FRS: ROAME FINAL SCIENTIFIC REPORT

1.	**Project Number:**		MF0761
2.	**Project Title:**		Spatially explicit model for Haddock populations in northern UK waters
3.	**Project Leader**	**Name:** **Phone:**	W. Gurney and K. Preedy (University of Strathclyde, e-mail bill@stams.strath.ac.uk, tel: 0131 548 3385) Contact at Marine Scotland, M.Heath (e-mail heathmr@marlab.ac.uk, tel 01224 876544)
4.	**Marine Directorate Customer Division:**		Sea Fisheries (Conservation)
5.	**Marine Directorate Contact**	**Name:** **Phone:**	Andrew Brown
6.	**Start and End Dates:**		1 September 2006 – 31 August 2009
7.	**Date of Agreed Proposal:** *(Date proposal agreed with customer)*		28/08/2006
	Date of This Document:		18/11/2009
8.	**Keywords:**		Haddock, population, assessment

9. Policy Rationale

Completed by, or in consultation with, policy customer. This section should repeat the information given in the original ROAME proposal.

In terms of management, the incidence of sporadic massive recruitment years of haddock causes problems for the conservation for other species. For example, diversion of fishing effort from the cod closure boxes in 2001, implemented to conserve cod, led to discarding of juvenile haddock from the massive 1999 year class, and strident complaints from the fishing industry. Lacking any spatial modelling capability for haddock, the advice that FRS was able to deliver was solely dependent on survey data and the large scale regional assessments. There is a need for a scientific model of haddock which resolves space and size, so that spatial patterns in the abundance of sizes likely to be discarded can be predicted.

10. Policy Objective *Only available for ROAMEs starting in 2007 onwards.*

Completed by, or in consultation with, policy customer. This section should repeat the information given in the original ROAME proposal

The policy objective of the project is to determine the exploitation strategy (mesh size, spatial pattern, response to strong year classes) which will enhance the conservation of haddock.

11. Scientific Rationale

This section should repeat the information given in the original ROAME proposal

Whilst the main focus of concern and research in Europe about declining groundfish stocks has been on cod, the more significant species for Scotland has always been, and remains, the haddock. The distribution of haddock in the northern North Sea and west of Scotland waters, means that the Scottish fleets are the major exploiters of this species.

Unlike cod, haddock stocks have been sustained by sporadic massive recruitments, separated by years with low or negligible recruitment, typically 10% or less of the massive years. There is no evidence of a simple underlying relationship between the number of eggs produced and subsequent recruitment. This is in contrast to cod, where there is some evidence of a relationship, sufficient that we can also demonstrate that the relationship itself is significantly correlated with sea temperatures. Haddock born into the massive year classes exhibit slower growth rates than those born into lean years, suggesting that competition for resources is a significant issue for juvenile haddock. There is less evidence of such a relationship for cod. Thus, the age structure and dynamics of haddock are radically different from those of cod.

Another key difference between haddock and cod lies in the rate of maturation. A high proportion of haddock mature precociously at age 2, but their specific fecundity (number of eggs produced per kg of fish) is approximately half that of the later age classes. There are suspicions that these eggs produce less viable larvae than those from older fish. However, because of the sporadic massive recruitment, in some years a very high proportion of the spawning fish are precocious 2-year olds. The consequences for the population dynamics might be significant, but we cannot meaningfully assess this without a spatial population dynamics modelling framework.

DEFRA funded project MF0427 (Population dynamics models of European Cod stocks; CEFAS, Strathclyde, FRS and DARD) resulted in the production at Strathclyde University of a spatially resolved model of cod population dynamics (STRATHCODY) for the whole European shelf (Andrews et al., 2006). The model is capable of delivering assessments, and in principle forecasts, of the spatial distribution of fish age and/or length class abundances for any time reference period. In contrast, the assessment and forecast models available to ICES Working Groups are unable to deliver such data. STRATHCODY represents a major step forward in the approach to fish population modelling.

Thus, the purpose of this project is to re-engineer STRATHCODY to represent haddock stocks across the European shelf (STRATHADDY). This will involve us in thoroughly reviewing the biology and ecology of haddock and how this may differ from cod, and then re-designing the model to reflect these differences. At the same time, we shall update the hydrodynamic input to the model with data from more up-to-date hydrodynamic model at the NERC Proudman Oceanographic Laboratory in Liverpool.

References:

Andrews, J.M., Gurney, W.S.C., Heath, M.R., Gallego, A., O'Brien, C.M., Darby, C., and Tyldesley, G. (2006). Modelling the spatial demography of cod on the U.K. continental shelf. *Canadian Journal of Fisheries and Aquatic Sciences 63, 1027-1048.*

12. Science Objective and Description

This section should repeat the information given in the original ROAME proposal

The objective of this project will be to re-design the spatially resolved model of cod population dynamics produced by MF0427 to represent haddock in European waters. This development will transform our ability to deliver advice on the spatial structure of haddock stocks and to properly address the collateral implication for haddock stocks of conservation measures proposed for the protection of other species such as cod. Hence, the project will be strongly focussed on raising the quality of advice for a species of key importance to the Scottish fishing industry.

The aim of the project is to understand the biological processes that affect the abundance and distribution of haddock in the North Sea and around the west of the UK. As a result of the project we expect to be able to advise on optimisation of the collection of data to monitor the state of haddock stocks, and on the spatial and temporal variability in key factors (reproduction, recruitment and mortality) that affect predictive models of the state of stocks under different harvesting strategies.

The project will have links to FRS ROAME MF0464 (Metapopulation structuring within gadoids in the northeast Atlantic), and draw heavily on past results from the EU-STEREO project (C648) and associated ROAME MF0462 (Reducing uncertainty in fish stock assessments: improving stock recruitment relationships).

The initial scientific objectives of the project were to:

1. To devise, implement and test a discrete space- time- model of the demography of haddock in the region from 45N to 65N and 9E to 15W over the time period 1970-2006.
2. To obtain, quality control and document temperature and flow field output from a general circulation model (POLCOMS) for the study region over the study period
3. To generate transfer matrices from these data of a suitable form to act as physical drivers for the STRATHADDY model, and to quality control the resulting physical predictions.
4. To conduct a literature survey concerning haddock diet and recommend an appropriate choice of metric to parameterise food availability for haddock at various life-history stages.
5. To produce a spatio-temporally resolved representation of the chosen metric over the study area during the period 1970-2006.
6. To obtain, quality control and document an internally self-consistent series of length resolved abundance data for haddock in the study region over the study period.
7. To make multi-decadal simulations of haddock abundance and test these against the spatial abundance data.
8. To develop revised model structures to optimise fit to the test dataset.
9. To develop simplified model structures to provide acceptable fit quality within a management paradigm.
10. To train FRS staff in the use and adaptation of the haddock population model.

13. Resources: Annual Costs

Year	Out-turn costs				
	Staff Including overtime and overheads	**Travel & Subsistence**	**Consumables**	**Ships** Inc. charters, sea allowances	**Total**

Total					

14. Additional research funding gained: *(Funding that contributed to this project)*

Brief description of level of funding and type of work | *Period of contract*

Natural Environment Research Council (NERC) grant
Sustainable Marine Bioresources Initiative

£114,363 (Strathclyde share) to support a Post-doctoral Research Assistant at Strathclyde University

Principal Investigator: Gary Carvalho (Bangor)
Co-Investigators & Partners: Douglas C. Speirs, William S.C. Gurney (Strathclyde), PeterWright & Michael R. Heath (FRS), Martin Taylor (Bangor), Clive Fox (SAMS), Peter Wright (FRS), Bill Hutchinson (Hull), David Righton (CEFAS), Julian Metcalfe (CEFAS) Einar Nielsen (Danish Institute for Fisheries Research).

Project Title: *Population structuring of cod around the UK; scale mechanism and dynamics*.

01/06/08-31/03/10

The project aims to integrate recent and new research using microsatellites, single nucleotide polymorphisms (SNPs), tagging studies, and otolith microchemistry across the UK fisheries laboratories (FRS, CEFAS & AFBI), at HEI's (Bangor & Strathclyde), a NERC Institute (SAMS). Data will be used with models based on earlier spatial models of cod stocks (STRATHCODY & METAFOR), and build on the techniques developed in this project on haddock, in order to address specific hypotheses of stock connectivity and the assessment of fisheries management decisions.

15. Scientific Report

This should provide a comprehensive picture of the outcome and achievements of the project to provide a complete record of work carried out by FRS in a readily accessible format and, together with any related scientific papers, will form the basis of information for peer reviews. The scientific report will be much more detailed than reports required by policy customers

For some projects, an FRS report may form the bulk of the scientific report. Many projects will have associated publications or contract reports. These should be annexed to the report to avoid duplication of effort. Further annexes can be added as work is published or contract reports completed.

Where a project scientific report has many annexes containing publications and contract reports, this scientific report may form a covering document that explains the overall aims of the project and the contribution made by associated contracts.

Where work has been carried out but is not included in other publications or reports, details should be included in this scientific report. The report should be succinct and readable but include sufficient detail on materials and methods that the work could be repeated if required. Standard methodologies should be referenced but innovative procedures should be detailed, preferably in an annex.

In summary, the ROAME Scientific Report should:
- *Be a complete record of work carried out in that project and associated contracts*
- *Record achievements against the original scientific objectives of the project*
- *Have sufficient detail to allow methods to be repeated if required*
- *Be succinct and readable*
- *Use publications and reports in annexes to avoid duplication of effort*
- *Be sent to the Data Manager to be placed on the shared drive in the folder 'ROAMEs_Contracts_SLAs' and to be sent for peer review*

Year 1. September 2006-March 2007

Milestone 1 (March 2007): Devise, test and document an initial space-time model of the demography of haddock -- COMPLETED.

The initial stage of the model was to undertake a prototype conversion o fthe pre-existing cod spatial model into a haddock model, merely by altering various biological parameter settings, to see what results could be obtained. The cod model operated in discrete space-time with a basic structure inherited from earlier work on *Calanus finmarchicus* (NERC – MARPROD) and cod (MF0427). At this stage we made various refinements to increase the realism and efficiency of the model, in particular, individual variation in growth and size at maturity were introduced.

Spatial mixing in the original cod model was driven by output from the Statistical North Atlantic Circulation Model (SNAC). In this project, we explored the validity of three different circulation model outputs as potential mixing drivers for the haddock model (POLCOMS output provided by the Proudman Oceanographic Laboratory, OCCAM output provided by NOC Southampton, and the HAMSOM/SNAC data provided by the University of Hamburg). By means of comparisons with drift buoy and current meter data, we determined that for the region of interest in this project, the POLCOM data provided the most realistic estimates of mixing between spatial cells in the model.

Mixing rates of eggs and larvae between spatial grid cells in the model is introduced by means of transfer matrices derived from the ocean circulation data sets. A transfer matrix, expresses the proportion of drifting particles present in a grid cell on a given date which are found in all other cells in the domain on some later date. A matrix for each date in a model run is required, and these are generated off-line by running a particle tracking model from the POLCOMS flow data sets.

To develop the model from a prototype to a fully operational state, further development was required. We developed a plan to analyse the bathymetry and sedimentology of the EU shelf to obtain improved estimates of the spatial variation of carrying capacity. An improved description of the effects of temperature and food on growth, and of the spatio-temporal food distribution, needed to be estimated by fitting the model to IBTS abundance and size-at-age data.

Year 2. April 2007 – March 2008

The aim of STRATHADDY is to produce a spatially resolved model of haddock populations on the north sea shelf for the period 1970-2006. However, in some areas, particularly in the early years and on the west coast, there is very little data and what exists tends to be of poor quality. A simple empirically fitted model is only as good as the data it is fitted to so a good mechanistic model is likely to offer more insight into the processes driving the distinctive fluctuations in haddock populations.

It was clear from the prototype model produced in March 2007 that the population regulation processes assumed for cod, cannot generate the patterns of extreme recruitments interspersed by very low recruitments that are seen in haddock. Hence, critical aspects of the life history of haddock have different regulating processes than cod. To explore the inherent dynamics of different candidate regulating mechanisms a strategic model was developed. It suggest that a combination of spatial exclusion of settlers by immature haddock and spawning migration by adults is a candidate driver for occassional peaks in recruitment.

Th staretgic model was extended to a simple 2 dimensional domain with both single and multiple spawning grounds. When multiple spawning grounds were included occassional years of massive recruitment were observed followed by varying numbers of low recruitment years. The frequency of strong recruitment years was strongly related to haddock growth rates.

Generation of transfer matrices from POLCOMS data, started in 2006-2007, was completed and POLCOMS data were made available to individuals at FRS. Transfer matrices enabled us to test the strategic model on the North Sea shelf domain. We found that, on an intra-annual basis, the distribution of biomass, and young recruits is compatible with that suggested by trawl survey data.

In preparation for migrating the strategic model to an explicit model of the European Shelf Seas, generation of transfer matrices from POLCOMS data, started in 2006-2007, was completed. Bathymetric data were used to construct initial maps of settlement capacity, to be refined by the resolution of different sediment types using data from the British Geological Surveys.

Preliminary analysis of length and age data from survey and landings suggests that there is a complex combination of factors which influence spatial and temporal variability in growth rate. Therefore a rigorous statistical analysis of IBTS data was undertaken in order to gain a better understanding of the interaction between haddock density, recruitment and growth rates on a global and local scale. In the course of this analysis it has become apparent that there are years and areas for which data are scarce and methods have been developed to address this problem through statistical modelling of age length keys. When finished, the work will be submitted for publication in a peer reviewed journal and the keys will be made available to FRS. Initial parameters for catchability and growth rates have been derived using simple smoothing of age length keys from the raw IBTS data.

There are various parameters in the model which cannot be derived directly from the data. These will be optimised to fit the existing data for fish abundance from 1965-2006 and to this end maps of fish abundance at length were constructed from data supplied by ICES. This was done by estimating the density of fish in each stat square from the bottom trawl survey data, for which an estimate of catchability at length was required. There are estimates of catchability in the literature but these have been developed from age-based data and converted to length based using poorly constructed age-lenth keys. We developed an alternative method to estimate of catchability at length of haddock by the GOV gear, using Markov Chain Monte Carlo methods to minimise the difference between survey estimates of population abundance at age, and assessment VPA estimates. This method was also used to investigate years in which the Aberdeen 48ft trawl waas been used for surveying, and so gain catchability estimates for that gear as well.

In summary, a model has been constructed which offers a canditate regulating process for occassional years of massive recruitment and which is consistent with observed patterns of fish distribution. Abundance maps against which to test the model and have been constructed for years post 1980 and the data from before then is being cleaned so that the same can be done for earlier years. Problems with the age-length keys have been addressed using statistical modelling methods. The length and age data has been rigorously examined to tease out the interactions between haddock population density, growth rates and recruitment and a strong correlation is found between numbers recruited in any given year and the growth rate of that cohort.

Year 3. April 2008 – March 2009

Analysis of age-length and catchability data

The analysis necessary to asses the validity of model predictions and drive the iterative process of model refinement has led to a number of ancillary benefits. A statistically rigorous method of producing and comparing robust age length keys has been developed. A paper on this method is, at present, under review at Fisheries Research. R code has been developed to generate the keys and staff at Strathclyde will present a seminar on the method at the convenience of those at FRS who have an interest in utilising the techniques. In addition to this, a rigorous method of estimating catchability at length had been developed and a paper is in preparation for the ICES Journal of Marine Science.

Range expansions, growth rate and year class strength

Inter-year class differences in growth rate are a distinctive feature of North Sea and west of Scotland haddock, and it has been suggested that these may be related to year class strength. The mechanistic model described in the 07/08 report was therefore refined using escalator boxcar train methods to allow investigations of inter-cohort variability in growth rates. To investigate the processes involved, further analysis of the IBTS data was undertaken to define candidate mechanisms for geographic time invariant control of growth rates. In the course of this it was established that population range expansion to the southern half of the North Sea occurs in years following strong recruitment. Two alternative hypotheses can then be proposed, 1) reduced growth rate at the population scale occurs as a result of range expansion into areas of less suitable habitat, 2) reduced growth rate at the population scale occurs as a result of competition for resources even in areas of prime habitat.

The data analysis showed that:
1) range expansion is limited to the largest size classes of fish.
2) the correlation between year class strength and mean length at age of cohorts is seen at the level of round fish areas as well as at the whole population level. Indeed it is strongest in roundfish area 1 in the northern North Sea.

Hence, it is apparent that the effects on growth rate are occurring at a local scale and the hypothesis of large scale range expansion being the driver behind the slower growth rates in strong year classes can be rejected.

Further analysis has shown that there is no significant correlation between year class strength and variance of length at age, but there is a significant negative correlation between year class strength and mean length at age. The first three years of growth were analysed and the effect persists up to the age class three when virtually all fish are mature. This would suggest a negative correlation between year class strength and size at maturity. The effect was apparent not only at the North Sea scale, but also down to the level of roundfish areas.

Range expansion of haddock into the Irish Sea

During the mid-1990's haddock colonised the Irish Sea and supported a fishery. There has been much debate as to whether this colonisation represents a transport of eggs and larvae from spawning off the west of Scotland, or an active migration of established fish. The outcome of this question has considerable influence on the representation of process in the spatial model of haddock that is being developed in this project.

Inspection of long-term landings data from ICES subarea VIIa (Irish Sea) suggests that colonisation of the Irish Sea in the mid 1990's may, in fact, have occurred before. It is clear that in quarter 4 of the years before large numbers of young fish are found in the Irish Sea, the landings of large haddock are also substantially higher. There are insufficient data for rigorous empirical analysis, but analysis of temperature data suggests that the temperature in the Irish Sea dips to a minimum immediately prior to the two pulses in landings data. On face value, these findings might suggest that expansion into the Irish Sea is an active response by adult fish in response to cool temperatures, rather than an advection of eggs and larvae. The model is being used to investigate possible links between local temperature fluctuations and the distribution of haddock on the west coast of Scotland and in the Irish Sea. In collaboration with FRS, the links between temperature and growth rate are being incorporated into the model and a variety of hypotheses about spawning migration are being considered.

Spatially resolved haddock fishing mortality rates

A key aspect of the model, and a key management issue that the model will be used to address, concerns the spatial and length distribution of fishing mortality rates. In order to fit the model to spatially resolved landings and/or distributions of haddock, we require spatial data on mortality rates. In order to address management issues such as the effects of changing mesh sizes, we need data on the length dependence of mortality rates.

The only readily available data on fishing mortalities are from the annual ICES stock assessments, which are in the form of annual age-specific mortalities resolved by the whole North Sea and the west of Scotland regions. Disaggregating these by space, and converting to length specific rates, requires an assessment of trawl survey, landings and discard abundances by length class.

The approach taken was to derive year-specific, length specific fishing mortality rates for each roundfish data collection area of the North Sea and west of Scotland. For each year, the starting point was the regional (North Sea, west of Scotland) catch (landings + discards) and stock numbers at age specified by the ICES assessments. These were first converted to catch and numbers in length classes by reference to regional age-length keys. The regional values were then disaggregated to roundfish sampling areas by reference to annual quarter 1 survey relative distributions by length class (in the case of stock numbers), and Scottish annual landed and discarded numbers by length class (in the case of catch numbers). The latter assumed that non-Scottish fishery catches are distributed in proportion to Scottsh catches. The ratio of roundfish area catch and stock numbers at length provided the fishing mortality rate. Special cases had to be resolved where landings or discard data indicated catches of length classes which were not represented in the survey abundance data, or in areas where the surveys failed to catch haddock.

Year 4. April 2009 – August 2009

Key features of the haddock stocks in the North Sea and west of Scotland regions are a) highly fluctuating recruitment, b) retarding effect of cohort abundance on growth rate, c) distinctive spatial distribution of age/size classes, e) occasional spatial expansion of haddock distribution into the southern North Sea and Irish Sea. Particular issues for management attention are a declining trend in haddock abundance in the west of Scotland region since 2002/2003 despite declining fishing mortality, and high rates of discarding by the fishery of recruit haddock during extreme recruitment events. The management challenge is to find a fishing strategy which conserves strong year classes for future exploitation and reverses the decline of haddock in the west of Scotland.

Assessment data provide the demographic history of the haddock stock, showing a sequence of extreme recruitment years interspersed by extremely weak year classes. However, the mechanisms leading to such dynamics are not illuminated by the assessments. The first task of the project was to explore internal population processes that might lead to the observed patterns of fluctuating recruitment. Experiments with structural variants of the model incorporating different alternative but plausible biological explanations for recruitment fluctuations showed that whilst competition between incoming year class individuals and previous year classes, could cause recruitment dynamics which were reminiscent of the observations, no reasonable parameter values could replicate the magnitude of the variations, or their statistical pattern of occurrence in time. Further experiments showed that the magnitude and pattern could also not be accounted for by the addition of variability in egg and larval survival. The most likely factor, additional to inter-year class competition, was variability in the ecosystem capacity for settlement of pelagic juvenile haddock to the seabed. The area-specific settlement capacity (ASSC; biomass per unit seabed area) was therefore treated as a region-specific (North Sea, and west of Scotland) fitting variable.

Fitting of the model was undertaken using independently determined values for a) growth rate and natural mortality as functions of body length, b) year-specific data on egg and larval dispersal by ocean currents, and c) year-specific sub-area resolved data on fishing mortality rates at length. The model was then capable of very accurately reproducing the observed time series of spawning biomass and recruitment for the North Sea and west of Scotland, purely by fitting year-specific values of multipliers of the regional ASSC (which we refer to as the ASSCM). Population length distributions of haddock, the distribution of catch between landings and discards (depending on the regulations concerning minimum landing sizes), and spatial distributions of haddock recruits and SSB, were all emergent properties of the fitted model. The emergent population length distributions in the North Sea and the predicted discards and landings agreed very well with the observations from survey data and the MS-S discard sampling programme.

A key conclusion from the model fitting task was that although the retarding effect of cohort abundance on growth rate is demonstrably a real effect in the field, inclusion of this phenomenon in the model produced no discernible improvement in the predictive capability with respect to the emergent population length distributions and discard weights of fish. Hence, we conclude that although the effect occurs, it's effect is too small to have a significant consequence for the population dynamics of haddock.

Once fitted to the observed recruitment and spawning biomass time series, and the emergent properties of the system validated against the available observations, the model was used to explore the consequences of varying environmental and fisheries management conditions. The effect on the fit to historical time series was investigated for variations of ocean circulation, regional fishing mortality rates and, to simulate the effects of changes in mesh size regulations, eliminating catches below thresholds of body length.

Imposition of 1965 rates of fishing mortality throughout the period 1965-2006 resulted in little change in present day catch or discards, but a greatly reduced spawning biomass (~30% of present day). Imposition of 2002 fishing mortalities throughout the period resulted in increased present day spawning biomass, catch and landings in the North Sea. but not in the west of Scotland regions, compared to the realised values. Systematically varying regional fishing mortality rates up or down by up to 30% over the entire period 1965-2006, produced little change in the fit of the model to the observed time series, though the west of Scotland region was more sensitive than the North Sea. A 30% decrease or increase in west coast F produced an increase or decrease in spawning biomass, but little or no change in catch or landings. In contrast, limiting catch to fish larger than either 27 or 30cm (be setting F on length smaller than these values to zero), produced marked increases in both spawning biomass and catch, and decreases in discards.

The conclusion of these experiments with the model was that the haddock stock is almost entirely environmentally controlled, by variations in the area-specific settlement capacity of the ecosystem. Egg production and the surviving number of late-pelagic stage larvae are always sufficient to saturate the available settlement capacity, except under extreme depletion of the spawning stock. Hence, the observed recruitment appears independent of spawning biomass over the entire range of historically observed values. As a consequence, the haddock stock is largely buffered against variations in overall fishing mortality rate. The one management intervention that does have a significant impact on the population dynamics is the length distribution of fishing mortality. So, limiting fishing mortality to fish >30cm had a large effect on the spawning biomass and landings, and more or less eliminated discards.

The final stage of the project was to conduct a series of forecasting runs with the model. Starting from the fitted model state in 2006, the model was run forward for 50 years with different scenarios of fishing and ocean circulation. In each case, the ASSCM was treated as a stochastic driving variable, and annual values assigned by drawing at random from the de-trended time series of fitted values between 1965 and 2005. An ensemble of runs was performed for each forecast, so the results were presented as probability distributions of predicted recruitment, spawning biomass, catch, landings and discards for each year of the forecast. Compared to a base-line forecast assuming fishing mortality and ocean currents as in 2005, assuming 1990 ocean currents resulted in notable increases in spawning biomass, catch and landings from the west of Scotland, but not in the North Sea. 1990 was a year of strong transport of ocean water into the North Sea, so we expect a greater dispersal of west coast eggs and larvae into the North Sea under these conditions. Varying fishing mortalities by +/- 10% had little or no impact on forecasts compared to the base-line. However, setting fishing mortalities on fish smaller than 30cm to zero, and leaving mortalities on larger fish at 2005 levels, had a large impact on forecasts. Spawning biomass and landings were significantly increased in the North Sea and west of Scotland regions, whilst discards were greatly reduced.

Final outcome in relation to Policy Objectives

The policy objective of the project was to determine the exploitation strategy (mesh size, spatial pattern, response to strong year classes) which will enhance the conservation of haddock. To this end, the project has been successful in that the clear management relevant conclusion is that more or less the only intervention which is effective in affecting the haddock stock would be mesh size regulation. Eradicating catches of fish too small to be legally landed has a very marked conservation benefit, enhancing the spawning biomass and landings. This is especially a property of the haddock stock because the population dynamics are almost entirely regulated by the environment through the area-specific settlement capacity.

Final outcome in relation to Science Objectives

The main scientific objectives of the project were focussed on raising the quality of advice for haddock - a species of key importance to the Scottish fishing industry. The aim was to understand the biological processes that affect the abundance and distribution of haddock in the North Sea and around the west of the UK, and the pattern of inter-annual variability in recruitment. As a result of the project we aimed to be able to advise on the spatial and temporal variability in key factors (reproduction, recruitment and mortality) that affect predictive models of the state of stocks under different harvesting strategies.

The project addressed the various hypotheses concerning population regulation of haddock, and identified what appears to be the key property – variation in settlement capacity of the ecosystem. Our studies do not provide enlightenment as to what may cause inter-annual variation or trends in settlement capacity. If further research on haddock population dynamics is required then the clear message from this project is that it should focus on what aspects of the environment and its variability may affect haddock settlement capacity. Possible candidates could be distrurbance by trawling, temperature, biomass of predator or competitor species, or production of benthic fauna.

A most important feature of the model was that it can be run forward in time with different levels, spatial patterns and length structures of fishing mortality, and can be expected to predict the future statistics of recruitment and trends in population distribution and abundance, given scenarios of ocean circulation and environmental variability in settlement capacity. This means that the model can be used to explore the consequences of, for example, changes in mesh size for maximum sustainable yield, or the effect of closed areas or seasons for fishing. This capability is important with respect to designing spatial management measures to protect other species, such as cod, which may displace fishing effort into areas of dense concentrations of haddock.

Final outcome in relation to the originally stated measures for evaluating the project

The original ROAME document stated that …

1. The deliverable from the project will be a model that will allow the investigation of management scenarios for sustaining the haddock fisheries around the UK, these being if prime interest to Scotland. This would inform managers on the appropriate geographical scale for haddock fishery management and allow more meaningful exploration of the consequences of different fleet-based management options for the overall well-being of the stocks.

2. Since, the programme will be focused on channelling science into management advice as a deliverable not a justification, we must demonstrate engagement with the stock assessment process and community. To this end, FRS stock assessment scientists will interact with the project.

3. The involvement of FRS staff with direct experience of stock assessment working groups is subject to their availability. Their time is currently fully occupied by an increasing workload of advisory commitments, and FRS will have to address this issue to ensure the success of this project.

4. The scientific outcome of the ROAME will be measured in terms of scientific publications and presentations at international conferences.

The project was successful to varying degrees with respect to these measures…

1. With respect to producing a model for investigating haddock management strategies having a spatial dimension, the project was very successful. Since the model was cast in terms of size rather than age, it provides the additional capability to truly resolve the consequences of size-based catching patterns for discarding rates and for conservation of strong year classes, and the achievement of long term sustainable yields.

2. A number of assessment scientists at the Marine Laboratory have had a significant engagement with the project, mainly in terms of providing biological, ecological and fishery advice. In addition, there has been an important role in the project for assessment scientists in terms of mining out fishery and discarding data and developing new techniques for handling age and length data.

3. A weakness of the project has been the lack of engagement of assessment scientists in hands-on use of the model. This was due to shortage of core Marine Scotland – Science staff time to devote to developing a close, hands-on association with the modelling work being carried out a Strathclyde. This was identified as a strategic problem area from the outset of the project, to which no available solution could be found. The result is that although a new and potentially powerful research modelling capability has been developed, it cannot easily be taken into operational use by Marine Scotland staff, at least not without extensive support from the expert users in the University.

4. The project has produced four manuscripts in various stages of readiness for publication. One has been submitted to a journal and is currently being revised. The other three are expected to be submitted in the few months following completion of the project. So far, presentations have primarily been at SG and MS-S organised events, but as the main results of the work are written up, oral presentations will be taken out to a wider audience.

16.1 **Communication Outputs**

Give authors, date, title, journal, conference or meeting

Publications or presentations that are anticipated to follow this project should be included, such as manuscripts in preparation or planned.

Publications in refereed journals

None, but see below.

Published reports

Stari, A., Preedy, K.F., McKenzie, E., Gurney, W.S.C., Heath, M. and Kunzlik, P. A Method for calculating and comparing smooth age at length keys. Fisheries Research (undergoing revision)

A method for the calculation of catchability at length (early stage manuscript to be finalized for submission to a journal)

Change in occupancy of the Southern North Sea by large haddock (early stage manuscript to be finalized for submission to a journal)

Variations in the growth rate of North Sea haddock (early stage manuscript to be finalized for submission to a journal)

Katharine F. Preedy, Douglas C. Speirs, William S. C. Gurney and Michael R Heath . A Spatially Explicit Model for Haddock Populations in Northern UK Waters. (Prototype of manuscript for submission to Fisheries Research)

Information leaflets

none

Articles in trade journals/popular press

none

Presentations at lectures/meetings

FRS ROAME Review Day, 29th March 2007.

Presentations to the Industry

It should be made clear which stakeholders were included in communication during the project or in planned communications arising from the project

none

Other (specify)

16.2 Communication Routes

Explain why the selected routes of communication were chosen, e.g. publication in peer-review journals or internal reports, presentations at scientific conference or stakeholder meeting.

The work undertaken in this project fundamentally involved adapting an existing model (for cod) to represent a different species (haddock). Clearly, there were many intricacies to the task, for example the source of hydrodynamic data inputs was changed, and the fundamental biological processes which are important for haddock, are different from those for cod. However, the primary customer for the results was the SG, and hence the primary communication was via annual progress reports. Now, at the end of the project, there are clearly a number of significant scientific developments and results to report to the science community which we are doing by peer reviewed papers. Ultimately, the SG will need to decide whether and how the science messages from the work should be communicated to the industry.

Appendices:

1. Assessment of Oceanographic Models POLCOM, OCCAM, HAMSOM for tracking near-surface particles. Richard Inger, Bill Gurney, Dougie Spears, Graham Tyldesley (January 2007)

2. A Size Structured Model of Haddock Populations on the European Shelf. Kath Preedy, Bill Gurney, Dougie Spears. (September 2007)

3. Change in Occupancy of the Southern North Sea by Large Haddock. Kath Preedy (January 2009)

4. Variation in the growth rate of haddock cohorts in the North Sea. Traiani Stari, Katharine F. Preedy, Eddie McKenzie (January 2009)

5. A Spatially Explicit Model for Haddock Populations in Northern UK Waters. Katharine F. Preedy, Douglas C. Speirs, William S. C. Gurney and Michael R Heath

Draft papers to be sent for peer review:

A Method for the Calculation of Catchability at Length for Ground_Fish Survey Trawls. Katharine F. Preedy, William S. C. Gurney, Mike Heath, Traiani Stari, Helen M Fraser, Eddie McKenzie, Graham Tyldesley

A Method for Calculating and Comparing Smooth Age at Length Keys. Traiani Staria, Katharine F. Preedy, Eddie McKenzie, William S. C. Gurney, Mike Heath, Phil Kunzlik