hoskuldur, MRI, Reykjavik, Icelandic waters and modelling input to Gadget
   * Verona Trenkel, IFREMER, Nantes, Celtic waters
   * Carl O'Brien, CEFAS, Lowestoft, Celtic Waters

   Schedule to be defined by Alessandro and Leif and Marc.

   IT database design group:
   * Leif Thomsen, DIFRES, Head of group.
   * Helgi Thorbergsson, SCUI.
   * Clive Kelman, MRI.
   * Sigfus Johannesson, MRI

   Schedule to be defined by group later.

2. Requirements to the DW.

   (a) Three different uses have been identified:

      i. ASCII file output for the Gadget model. The specification will include predefined aggregation strategies to be implemented. (Implemented in prototype one)

      ii. Interactive SQL query building. (Implemented in prototype one)

      iii. Browsing and exploring data interactively. Graphic or text based user interface This will be based on a couple of predefined views where the scope and aggregation level of the returned data can be defined interactively. (Will not be implemented in prototype one)

   (b) User interface: The first prototype will not include a web interface and XML will not be used in any way. Users wished web interface in later prototypes. Whether CORBA are to be used or not will be decided later by the DW development group. At this point modellers were not ready to implement direct database access by means of CORBA modules or embedded SQL statements.

   (c) The use and definition of metadata was not discussed.

(d) Security. Three different security levels: Server maintenance, data input and data output. The security levels will be defined by the local DB manager.

(e) Maintenance of data and software. Each study case group defines its own data maintenance scheme. The maintenance of the software is performed by the DW development group until the end of this project. What will happen afterwards was not discussed.

(f) The size of each study case database will be below 1Gbyte.

(g) The databases for the three study cases will not be queried against each other.

3. Problems with Aggregation levels and time and space have not been discussed yet.

   (a) One level: ICES square by month.

   (b) Hierarchies of areas and periods.

4. Agreement on Architecture.

   (a) Nobody wants to maintain a Central database. The same fixed database structure will be used for the three study case datasets. The study datasets will not be merge into the same physical DB, they will be held on separate computers maintained by appropriate institute. It will be nice to have remote access to all three DB servers, but it is not required.

5. Agreement on Platforms/Tools.

   (a) Server implemented and tested on one platform only: LINUX (Redhat 6.2), DBMS: chose between PostgreSQL and MySQL and mSQL.

   (b) Client implemented and tested on two platforms only: LINUX (Redhat 6.2) and Windows 2000.

   (c) If possible: use open source tools, but portability to other UNIX platforms has main interest.

   (d) Development tools will be decided later by DW development team. e. Hardware platform: Intel pc or compatible.

6. Agreement on working plan for 1st phase of DW development. (Not confirmed yet)

   (a) Goal of 1st phase: DB, CORBA interface, Client functionality: load and extract data, Gadget input files and SQL queries.

   (b) Schedule.

7. Discuss Goal of 2nd phase. (Not discussed yet)

8. What to do next. Web interface?

L.6 Proposed ASCII table definitions

DST2 Data warehouse.
Nantes meeting. June 27-29 2000.
Basic definitions of ASCII tables.

The first three tables contain descriptions of bathymetric, environmental and related information.

The spatial scales will inevitably vary depending on the object of interest. Thus, there is interest in considering the total catches within an entire area such as the area corresponding to a case study (e.g. North Sea; around Iceland; Celtic+Irish Sea), and around smaller areas such as the Bormicon areas around Iceland.

The spatial scale normally used as a fine scale will also depend on the region of interest as well as the aggregation. This scale is defined by the statistical rectangles in the North Sea and Celtic+Irish Seas but by depth-stratified subareas of Bormicon areas around Iceland. These spatial areas are referred to as subdivisions throughout.

However, different applications require spatial scales which will sometimes be inconsistent with these subdivisions and hence the spatial scale will be extended down to a grid sufficiently fine to encompass such further needs.

In general, therefore, it is assumed that there may be 4 levels of spatial aggregation of data sources, these being termed "Region", "Division" and "Subdivision" and "Subsubdivision" where the last is also referred to as a "gridcell" (it should be noted that there is no relationship with possibly similar names from other contexts). Where geo-stratified collections of age-length data are performed, "Divisions" must correspond to these geo-strata.

Several important pieces of information are static as far as the time horizon in dst2 is concerned. In particular, mean depth per area can be taken as fixed, as can descriptions of the dominant substrate in each area.

1. Fixed descriptions of topography etc

Table 1: Fixed descriptions of topography etc

Region	(Icel/N.S./Celtic+Irish Sea)
Division	(Bormicon area - or otolith geo-stratum)
Subdivision	(stat sq/Borm subarea)
Subsubdivision	(depth stratum w/in stat sq or stat subsq)=gridcell
Area of subsubdivision	
Dominant substrate	
Mean bottom depth	

Environmental parameters may be obtained from actual measurements or from output from separate models of environmental processes. Such models can produce output on arbitrarily fine spatial and temporal scales. Although for most purposes it is enough to have the spatial resolution at the defined subdivisional scales, it is clear that for larval processes there is a need to have a very short temporal scale at a level such as a week (or, more specifically, 1/4 of a month).

The current draft model includes the (untested) possibility of including finer scales for processes such as growth. However, if larval growth is to be adequately implemented, the appropriate temperature will need to be provided to that model process. Hence it will be assumed that some environmental data may be provided on a weekly time scale.

There are several approaches to coding the variable time scales. In the table several columns are used.

2. Variable environmental parameters

Table 2: Variable environmental parameters

Sampling institute	
Year	
Quarter	
Month	(Include possibility to interpolate, e.g. weekly timesteps for larval growth on substeps)
Week (1/4 month)	(may be missing or +=average)
Region	(Icel/N.S./Celtic+Irish Sea)
Division	
Subdivision	(stat sq/Borm subarea)
Subsubdivision	
Depth stratum	
Temperature	
Salinity	
Zooplankton	

It should be noted that one could also code Y+Q+M+W in 2 columns (time step+fraction of year). Either method of coding allows the possibility for including the same data at different levels of aggregation within the same table. In general this is needed since the aggregation procedure may be quite nonlinear and not just a simple sum.

It must be possible to extract a bottom temperature out of this table. Possibly this should be done by using a special depth stratum code for the bottom.

In any case there is a need to be able to specifically look for an aggregate measure. In earlier data bases this might have been coded using a special symbol. For example, if possible subdivisions include the codes 1-4, then '+' could be used to mean an aggregate across all the subdivisions. In each case a clear definition of the operator would need to be provided.

Larval drift and migrations of adult fish may depend on the movements of water masses, some of which may be described using specific hydrographic models. Therefore, the DW will need to contain such information as the "exchange coefficient" between different areas in a given time periods.

3. Water mass movements

Table 3: Water mass movements

Year		Mandatory
Quarter		Mandatory
Month		
Week(1/4 month)		
Region		Mandatory
Division	From	Mandatory
Subdivision		
Subsubdivision		
Depth stratum		
Division	To	Mandatory
Subdivision		
Depth stratum		
Exchange coefficient		Mandatory

The typical indexing of the following tables is:

Year	Mandatory
Quarter	Mandatory
Month	
Region	Mandatory
Division	Mandatory
Subdivision	
Subsubdivision	
Gear class	
Gear subclass	
Vessel class	
Vessel subclass	

where the combination of "gear class" (e.g. long line or gillnets), "gear subclass" (e.g. the mesh size, trawl type etc), "vessel class" (e.g. 100-200 GRT) and "vessel subclass" are used to define a "metier" or "fleet".

In practice these definitions may well be used to define an index for all the tables to follow. Such a combination can also be referred to as a "sampling cell".

4. Catch, landings and logbook data

Data on catches, landings, discards and effort are quite variable and the DW needs to accommodate different needs in this regard. Typically, raw landings data will be available at very coarse spatial scales but CPUE (or effort) data will be available at fine spatial scales. In addition, discard data may be available at even coarser scales. Together these data may be used to derive catch information on very fine scales.

Table 4: Catch, landings and logbook data

Sampling institute		
Year		Mandatory
Quarter		Mandatory
Month		
Region		Mandatory
Division		Mandatory
Subdivision	(possibly=+ for aggreg'n)	
Subsubdiv'n		
Gear class		Mandatory
Gear subclass		
Vessel class		
Vessel subclass		
Number of vessels		
Number of trips		
Mean HP (or KW)		
Mean GRT		
Species		
Stock		
Market size category		
Landings		Mandatory
Discards		
Effort		
CPUE		

In this table as in many others there is a need for a qualifier which describes how the data were derived.

5. Sampling information

Before getting to the actual biological sampling data, there is a need for a table which describes the level of sampling. This is needed in order to approximate the statistical properties of the data themselves.

In addition to information about the area of fishing, there is a further need to indicate the authority performing the sampling and this is reflected in the "sampling institute" column.

The term "sampling type" refers to "port", "sea" or "discard" for commercial samples and "survey" for survey data.

The term "market category" refers to whatever market classification is important in the corresponding area (not used for surveys???).

Table 4: A column has been included for stock id of each species. Is this needed - yes. Also need to include number of vessels in a class, number of trips, their mean size and/or power, and mean GRT.

Which fields are mandatory? - Location, time and landings

NB: the market sampling method is heavily dependent on sampling institute.

Table 5: Sampling information

Sampling institute	
Sampling type	(port, sea, survey or discards)
Market category	
Year	
Quarter	
Month	
Region	
Division	
Subdivision	
Subsubdivision	
Gear class	
Gear subclass	
Vessel class	
Vessel subclass	
Species	
Stock	
Sampling strategy	(stratified (by what) or random)
Number of length samples (or stations)	
Number of fish measured	
Number of age samples	
Number of aging structures sampled	
Weight of samples	

The above table describes the sampling strategy used for obtaining the data (e.g. is the data stratified by length group, etc), the number of length samples taken and the actual number of length measured fish in the given sampling cell. The reason for recording not only the number of fish but also the number of samples is the intra-haul correlation noted by Pennington and Volstad. In addition to this information for the length samples, the corresponding information for the age sampling is needed.

Length, age, sex and maturity form a natural split of all biological data into groups. Since migration is known to vary according to maturity stage, this is an important factor. Similarly, growth is sex-dependent for many species, consumption is length-dependent and age is an important index. For this reason, these are treated in the following as classification variables used as indexes in tables of e.g. abundance index values, mean weight and so on.

It will be assumed that information about sex and maturity stage is obtained during the age structure sampling. In many cases sex and maturity information will not be available, not of interest or at least not used during modelling. In such cases these categorical data will be set to a fixed level (NULL).

Table 5: Stock column is needed. Discussion of this table flagged up the need for sub-sub-divisions in the Celtic Sea. The consequences of this revelation are reflected in the general notes above.

6. Data in length cells

Table 6: Data in length cells

Sampling institute	
Sampling type	
Market category	
Year	
Quarter	
Month	
Region	
Division	
Subdivision	
Subsubdivision	
Gear class	
Gear subclass	
Vessel class	
Vessel subclass	
Species	
Stock	
Length cell	(possibly + or whatever, to indicate total abundance)
Number of fish in length cell	
Sex	
Maturity stage	
Mean weight of fish in cell	
Index	
CV of index	

Zooplankton will be moved from Table 2 to Table 6.

The term "length cell" refers to a length interval defined in a separate table.

In the above table, "Number of fish in length cell" is (for surveys) a simple count of the number of fish observed at this length, totalled across stations within the area, whereas the "index" column denotes the survey index in the area (possibly the latter is computed as a geometric mean or using Pennington's estimator). For data from commercial vessels, "number of fish in length cell" refers to (what?) This table should include data from all length measured fish, if possible, thus also including fish without an age reading (for whatever reason).

Probably store data in the DW as numbers in the smallest class intervals we have available, and aggregate them at output from the DW to ASCII files. The column length cell refers to a length interval defined in a separate table. The aggregation of these data to modelled length class intervals will take place on the output side of DW.

Table 6: This table contains length distribution data do we want to have variable length intervals for different species - probably we store data in the DW as numbers in the smallest class intervals we have available, and aggregate them at output from the DW to ASCII files. The column length cell refers to a length interval defined in a separate table. The aggregation

of these data to modelled length class intervals will take place on the output side of DW.

7. **Data in age and length cells**

   In cases when age is available in addition to length, the same sort of table is made available, with age as an additional index.

   These data are the biological data collected over otolith sub-strata. Categorical variables are age, length class, sex, maturity class. In each cell, we need mean weight, n and sd, and so on for other continuous variables.

   For Table 7 most of the same points apply as for Table 6.

   We will need to devise some algorithms to cope with lengths in table 6 for which there are no age measurements.

Table 7: Data in age and length cells

Sampling institute
Sampling type
Market category
Year
Quarter
Month
Region
Division
Subdivision
Subsubdivision
Accuracy of position?
Gear class
Gear subclass
Vessel class
Vessel subclass
Species
Stock
Length cell
Age
Sex
Maturity stage
Number of fish measured
Mean weight of fish in cell
SD of weight of fish in cell
Disease rate
Other fields (possibly just list what is available or sample size etc)

   The term “length cell” refers to a length interval defined in a separate table.

   The column “Accuracy of position” refers to whether the “subsubdivision” is accurate or not. When this column indicates an inaccurate position, the location indicator “subsubdivision” should not be used in disaggregated form but only for aggregating purposes. The inclusion (or not) of this column has not been finalised.

In addition to the above tables, there is a need to include information from various sources. These include the catches in numbers at age at the finest available level...

**** We might need to consider NOT having tables 6 and 7 as separate tables because it may produce problems for us. We could hold raised population numbers at age*length*... in table 7 and do away with Table 6 altogether. In that case, length which have no otolith are put into an unknown age category. In that case, Table 7 is a highly derived data set at the sub-division level, rather than an observation dataset at the division level

8. Misc reference information available by age group

Various different pieces of information are frequently required by age group. The most common of these are the "final run summary table" from ICES VPA runs.

Table 8: Misc reference information available by age group

Sampling institute	
Source year	
Sampling type	
Market category	
Year	
Quarter	(possibly +)
Month	(possibly +)
Region	
Division	(possibly +)
Subdivision	(possibly +)
Subsubdivision	
Gear class	
Gear subclass	(possibly +)
Vessel class	
Vessel subclass	(possibly +)
Species	
Stock	
Age	
Sex	(possibly +)
Maturity stage	(possibly +)
Number of measured fish	
Mean length of fish in cell	
Mean weight of fish in cell	
Survey index	
CV of survey index	
Catches in numbers at age	
Stock numbers at age	
Disease rate	
Need to describe very clearly how this table is derived	

Initially this table will not be linkable to other tables in the database.

Table 8: This table is partly for all sorts of other useful information - perhaps including data from stock level VPA runs. Do we need this table?

The table is intended to be reference information rather than data which is necessarily linked to data from other tables to generate Gadget input files, except for possible use of "definitive" catches in numbers at age, which can be used in Gadget and may not be easily computable from the raw date in cases when considerable "smoothing" has been used to obtain them.

In effect we can treat Table 8 as a separate database. For VPA data, the source year of the VPA run needs to be identified as well.

9. **Missing tables, not to be forgotten:**

   (a) Stomach contents - send out example(s) based on Madrid meeting

   (b) length distributions of prey - send out example(s) based on Madrid meeting

   (c) tagging data - send out example(s) based on Madrid meeting

   (d) acoustic data - send out example(s) based on Madrid meeting

   (e) larval survey data - send out example(s) based on Madrid meeting

   (f) egg surveys

   Take zooplankton abundance data out of Table 2 and Include in Table 6

L.7 Conclusions on coding issues

Exchange of software was discussed and some standards were agreed upon in principle, although a few details still need to be worked out.

The group agreed in principle to use CVS as a standard method for maintaining the "official" version of the software. This requires testing of a technique for the use of CVS through firewalls. Possible techniques include leaving the CVS computer outside firewalls or using specialised mail-filters to enter and extract modules into CVS.

Standard, documented test data sets are needed, as only one is available at present.

Need to nominate a code coordinator.

Revised user manual is needed. Include this in the CVS.

Coding standards. Formatting of code should be standardised. Subgroup to decide on standard (led by Kristin).

Quality of code: Code should be tested on several hardware platforms, run by different individuals and tested on standard data sets.

Code, external to Gadget, written in SAS, Splus or as shell scripts are available but need to become a part of the distribution.

Proposed code changes: character format to describe estimable parameters.

DST2 Data warehouse.
Nantes meeting. June 27-29 2000.
Proposed coding standards for GADGET

By Morten N. Åsnes and Kristin Guldbrandsen Frøysa.

1. **Naming conventions:**

   (a) Class names:

   - Class names should always begin with a capital letter.
   - Names consisting of multiple words should be written with each word capitalized.

   (b) Class members, other variables and functions:

   - These should always start with a lower case letter. Additional words in the name should be separated by capitalizing each word.

   Examples:

```
class TimeClass {
  // ...
}

Timeclass*  currenTime;

void doSomething( TimeClass time ) {
  // ...
}
```

2. **Indentation and brackets:**

   (a) Only spaces should be used for indentation, two spaces for each level of indentation. A block opening curly bracket should be at the end of the line that defines the block. The matching end bracket is placed on a line of its own, at the same level of indentation as the line that starts the block. If the if block is followed by an else clause, the next block should be started on the same line as the closing curly bracket of the previous block.

   (b) An opening round bracket following a keyword (in a while loop, for loop, etc.) should be separated from the keyword with a space. In function calls, the opening bracket for the function arguments should not be separated from the function name.

   Examples:

```
for (i=0; i<n; i++) {
  // ...
}
```

```
if (isDone()) {
  // ...
} else if (something()) {
  // ...
} else {
  // ...
}

doSomething(a, b, c);
```

3. Local variables in for loops:

Because of the limitations of some compilers, variables defined and initialized in the opening of a for loop, will not always have a local scope for that loop. Therefore these variables should be defined outside the loop.

Example:

```
int i = 0;
for (i=0; i<n; i++) {
  //...
}
```

4. Method documentation:

Any non-trivial method should have a short description in the code, in addition to the documentation in the programmers manual.

Example:

```
/* int calculateLikelihood
 * Purpose:
 *  Calculate and return the total likelihood
 *  component for the given time step.
 * Last changed: 28 June 2000, mortenn@imr.no
 */
int calculateLikelihood( TimeInfo* currentTime ) {
  // ...
  return totalLikelihood;
}
```

L.8 Gadget example

This is a simple example for GADGET, with one stock that lives in one area. The stock in question is haddock in Icelandic waters. As you will see later on, some possible important factors are skipped for simplicity, for instance the stock is not supposed to eat or become mature.

Data files

main

main is the main input file. This is the first file that is read in and it gives pointers to all data sources, printout required etc. Here is also a description of the likelihood components used; any likelihood component used must be listed here.

```
;
; main file for haddock
;
timefile        time                                ; Years 1978-2006
areafile        area                                ; Only one area
catch
stockfiles      had    had                          ; The description of the
                                                    ; stock is in this file
otherfoodfiles  ;
totalfleet      survey had.survey                   ; Survey
                commercialcatch  had.fleet          ; Commercial catch
linearfleet     predc    had.predc
;
; Description of printing.  Make sure the name of the file is commented out unless
; printouts are desired
;
printing       ;printfile
;
; Description of likelihood components
;
likelihood
;component name-file giving data struct - weight
meanl.sur       had.meanle.sur             2e-6
meanl.catch     had.meanle.catch         0.3e-6
ldist.sur       had.lengthdist.sur      0.05e-6
ldist.catch     had.lengthdist.catch       3e-6
alkeys.sur      had.alkeys.sur             7e-6
alkeys.catch    had.alkeys.catch           2e-6
Understocking   had.undersum               1e-30
si10            si10.dat                  70e-4
si15            si15.dat                 100e-4
si20            si20.dat                 100e-4
si25to45        si25to45.dat             100e-4
si50to60        si50to60.dat             100e-4
si65to75        si65to75.dat              70e-4
nvpa            had.Nvpa.fixed             0
bounds          had.bounds.lik             1
```

had

had is base file for haddock. This file provides descriptions of all basic parameters such as the areas, age and length ranges, functions etc. It also provides parameters for the growth function used. The growth function used here is:

$$\Delta w = \Delta t q_0 e^{q_1 T} \left(\left(\frac{W}{q_2} \right)^{q_4} - \left(\frac{W}{q_3} \right)^{q_5} \right) \tag{1}$$

where W is mean weight, T is temperature and q is vector of parameters. Now we let

$$r := \frac{W - (p_0 + p_8 (p_1 + p_2 p_8)) W_{ref}}{W}$$

where W_{ref} is the reference weight and

$$f(x) := \begin{cases} 0 & \text{if } p_3 + p_4 x \leq 0, \\ p_5 & \text{if } p_3 + p_4 x \geq p_5, \\ p_3 + p_4 x & \text{otherwise.} \end{cases}$$

Then we let

$$\Delta l = \frac{\Delta w}{p_6 p_7 l^{p_7 - 1}} f(r) \tag{2}$$

where p is vector of parameters.

```
livesonareas     1    ; There is only one area in this run
minage           1    ; The stock is assumed to have ages from 1 to 10
maxage           10
minlength        4.5  ; Length range for 1-10 year old haddock
maxlength        90.5
dl               1    ; Size of a lengthstep is dl*2
; Minimum and maximum allowed length for each age group
; age           1      2      3      4      5      6      7      8      9      10
lowerabslength 5.5    8.5    13.5   17.5   21.5   25.5   29.5   33.5   37.5   37.5
upperabslength 30.5   40.5   50.5   60.5   70.5   80.5   85.5   90.5   90.5   90.5
;
; Growth and consumption are possible calculated on a coarser scale
; than the population itself.  Therefore the lengthgroups for that
; have different endpoints than usual.
growthandeatlengths     4.5   6.5   8.5  10.5  12.5  14.5  16.5  18.5  20.5  22.5  24.5  26.5
                       28.5  30.5  32.5  34.5  36.5  38.5  40.5  42.5  44.5  46.5  48.5  50.5
                       52.5  54.5  56.5  58.5  60.5  62.5  64.5  66.5  68.5  70.5  72.5  74.5
                       76.5  78.5  80.5  82.5  84.5  86.5  88.5  90.5
;
; The individuals of the stock exhibit growth, so the following defines the growth function
;
doesgrow 1
growthfunctionnumber 3 ; Growth function, see above.
;
; Parameters for growth function (1)
;
                   ; q0      q1      q2      q3      q4      q5
Wgrowthparameters    5#900   0       7#901   7#901   0.666   1
;
; Parameters for growth function (2)
;
                  ; p0     p1     p2     p3     p4     p5     p6            p7      p8
Lgrowthparameters   1      0      0      1      2.2    1.4    0.00885e-3   3.0257  0.5
refweightfile Refweights.had        ; Keeps Wref
        power   3                   ; The power in the length-weigth relationship
        maxlengthgroupgrowth 5      ; Binomial-style n for beta-binomial
        beta    1#567               ; Beta-parameter in beta-binomial distribution
;
;  Natural mortality is a vector with one number per age group - this is residual M (i.e. M1)
;
```

```
; age                   1   2    3   4   5   6   7   8   9   10
naturalmortality        0.5 0.35 0.2 0.2 0.2 0.2 0.2 0.3 0.4 0.7
iscaught        0       ; The fleet is considered as predator, so it eats instead of catches
iseaten         1
;
; The endpoints of the lengthgroups used when acting as a prey
        preylengths 4.5   6.5   8.5  10.5  12.5  14.5  16.5  18.5  20.5  22.5  24.5  26.5
                   28.5  30.5  32.5  34.5  36.5  38.5  40.5  42.5  44.5  46.5  48.5  50.5
                   52.5  54.5  56.5  58.5  60.5  62.5  64.5  66.5  68.5  70.5  72.5  74.5
                   76.5  78.5  80.5  82.5  84.5  86.5  88.5  90.5 100.5 110.5
doeseat         0       ; No eating is included
; Initial conditions are specified for each area, so only once here
initialconditions
   numbers
           minage    1       ; The fish comes into the model at age 1
           maxage    10      ; Assume they only get 10 years old
           minlength 5.5
           maxlength 85.5
           dl        1       ; Size of lengthsteps, the size is dl*2
           ; age       1 2               3               4               5
           agemultiple 0 10000*0.0043#2 6065.3*0.0043#3 3678.8*0.0043#4 2231.3*0.0043#5
           ;           6               7               8               9            10
                       1353.4*0.0043#6 820.8*0.0043#7 497.9*0.0043#8 302*0.0043#9 10*0.0043#9
;
; Multiply the agemultiple with the distribution for each age to get the initial
; number of haddock for each age.
;
; age        1   2   3   4   5   6   7   8   9   10
distribution 100 100 100 100 100 100 100 100 100 100
;
; Meanlengths for each age group and area (only one area)
meanlengths  ; age
16.41203     ; 1
27.15520     ; 2
36.98713     ; 3
43.77545     ; 4
49.43773     ; 5
53.76334     ; 6
58.64396     ; 7
66.10526     ; 8
60.88235     ; 9
63.00000     ; 10
;
; Standard deviation for each age group
sdev    1    ; The standard deviation multiplier
2.247188     ; age 1
2.898219     ; 2
4.070510     ; 3
4.927558     ; 4
5.540416     ; 5
5.807182     ; 6
6.023261     ; 7
8.00         ; 8
9.00         ; 9
9.00         ; 10
;
; There should be one number file and one weight file for each area.
; But as the mean lengths and standard deviation are specified, the number file
; is not used.  It has to be specified though, and therefore the weight file is
; specified twice.
      files     had.init.w      had.init.w
doesmigrate     0       ; Only one area in this example, so there is no migration
doesmature      0       ; Maturation is not included here
doesmove        0       ; There is only one stock, so no movements between stocks
doesrenew       1       ; Recruitment is included in this example
      renewaldatafile had.rec  ; Get recruitment information from had.rec
doesspawn       0       ; As they don't mature, they don't spawn
```

Refweigths.had

Refweights.had lists mean weight of haddock by length. This is a reference file for the growth functions, see file had.

```
;length weight
;(cm)   (kg)
5       0.001307
6       0.002154
7       0.003285
8       0.004735
9       0.006538
10      0.008725
11      0.011328
12      0.013848
13      0.017795
14      0.021701
15      0.025792
16      0.030797
17      0.036149
18      0.045531
19      0.052379
20      0.064773
21      0.080277
22      0.092542
23      0.104681
24      0.116645
25      0.13377
26      0.150614
27      0.169381
28      0.191297
29      0.214112
30      0.239923
31      0.264129
32      0.294917
33      0.327372
34      0.359647
35      0.3959
36      0.428294
37      0.471261
38      0.509609
39      0.548045
40      0.598536
41      0.637858
42      0.690509
43      0.748789
44      0.803405
45      0.853545
46      0.911109
47      0.973097
48      1.026803
49      1.097577
50      1.157402
51      1.246044
52      1.299803
53      1.402872
54      1.470497
55      1.551242
56      1.623735
57      1.753425
58      1.797007
59      1.901131
60      2.0008
61      2.104438
62      2.188638
63      2.287837
64      2.374912
65      2.471904
66      2.634188
```

```
67      2.760182
68      2.787833
69      2.980571
70      3.105583
71      3.30275
72      3.421267
73      3.512941
74      3.742462
75      3.833603
76      3.97811
77      4.126067
78      4.277512
79      4.43248
80      4.591006
81      4.753127
82      4.918877
83      5.088293
84      5.261409
85      5.438262
86      5.618887
87      5.803317
88      5.99159
89      6.183739
90      6.3798
```

had.init.w

had.init.w is a matrix $A_{10\times 80} = [a_{i,j}]$ where $a_{i,j}$ is the weight (in kilos) of a i years old, $j + 5$ centimeters long haddock. This file is used to get initial weight of the stock.

```
; The numbers are weight in kilos
;
;                                                                                      length
; age 1  2        3        4        5        6        7        8        9        10        (cm)
0.002154 0.002154 0.002154 0.002154 0.002154 0.002154 0.002154 0.002154 0.002154 0.002154  ;6
0.003285 0.003285 0.003285 0.003285 0.003285 0.003285 0.003285 0.003285 0.003285 0.003285  ;7
0.004735 0.004735 0.004735 0.004735 0.004735 0.004735 0.004735 0.004735 0.004735 0.004735  ;8
0.006538 0.006538 0.006538 0.006538 0.006538 0.006538 0.006538 0.006538 0.006538 0.006538  ;9
0.008725 0.008725 0.008725 0.008725 0.008725 0.008725 0.008725 0.008725 0.008725 0.008725  ;10
0.011328 0.011328 0.011328 0.011328 0.011328 0.011328 0.011328 0.011328 0.011328 0.011328  ;11
0.013848 0.013848 0.013848 0.013848 0.013848 0.013848 0.013848 0.013848 0.013848 0.013848  ;12
0.017795 0.017795 0.017795 0.017795 0.017795 0.017795 0.017795 0.017795 0.017795 0.017795  ;13
0.021701 0.021701 0.021701 0.021701 0.021701 0.021701 0.021701 0.021701 0.021701 0.021701  ;14
0.025792 0.025792 0.025792 0.025792 0.025792 0.025792 0.025792 0.025792 0.025792 0.025792  ;15
0.030797 0.030797 0.030797 0.030797 0.030797 0.030797 0.030797 0.030797 0.030797 0.030797  ;16
0.036149 0.036149 0.036149 0.036149 0.036149 0.036149 0.036149 0.036149 0.036149 0.036149  ;17
0.045531 0.045531 0.045531 0.045531 0.045531 0.045531 0.045531 0.045531 0.045531 0.045531  ;18
0.052379 0.052379 0.052379 0.052379 0.052379 0.052379 0.052379 0.052379 0.052379 0.052379  ;19
0.064773 0.064773 0.064773 0.064773 0.064773 0.064773 0.064773 0.064773 0.064773 0.064773  ;20
0.080277 0.080277 0.080277 0.080277 0.080277 0.080277 0.080277 0.080277 0.080277 0.080277  ;21
0.092542 0.092542 0.092542 0.092542 0.092542 0.092542 0.092542 0.092542 0.092542 0.092542  ;22
0.104681 0.104681 0.104681 0.104681 0.104681 0.104681 0.104681 0.104681 0.104681 0.104681  ;23
0.116645 0.116645 0.116645 0.116645 0.116645 0.116645 0.116645 0.116645 0.116645 0.116645  ;24
0.13377  0.13377  0.13377  0.13377  0.13377  0.13377  0.13377  0.13377  0.13377  0.13377   ;25
0.150614 0.150614 0.150614 0.150614 0.150614 0.150614 0.150614 0.150614 0.150614 0.150614  ;26
0.169381 0.169381 0.169381 0.169381 0.169381 0.169381 0.169381 0.169381 0.169381 0.169381  ;27
0.191297 0.191297 0.191297 0.191297 0.191297 0.191297 0.191297 0.191297 0.191297 0.191297  ;28
0.214112 0.214112 0.214112 0.214112 0.214112 0.214112 0.214112 0.214112 0.214112 0.214112  ;29
0.239923 0.239923 0.239923 0.239923 0.239923 0.239923 0.239923 0.239923 0.239923 0.239923  ;30
0.264129 0.264129 0.264129 0.264129 0.264129 0.264129 0.264129 0.264129 0.264129 0.264129  ;31
0.294917 0.294917 0.294917 0.294917 0.294917 0.294917 0.294917 0.294917 0.294917 0.294917  ;32
0.327372 0.327372 0.327372 0.327372 0.327372 0.327372 0.327372 0.327372 0.327372 0.327372  ;33
0.359647 0.359647 0.359647 0.359647 0.359647 0.359647 0.359647 0.359647 0.359647 0.359647  ;34
0.3959   0.3959   0.3959   0.3959   0.3959   0.3959   0.3959   0.3959   0.3959   0.3959    ;35
0.428294 0.428294 0.428294 0.428294 0.428294 0.428294 0.428294 0.428294 0.428294 0.428294  ;36
0.471261 0.471261 0.471261 0.471261 0.471261 0.471261 0.471261 0.471261 0.471261 0.471261  ;37
```

```
0.509609 0.509609 0.509609 0.509609 0.509609 0.509609 0.509609 0.509609 0.509609 0.509609  ;38
0.548045 0.548045 0.548045 0.548045 0.548045 0.548045 0.548045 0.548045 0.548045 0.548045  ;39
0.598536 0.598536 0.598536 0.598536 0.598536 0.598536 0.598536 0.598536 0.598536 0.598536  ;40
0.637858 0.637858 0.637858 0.637858 0.637858 0.637858 0.637858 0.637858 0.637858 0.637858  ;41
0.690509 0.690509 0.690509 0.690509 0.690509 0.690509 0.690509 0.690509 0.690509 0.690509  ;42
0.748789 0.748789 0.748789 0.748789 0.748789 0.748789 0.748789 0.748789 0.748789 0.748789  ;43
0.803405 0.803405 0.803405 0.803405 0.803405 0.803405 0.803405 0.803405 0.803405 0.803405  ;44
0.853545 0.853545 0.853545 0.853545 0.853545 0.853545 0.853545 0.853545 0.853545 0.853545  ;45
0.911109 0.911109 0.911109 0.911109 0.911109 0.911109 0.911109 0.911109 0.911109 0.911109  ;46
0.973097 0.973097 0.973097 0.973097 0.973097 0.973097 0.973097 0.973097 0.973097 0.973097  ;47
1.026803 1.026803 1.026803 1.026803 1.026803 1.026803 1.026803 1.026803 1.026803 1.026803  ;48
1.097577 1.097577 1.097577 1.097577 1.097577 1.097577 1.097577 1.097577 1.097577 1.097577  ;49
1.157402 1.157402 1.157402 1.157402 1.157402 1.157402 1.157402 1.157402 1.157402 1.157402  ;50
1.246044 1.246044 1.246044 1.246044 1.246044 1.246044 1.246044 1.246044 1.246044 1.246044  ;51
1.299803 1.299803 1.299803 1.299803 1.299803 1.299803 1.299803 1.299803 1.299803 1.299803  ;52
1.402872 1.402872 1.402872 1.402872 1.402872 1.402872 1.402872 1.402872 1.402872 1.402872  ;53
1.470497 1.470497 1.470497 1.470497 1.470497 1.470497 1.470497 1.470497 1.470497 1.470497  ;54
1.551242 1.551242 1.551242 1.551242 1.551242 1.551242 1.551242 1.551242 1.551242 1.551242  ;55
1.623735 1.623735 1.623735 1.623735 1.623735 1.623735 1.623735 1.623735 1.623735 1.623735  ;56
1.753425 1.753425 1.753425 1.753425 1.753425 1.753425 1.753425 1.753425 1.753425 1.753425  ;57
1.797007 1.797007 1.797007 1.797007 1.797007 1.797007 1.797007 1.797007 1.797007 1.797007  ;58
1.901131 1.901131 1.901131 1.901131 1.901131 1.901131 1.901131 1.901131 1.901131 1.901131  ;59
2.0008   2.0008   2.0008   2.0008   2.0008   2.0008   2.0008   2.0008   2.0008   2.0008    ;60
2.104438 2.104438 2.104438 2.104438 2.104438 2.104438 2.104438 2.104438 2.104438 2.104438  ;61
2.188638 2.188638 2.188638 2.188638 2.188638 2.188638 2.188638 2.188638 2.188638 2.188638  ;62
2.287837 2.287837 2.287837 2.287837 2.287837 2.287837 2.287837 2.287837 2.287837 2.287837  ;63
2.374912 2.374912 2.374912 2.374912 2.374912 2.374912 2.374912 2.374912 2.374912 2.374912  ;64
2.471904 2.471904 2.471904 2.471904 2.471904 2.471904 2.471904 2.471904 2.471904 2.471904  ;65
2.634188 2.634188 2.634188 2.634188 2.634188 2.634188 2.634188 2.634188 2.634188 2.634188  ;66
2.760182 2.760182 2.760182 2.760182 2.760182 2.760182 2.760182 2.760182 2.760182 2.760182  ;67
2.787833 2.787833 2.787833 2.787833 2.787833 2.787833 2.787833 2.787833 2.787833 2.787833  ;68
2.980571 2.980571 2.980571 2.980571 2.980571 2.980571 2.980571 2.980571 2.980571 2.980571  ;69
3.105583 3.105583 3.105583 3.105583 3.105583 3.105583 3.105583 3.105583 3.105583 3.105583  ;70
3.30275  3.30275  3.30275  3.30275  3.30275  3.30275  3.30275  3.30275  3.30275  3.30275   ;71
3.421267 3.421267 3.421267 3.421267 3.421267 3.421267 3.421267 3.421267 3.421267 3.421267  ;72
3.512941 3.512941 3.512941 3.512941 3.512941 3.512941 3.512941 3.512941 3.512941 3.512941  ;73
3.742462 3.742462 3.742462 3.742462 3.742462 3.742462 3.742462 3.742462 3.742462 3.742462  ;74
3.833603 3.833603 3.833603 3.833603 3.833603 3.833603 3.833603 3.833603 3.833603 3.833603  ;75
3.97811  3.97811  3.97811  3.97811  3.97811  3.97811  3.97811  3.97811  3.97811  3.97811   ;76
4.126067 4.126067 4.126067 4.126067 4.126067 4.126067 4.126067 4.126067 4.126067 4.126067  ;77
4.277512 4.277512 4.277512 4.277512 4.277512 4.277512 4.277512 4.277512 4.277512 4.277512  ;78
4.43248  4.43248  4.43248  4.43248  4.43248  4.43248  4.43248  4.43248  4.43248  4.43248   ;79
4.591006 4.591006 4.591006 4.591006 4.591006 4.591006 4.591006 4.591006 4.591006 4.591006  ;80
4.753127 4.753127 4.753127 4.753127 4.753127 4.753127 4.753127 4.753127 4.753127 4.753127  ;81
4.918877 4.918877 4.918877 4.918877 4.918877 4.918877 4.918877 4.918877 4.918877 4.918877  ;82
5.088293 5.088293 5.088293 5.088293 5.088293 5.088293 5.088293 5.088293 5.088293 5.088293  ;83
5.261409 5.261409 5.261409 5.261409 5.261409 5.261409 5.261409 5.261409 5.261409 5.261409  ;84
5.438262 5.438262 5.438262 5.438262 5.438262 5.438262 5.438262 5.438262 5.438262 5.438262  ;85
```

had.survey

had.survey contains data for the amount of haddock caught in a survey in March and parameters for suitability function that describes how likely it is that haddock of certain length will be caught. Even though the survey is done in March it is put on the second step of the year for better results.

This file also includes parameters for suitability function that describes how likely it is, that haddock of certain length will be caugth. The suitability function used here is

$$S(l, L) = \frac{1}{1 + e^{-\alpha - \beta l - \gamma L}}$$

where l is length of prey and L is length of predators. Upperbound for the suitability function is also defined, but here it has no meaning. It is used for instance, if two stocks of the same species live in the same area, then the upperbounds for suitability functions for these two stocks will add up to 1.

```
; Survey data for haddock
;
; Number of areas
livesonareas 1
;
; Length of predator, has no meaning here as the value of gamma is 0
lengths 20 30
;
suitability
;       stock   type    alpha    beta   gamma   upperbound
        had     0       -20#403  1#404  0       1
amount
;year     step    amount
                  (kilos)
1970       1       000
1970       2       30000
1970       3       000
1970       4       000
1971       1       000
1971       2       30000
1971       3       000
1971       4       000
1972       1       000
1972       2       30000
1972       3       000
1972       4       000
1973       1       000
1973       2       30000
1973       3       000
1973       4       000
1974       1       000
1974       2       30000
1974       3       000
1974       4       000
1975       1       000
1975       2       30000
1975       3       000
1975       4       000
1976       1       000
1976       2       30000
1976       3       000
1976       4       000
1977       1       000
1977       2       30000
1977       3       000
1977       4       000
1978       1       000
1978       2       30000
1978       3       000
1978       4       000
1979       1       000
1979       2       30000
1979       3       000
1979       4       000
1980       1       000
1980       2       30000
1980       3       000
1980       4       000
1981       1       000
1981       2       30000
1981       3       000
1981       4       000
1982       1       000
1982       2       30000
```

```
1982        3        000
1982        4        000
1983        1        000
1983        2        30000
1983        3        000
1983        4        000
1984        1        000
1984        2        30000
1984        3        000
1984        4        000
1985        1        000
1985        2        30000
1985        3        000
1985        4        000
1986        1        000
1986        2        30000
1986        3        000
1986        4        000
1987        1        000
1987        2        30000
1987        3        000
1987        4        000
1988        1        000
1988        2        30000
1988        3        000
1988        4        000
1989        1        000
1989        2        30000
1989        3        000
1989        4        000
1990        1        000
1990        2        30000
1990        3        000
1990        4        000
1991        1        000
1991        2        30000
1991        3        000
1991        4        000
1992        1        000
1992        2        30000
1992        3        000
1992        4        000
1993        1        000
1993        2        30000
1993        3        000
1993        4        000
1994        1        000
1994        2        30000
1994        3        000
1994        4        000
1995        1        000
1995        2        30000
1995        3        000
1995        4        000
1996        1        000
1996        2        30000
1996        3        000
1996        4        000
1997        1        000
1997        2        30000
1997        3        000
1997        4        000
1998        1        000
1998        2        30000
1998        3        000
1998        4        000
1999        1        000
1999        2        30000
1999        3        000
1999        4        000
```

```
2000        1         000
2000        2         30000
2000        3         000
2000        4         000
2001        1         000
2001        2         30000
2001        3         000
2001        4         000
2002        1         000
2002        2         30000
2002        3         000
2002        4         000
2003        1         000
2003        2         30000
2003        3         000
2003        4         000
2004        1         000
2004        2         30000
2004        3         000
2004        4         000
2005        1         000
2005        2         30000
2005        3         000
2005        4         000
2006        1         000
2006        2         30000
2006        3         000
2006        4         000
```

had.fleet

had.fleet contains data for the total amount of haddock caught and parameters for suitability function that describes how likely it is, that haddock of certain length will be caught. The suitability function used here is

$$S(l, L) = \frac{1}{1 + e^{-\alpha - \beta l - \gamma L}}$$

where l is length of prey and L is length of predators. Upperbound for the suitability function is also defined, but here it has no meaning. It is used for instance, if two stocks of the same species live in the same area, then the upperbounds for suitability functions for these two stocks will add up to 1.

```
; Number of areas
livesonareas 1
;
; Length of predator, has no meaning here as the value of gamma is 0
lengths 20 30
;
suitability
;       stock   type    alpha   beta     gamma  upperbound
        had     0       -20#401 0.65#402 0      1
;
amount
;year   step    amount
;               (kilos)
1978    1       8443611
1978    2       14834510
1978    3       9985415
1978    4       10184462
1979    1       10753517
1979    2       18892764
1979    3       12717109
1979    4       12970609
```

1980	1	9932826
1980	2	17450899
1980	3	11746560
1980	4	11980713
1981	1	12352144
1981	2	21701378
1981	3	14607645
1981	4	14898831
1982	1	13023000
1982	2	22880000
1982	3	15401000
1982	4	15708000
1983	1	15853000
1983	2	25218000
1983	3	14014000
1983	4	8729000
1984	1	13890000
1984	2	16343000
1984	3	7957000
1984	4	9010000
1985	1	10768000
1985	2	20703000
1985	3	9697000
1985	4	8404000
1986	1	10975000
1986	2	22039000
1986	3	7936000
1986	4	6384000
1987	1	8772000
1987	2	14770000
1987	3	7020000
1987	4	9190000
1988	1	13313000
1988	2	16910000
1988	3	10791000
1988	4	11985000
1989	1	12891000
1989	2	19377000
1989	3	14143000
1989	4	15305000
1990	1	11588000
1990	2	25056000
1990	3	15592000
1990	4	13660000
1991	1	9415000
1991	2	19387000
1991	3	13928000
1991	4	11223000
1992	1	8988000
1992	2	16030000
1992	3	9686000
1992	4	10824000
1993	1	11399000
1993	2	16370000
1993	3	9189000
1993	4	9860000
1994	1	15081000
1994	2	18531000
1994	3	12414000
1994	4	12396000
1995	1	17428000
1995	2	19602000
1995	3	10859000
1995	4	12478000
1996	1	12737000
1996	2	16417000
1996	3	11858000
1996	4	15307000
1997	1	10768000
1997	2	15508000

```
1997    3       7720000
1997    4       9505000
1998    1       6852000
1998    2       13256000
1998    3       8453000
1998    4       12228000
1999    1       6852000
1999    2       0
1999    3       0
1999    4       0
2000    1       0
2000    2       0
2000    3       0
2000    4       0
2001    1       0
2001    2       0
2001    3       0
2001    4       0
2002    1       0
2002    2       0
2002    3       0
2002    4       0
2003    1       0
2003    2       0
2003    3       0
2003    4       0
2004    1       0
2004    2       0
2004    3       0
2004    4       0
2005    1       0
2005    2       0
2005    3       0
2005    4       0
2006    1       0
2006    2       0
2006    3       0
2006    4       0
```

had.predc

had.predc is for estimating the catch in the future. Instead of having data for the catch as in the past, we make data for the effort in the future and then use that to estimate the catch.

As when we have the catch from the past, we have the suitability function

$$S(l, L) = \frac{1}{1 + e^{-\alpha-\beta l-\gamma L}}$$

```
; Number of areas
livesonareas    1
;
; Length of predator, has no meaning here as the value of gamma is 0
lengths 20 30
;
suitability
;       stock   type    alpha   beta     gamma  upperbound
        had     0       -20#401 0.65#402 0      1
;
; The amount number is multiplied by this to get the real amount used
multiplicative 0.5
amount
```

```
;
; The amount is 0 for all the years where we have catch data
;year   step  amount
1978       1       0
1978       2       0
1978       3       0
1978       4       0
1979       1       0
1979       2       0
1979       3       0
1979       4       0
1980       1       0
1980       2       0
1980       3       0
1980       4       0
1981       1       0
1981       2       0
1981       3       0
1981       4       0
1982       1       0
1982       2       0
1982       3       0
1982       4       0
1983       1       0
1983       2       0
1983       3       0
1983       4       0
1984       1       0
1984       2       0
1984       3       0
1984       4       0
1985       1       0
1985       2       0
1985       3       0
1985       4       0
1986       1       0
1986       2       0
1986       3       0
1986       4       0
1987       1       0
1987       2       0
1987       3       0
1987       4       0
1988       1       0
1988       2       0
1988       3       0
1988       4       0
1989       1       0
1989       2       0
1989       3       0
1989       4       0
1990       1       0
1990       2       0
1990       3       0
1990       4       0
1991       1       0
1991       2       0
1991       3       0
1991       4       0
1992       1       0
1992       2       0
1992       3       0
1992       4       0
1993       1       0
1993       2       0
1993       3       0
1993       4       0
1994       1       0
1994       2       0
1994       3       0
```

```
1994        4       0
1995        1       0
1995        2       0
1995        3       0
1995        4       0
1996        1       0
1996        2       0
1996        3       0
1996        4       0
1997        1       0
1997        2       0
1997        3       0
1997        4       0
1998        1       0
1998        2       0
1998        3       0
1998        4       0
1999        1       0
1999        2       1
1999        3       1
1999        4       1
2000        1       1
2000        2       1
2000        3       1
2000        4       1
2001        1       1
2001        2       1
2001        3       1
2001        4       1
2002        1       1
2002        2       1
2002        3       1
2002        4       1
2003        1       1
2003        2       1
2003        3       1
2003        4       1
2004        1       1
2004        2       1
2004        3       1
2004        4       1
2005        1       1
2005        2       1
2005        3       1
2005        4       1
2006        1       1
2006        2       1
2006        3       1
2006        4       1
```

where l is length of prey and L is length of predator. And as before, the upperbound has no meaning.

had.rec

The file had.rec contains data for recruitment. The recruitment for the years 1978-1999 is estimated parameters, but after that it is a constant.

Weight of the recruitment is given by the function

$$W = \alpha l^{\beta}$$

where l is mean length of the recruitment.

```
Normaldistribution
minlength 4.5   ; Minimum length of recruitment
maxlength 28.5  ; Maximum length of recruitment
dl 1            ; Length steps for recruitment
;
;year   step    area    age     number          mean len  stdev  alpha          beta
1978    1       1       1       1000*2#378      16.41     2.25   0.00825e-3     3.0257
1979    1       1       1       1000*2#379      16.41     2.25   0.00825e-3     3.0257
1980    1       1       1       1000*2#380      16.41     2.25   0.00825e-3     3.0257
1981    1       1       1       1000*2#381      16.41     2.25   0.00825e-3     3.0257
1982    1       1       1       1000*2#382      16.41     2.25   0.00825e-3     3.0257
1983    1       1       1       1000*2#383      16.41     2.25   0.00825e-3     3.0257
1984    1       1       1       1000*2#384      16.41     2.25   0.00825e-3     3.0257
1985    1       1       1       1000*2#385      16.41     2.25   0.00825e-3     3.0257
1986    1       1       1       1000*2#386      16.41     2.25   0.00825e-3     3.0257
1987    1       1       1       1000*2#387      16.41     2.25   0.00825e-3     3.0257
1988    1       1       1       1000*2#388      16.41     2.25   0.00825e-3     3.0257
1989    1       1       1       1000*2#389      16.41     2.25   0.00825e-3     3.0257
1990    1       1       1       1000*2#390      16.41     2.25   0.00825e-3     3.0257
1991    1       1       1       1000*2#391      16.41     2.25   0.00825e-3     3.0257
1992    1       1       1       1000*2#392      16.41     2.25   0.00825e-3     3.0257
1993    1       1       1       1000*2#393      16.41     2.25   0.00825e-3     3.0257
1994    1       1       1       1000*2#394      16.41     2.25   0.00825e-3     3.0257
1995    1       1       1       1000*2#395      16.41     2.25   0.00825e-3     3.0257
1996    1       1       1       1000*2#396      16.41     2.25   0.00825e-3     3.0257
1997    1       1       1       1000*2#397      16.41     2.25   0.00825e-3     3.0257
1998    1       1       1       1000*2#398      16.41     2.25   0.00825e-3     3.0257
1999    1       1       1       1000*2#399      16.41     2.25   0.00825e-3     3.0257
2000    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
2001    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
2002    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
2003    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
2004    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
2005    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
2006    1       1       1       9000            16.41     2.25   0.00825e-3     3.0257
```

printfile

printfile contains description of desired output; stock sizes, abundance number of stock etc. The printfile is normally commented out in the main file as we don't want these informations every time we get function evaluation when running GADGET for minimization.

```
Stockstdprinter               ; Standard stock printout
stockname
        had                   ; The stock for which printout is done
scale   1                     ; The stock size will be scaled with this number
areas
1                     ; The areas for which the printout is done
printfile out/had.std         ; The printout will be written to this file
YearsAndSteps all all         ; The years and step for which the printout is done

Stockprinter                  ; Defines how the abundance numbers of stocks
                              ; should be written to files
stocks
        had                   ; The stock for which printout is done
areas   1                     ; The areas for which printout is done
ages    1 2 3 4 5 6 7 8 9 10  ; The ages for which printout is done
lengths  6.5  8.5 10.5 12.5 14.5 16.5 18.5 20.5 22.5 24.5 26.5 28.5 30.5 32.5 34.5
        36.5 38.5 40.5 42.5 44.5 46.5 48.5 50.5 52.5 54.5 56.5 58.5 60.5 62.5 64.5
        66.5 68.5 70.5 72.5 74.5 76.5 78.5 80.5 82.5 84.5 86.5 88.5
                              ; The lengths for which the printout is done
printfiles      out/had.num  out/had.wt  ; The printout will be written to
                                         ; these files
YearsAndSteps   all  all      ; The years and steps for which printout is done

Stockfullprinter              ; Full printout on stock sizes
```

```
stockname
        had                   ; The stock for which printout is done
areas   1                     ; The areas for which printout is done
ages    1 2 3 4 5 6 7 8 9 10  ; The ages for which printout is done
printfile       out/had.stock ; The printout will be written to this file
YearsAndSteps   all  all      ; The years and steps for which printout is done
```

had.meanle.sur

The file had.meanle.sur describes the data on mean length at age from a survey in March. The data in this file will be compared to model output through a specific log-likelihood function. The function used is

$$\sum \frac{(\bar{l} - \hat{l})^2}{s^2}$$

where $\bar{l}$ is the mean length in the sample, $\hat{l}$ is the model output and s is the variance, as we expect the data to be distributed according to Pearson's distribution.

```
CatchStatistics
functionnumber   2          ; The log-likelihood function used, see above.
overconsumption  0          ; Overconsumption of the stock is not to be taken
                            ; into account.
fleetnames  survey
stocknames  had
areas    1                  ; One area only
ages     1
         2
         3
         4
         5
         6
         7
         8
         9
         10
StatisticsData
;
;  One block of data for each year and step
;
1989 2     ; Year and step
numbers    ; Number of fish behind each mean length
;age 1  2       3       4       5       6       7       8       9       10
60      124     238     829     336     106     8       8       4       3
mean       ; Mean length in age group
15.35   28.01   36.14   45.64   54.41   63.42   67.88   72.88   70.75   75
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1990 2
numbers
235     227     192     267     620     299     38      9       2       0
mean
15.63   27.51   37.13   44.58   51.01   59.47   67.29   72.11   71      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1991 2
numbers
350     808     364     175     180     306     76      3       1       1
mean
15.85   27.49   38.96   47.97   53.66   58.64   64.63   70.33   78      82
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1992 2
```

```
numbers
58      949     1074    332     113     96      119     22      2       1
mean
15.34   26.83   38.13   46.36   53.32   59.86   63.42   68.27   75      91
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1993 2
numbers
78      162     1429    783     128     36      24      51      12      0
mean
15.76   25.54   35.63   46.15   53.8    58.47   66.17   66.78   72.17   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1994 2
numbers
233     257     248     1055    318     58      19      11      28      1
mean
15.86   27.23   34.88   42.45   51.43   57.84   56.11   68.55   58.71   50
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1995 2
numbers
98      267     172     133     429     54      7       0       1       0
mean
16.9    26.51   37.84   42.32   48.53   57.98   65      0       51      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1996 2
numbers
205     256     693     254     205     471     59      5       2       1
mean
16.39   27.71   37.77   45.78   47.32   52.96   60.44   69      75      63
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1997 2
numbers
129     980     441     661     157     155     238     22      3       1
mean
17.07   27.2    36.61   45.4    50.66   53.18   58.21   64.23   75      76
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1998 2
numbers
402     225     1657    467     492     122     98      133     9       0
mean
16.86   28.35   36.06   44.07   51.46   56.41   57.95   62.86   67.89   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1999 2
numbers
310     312     148     174     24      15      4       6       1       0
mean
14.67   27.63   36.2    44.36   50.21   55.53   63.25   60.33   69      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
```

had.meanle.catch

had.meanle.catch contains division of the catch into age groups and mean lengths for each age group for each year. The data in this file will be compared to model output through a specific log-likelihood function. The function used is

$$\sum \frac{(\bar{l}-\hat{l})^2}{s^2}$$

where $\bar{l}$ is the mean length in the sample, $\hat{l}$ is the model output and s is the variance, as we expect the data to be distributed according to Pearson's distribution.

```
CatchStatistics
functionnumber  2  ; The log-likelihood function used, see above
overconsumption 1  ; Overconsumption of the stock is to be taken into account
fleetnames      commercialcatch
stocknames     had
areas    1
ages     1
         2
         3
         4
         5
         6
         7
         8
         9
         10
StatisticsData
;
; One block of data for each year and step
;
1979 1     ; Year and step
numbers    ; Number of fish behind each mean length
;age 1  2       3       4       5       6       7       8       9       10
0       0       0       7       48      96      36      4       1       0
mean       ; Mean length in each age group
0       0       0       55.43   58.92   64.2    68.61   73.5    73      0
; Variance for the length distribution
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1979 2
numbers
0       0       13      73      224     258     20      8       1       0
mean
0       0       42.15   51.44   58.56   62.16   69.6    70.5    72      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1979 3
numbers
0       0       31      35      15      17      2       0       0       0
mean
0       0       45.94   53.57   62.13   65.71   75      0       0       0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1979 4
numbers
0       17      95      76      58      52      1       1       0       0
mean
0       43.24   50.35   59.28   65.09   62.67   66      63      0       0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1980 1
numbers
0       0       2       197     246     299     380     56      12      6
mean
0       0       49      48.09   57.58   63.86   67.84   72.16   77.08   77.17
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1980 2
numbers
0       0       15      132     71      41      38      3       1       0
mean
0       0       44.4    50.94   60.7    64.78   67.66   68      83      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1980 4
numbers
0       0       29      429     108     83      45      5       1       0
```

```
mean
0       0       46.31   54.54   62.25   65.4    69.71   75.8    81      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1981 1
numbers
0       0       1       110     390     170     124     90      13      1
mean
0       0       76      46.98   53.67   61.71   69.23   70.64   74.92   73
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1981 2
numbers
0       0       1       32      95      45      58      49      16      4
mean
0       0       47      48.97   54.09   62.6    70.78   74.43   77.44   77.75
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1981 3
numbers
0       0       19      56      178     72      43      31      1       0
mean
0       0       39.42   45.75   55.83   63.28   71.7    73.39   77      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1981 4
numbers
0       0       1       11      76      11      0       1       0       0
mean
0       0       48      54.18   57.96   62      0       67      0       0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1982 1
numbers
0       0       0       12      317     421     151     105     77      13
mean
0       0       0       48.5    53.63   59.74   67.58   71.17   73.47   74
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1982 2
numbers
0       0       1       16      340     353     129     143     173     28
mean
0       0       44      46.75   53.87   62.37   72.19   75.4    77.72   77.86
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1982 3
numbers
0       1       4       44      127     275     31      7       6       4
mean
0       34      41.25   52.18   57.7    62.86   68.94   72.43   72.67   72.25
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1982 4
numbers
0       1       13      192     285     432     52      14      6       3
mean
0       38      49.31   52.75   57.55   61.99   64.25   65.5    68.17   70.33
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1983 1
numbers
0       0       7       43      261     326     494     113     24      26
mean
0       0       40.71   50.42   53.32   59.02   65.04   71.09   73.21   75.46
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1983 2
numbers
0       0       5       38      68      481     353     46      21      31
```

```
mean
0       0       46.4    53      57.78   62.05   66.39   73.43   76.57   77.26
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1983 3
numbers
0       0       1       10      68      122     185     6       4       3
mean
0       0       52      54      57.56   63.67   66.77   74      76      80.67
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1983 4
numbers
0       0       30      17      111     20      117     2       1       1
mean
0       0       46.93   55.47   59.12   66.95   64.13   67      91      69
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1984 1
numbers
0       0       2       42      34      144     122     135     13      4
mean
0       0       43      50.86   57.82   61.04   66.89   65.39   72.38   75.25
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1984 2
numbers
0       0       0       0       0       2       75      22      1       0
mean
0       0       0       0       0       67.5    71.09   74.32   81      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1984 3
numbers
0       1       7       79      12      94      16      89      0       0
mean
0       46      47.71   53.35   60.67   62.51   66.19   66.92   0       0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1984 4
numbers
0       2       19      134     24      93      57      68      2       0
mean
0       45      48.68   55.6    65.12   68.22   69.93   71.81   72      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1985 1
numbers
0       1       37      173     251     52      130     180     157     12
mean
0       39      45.11   53.09   56.9    63.48   69.17   70.57   74.29   75.33
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1985 2
numbers
0       4       45      142     77      29      152     249     252     25
mean
0       33.5    48.09   57.05   61.79   65.41   70.45   72.78   74.39   78.2
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1985 3
numbers
0       0       0       4       72      0       14      0       10      0
mean
0       0       0       51.5    58.28   0       66.5    0       72.9     0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1985 4
numbers
0       44      20      167     291     15      31      13      18      0
```

```
mean
0       42.61   52.65   56.86   60.98   66.73   70.42   67.23   72.17   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1986 1
numbers
0       0       57      122     260     397     58      91      115     50
mean
0       0       43.93   53.91   62.05   66.12   71.9    73.21   74.62   77.64
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1986 2
numbers
0       0       103     197     274     335     34      101     88      49
mean
0       0       46.86   55.7    62.83   64.61   71.94   72.59   76.75   75.04
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1986 3
numbers
0       7       65      73      190     134     7       17      11      2
mean
0       43      49.08   58.18   63.09   66.34   67.71   72.24   70.73   88
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1986 4
numbers
0       10      183     84      81      121     5       6       8       1
mean
0       45.6    52.08   58.46   63.88   66.08   76.8    72.83   80.12   82
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1987 1
numbers
0       3       110     418     164     210     114     16      24      22
mean
0       43      44.66   51.9    61.09   66.31   71.79   77.06   77.42   74
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1987 2
numbers
0       7       320     215     117     126     116     16      12      11
mean
0       38.57   46.89   53.77   62.5    68.32   71.16   76.5    80.08   78.82
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1987 3
numbers
0       1       56      24      15      2       1       0       0       1
mean
0       41      49.38   59.04   66.8    75      63      0       0       77
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1987 4
numbers
0       103     249     222     44      42      32      2       2       2
mean
0       34.84   48.34   58.22   64.5    70.48   71.66   75      75.5     76
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1988 1
numbers
0       2       203     480     308     96      76      33      7       7
mean
0       45      37.97   50.56   59.07   64.85   70      69.73   77.71   73.71
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1988 2
numbers
0       5       183     365     231     78      87      85      2       11
```

```
mean
0       31.2    41.21   52.52   60.47   67.74   71.59   72.92   74      75.36
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1988 3
numbers
0       1       233     478     136     37      10      8       2       1
mean
0       40      46.41   54.93   62.6    68.84   69.4    72.62   74      86
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1988 4
numbers
0       2       198     524     246     39      72      22      7       7
mean
0       30.5    47.09   58.14   66.06   72.46   76.36   78      80.71   87.86
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1989 1
numbers
0       0       12      474     422     310     67      62      21      8
mean
0       0       38.67   45.99   57.08   67.16   76.03   75.58   77.52   80.12
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1989 2
numbers
0       0       14      409     261     113     40      41      10      2
mean
0       0       46.21   48.67   57.41   67.5    74.97   72.85   78      72
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1989 3
numbers
0       4       84      301     106     19      4       4       0       0
mean
0       44.75   46.4    51.7    61.8    68.53   78.25   69.25   0       0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1989 4
numbers
0       1       77      695     254     73      28      16      10      7
mean
0       37      43.47   51.07   62.39   70.56   77.54   81.5    80.5    87.14
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1990 1
numbers
0       0       8       93      494     341     111     32      14      10
mean
0       0       40.62   46.45   53.49   65.97   72.61   76.03   79.21   80.7
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1990 2
numbers
0       5       12      158     725     262     49      7       4       1
mean
0       36      45.67   48.63   56.15   65.04   70.31   74.29   79.25   81
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1990 3
numbers
0       9       80      280     701     271     22      2       0       0
mean
0       25.22   42.65   47.79   53.27   60.95   67.23   72      0       0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1990 4
numbers
0       35      130     277     937     241     28      12      7       0
```

```
mean
26.1    31.71   40.73   46.04   52.42   60.63   71.39   80.5    83.29   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1991 1
numbers
0       0       19      152     375     869     257     29      3       2
mean
0       0       44.21   48.29   53.21   59.31   67.33   71.21   80.67   82.5
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1991 2
numbers
0       59      37      150     313     654     200     38      6       1
mean
16      29.02   40.43   47.26   54.05   60.46   67.16   71.84   75      81
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1991 3
numbers
0       62      54      153     253     552     102     10      1       0
mean
0       34.32   44.52   47.56   54.14   58.3    64.04   67.8    73      0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1991 4
numbers
0       226     76      140     171     352     58      10      4       2
mean
24.31   34.82   45.49   49.7    53.54   57.19   65.4    78.9    84.25   86.5
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1992 1
numbers
0       9       109     149     235     244     406     101     8       0
mean
0       24.89   40.14   48.88   53.39   58.01   61.46   66.54   69.62   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1992 2
numbers
0       153     318     107     169     200     318     74      14      1
mean
13.5    27.54   39.41   49.06   53.86   60.7    65.21   71.45   76.57   76
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1992 3
numbers
0       115     355     201     121     109     108     21      3       0
mean
0       31.67   44.77   50.48   57.49   61.9    64.89   67.62   74.33   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1992 4
numbers
0       215     272     131     87      76      138     39      3       4
mean
26      33.79   44.53   49.17   54.51   59.88   66.75   73.26   82.67   85.25
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1993 1
numbers
0       0       113     457     226     148     134     169     44      3
mean
0       0       42.29   49.5    55.18   62.69   67.87   70.98   72.39   77.67
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1993 2
numbers
0       1       361     793     246     179     193     302     47      9
```

```
mean
0       36      42.64   51.22   57.46   62.64   67.33   67.9    70.04   74
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1993 3
numbers
0       15      606     640     130     116     98      178     19      0
mean
22.84   31.67   41.27   52.63   59.82   64.17   66.86   66.84   71.16   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1993 4
numbers
0       17      695     660     124     44      32      47      8       0
mean
27.88   37.47   44.4    53.2    59.6    59.09   65.31   59.91   68.75   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1994 1
numbers
0       0       19      592     447     68      18      10      33      0
mean
0       0       40.68   47.21   52.76   58.87   60.28   66      58.73   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1994 2
numbers
0       1       58      933     590     168     85      88      146     31
mean
0       36      42.64   47.41   58.45   64.43   67.85   71.82   73.58   74.29
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1994 3
numbers
0       4       63      512     228     39      15      6       8       1
mean
0       38.25   43.41   48.51   57.36   65.92   59.27   69.5    62      59
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1994 4
numbers
0       19      97      798     270     21      25      7       9       3
mean
0       39.37   44.71   50.38   55.99   60.71   63.12   57.71   56      65.33
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1995 1
numbers
0       0       48      113     884     431     60      33      21      20
mean
0       0       41.65   46.96   50.1    59.39   66.17   67.24   67      66.7
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1995 2
numbers
0       1       96      190     663     335     60      29      28      48
mean
77      35      42.45   48.73   51.26   59.73   67.7    70.83   75      70.46
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1995 3
numbers
0       62      419     238     1018    205     13      6       10      11
mean
0       34.03   44.56   48.5    52.23   60      64.92   68      65.7    63.91
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1995 4
numbers
0       127     282     279     1045    230     17      5       6       12
```

```
mean
0       40.33   48.2    51.44   54.51   61.03   67.29   62.8    63.5    65.17
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1996 1
numbers
0       0       163     333     299     949     262     32      9       5
mean
54      0       41.37   47.49   51.97   55.93   63.27   69.97   67.78   76.2
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1996 2
numbers
0       0       151     286     249     887     201     17      13      8
mean
0       0       43.91   49.3    54.09   57.67   66      69.88   74.15   69.25
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1996 3
numbers
0       19      386     322     142     470     97      25      6       8
mean
25.5    36.37   46.15   51.89   55.03   58.67   70.19   79.28   82.5    79.62
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1996 4
numbers
0       15      328     209     182     451     88      5       7       5
mean
0       39.73   47.33   52.05   56.85   58.78   63.38   65.6    66.29   66.4
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1997 1
numbers
0       1       56      742     375     216     390     55      8       1
mean
0       40      40.73   47.93   53.77   56.25   59.34   65      69.5    57
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1997 2
numbers
0       0       41      625     371     207     599     103     6       0
mean
0       0       42.17   48.59   55.19   58.65   61.64   65.36   66.17   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1997 3
numbers
0       27      261     709     327     180     313     38      3       0
mean
0       40.96   45.95   51.11   55.83   58.32   61.94   64.34   59.67   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1997 4
numbers
0       62      222     647     222     176     297     41      1       1
mean
0       39.85   46.5    52.52   57.91   57.97   63.75   69.71   52      56
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1998 1
numbers
0       0       33      139     449     124     113     110     24      0
mean
0       0       43.33   47.94   54.04   57.81   58.75   64.48   65.67   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1998 2
numbers
0       0       19      111     234     76      56      74      14      2
```

```
mean
0       0       41.16   47.96   54.69   62.26   61.54   65.91   68.14   66.5
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
1998 3
numbers
0       0       17      33      78      19      16      28      3       0
mean
0       0       45      49.42   56.26   58.26   63.31   66.04   74.67   0
variance
2.0     3.7     6.2     5.0     5.5     6.3     7.1     6.6     5.8     5.6
```

had.lengthdist.sur and had.lengthdist.catch

had.lengthdist.sur contains division of a survey in March into lengthgroups and had.lengthdist.catch contains division of the catch into lengthgroups.

In these files, all the data is collapsed into a single length distribution. The proportions for each length-cell are then calculated:

$$\pi_l = \frac{\hat{N}_l}{\sum_{i=1}^{n_l} \hat{N}_i}$$

where l is length group or aggregation of length groups, n_l is number of length groups and $\hat{N}_i$ is model output of number of fishes.

The corresponding objective function is based on the likelihood function from the multinomial distribution so that:

$$l = 2\sum_{t,r}\left(\log N_{tr}! - \sum_{l=1}^{n_l}\log N_{trl}! - \sum_{l=1}^{n_l} N_{trl}\log \pi_{trl}\right)$$

where r is region (only one in this example), t is time or time step, l is length group or aggregation of length groups and N is number of fish according to the data file.

```
; had.lengthdist.sur
CatchDistribution
functionnumber  1        ; The distribution of the data is multinomial, see above
overconsumption 1        ; Overconsumption of the stock is to be taken into account
minimumprobability   20  ; This is used if the outcome that occurs is very inprobable
fleetnames  survey
stocknames  had
areas    1
ages     1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
lengths 4.5  6.5  8.5 10.5 12.5 14.5 16.5 18.5 20.5 22.5 24.5 26.5 28.5 30.5 32.5 34.5
       36.5 38.5 40.5 42.5 44.5 46.5 48.5 50.5 52.5 54.5 56.5 58.5 60.5 62.5 64.5 66.5
       68.5 70.5 72.5 74.5 76.5 78.5 80.5 82.5 84.5 86.5 88.5 90.5
DistributionData
;
; One lengthkey for step 2 each year
;
1985 2    ; Year and step
0 0 4 112 1718 4419 3503 1408 403 216 880 2423 4311 4699 2663 1204 683 962 1588 1935 2508
2222 2072 2376 2188 2537 2090 1492 1324 943 947 850 745 729 590 489 272 167 86 35 9 5 1
1986 2
0 0 9 344 7100 18539 14016 3359 1190 965 3612 7998 11207 8637 5922 3253 2422 3711 5268 5386
4066 2233 1286 1213 1445 1567 1560 1533 1417 1167 992 788 598 440 344 268 207 142 88 48 23 9 2
1987 2
```

```
0 1 1 112 1836 3881 2199 1548 6445 14246 24380 27384 19378 9017 4529 6348 9777 12885
13463 9493 8039 4430 4085 3960 3297 2861 2033 1745 1528 1426 1300 1357 987 736 535 390
190 178 97 96 7 10 1
1988 2
0 0 5 59 526 2248 2137 392 450 1770 3820 5914 6049 6115 6967 12361 17802 17220 11527 6735
6120 5592 5110 4355 2828 2238 1527 1044 872 536 653 301 255 245 146 151 70 51 42 15 9 5 6
1989 2
0 0 20 170 1636 2681 613 82 186 913 2084 2710 2315 2231 2964 4756 5853 5878 6410 8021 10035
9945 8084 5808 3540 2580 2124 1710 1304 932 685 466 326 266 154 121 68 46 21 15 14 6 2
1990 2
0 0 3 229 6188 13302 4721 1124 352 1529 2815 3758 3064 2283 2158 2953 3357 3282 3854 4284
4837 5075 5231 4892 5030 4372 3666 2800 1642 1277 689 657 307 226 159 89 53 43 27 12 12 5 7
1991 2
0 3 10 461 5866 16794 9371 1366 2238 9570 13903 11608 7196 5729 4699 4007 3625 2846 2297 2106
2130 2257 2272 2548 2366 2175 2124 1729 1668 1279 915 649 493 304 139 100 60 32 20 10 19 4 3
1992 2
0 10 85 525 2506 3231 702 518 5709 17098 21789 19335 12191 8053 9479 12250 10055 8411 7391
6901 5449 3800 3086 2174 1852 1642 1371 1267 1158 1046 689 814 579 281 335 232 82 43 23 6 9 1 1
1993 2
4 7 43 289 1095 3192 4304 1197 909 2778 4972 5924 11647 17487 22787 22614 17997 13291 10614
7545 6899 4781 3652 3145 2093 1488 1194 806 476 416 359 379 227 201 173 78 66 28 20 6 6 4 3
1994 2
60 0 17 357 3526 10556 5916 1087 366 1814 6291 6484 5803 5373 5712 6424 8537 11296 11978
11268 9685 8002 5632 4251 2787 2260 1468 945 784 446 325 214 170 138 67 84 66 47 24 4 5 9 0
1995 2
0 4 5 80 708 4446 5839 1774 1786 5432 8317 6124 4901 4008 4485 4332 4677 5015 4364 4317
4536 4728 4058 3002 2318 1605 1171 681 427 334 214 139 110 81 73 28 26 15 15 6 3 5 0
1996 2
0 16 13 191 2285 11290 12816 2936 998 4114 5833 5977 5902 5936 5578 7164 8334 8701 6719
4559 4083 4060 3671 3509 2714 2149 1631 1239 808 536 394 262 160 92 71 38 98 13 22 7 3 0 0
1997 2
2 1 2 106 541 1508 773 750 2966 6473 8277 11824 9247 5351 4329 4536 4211 3608 3595 3572
3550 3786 2900 2146 1620 1308 1113 806 711 527 402 273 149 112 75 34 18 6 12 2 2 2 2
1998 2
1 1 17 68 689 3484 3467 1162 342 939 2636 5206 5811 5472 6022 6748 6853 5753 4574 3365
2464 2040 1913 1759 1480 1378 1048 796 550 440 286 230 182 137 97 47 49 38 24 10 4 1 0
1999 2
4 2 14 1245 8992 16164 7545 1629 921 3265 7560 10991 8533 7375 6945 6636 5429 4578 5133
5379 5157 4195 2660 1941 1296 1122 808 641 636 456 483 378 199 192 87 137 63 39 11 16 1 1 1


; had.lengthdist.catch
CatchDistribution
functionnumber  1       ; The distribution of the data is multinomial, see above
overconsumption 1       ; Overconsumption of the stock is to be taken into account
minimumprobability  20  ; This is used if the outcome that occurs is very inprobable
fleetnames  commercialcatch
stocknames  had
areas    1
ages     2 3 4 5 6 7 8 9 10
lengths 4.5  6.5  8.5 10.5 12.5 14.5 16.5 18.5 20.5 22.5 24.5 26.5 28.5 30.5 32.5 34.5
       36.5 38.5 40.5 42.5 44.5 46.5 48.5 50.5 52.5 54.5 56.5 58.5 60.5 62.5 64.5 66.5
       68.5 70.5 72.5 74.5 76.5 78.5 80.5 82.5 84.5 86.5 88.5 90.5
DistributionData
;
; One length key for each year and step
;
1979 1    ; Year and step
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 3 11 17 32 53 97 145 248 334 375 433 444 486 427 395 407
348 369 264 190 164 101 67 53 15 17 5 2
1979 2
0 0 0 0 0 0 0 0 0 0 1 1 12 20 19 31 55 131 124 133 163 184 252 343 411 450 520 506 481
457 429 347 345 219 154 90 63 39 20 9 3 0 0
1979 3
0 0 0 0 0 0 0 0 0 0 1 5 9 10 14 29 73 99 144 128 152 206 206 176 239 304 362 387 383 383
419 344 267 182 112 66 25 23 5 0 0 0 1
1979 4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 1 22 26 65 105 193 238 245 255 272 363 502 559 573 547 563
473 400 298 236 131 55 37 16 3 2 2 0
1980 1
0 0 0 0 0 0 0 0 2 2 2 1 1 11 32 47 42 81 165 249 391 474 478 494 438 647 665 755 797 643
```

```
628 512 454 428 276 221 140 88 42 16 10 6 2
1980 2
0 0 0 0 0 0 0 1 0 0 1 6 9 28 73 191 321 456 484 634 1111 927 801 540 379 376 402 433 426
400 405 295 258 181 133 88 69 30 10 6 1 0 0
1980 3
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 5 42 32 60 88 67 135 121 70 102 33 44 53 49 50 62 53 28
19 20 11 7 5 1 0 1 0
1980 4
0 0 0 0 0 0 0 0 1 0 7 0 2 7 37 40 66 71 84 104 213 319 517 582 665 671 613 421 279 250
245 217 193 154 97 67 42 31 12 5 3 3 4
1981 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 11 26 67 90 166 275 406 371 345 235 193 144 123 148
124 124 99 91 80 49 25 11 4 2 1 0
1981 2
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 5 14 48 100 167 282 318 334 336 330 296 185 108 85 61 58
54 57 49 45 46 32 18 11 9 3 4 1
1981 3
1 0 1 0 0 1 2 4 0 0 0 0 5 0 2 2 26 46 65 94 120 162 162 206 230 249 308 314 275 189 148
116 116 92 68 53 45 26 11 2 1 0 0
1981 4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 7 4 17 50 69 156 214 278 357 402 449 458 352 244 156 103
70 56 27 8 16 3 3 2 1 0 0
1982 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 3 15 21 79 180 259 364 412 403 339 307 248 209 173 118
116 148 155 144 132 83 36 18 8 5 1
1982 2
0 0 0 0 0 0 0 1 0 0 4 8 6 5 5 4 20 44 106 122 198 264 429 521 574 673 686 630 482 417 280
212 158 198 157 207 166 88 67 36 22 9 5
1982 3
0 0 0 0 0 0 0 0 0 0 0 0 2 2 5 2 3 12 15 44 96 204 311 539 646 706 813 805 825 725 559 437
321 215 136 64 49 37 13 4 3 2 0
1982 4
0 0 0 0 0 0 0 0 10 10 6 5 3 7 4 2 14 11 22 55 113 172 284 414 552 624 740 758 752 665 579
430 319 209 121 57 26 17 8 7 1 0 0
1983 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 9 23 28 75 161 330 464 646 735 956 900 819 736 637 512
417 344 271 178 114 68 32 16 18 2 3
1983 2
0 0 0 0 0 0 0 0 0 0 0 0 2 2 3 1 1 14 31 37 100 146 186 310 393 462 694 696 714 709 581
493 388 284 185 112 73 47 25 18 6 6 0
1983 3
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 7 15 26 62 50 68 96 139 198 235 332 377 361 385 288 222
181 78 61 21 11 3 0 0 2 1
1983 4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 5 11 5 28 69 50 67 37 48 58 91 149 211 243 218 184 169
125 69 31 21 8 2 0 1 0 0
1984 1
0 0 0 0 1 5 9 0 0 2 2 4 10 17 64 64 44 41 48 51 39 61 83 95 110 151 150 177 216 193 197
163 160 134 108 67 40 25 14 6 1 0 0
1984 2
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 5 8 26 34 41 61 62 61 81 61 65 73 87 71 68 78 39 30
14 5 3 5 2 0 0 0
1984 3
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 3 1 10 22 59 88 99 95 78 94 100 91 84 105 98 68 65 43 35
20 7 0 0 0 0 0 0
1984 4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 3 4 32 27 59 76 96 102 114 113 104 103 112 139 129
116 92 61 39 17 6 2 0 0 0
1985 1
0 0 0 0 0 0 0 0 0 0 0 0 0 1 6 3 1 1 5 29 55 90 123 130 223 272 272 355 324 276 269 256 271
261 276 275 261 241 157 107 27 14 6 1
1985 2
0 0 0 0 0 0 0 2 1 0 0 0 7 17 26 21 16 27 46 103 160 228 217 223 283 362 437 440 373 316
335 361 359 363 382 348 244 187 106 56 19 10 2
1985 3
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 1 4 10 38 40 35 48 61 55 73 40 36 21 18 10 11 8 8
5 2 0 0 0 0 0
1985 4
0 0 0 1 2 0 0 0 4 5 15 21 21 3 1 1 19 59 83 82 42 28 39 71 165 262 353 432 408 331 264
174 117 76 61 38 35 21 17 9 1 1 1
```

```
1986 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 3 4 16 34 45 112 82 110 167 256 280 311 334 342 284 270
237 244 189 241 204 153 117 76 40 25 12 2
1986 2
0 0 18 83 59 3 2 13 78 147 107 17 1 4 12 7 3 25 65 72 135 178 196 222 268 394 402 490
507 529 486 407 372 318 241 246 217 168 105 73 29 19 4
1986 3
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 3 15 49 86 135 90 84 91 124 139 197 242 256 291 220
148 91 57 23 18 9 5 0 3 2 0
1986 4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 10 23 49 60 94 119 93 78 107 98 124 99 81 58 31
29 8 6 5 5 1 3 0 0
1987 1
0 0 0 0 0 0 0 0 0 0 1 1 0 0 2 10 20 50 112 152 182 195 301 344 409 390 315 258 234 221
207 200 162141 97 93 62 49 27 21 6 6 1
1987 2
0 0 0 0 0 0 0 1 0 2 1 6 39 26 29 41 56 178 329 533 715 632 783 557 465 652 497 548 324
318 402 321 292 193 148 134 67 51 38 21 13 7 3
1987 3
0 0 0 0 0 0 0 0 1 2 6 7 35 93 234 294 321 295 294 371 455 603 652 634 560 417 322 238
216 182 129 112 106 69 45 40 27 10 9 5 5 2 0
1987 4
0 0 0 0 0 0 0 0 0 18 26 38 76 170 279 367 341 326 249 281 389 556 775 791 710 596 477
427 308 256 147 142 126 61 46 44 23 18 7 2 1 2 0
1988 1
0 0 0 0 0 0 0 0 2 2 1 7 79 111 172 167 294 422 435 360 356 505 687 804 698 657 531 394
283 247 230 187 131 113 120 93 55 31 34 10 5 2 1
1988 2
0 0 0 0 0 0 0 1 0 0 1 5 15 38 101 154 276 547 578 601 713 762 905 943 898 894 740 598
468 401 276 242 227 199 164 129 71 50 20 16 3 0 0
1988 3
0 0 0 0 0 0 0 0 0 0 0 0 1 17 30 38 51 149 249 492 695 777 880 835 650 712 630 607 481
359 273 216 143 93 74 41 18 10 6 4 1 1 1
1988 4
0 0 0 0 0 0 0 0 1 2 5 9 32 70 143 331 427 778 931 1159 1554 1515 1322 1094 818 789 724
624 525 443 377 289 210 178 144 103 79 49 37 28 13 8 7
1989 1
0 0 0 0 0 0 0 0 5 29 50 58 43 51 128 258 421 658 782 912 1089 1153 1173 929 792 738 688
656 499 448 413 306 248 190 179 129 112 81 55 31 23 11 10
1989 2
0 0 0 0 0 0 0 0 0 1 4 3 20 41 88 141 259 416 604 718 977 1036 1058 994 807 692 518 467
385 303 275 204 191 121 94 93 65 42 34 23 9 4 3
1989 3
0 0 0 0 0 0 0 0 0 1 0 4 24 20 57 87 194 391 495 646 857 972 1254 1230 1324 1195 927 799
525 462 305 257 191 116 79 58 31 23 11 14 3 2 0
1989 4
0 0 0 0 0 0 0 0 0 0 0 2 4 17 41 79 182 335 543 672 830 829 828 728 672 735 598 528 372
285 218 163 118 86 57 40 25 34 11 16 12 12 5
1990 1
0 0 0 0 0 0 0 0 0 0 0 0 2 11 22 85 163 376 571 676 793 845 859 941 831 816 654 563 426
329 258 221 202 209 197 160 123 90 48 23 14 7 2
1990 2
0 0 0 0 0 3 4 4 1 5 6 2 17 59 93 158 296 501 677 831 1035 1308 1365 1532 1371 1285
1049 838 712 591 477 386 277 190 113 90 52 32 27 11 3 3 0
1990 3
0 0 0 0 0 0 3 23 18 21 26 25 28 35 69 148 285 458 692 818 971 1145 1241 1183 1141 1147
1071 909 684 588 411 289 168 120 57 42 18 15 10 2 4 0 0
1990 4
0 0 0 0 0 0 0 0 0 7 63 82 58 52 67 146 273 483 721 827 997 1000 986 1041 1003 962 861
767 596 425 331 182 140 66 53 42 22 19 11 6 5 5 4
1991 1
0 0 0 0 0 0 0 0 0 0 2 11 0 2 7 17 62 161 308 409 572 681 766 757 806 835 802 708 561
447 412 327 234 160 127 85 55 33 11 13 8 4 2
1991 2
0 0 0 0 0 1 1 1 2 1 12 15 21 57 107 128 90 131 205 291 420 606 647 806 846 879 1014 901
894 801 863 735 597 410 243 198 114 58 25 8 6 7 0
1991 3
0 0 0 0 0 0 0 0 8 16 18 13 108 190 251 277 331 320 347 454 629 737 812 807 877 899 916
853 776 674 555 443 298 207 144 84 47 26 10 4 3 0 1
1991 4
```

```
0 0 0 0 0 0 0 8 72 232 290 193 168 352 591 676 527 419 371 541 689 705 776 738 596 565
460 392 295 232 173 123 77 59 29 26 16 10 10 7 6 8 2
1992 1
0 0 0 0 0 0 0 0 7 28 30 14 17 43 74 86 117 172 250 327 404 421 384 457 424 433 422 361
320 289 270 223 192 191 163 163 94 45 21 16 3 2 0
1992 2
0 0 0 0 2 1 0 1 6 54 119 126 92 103 129 185 193 269 416 709 929 1148 1150 873 835 827
783 791 697 702 679 587 526 387 347 194 116 74 38 15 5 0 3
1992 3
0 0 0 0 0 0 7 2 8 17 140 549 741 713 374 299 347 521 633 786 924 1057 1054 902 834 775
630 577 515 468 400 365 301 210 143 108 54 34 10 3 3 1 1
1992 4
0 0 0 0 0 0 0 0 1 6 23 38 181 450 571 447 409 386 437 581 641 690 687 591 476 443 342 278
240 206 206 149 144 91 82 65 64 45 38 26 11 8 4
1993 1
0 0 0 0 0 0 0 0 0 0 0 1 11 16 44 120 195 332 423 511 553 623 570 615 570 633 479 408 338
259 246 240 214 188 198 154 119 88 46 33 7 5 2
1993 2
0 0 0 0 0 0 0 0 3 1 3 13 28 115 300 607 1144 1713 1760 1538 1237 1192 1380 1426 1436
1313 1060 909 624 514 460 424 382 276 263 211 148 110 52 24 11 7 0
1993 3
0 0 0 0 0 0 1 19 138 212 66 25 63 170 314 533 814 1408 1713 1870 1612 1300 1056 797 864
842 860 809 610 452 407 317 247 179 132 109 69 44 16 8 6 9 1
1993 4
0 0 0 0 0 2 0 0 0 3 9 26 27 23 53 115 274 469 721 917 1146 1295 1101 866 708 596 536 510
369 258 162 107 80 47 34 27 27 8 5 3 2 1 1
1994 1
0 0 0 0 0 2 0 0 0 1 20 23 17 57 107 163 215 351 504 810 1263 1686 1515 1177 911 721 637
587 428 317 229 151 111 64 61 49 27 17 9 7 0 0 0
1994 2
0 0 0 0 0 0 4 16 7 3 12 51 126 218 378 665 871 1260 1705 2386 2979 3647 3482 2542 1832
1311 1087 912 841 779 627 542 406 294 249 182 113 81 39 32 24 8 5
1994 3
0 0 0 0 0 0 0 0 0 0 2 0 4 11 16 26 56 106 260 375 489 529 499 359 297 189 170 140 102
87 65 72 50 21 17 14 6 4 3 2 1 0 0
1994 4
0 0 0 0 0 0 0 0 0 0 2 1 4 10 25 94 216 536 920 1497 1975 1979 1784 1419 1044 777 522 355
208 120 95 54 45 18 16 5 5 1 3 4 4 1 1
1995 1
5 1 0 0 0 0 0 0 0 3 16 34 52 74 78 76 142 284 388 612 628 814 863 722 568 457 477 350
234 182 171 128 79 54 31 21 13 5 5 4 1 1 0
1995 2
0 0 0 0 0 0 0 5 3 2 10 22 80 161 138 152 324 555 975 1126 1359 1476 1460 1395 1163 862
683 539 339 298 231 191 164 125 101 68 63 35 26 17 21 17 7
1995 3
0 0 0 1 0 0 0 0 3 5 4 25 58 94 95 206 326 380 603 730 970 1130 1065 1028 798 740 551 467
356 233 183 98 74 48 33 20 19 8 5 7 8 4 1
1995 4
1 0 0 0 0 0 0 0 0 0 2 2 6 12 30 76 154 253 314 364 623 819 1033 930 798 742 580 475 352
243 165 92 90 68 28 25 9 3 4 3 0 1 0
1996 1
1 1 0 0 10 132 175 40 60 180 275 181 150 172 222 163 241 376 454 481 739 955 1020 907
883 856 730 677 405 280 225 190 120 78 56 42 27 15 9 7 2 3 0
1996 2
0 0 0 0 0 7 10 2 5 13 13 36 67 79 111 170 236 286 346 464 588 749 907 1029 991 914 764
674 498 433 320 272 186 130 89 74 31 19 14 3 8 3 0
1996 3
0 0 0 0 0 0 0 1 4 6 6 7 32 69 123 194 307 422 545 812 1034 1144 1032 1047 956 841 702 519
417 301 210 177 94 92 49 58 33 22 23 15 16 9 4
1996 4
0 0 0 0 0 0 0 0 0 0 2 1 5 13 16 38 79 126 211 391 848 1296 1235 1090 847 839 834 674 541
407 279 226 165 116 63 31 17 13 7 2 2 1 1
1997 1
1 1 0 0 0 0 0 0 0 2 16 11 26 27 39 57 132 220 314 483 839 984 979 839 713 647 525 441 308
211 152 144 90 67 57 31 24 8 4 3 3 1 1
1997 2
0 0 0 0 0 1 1 0 0 1 13 33 84 86 101 154 284 413 536 678 933 1163 1255 1105 1007 930 860
900 668 559 474 392 321 223 161 125 75 54 25 16 12 4 3
1997 3
1 0 1 3 0 0 0 0 3 25 52 58 109 141 187 282 381 574 699 848 1263 1204 1244 1073 967 886
```

```
743 610 460 344 225 165 147 82 55 30 29 16 4 0 0 1 0
1997 4
0 0 0 0 0 0 0 0 0 0 0 0 0 1 7 32 54 100 120 180 294 362 421 484 446 503 442 330 269 171
161 118 77 69 72 43 38 33 11 8 6 2 0
1998 1
0 0 0 0 0 0 0 0 0 2 2 10 39 44 97 130 198 232 337 469 628 819 852 968 945 877 740 552
425 339 256 233 189 146 103 84 79 48 29 25 7 4 5
1998 2
0 0 0 0 0 0 3 1 1 2 7 37 104 222 378 432 646 684 741 789 1009 1108 1174 1334 1397 1333
1268 1073 795 600 399 316 242 187 117 110 62 37 23 12 10 10 5
1998 3
0 0 1 0 0 0 0 0 0 0 0 1 0 12 27 51 108 154 284 399 462 440 485 484 429 405 410 366 275
252 178 159 93 55 37 29 18 11 4 5 0 0 0
1998 4
0 0 0 0 0 0 0 0 0 0 0 0 0 1 10 24 69 176 395 558 590 580 486 471 403 380 343 315 312 273
173 179 121 116 67 64 36 14 10 5 6 1 1
1999 1
0 0 0 0 0 0 0 0 0 0 0 0 0 3 17 57 151 239 335 364 394 410 400 395 368 374 318 299 213
167 122 101 102 56 38 31 22 14 12 5 0 0 1
```

had.alkeys.sur and had.alkeys.catch

had.alkeys.catch contains data for distribution of the catch into length groups by age and had.alkeys.sur contains the same for a survey in March. Even though the survey is done in March it is put on the second step of the year for better results.

Here we have age-length information, so we can obtain an age-length key, i.e. provide information on the distribution of ages at a given length:

$$\pi_{al} = \frac{\hat{N}_{al}}{\sum_{j=1}^{n_a} \hat{N}_{jl}}$$

i.e. provide conditional probabilities of ages at length. Here, a is an age group, n_a is number of agegroups, l is length group or aggregation of length groups and $\hat{N}$ is model output of number of fishes.

The corresponding objective function is based on the likelihood function from the multinomial distribution so that:

$$l = 2\sum_{t,r,a}\left(\log N_{tra}! - \sum_{l=1}^{n_l}\log N_{tral}! - \sum_{l=1}^{n_l} N_{tral}\log \pi_{tral}\right)$$

where r is region (only one in this example), t is time or time step, l is length group or aggregation of length groups, a is an age group and N is number of fish according to the data file.

```
; had.alkeys.sur
CatchDistribution
functionnumber  1        ; The distribution of the data is multinomial, see above
overconsumption 1        ; Overconsumption of the stock is to be taken into account
minimumprobability   20  ; This is used if the outcome that occurs is very inprobable
fleetnames  survey
stocknames  had
areas    1
ages     1
         2
```

```
         3
         4
         5
         6
         7
         8
         9
         10
lengths 4.5  6.5  8.5 10.5 12.5 14.5 16.5 18.5 20.5 22.5 24.5 26.5 28.5 30.5 32.5 34.5
       36.5 38.5 40.5 42.5 44.5 46.5 48.5 50.5 52.5 54.5 56.5 58.5 60.5 62.5 64.5 66.5
       68.5 70.5 72.5 74.5 76.5 78.5 80.5 82.5 84.5 86.5 88.5 90.5
DistributionData
;
; Age length key for each year and step
;
1985 2     ; Year and step
;areas 1
0 0 1 10 82 55 50 35 13 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 ...
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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 1 3 11 10 20 11 33 27 27 39 13 13 9 9 2 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 1 0 0 0 3 0 1 5 2 2 2 4 0 0 0
1986 2
;areas 1
0 0 1 9 93 62 38 23 10 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 ...
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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 1 1 1 0 6 5 9 10 10 5 7 6 5 1 0
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;areas 1
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; had.alkeys.catch
CatchDistribution
functionnumber  1            ; The distribution of the data is multinomial, see above
overconsumption 1            ; Overconsumption of the stock is to be taken into account
minimumprobability      20   ; This is used if the outcome that occurs is very inprobable
fleetnames  commercialcatch
stocknames  had
areas    1
ages     1
         2
         3
         4
         5
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         7
         8
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        10
lengths 4.5  6.5  8.5 10.5 12.5 14.5 16.5 18.5 20.5 22.5 24.5 26.5 28.5 30.5 32.5 34.5
       36.5 38.5 40.5 42.5 44.5 46.5 48.5 50.5 52.5 54.5 56.5 58.5 60.5 62.5 64.5 66.5
       68.5 70.5 72.5 74.5 76.5 78.5 80.5 82.5 84.5 86.5 88.5 90.5
DistributionData
;
; Age length key for each year and step
;
1979 1                       ; Year and step
;areas 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
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1979 3
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 6 30 41 57 88 104 100 86 64 43 15 4 2 2 2 0 2 0 ...
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 9 17 24 14 29 27 18 25 14 22 4 5 5 2 1 0 1 0 ..
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 8 12 19 22 15 19 21 12 10 12 5 7 2 6 1 1 0 ...
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 4 5 10 24 29 33 40 25 24 26 21 15 18 11 7 4 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 2 1 4 1 6 1 3 2 3 1 3 3 4 1 1 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 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 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1998 1
;areas 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 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 3 5 13 6 3 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 1 1 1 18 28 35 25 18 7 4 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 1 0 2 16 16 22 45 55 77 73 68 37 18 8 9 1 1 0 0 0 ...
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 7 10 12 18 19 10 4 11 7 6 8 3 5 2 1 0 0 ...
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 5 7 9 20 15 7 12 9 9 2 3 3 3 4 1 2 1 1 0 ..
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 3 7 9 6 8 10 12 8 15 8 4 6 7 3 1 2 0 ..
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 3 1 2 3 3 2 1 2 1 1 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
1998 2
;areas 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 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 5 7 2 3 0 1 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 2 2 2 3 13 14 31 15 14 6 6 1 0 2 0 0 0 0 0 0 0 0 0 ...
0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0 0 1 1 6 5 19 23 21 28 37 25 31 20 10 3 1 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 1 0 1 2 0 2 5 10 7 8 11 11 7 7 3 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 2 3 6 9 8 8 8 1 2 2 2 2 2 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 2 2 5 10 8 6 5 7 8 6 7 4 4 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 1 1 2 1 2 1 1 1 0 1 0 0 0 0 1 2 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 1 1 0 0 0 0 0 0 0 0 0 0 0
1998 3
;areas 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 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 0 0 1 0 2 3 6 2 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 1 3 3 4 3 8 2 2 3 2 2 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 1 0 1 2 6 11 9 9 13 11 5 3 4 3 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 1 1 3 0 4 3 2 1 0 1 2 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 1 5 0 1 4 1 0 2 0 1 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 1 0 0 0 0 1 2 4 1 3 4 2 1 3 1 2 1 2 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 1 0 0 0 0 1 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
```

had.undersum

had.undersum lists when and where to check for understocking. This compares the catch by fleet in region to the biomass of the stock in that region to make sure there is enough stock in the region for the catch.

```
Understocking
fleets   commercialcatch
areas    1
; Check for understocking on every timestep
YearsAndSteps    all all
```

Survey indices

The files si10.dat, si15.dat, si20.dat, si25to45.dat, si50to60.dat and si65to75.dat contain stock indices from survey in March using abundance in numbers by length groups. The development of the stock is then compared to these indices.
The likelihoodfunction used here is

$$l := \sum_t \left[logI_t - (\alpha + \beta \log N_t)\right]^2 \qquad (3)$$

where t is time,I_t is survey index and N_t is the corresponding number of fish in a substock according to the model. The coefficients α and β can be estimated in a number of different ways.

```
; si10.dat
SurveyIndices
;
; One area and one stock as before
stocknames      had
areas            1
;
; Length of stock
;       minlength   maxlength
lengths   7.5        12.5
;
; Type of fitting.  In this case alpha is given, alpha := 0
fittype FixedSlopeLogLinearFit
        slope 1 ; beta is fixed
; year  step number
1985     1      258
1986     1      808
1987     1      286
1988     1      131
1989     1      361
1990     1      568
1991     1     1163
1992     1     1713
1993     1      642
1994     1      782
1995     1      171
1996     1      508
1997     1      217
1998     1      197
1999     1     2690
```

```
; si15.dat
SurveyIndices
;
; One area and one stock as before
stocknames      had
areas            1
;
; Length of stock
;        minlength  maxlength
lengths    12.5       17.5
;
; Type of fitting.  In this case alpha is given, alpha := 0
fittype FixedSlopeLogLinearFit
        slope 1 ; beta is fixed
;year   step   number
1985     1      20063
1986     1      91563
1987     1      20086
1988     1      12051
1989     1       8853
1990     1      64132
1991     1      76318
1992     1      16199
1993     1      18123
1994     1      48309
1995     1      25242
1996     1      64661
1997     1       5167
1998     1      15324
1999     1      61254
```

```
; si20.dat
SurveyIndices
;
```

```
; One area and one stock as before
stocknames     had
areas           1
;
; Length of stock
;         minlength   maxlength
lengths     17.5        22.5
;
; Type of fitting.  In this case alpha is given, alpha := 0
fittype FixedSlopeLogLinearFit
        slope 1 ; beta is fixed
; year  step   number
1985     1       7293
1986     1      29166
1987     1      31233
1988     1       4949
1989     1       1005
1990     1       8075
1991     1      19365
1992     1      17743
1993     1      12033
1994     1       9577
1995     1      15488
1996     1      29353
1997     1      11186
1998     1       7285
1999     1      15337


; si25to45.dat
SurveyIndices
;
; One area and one stock as before
stocknames      had
areas            1
;
; Length of stock
; Lower- and upperbounds for lengthgroups
lengths   22.5 27.5 32.5 37.5 42.5 47.5
;
; Type of fitting.  In this case alpha is given, alpha := 0
fittype FixedSlopeLogLinearFit
        slope 1 ; beta is fixed
;              meanlength in each group (cm):
;               25     30      35     40     45
; year step    number in each lengthgroup
1985     1    5133  23215    9342   6528  12473
1986     1   20835  61729   22758  24284  23844
1987     1  156384  99396   33107  67641  44081
1988     1   25268  45172   70499  85052  36930
1989     1   13139  15765   28700  39525  61166
1990     1   15439  18244   19364  24437  32072
1991     1   84926  47175   25437  16605  16046
1992     1  130716  69629   61084  44022  32443
1993     1   27178  91305  135966  76120  39347
1994     1   35937  38239   44761  69114  65634
1995     1   48748  32511   38138  31657  30999
1996     1   40790  48290   53746  52614  29638
1997     1   64325  55766   33424  26583  25228
1998     1   14937  40545   45178  37523  19824
1999     1   40917  46524   42300  34138  33980


; si50to60.dat
SurveyIndices
;
; One area and one stock as before
stocknames      had
areas            1
;
; Length of stock
```

```
; Lower- and upperbounds for lengthgroups
lengths   47.5 52.5 57.5 62.5
;
; Type of fitting.  In this case alpha is given, alpha := 0
fittype FixedSlopeLogLinearFit
        slope 1 ; beta is fixed
;              meanlength in each group (cm):
;                 50     55     60
;year   step    number in each lengthgroup
 1985     1    13501  14515   9964
 1986     1     8092   9865  10949
 1987     1    25936  18288  11062
 1988     1    30964  16704   8865
 1989     1    48066  20965  12361
 1990     1    35847  32501  17452
 1991     1    17646  17503  13337
 1992     1    16923  12675   9231
 1993     1    22645  11711   5238
 1994     1    35504  15189   6585
 1995     1    27208  13186   5080
 1996     1    25545  16964   9182
 1997     1    18984   9690   5269
 1998     1    13318   9891   5296
 1999     1    17344   8329   4767


; si65to75.dat
SurveyIndices
;
; One area and one stock as before
stocknames      had
areas            1
;
; Length of stock
; Lower- and upperbounds for lengthgroups
lengths   62.5 67.5 72.5 77.5
;
; Type of fitting.  In this case alpha is given, alpha := 0
fittype FixedSlopeLogLinearFit
        slope 1 ; beta is fixed
;              meanlength in each group (cm):
;                  65    70    75
; year  step    number in each lengthgroup
1985     1       6365  5528  3556
1986     1       7693  4167  2130
1987     1       9203  6239  2730
1988     1       4552  2076  1166
1989     1       5930  2948  1132
1990     1       7256  2921  1035
1991     1       7917  3474   945
1992     1       6585  4118  2101
1993     1       2961  1706   948
1994     1       2283  1236   533
1995     1       1940   769   371
1996     1       3602  1286   553
1997     1       2812   995   318
1998     1       2505  1167   505
1999     1       3192  1591   674
```

had.Nvpa.estim and had.Nvpa.fixed contain stock size numbers coming from normal VPA analysis on the same original data as is used in GADGET.

The likelihoodfunction used here is

$$l := \sum_t \left[logI_t - (\alpha + \beta \log N_t)\right]^2 \tag{4}$$

where t is time,I_t is survey index and N_t is the corresponding number of fish in a substock according to the model. The coefficients α and β can be estimated in a number of different ways.

```
; had.Nvpa.estim
SurveyIndices
stocknames had
areas 1
; There is only available data for 2-9 year old haddock
ages  2
      3
      4
      5
      6
      7
      8
      9
fittype LogLinearFit ; Type of fitting
; In LogLinearFit neither alpha nor beta are to be specified
;
; Number of fish for each age for each year and step
; The numbers here are estimated, more precision is used for actual running.
;
;year step  age 2       3          4          5          6         7         8         9
1979   1    82.86e+06 123.78e+06  27.71e+06  20.25e+06  21.46e+06  3.27e+06  0.76e+06  0.11e+06
1980   1    36.30e+06  67.69e+06  99.47e+06  19.02e+06  10.69e+06  8.84e+06  1.00e+06  0.20e+06
1981   1    9.65e+06   29.19e+06  54.17e+06  71.10e+06  11.71e+06  5.35e+06  3.90e+06  0.34e+06
1982   1    41.69e+06   7.90e+06  23.43e+06  39.91e+06  42.97e+06  4.22e+06  1.86e+06  1.58e+06
1983   1    29.83e+06  34.09e+06   6.21e+06  16.75e+06  23.06e+06 22.52e+06  1.42e+06  0.49e+06
1984   1    19.73e+06  24.42e+06  27.27e+06   3.74e+06   9.54e+06  9.68e+06 10.56e+06  0.39e+06
1985   1    41.34e+06  16.10e+06  19.32e+06  17.86e+06   2.01e+06  3.47e+06  4.55e+06  4.67e+06
1986   1    88.35e+06  33.46e+06  11.58e+06  11.34e+06   9.19e+06  0.89e+06  1.44e+06  1.52e+06
1987   1   165.82e+06  72.16e+06  24.08e+06   6.06e+06   4.88e+06  2.42e+06  0.29e+06  0.42e+06
1988   1    47.27e+06 133.74e+06  52.27e+06  12.98e+06   2.55e+06  1.98e+06  0.91e+06  0.11e+06
1989   1    26.44e+06  38.58e+06 100.41e+06  28.50e+06   5.63e+06  0.96e+06  0.72e+06  0.24e+06
1990   1    22.17e+06  21.58e+06  29.24e+06  61.47e+06  14.64e+06  1.83e+06  0.31e+06  0.15e+06
1991   1    79.86e+06  17.75e+06  15.32e+06  16.76e+06  29.02e+06  6.04e+06  0.74e+06  0.10e+06
1992   1   169.31e+06  63.16e+06  13.37e+06   9.00e+06   7.72e+06 11.57e+06  2.31e+06  0.25e+06
1993   1    37.04e+06 136.16e+06  45.09e+06   7.20e+06   3.66e+06  2.76e+06  4.18e+06  0.72e+06
1994   1    41.32e+06  30.13e+06 101.00e+06  25.57e+06   3.06e+06  1.40e+06  0.92e+06  1.41e+06
1995   1    76.32e+06  33.58e+06  21.94e+06  58.42e+06  11.35e+06  1.13e+06  0.47e+06  0.40e+06
1996   1    35.94e+06  60.36e+06  21.80e+06  12.87e+06  26.93e+06  4.29e+06  0.38e+06  0.15e+06
1997   1    98.00e+06  28.10e+06  41.33e+06  11.50e+06   6.28e+06  9.61e+06  1.34e+06  0.11e+06
1998   1    20.00e+06  78.94e+06  19.68e+06  23.84e+06   5.05e+06  2.87e+06  3.43e+06  0.48e+06
1999   1    55.00e+06  16.20e+06  56.70e+06  11.56e+06  12.29e+06  2.04e+06  0.96e+06  1.21e+06
```

```
; had.Nvpa.fixed
SurveyIndices
stocknames had
areas 1
ages  2
      3
      4
      5
      6
      7
      8
      9
fittype FixedLogLinearFit
        slope 1       ; value for beta
        intercept 0   ; value for alpha
;
; Number of fish for each age for each year and step
```

```
; The numbers here are estimated, more precision is used for actual running.
;
;year step  age 2       3          4          5          6          7          8          9
1979   1    82.86e+06 123.78e+06  27.71e+06  20.25e+06  21.46e+06  3.27e+06  0.76e+06  0.11e+06
1980   1    36.30e+06  67.69e+06  99.47e+06  19.02e+06  10.69e+06  8.84e+06  1.00e+06  0.20e+06
1981   1     9.65e+06  29.19e+06  54.17e+06  71.10e+06  11.71e+06  5.35e+06  3.90e+06  0.34e+06
1982   1    41.69e+06   7.90e+06  23.43e+06  39.91e+06  42.97e+06  4.22e+06  1.86e+06  1.58e+06
1983   1    29.83e+06  34.09e+06   6.21e+06  16.75e+06  23.06e+06 22.52e+06  1.42e+06  0.49e+06
1984   1    19.73e+06  24.42e+06  27.27e+06   3.74e+06   9.54e+06  9.68e+06 10.56e+06  0.39e+06
1985   1    41.34e+06  16.10e+06  19.32e+06  17.86e+06   2.01e+06  3.47e+06  4.55e+06  4.67e+06
1986   1    88.35e+06  33.46e+06  11.58e+06  11.34e+06   9.19e+06  0.89e+06  1.44e+06  1.52e+06
1987   1   165.82e+06  72.16e+06  24.08e+06   6.06e+06   4.88e+06  2.42e+06  0.29e+06  0.42e+06
1988   1    47.27e+06 133.74e+06  52.27e+06  12.98e+06   2.55e+06  1.98e+06  0.91e+06  0.11e+06
1989   1    26.44e+06  38.58e+06 100.41e+06  28.50e+06   5.63e+06  0.96e+06  0.72e+06  0.24e+06
1990   1    22.17e+06  21.58e+06  29.24e+06  61.47e+06  14.64e+06  1.83e+06  0.31e+06  0.15e+06
1991   1    79.86e+06  17.75e+06  15.32e+06  16.76e+06  29.02e+06  6.04e+06  0.74e+06  0.10e+06
1992   1   169.31e+06  63.16e+06  13.37e+06   9.00e+06   7.72e+06 11.57e+06  2.31e+06  0.25e+06
1993   1    37.04e+06 136.16e+06  45.09e+06   7.20e+06   3.66e+06  2.76e+06  4.18e+06  0.72e+06
1994   1    41.32e+06  30.13e+06 101.00e+06  25.57e+06   3.06e+06  1.40e+06  0.92e+06  1.41e+06
1995   1    76.32e+06  33.58e+06  21.94e+06  58.42e+06  11.35e+06  1.13e+06  0.47e+06  0.40e+06
1996   1    35.94e+06  60.36e+06  21.80e+06  12.87e+06  26.93e+06  4.29e+06  0.38e+06  0.15e+06
1997   1    98.00e+06  28.10e+06  41.33e+06  11.50e+06   6.28e+06  9.61e+06  1.34e+06  0.11e+06
1998   1    20.00e+06  78.94e+06  19.68e+06  23.84e+06   5.05e+06  2.87e+06  3.43e+06  0.48e+06
1999   1    55.00e+06  16.20e+06  56.70e+06  11.56e+06  12.29e+06  2.04e+06  0.96e+06  1.21e+06
```

had.bounds.lik

had.bounds.lik contains list of the marked variables, that is the actual parameters for GADGET. Any parameter must be listed here. The variables in the input file must be in the same order as they are listed here.
Here upper- and lowerbounds for the variables are also defined here. Furthermore, if a variable is given a value, x, that is lower than lowerbound, it gets the value

$$W_1(x - lowerbound)^P$$

If the variable is given a value, x, that is higher than upperbound, it gets the value

$$W_2(x - upperbound)^P$$

where W_1, W_2 and P are listed in the file as well.

```
BoundLikelihood
;
;marked var. - lowerb. - upperb. - P - W1  -  W2
900            1         10        2   10000  10000
901            5         20        2   10000  10000
567            0.1       5         2   10000  10000
2              0.001     0.1       2   10000  10000
3              0.001     0.1       2   10000  10000
4              0.001     0.1       2   10000  10000
5              0.001     0.1       2   10000  10000
6              0.001     0.1       2   10000  10000
7              0.001     0.1       2   10000  10000
8              0.001     0.1       2   10000  10000
9              0.001     0.1       2   10000  10000
378            0.2       34        2   10000  10000
379            0.2       34        2   10000  10000
380            0.2       34        2   10000  10000
381            0.2       34        2   10000  10000
```

```
382            0.2       34        2   10000  10000
383            0.2       34        2   10000  10000
384            0.2       34        2   10000  10000
385            0.2       34        2   10000  10000
386            0.2       34        2   10000  10000
387            0.2       34        2   10000  10000
388            0.2       34        2   10000  10000
389            0.2       34        2   10000  10000
390            0.2       34        2   10000  10000
391            0.2       34        2   10000  10000
392            0.2       34        2   10000  10000
393            0.2       34        2   10000  10000
394            0.2       34        2   10000  10000
395            0.2       34        2   10000  10000
396            0.2       34        2   10000  10000
397            0.2       34        2   10000  10000
398            0.2       34        2   10000  10000
399            0.2       34        2   10000  10000
403           -100     - 1         2   10000  10000
404            0.1       10        2   10000  10000
401           -100     - 1         2   10000  10000
402            0.1       10        2   10000  10000
```

Files for minimization

mainconstants, simconstants, hjconstants, bfgsconstants contain magic constants used in minimization algorithms.

```
Constants that are used in paramin.cc:

This file may not contain any numbers that are not being used, and there always have to
be space after each number.


Maximum number of variables:
  int NUMVARS = 200
Size of vm, the step length vector for simulated annealing:
  each component of vm = 10.0
Size of the step length adjustment for simulated annealing:
  each component of c = 2.0
Starting temperature for simulated annealing.
  int T = 2000000
Number of iterations for one running of simulated annealing:
  int sim_iter = 30000
Total number of function evaluations used by Hooke & Jeeves:
  int hooke_iter = 30000
Halt criteria (is not in use):
  double EPSILON = 0.5
Scaling parameters:
  int scaling = 0
Which minimization methods should be used:
  int SA = 1
  int HJ = 1
  int BFGS = 1



"Magic" constants needed for the running of Simulated Annealing.

For the numbers to be read correctly, do not write any other numbers before any of the
constants here in this file - then the computer will read that number instead of the
right one.


The number of times through function before V adjustment (see
mainconstants)
```

```
  NS = 20
The number of times through NS loop before temperature reduction.
  NT = 100
Number of times that epsilon tolerance is achieved before termination.
  NEPS = 4
Temperature reduction factor.
  RT = 0.8
Epsilon, used for halt criteria.
  EPS = 0.00001


"Magic" constants needed for the running of Hooke&Jeeves.

For the numbers to be read correctly, do not write any other numbers before any of the
constants here in this file - then the computer will read that number instead of the
right one.


Halt criteria:
  epsilon = 1e-5
Maximum number of iterations per minimization:
(this should be the same number as in the file mainconstants)
  MAXITER = 30000
Initial value of rho: (resizing multiplier for the stepsize)
  rho = 0.8


"Magic" constants needed for the running of BFGS.

For the numbers to be read correctly, do not write any other numbers before any of the
constants here in this file - then the computer will read that number instead of the
right one.

Max iterations for each bfgs-minimization:
 MAXITER = 1000
Error tolerance for termination criteria (gradient related):
 ERRORTOL = 0.01
Tolerance for x:
 XTOL = 0.000001
Max number of minmizations:
 MAXROUNDS = 50
Scale direction vector (Shannon Scaling):
 SHANNONSCALING = 0
Gradient calculations (difficulity level) :
 DIFFICULTGRAD = 1
Use bfgs (I) or steepest descent (O):
 BFGSPAR = 1
Magic constants for armijo-linesearch:
 BETA = 0.3
  SIGMA = 0.01
```

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