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REPORT OF THE

ICES/GLOBEC WORKSHOP ON APPLICATION OF ENVIRONMENTAL DATA IN STOCK ASSESSMENT

Bergen, Norway
23–25 March 1998

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK-1261 Copenhagen K Denmark

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The workshop was held in accordance with C.Res. 1997/ 2:10: The ICES/GLOBEC Workshop on Application of Environmental Data in Stock Assessment (WKEDSA) will be held under the chairmanship of Mr O. Nakken (Norway) in Bergen, Norway from 23–25 March 1998 with the Terms of Reference as set out in C.Res. 1996/2: 11. WKEDSA will report to the OCC at the 1998 Annual Science Conference.

1 TERMS OF REFERENCE

a) Explore growth, mortality and distribution of juvenile and adult fish in relation to feeding conditions and the physical environment, particularly in relation to the influence of temperature and food abundance on such stock assessment parameters as

- Spawning stock biomass
- Fecundity
- VPA

b) evaluate the sensitivity of stock assessment models to environmental data

c) consider the role of statistical techniques including exploring autocorrelations.

The Working Group on Comprehensive Fishery Evaluation, The Multispecies Assessment Working Group and the Zooplankton Ecology Group were invited to co-sponsor the workshop.

2 PARTICIPANTS

M. Castonguay and D. P. Swain (Canada), J. M. Cabanas (Spain), C. Fox (United Kingdom), K. Brander (ICES), Ø. Ulltang, G. Blom, S. Skreslet, G. Ottersen, B. Bogstad, J. Chr. Holst, P. Fossum, K. Michalsen, H. Loeng, S. Sundby, B. Stensholt and O. Nakken (Norway).

Full names and addresses are given in appendix I.

3 WORKING PROCEDURE AND WORKING DOCUMENTS

Prior to the meeting K. Brander circulated material related to the question:

– How can we improve the application of environmental data to stock assessment?

The circulated material (Appendix II) also included data on several cod stocks (which can be obtained on request from Dr Brander - keith@ices.dk) and the executive summary of a recent NOAA workshop (Convenors: George Boehlert and Jim Schumacher).

The time table for the meeting is given in Appendix III. Thirteen working documents were presented and are attached to this report. In order to facilitate discussions three working groups were established, one for each term of reference, and given tasks related to the questions above as follows:

- WG 1: Providing appropriate data sets and developing «environmental indices» (temperature, wind, zooplankton, etc.) and showing how these can be applied.
- WG 2: Evaluating the sensitivity of stock assessment to environmental data and identifying promising examples for further study.
- WG 3: Commenting on statistical techniques including auto correlation and prediction of environmental variables.

Reports from the working groups are included in section 5.

4 ENVIRONMENTAL DATA AND STOCK ASSESSMENT

A brief description of stock assessment methodology and how environmental conditions may influence input data and parameters is given below together with some results from the working documents.

4.1 Stock assessment and input data

In most stock assessments estimates of stock numbers, N, and fishing mortalities at age, F, are obtained using cohort analysis (VPA-techniques). For the starting year of the analysis, usually the most recent year for which catch data are available, one has to assume or estimate a value for N or F, the so-called "terminal F-assumption". Often terminal F or N values are estimated using abundance indices at age, from surveys or commercial CPUE in relationships like:

$$I = q.\ N \text{ or } I = x.\ N^{\beta} \qquad \text{(I)}$$

where q, x and β are age specific "constants". q is often termed the catchability coefficient.

Input data to the VPA are catch number at age C, natural mortality rate at age, M, and abundance indices at age I. By iterations the VPA-technique generates for each cohort (year-class) the set of values of N and F which "best fit" the input data. The procedure produce estimates of N and F backwards in time for the period catches and natural mortality values are available. Prediction of stock numbers are obtained by taking the current stock number as the starting point and run the VPA forward in time. Estimates of the number of recruits are usually generated from relationships like (I) using the abundance indices of prerecruits as input.

Spawning stock numbers at age are found by applying the appropriate values of the fraction mature at age, m, to the estimated stock numbers, and biomass by multiplying the estimated numbers by the appropriate mean weights, w.

The dependency of the estimates of N and F in the various input data might be categorised as follows:

- Historic values of F and N, the converged part of the VPA, depend exclusively on catch data and natural mortality.

- Current and recent years estimates depend also on the survey indices, I, as well as the relationship used between these indices and stock numbers, N.

- Predicted values for stock numbers depend on current stock numbers and on number of recruits usually estimated from relationships of the type:

$$N_{recruits} = k \cdot I_{prerecruits}$$

where I_{pre} are survey indices and k is established by a regression procedure. For long term predictions of recruitment a spawning stock recruitment relationship is often used.

When preparing the time series of input data to a stock assessment the question thus is: To what extent have or may environmental impacts influence the time series of the input data, C, M, I, m and w?

4.2 Catchability

Since our perception of stock status entirely depends on the estimates of terminal F (or N), i.e., on the estimated catchability coefficient, it is important to investigate whether or not such estimates are influenced by environmentally induced catchability variations. Swain et. al (working paper) dealt with this aspect for cod in the southern Gulf of St. Lawrence. Survey catch rates in that area are correlated with indices of cod distribution and environmental conditions. This could reflect an effect on catchability. The information on distribution and environment was incorporated using VPA calibration tests as well as residuals from multiplicative analyses of survey catch rates. Neither of the two approaches provided support for an effect of cod temperature or depth distribution on catchability. It was therefore concluded that the correlations between survey catch rates and indices of cod distribution or environmental conditions did not reflect effects on catchability and that survey indices should not be adjusted based on these relationships. On the other hand Michalsen (working paper) indicated that the time series of Norwegian bottom trawl indices for northeast arctic cod was influenced by environment related changes in fish distribution and that adjustment of the survey indices should be considered. Smith and Page (1996) suggested that survey indices of cod in the eastern Scotian shelf should be adjusted because of changes in survey availability due to fluctuations in the extent of the cold intermediate water layer.

Recently Thorarinsson and Jóhannesson (1997) developed a framework for correcting for variations in catchability and applied the method for fluctuations in maturation of Icelandic cod. Similar methods could be developed to correct for environmentally induced catchability variations.

4.3 Natural mortality rate

In recent years estimates of the natural mortality rate have been based on prey-predator considerations and estimates of consumption for a number of stocks. The consumption is, among other things, dependent on the ambient temperature of the predator and consumption increases with increasing temperature. It is thus essential that the correct ambient temperature is used when calculating consumption. For north-east Arctic cod Michalsen (working paper) and Michalsen et. al (1998) have shown that the temperatures used in consumption calculations are 1–3°C higher than the ambient temperature in some years, indicating that consumption estimates might have been biased upwards by 10–40 percent. These results are of importance for assessments of several stocks in the Barents Sea because cod diet includes significant amounts of many commercially important species (capelin, redfish, cod, haddock, herring) as well as a wide range of size groups. Hence, in single stock assessments both the mortality rate used as well as the recruitment estimated from prerecruit surveys might be influenced.

4.4 Growth

The effect of temperature on fish growth is substantial as demonstrated in feeding experiments (Jobling, 1994 and 1995) and indicated by studies of field data for cod (see Brander 1995, Michalsen *et al.* 1998, Castonguay *et.al.* and Dutil *et.al* 1998 (working papers) for references). For example, 1°C increase in temperature during the feeding season will result in a weight gain of 10 percent for age 3–4 years old northeast Arctic cod (see later). Since interannual variations in ambient temperature might be as great as 4°C for 3 year olds decreasing to 2°C for older ages in this stock, this might have substantial effects upon stock biomass. This underlines the need for reliable ambient temperature values and predictions of such values for use in models predicting growth.

Most cod stocks in the Northwest Atlantic have experienced a decline in growth during the past 10–15 years and possible causes, including reduced sea temperatures, have been discussed by many authors (see references in working paper by Dutil *et.al*). Swain *et. al* (working paper) tested the effects of abundance and temperature on growth of cod in the southern gulf of St. Lawrence, but although there was evidence for effects of both temperature and abundance, growth models that incorporated these effects failed to predict the slow growth observed in recent years. (Castonguay *et.al* and Dutil *et.al* (working papers) suggested that reduced duration of the feeding period due to colder waters was partly or largely responsible for the growth decline of cod in the northern Gulf of St. Lawrence in the late 1980's early 1990's.

In Norwegian spring spawning herring, the condition factor has shown variations which relate to ocean climate (Holst, working paper). A decline in 1997 summer growth resulting in low weight at age in winter 1998 might be caused by reduced zooplankton amounts (production) during spring/summer 1997 as compared with previous years (Fossum, Dalpadado and Melle, working paper). It was thought that the timing of the spring bloom, which to a large extent determines the onset of the production period, and the duration of the feeding period for herring was important in this context.

4.5 Recruitment

There is a vast amount of literature on recruitment mechanisms in fish stocks including environmental effects, particularly temperature. For regular use in stock assessments such relationships must be quantified and have predictive power (Bogstad, working paper). In stock assessments predictions of recruitment as a rule are based on prerecruit survey indices (short and medium term predictions) and spawning stock-recruitment relationships (long-term predictions). For northeast Arctic cod Ulltang (1996 and working paper) suggested a methodology in which temperature and predation were incorporated in recruitment predictions; the number of 0-group mainly being dependent on spawning stock biomass (egg production, see later) and temperature, while predation, including cannibalism, determines the survival from 0-group to age 3 (recruits to fishery). In recent years the Arctic Fisheries Working Group has included cannibalism in the assessments and this has improved the fit between survey indices and VPA estimates.

Ottersen (working paper) showed that the lengths of 0-group cod, haddock and herring in the Barents Sea showed the same fluctuation patterns and were positively correlated with ocean temperature. New results also show that cod length and abundance at the 0-group stage are positively correlated. More interesting for assessments is the finding that 0-group length and abundance at age 3 shows a linear relationship for all three species; correlations being 0.6 for cod and haddock and 0.7 for herring.

For Irish Sea cod, which is at the warm limit of the range, Planque and Fox (working paper) found a negative relationship between cod recruitment and water temperature, and suggested that this should be taken into account in future predictions of cod recruitment.

Cabanas and Porteiro (working paper) demonstrated how year-class strength of Iberian sardine is affected by varying climatic conditions characterised by various indices (NAO, SOI, GULF, TEMA and SST). Of these the NAO index has the largest impact on sardine recruitment.

The substantial knowledge which exists on environmental impacts on recruitment in northeast Arctic cod and other stocks (see Ottersen 1996 and Skreslet (working paper) for references) is, however, difficult to utilise fully in assessments unless the key environmental variables can be predicted.

4.6 Spawning stock-recruitment relationships

Such relationships are used to estimate long term recruitment as well as biological reference points and safe biological limits (minimum biologically accepted level of spawning stock, MBAL). Usually these relationships are established from values of spawning stock biomass and numbers of recruits to the fisheries as generated by the VPA under the assumption that spawning stock biomass is approximately proportional to egg production. Investigations in recent years on northeast Arctic cod show large deviations from proportionality (Marshall et al. in press) because of variations in fecundity and maturation. Ulltang (working paper) therefore proposed to replace spawning stock biomass by egg production in spawning stock recruitment relationships, as also discussed by the AFWG (ICES, 1998). For use in regular stock assessment this would imply that a general relationship between egg production and routinely observed biological variables is quantified.

In accordance with suggestions in ICES Cooperative Research Report No. 185, (Figure 2.1.2) environmental effects are in recent years incorporated in spawning stock-recruitment relationships for some stocks, for example Baltic cod and Icelandic summer spawning herring and used in the assessments (Bogstad (working paper) and Jakobsson and Gunnarsson (in press)).

5 HOW TO IMPROVE THE APPLICATION OF ENVIRONMENTAL DATA TO STOCK ASSESSMENT?

5.1 Appropriate sets of environmental indices

In a stock assessment context appropriate environmental indices means indices which can be used to explain and predict variations in the input data series and parameters. A complicating factor is that the same environmental parameter may influence different stocks in different fashions either directly through physical forcing or indirectly through the ecosystem. Environmental influences might be divided into organismic, population and ecosystem influences. Appropriateness depends on the stock under study and what aspects of the stock are being studied. An environmental index series that is quite powerful in explaining recruitment or larval growth and/or survival, might be inadequate for use in growth and mortality (consumption) estimation at later stages.

Temperature

It is commonly agreed that the Kola temperature index is very useful in describing the fluctuations in the heat content of the inflow to the eastern part of the Barents Sea and positive correlations are established between that index and abundance and growth of 0-group fish. However, Ottersen *et.al.*, (1988) have shown that there are large discrepancies between the year to year variations in Kola temperature and the corresponding variations in the ambient temperature of cod. Hence, the Kola index series should not be used directly in bioenergetic models for the estimation of consumption and growth. For such purposes the spatial distribution (and migration) of the species, stocks and age groups must be considered.

The main temperature indices available in Eastern Canada are the Gulf of St. Lawrence cold intermediate layer (CIL) temperature index and the Station 27 temperature indices of St. John's, Newfoundland. The former has been positively correlated with cod growth although it appears that the relationship is indirect, through distribution changes of cod. An index of flow from the St. Lawrence river has also been previously correlated with lobster catches and cod and mackerel recruitment but these correlations typically work for a time period and then break down and the mechanistic basis of these relationships remains unknown. In Eastern Canada there is only one case where information from environmental indices has been used in stock assessment and then indirectly: In 1998 it was decided to change the annual instantaneous mortality rate in cohort analysis of cod stocks from 0.2 to 0.4 starting in 1986. The year 1986 was chosen in part on the basis of information from the CIL temperature index in the Gulf of St. Lawrence.

Zooplankton

In a stock assessment context zooplankton is important as food for the various stages (larvae, juveniles and adults) of the stocks which are being assessed. These stages usually have different food preferences (species and size groups) but they also often have quite different spatial distribution (migration, behaviour) patterns which have to be considered when «food indices» are to be established. Time series of standing stock of zooplankton are widely used as fish (and larvae) food indices. However, generally what is most needed are indices of zooplankton production. In the Gulf of St. Lawrence observed female zooplankton abundance provides a proxy for production of food for fish larvae.

Estimates of zooplankton production indices for the various parts of the feeding area of a stock, incorporating the seasonality aspect, would increase our ability to analyse, explain and predict fish growth and mortality, particularly for plankton feeders (capelin, herring). In these stocks it is to be expected that food shortage leading to reduced growth also indirectly will result in increased natural mortality at given levels of predator stocks. The recent decline in summer growth of Norwegian spring spawning herring offers a possibility for investigating to what extent zooplankton production indices are useful for predicting herring growth provided that such indices are established for the area.

An important product of stock assessments is the life history tables for the stock. Both input and output data series are given as matrixes with the dimensions age and time usually with one year as unit on both axis. Numbers (catch and indices of abundance), mean length and weight, mortality rates and maturation) are all given because they are required for cohort analysis. This makes it fairly easy to compare time series of the variables and/or parameters. Similar matrixes of relevant environmental indices (temperature, salinity, food availability, etc.)should be produced to facilitate the comparison of environmental indices and stock variables. The methodology needed for producing environmental indices in such a scheme on a routine basis must be developed in close cooperation between scientists from the various disciplines and fields of science with in depth knowledge of the particular stock(s) and its (their) environment.

5.2 The sensitivity of stock assessment to environmental data

In this context, stock assessment is taken to mean both estimates of current stock size and predictions of how the stock will develop given various exploitation rates.

The examples which are given here, explore the sensitivity of stocks to environmental factors, and in some cases go on to develop tools for taking account of the environmental factors in stock assessment. As stocks are reduced due to fishing, they will become less resilient to environmental fluctuations.

When determining the current stock size, temperature is used when models including predation are used (the stomach evacuation rate is temperature-dependent), and temperature and other oceanographic data may also be used to adjust abundance indices for incomplete spatial coverage (horizontal and vertical).

Working groups now usually give short/medium-term prognosis as well as investigating harvest control rules by performing long-term simulation studies. Risk analyses are carried out, meaning that the uncertainty associated with predictions of e.g., environmental variables can be included in the predictions.

The effects of the environment on a stock assessment should be included when they affect the outcome (e.g., estimated TAC or critical level of fishing mortality) in a practical way. Practical significance is not the same as statistical significance. A 50 % confidence limit (i.e., balance of probability in favour) should be enough to warrant including an effect, but the weight given to it when evaluating risks and uncertainties will depend on the level of confidence.

North-east Arctic cod

This stock has been extensively studied over the last decades. Recruitment to this stock has been shown to be affected by temperature as well as wind conditions. Growth rates of juveniles are affected by water temperature which may in turn affect survival up to 3 years old. Growth rates and food consumption rates of older cod are affected by water temperatures. A comprehensive overview of this is given by Ottersen (1996).

The consumption of various prey species by cod is calculated annually by the AFWG (ICES, 1998), and the method is described by Bogstad and Mehl (1997). The consumption estimates are taken into account in the assessments of cod and haddock (ICES, 1998) and capelin (Tjelmeland, 1997) in the Barents Sea. The consumption is dependent among other things on the temperature; a 1 degree increase in temperature leads to an 14 % increase in consumption. Thus, it is essential that the correct ambient temperature is used. Michalsen *et al.* (1998) have shown that the temperatures that have been used in consumption calculations are 1–3 degrees higher than the ambient temperature in some years.

Models which include the effect of environmental variables on growth, recruitment and maturation of cod are being developed. As an example of the scale of effect which can be expected we have roughly calculated based upon data in Michalsen *et al.* (1998) that a degree increase in ambient water temperature during the feeding season for cod will result in an increase weight gain of about 10 % (for age 3–4 years old fish). Since inter-annual variation in ambient temperature in this region may be as high as 4 degrees for 3 year old fish decreasing to 2 degrees for older fish, this will have a significant effect upon total stock biomass. The estimated effect on the biomass of age groups 3–5 using the stock composition from 1996 is an increase in biomass from 600 to 656 thousand tonnes with a 1 degree increase in temperature.

Baltic cod recruitment

The cod recruitment prediction model of Sparholt (1996), uses cod spawning stock biomass, sprat biomass (as predator on cod eggs), and reproduction volume as inputs. This model is now used in the medium-term predictions for Baltic cod made by the Baltic Fisheries Assessment Working Group (WGBFAS) (ICES 1997). These simulations were made using a mean sprat spawning biomass of 1.5 million tonnes and a mean reproductive volume of 107 km$^{3.}$ This gave a mean catch of 100–120 thousand tonnes and a spawning biomass of about 250,000 tonnes. A mean spawning volume of 50 km^3 will result in a substantial decrease of medium-term catch and spawning biomass levels at *status quo* F. An approximate doubling of catch and spawner biomass could be expected if there was a reproductive volume of 150 km^3. The observed range of reproductive volume between 1966 and 1992 was from 45 - 605 km$^{3.}$

Greenland cod recruitment

The existence of this stock probably depends to a considerable extent on transport of pelagic stages of Icelandic cod across the Denmark Strait and also on sufficiently high water temperatures to allow successful spawning and survival. These physical variables in turn maybe related to changes in wind fields between years (Buch *et al.* 1994). The strong dependence of this stock and fishery on environmental conditions has been recognised for a long time (see e.g., Jensen, 1939) and should be taken into account in strategic planning of the development and management of the fishery and any associated infrastructure.

Since very large numbers of Icelandic spawned cod also migrate back to Iceland from Greenland when they mature the consequences for the Icelandic fishery also need to be considered (Schopka, 1994).

Other examples

Examples where environmental variables are used in assessment of stocks in waters outside ICES areas, are: New Zealand snapper (Francis *et al.* 1997); prawns in the Gulf of Carpentaria, Western Australian rock lobster, south eastern Australian gemfish (Thresher, 1994)

Within ICES areas many assessments could probably be improved by including environmental variables. Some examples are:

Norwegian Spring-spawning herring relationship with temperature and plankton production (working documents to this meeting, Holst and Fossum *et.al.*)

Irish Sea cod recruitment and temperature (working document to this meeting, Planque and Fox)

North Sea sole distribution and mortality and winter temperature (van Beek, working document to the Working Group on Demersal Stocks in the North Sea and Skagerrak, 1997).

5.3 Statistical techniques including exploring autocorrelation and prediction of ocean temperature

5.3.1 Statistical approach

Statistical methods such as t and f-tests, correlation analysis, linear regression, ANOVA and many non-parametric tests all put assumptions on the data. These presumptions are only seldom met by biological time series. Autocorrelation, non-stationarity and non-normality may effect the analysis in such a way that the true level of significance deviates from the intended nominal level. Thompson and Page (1989) divide the appropriate ways to proceed into two groups. The first approach is to transform the data to meet the assumptions of traditional methods; the second to apply specialised methods allowing for time series properties when assessing statistical significance.

To transform data to (near) normality there are in some cases theoretically founded suggestions, but often the best transformations are found by a direct analysis of the data set in question. Power and logarithmic transformations are much used. Box and Cox (1964) present a way of selecting the optimal power transformation. In agreement with Hennemuth *et.al* (1980) Thompson and Page (1989) argued for logtransformations being appropriate for recruitment series by pointing to frequency distributions of such series being approximately lognormal. Logarithmic transformation was also used in some of the analyses presented by G. Ottersen at the Workshop (from Ottersen et al., 1994).

A time series may exhibit one or several forms of non-stationarity: i) trend, ii) systematic change in variance or iii) periodic fluctuations, e.g., seasonal. Differencing a series may remove trend or periodic variation, while a logarithmic transformation in some cases can reduce the effect of trend and make the variance constant. Cohen et al. (1986), looking into possible coherence in cod and haddock recruitment in the Northwest Atlantic, used first order differences of natural logtransformed data.

Stock	AUTOCORRELATION	Age
ARCTO-NORWEGIAN	+0.48	3
BALTIC	+0.58	1
FAROE	+0.35	2
ICELAND	+0.18	3
IRISH SEA	-0.31	0
NORTH SEA	-0.09	1
W. GREENLAND	+0.52	3
W. SCOTLAND	-0.23	1

Table 1 Autocorrelation, lag 1, in some North Atlantic cod recruitment time series (data from ICES 1997 stock summaries).

Several of the cod recruitment time series are clearly autocorrelated at lag 1 (Table 1). However, the main point of interest when determining if traditional multiple linear (ordinary least squares, OLS) regression is appropriate is if the residuals of the models (error terms) are uncorrelated. To determine if models fulfil this requirement the estimated autocorrelation function can be studied and (for lag 1 autocorrelation) a test on the Durbin-Watson statistic (SAS, 1992) applied. If the error terms can not be assumed to be white noise, several alternative approaches are possible.

In his presentation, dealing with the influence of environment on the growth and condition of cod in the Gulf of St. Lawrence, M. Castonguay used the «effective n» approach (Bayley and Hammersley, 1946) which takes autocorrelation into account by reducing the degrees of freedom and thus increasing the critical values. D. Swain looked into the effect of environmental changes on distribution of southern Gulf of St. Lawrence cod. He demonstrated how test results which seemed significant when derived without taking autocorrelation in the distribution into account, were nonsignificant when adjusted for autocorrelation.

Box and Jenkins (1970) describe the ARIMA class of models, dealing with autoregressive (AR) and moving average (MA) terms. This approach is widely applied in time series modelling and can be regarded as the time series alternative to OLS regression. G. Ottersen showed an autoregressive model relating variability in year class strength of Arcto-Norwegian cod at age 3 to SSB and ocean temperature. To apply ARIMA modelling you should have at least 20–40 data points, depending on the structure. Before looking into the autocorrelation the data should be detrended and decycled. For several of the stocks in Table 1, notably the West Greenland and Baltic, the high autocorrelation at lag 1 is a result of a clearly decreasing trend.

Further methods were demonstrated at the ICES/GLOBEC cod and climate database workshop (ICES 1996): State Space methodology for modelling groundfish abundance, General Additive Models for relating fish abundance from R/V surveys to location and associated environmental variables, and Change Point Modelling of stock-recruitment relationships.

A number of interesting relations have been found that hold for a certain time span and then break down. This is certainly the case for many recruitment relations. One reason is that many of nature's processes develop dynamically with time. An example is the NAO which seems to have had a pronounced impact on many biotic and abiotic processes in the North Atlantic region for the last 30 years or so. If the time series are expanded back in time nearly all of these connections are blurred or disappear altogether.

A second reason for relations breaking down is that models often are derived to explain as much as possible of the variability for a specific data set. Models which explain a lot of the variability for the period for which they have been developed, but which don't cope with other periods have more likely than not been overfitted. To avoid this a recommended way to proceed would be to develop the statistical model on part of the available data set and use the rest of the data for evaluation.

5.3.2 Prediction

The forecasting ability of dynamic ocean models is limited. The main reason is the restricted predictability in the atmospheric models providing forecasts for the driving forces such as wind stress and heat exchange. Ultimately the reason is that the coupled atmosphere-ocean system is a chaotic dynamical system. Due to high heat capacity, presence of land boundaries etc., the forecast horizon in the ocean may be larger than in the atmosphere.

Another use of ocean models is to produce new time series by hindcast runs. This can provide environmental time series that are difficult to measure, such as e.g., flux of water and heat into an area or total primary production. The quality of these time series is often uncertain, unless extensive model validation has been carried out. Examples of such use is the connection between the modelled inflow to the Barents Sea (Ådlandsvik and Loeng, 1991) and cod recruitment, or the modelled winter inflow to the North Sea with a close connection with catches of horse mackerel the next season (Iversen *et. al.*, 1997).

Statistical models like ARIMA models might provide an alternative to dynamic ocean models for forecasting. These models would take advantage of autocorrelation in the time series to predict future values. The models can also incorporate information from external time series in forecasts, provided (1) forecasts of the external time series are available or (2) current or past values of the external explanatory variable predict future values of the dependent variable because of lagged relationships. This approach could be tested on long time series by using the first part of the time series to identify the model and the second part to test forecasts.

Reliable systems for forecasting ocean climate a year or more ahead do not seem to be feasible at present. However, medium range predictions, as the six month Barents Sea temperature forecast demonstrated by B. Ådlandsvik working paper, are more promising.

6 CONCLUSIONS AND RECOMMENDATIONS

- We believe that there are now several examples where there is sufficient understanding of the effects of environment upon fish stocks for these relationships to be incorporated into assessments. In some cases this process has already begun. This has been described above. Where this has been achieved, it is based upon a good understanding of the ecology of the system allowing some understanding of the mechanisms underlying statistical correlations. This is clearly a long-term and expensive process but it is a necessary prerequisite to incorporating environmental data into assessments. However, statistical correlations in their own right may be useful in producing qualitative forecasts.

- In order to facilitate the use of environmental data in stock assessment, environmental life history indices, preferrably for each age (stage) and year, should be established for each particular stock according to the scheme used for stock variables (parameters). The available time series of environmental indices together with the substantial amount of information on spatial distributions gained from surveys in recent decades could be utilized for the purpose. The work necessitates close cooperation between experts in various fields of marine science with in depth knowledge of the ecology (the fish and its environment) of the area, and should be conducted as an integral part of the preparatory work for each assessment working group meeting.

- The present limited ability to predict changes in ocean climate may seem discouraging. However, for a number of stocks, predictions of for instance temperature and food availability half a year ahead may result in substantial improvements of estimates of growth and mortality (consumption) and hence in predictions of harvestable biomass one year ahead.

- It is recommended that time series of zooplankton production estimates to be used as indices of available food for Norwegian spring spawning herring are developed for the Norwegian Sea.

- It is recommended that existing zooplankton time series are maintained. These series provide information on food availability for various life stages in fish and are prerequisites for gaining knowledge that may improve stock assessments.

7 ISSUES RAISED BY THE WORKING GROUP ON COMPREHENSIVE FISHERIES EVALUATION AND THE WORKING GROUP ON ZOOPLANKTON ECOLOGY

COMFIE considered it useful for GLOBEC to:

- Find numerical relationships between temperature and growth/recruitment, including the error structure, for as many stocks as possible and in particular those which are included in COMFIE's terms of reference.
- Ensure that all potentially useful time series of temperature are readily available, also for scientists working with stock assessment models.
- Improve the precision of predictions of environmental parameters.
- Develop models for long-term variations in environmental parameters in relevant areas.
- Investigate if the current programmes for collecting environmental data are optimal for evaluating environmental effects on fish stocks.

As indicated above these tasks should be carried out by groups of scientists having substantial experience with the stock(s) and ecosystem in question; each group given terms of reference which limit the work to stocks within one ecosystem.

Working Group on Zooplankton Ecology recommended that:

- The Workshop on Application of Environmental Data to Stock Assessment should recognise the importance of supporting and exploiting ongoing zooplankton monitoring activities.
- The Workshop should also be aware of the summary of monitoring activities prepared by the WGZE and be invited to pose specific questions based on these data sources.
- In addition the WGZE recommends that the Workshop should take note of discussions held at previous the previous IOC meeting.
- The WGZE is concerned that data acquired in zooplankton monitoring activities is not being used to it's full potential in stock and other assessment activities.

WKEDSA supports the ongoing zooplankton monitoring activities (see recommendations). Utilization of these data series in a stock assessment context should be undertaken by groups as mentioned in the response to COMFIE above and earlier in this report.

8 LIST OF WORKING DOCUMENTS IN APPENDIX IV

Bogstad, B.: Some thoughts on the evaluation of the sensitivity of stock assessment models to environmental data. (Including a research proposal: Tracking the evolution of year-class strength in Northeast Arctic cod). – **Page 20**

Cabanas, J. M. and Porteiro, C.: Hydrographic variability of the Atlantic shelf waters of the Iberian peninsula and their relationship with the recruitment and distribution of coastal pelagic fish. – **Page 22**

Castonguay, M., Rollet, C., Fréchet, A., Gagnon, P., Gillbert, D. and Brêthes, J.-C.: Distribution changes of Atlantic cod (*Gadus morhua*) in the northern Gulf of St. Lawrence in relation to an oceanic cooling. – **Page 28**

Dutil, J.-D., Castonguay, M. and Gilbert, D.: Did an environmentally driven decline in growth and condition play a role in the collapse of cod in the Gulf of St. Lawrence? – **Not included.**

Fossum, P., Dalpadado, P. and Melle, W.: Norwegian spring spawning herring. Recent years development of condition factor in relation to zooplankton availability. – **Page 42**

Holst, J. C.: Norwegian spring spawning herring. Changes in the condition factor related to environmental conditions. - **Page 43**

Michalsen, K.: Ambient temperature, horizontal distribution and growth of Northeast Arctic cod. – **Page 47**

Ottersen, G.: Abundance and growth of juveniles in the Barents Sea in relation to environment. – **Page 53**

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APPENDIX I

PARTICIPANTS ICES/GLOBEC WORKSHOP

BERGEN 23–25 MARCH 1998

Martin Castonguay
Institut Maurice - Lamontange
850, Route de la Mer, C.P. 1000
Mont-Joli, Quebec, Canada
G5H 3Z4
(castonguaym@dfo-mpo.gc.ca.) Fax: 001 418 775 0740

Douglas P. Swain
Gulf Fisheries Centre, P.O. Box 5030
Moncton, NB E1C 9B6, CANADA
Phone: 506–851–6237, Fax: 506–851–2620

Stig Skreslet
Bodø College, Department of Fisheries and Science,
N-8002 Bodø, NORWAY
Phone: +47 75517496, Fax: +47 75517484
(stig.skreslet@hibo.no

Øyvind Ulltang
Department of Fisheries and Marine Biology, University of Bergen,
N-5020 Bergen, NORWAY
Phone: +47 55584400, Fax: +47 55584450
(oyvind.ulltang@ifm.uib.no

Geir Blom
Department of Fisheries and Marine Biology, University of Bergen,
N-5020 Bergen, NORWAY
Phone: +47 55584400, Fax: +47 55584450
(geir.blom@ifm.uib.no

Keith Brander
ICES/GLOBEC Coordinator
ICES, Palægade 2–4, DK-1261, Copenhagen K., DENMARK
Phone: +45 331 54 225, Fax: +45 339 34 215
(keith@ices.dk

Geir Ottersen
Biologisk Institutt, Avd. for zoologi
Box 1050 Blindern, 0316 Oslo, NORWAY
Phone: +47 22857288 (geir.ottersen@bio.vio.no)

José Manuel Cabanas
Instituto Espanol de Oceanografia
Centro Oceanografico de Vigo
Cabo Estay-Canido
Apartado 1552
38200 Vigo, SPAIN
Phone: +34 864 92 111, Fax: +34 864 92 351
(jmanuel.cabanas@vi.ico.es)

Clive Fox
Lowestoft Laboratory
Pakefield road, Lowestoft
NR33 OHT, UK
Phone: +44 1 502 524 237, Fax: +44 1 502 513 865

Bjarte Bogstad
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238687
(bjarte.bogstad@iMrno)

Jens Chr. Holst
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238687
(jens.christian.holst@iMrno)

Kathrine Michalsen
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238687
(kathrine.michalsen@iMrno)

Petter Fossum
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238531
(petter.fossum@iMrno)

Bjørn Ådlandsvik
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238531
(bjoern.aadlandsvik@iMrno)

Harald Loeng
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238531
(harald.loeng@iMrno)

Svein Sundby
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238531
(svein.sundby@iMrno)

Boonchai Stensholt
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238687
(boonchai.stensholt@iMrno)

Odd Nakken
Institute of Marine Research
P.O.Box 1870 Nordnes, N-5024 Bergen, NORWAY
Phone: +47 55238500, Fax: +47 55238687
(odd.nakken@iMrno)

APPENDIX II

HOW CAN WE IMPROVE THE APPLICATION OF ENVIRONMENTAL DATA TO STOCK ASSESSMENT?

1. By providing appropriate data sets e.g., temperature, wind.
2. By developing tools (e.g., bioenergetic models of growth; methods for improved nowcasting or forecasting of recruitment) for applying environmental information to actual current stock assessments
3. By evaluating sensitivity of stock assessments to environmental data.
4. By identifying promising examples for further study.
5. By considering the consequences of environmental factors on strategic management and long term changes in the fisheries and the ecosystem.
6. By developing "environmental indices" and showing how these can be applied. *Norway, Iceland and Canada have made a start with this*

How might we apply environmental data in fisheries assessments?

1. Direct input to stock assessment and catch forecasting

Parameter	**Environmental factor**	**Notes**	**Further work**
Growth	Temperature Food availability	Temperature and bioenergetic models can be used.	Estimating ambient temperature. Model development and application.
Mortality	Temperature *also indirect, via growth*	e.g. Cold winter mortality on North Sea flatfish?	? Other good examples
Recruitment	Many factors affect survival in early life history	A separate table of factors governing 'net fecundity' is given below.	This is a major research area

2. Indirect input to stock assessment and catch forecasting

Component	**Environmental factor**	**Notes**	**Further work**
Migration Distribution Interpreting survey data	Temperature Salinity	Transport and migration are quite well known for some species/stocks e.g., Labrador and Greenland cod.	Physical/biological models of interannual variability. Environmental covariates for estimating abundance.

3. Effects on strategic management

Component	**Environmental factor**	**Notes**	**Further work**
MBAL (and S/R). Reference points and control laws.	Many factors which affect net fecundity, growth	This not the same as short term recruitment estimation. Most population models assume either that recruitment, growth etc. are constant or have a stationary mean	Retrospective analysis of long time series in order to interpret and apply relevant environmental forcing

Component	Environmental factor	Notes	Further work
Long term shifts in distribution	Temperature, oxygen levels	Mainly affects cod at limits of range e.g., Greenland, Baltic, Biscay, Labrador	Improved environmental data series; historic information and reconstruction
Shifts in relative abundance of species	Many factors	Regime shifts?	Effects of climate change
Changes in total productivity	Nutrient budgets Windiness, temperature	Regime shifts?	Effects of climate change

4. Effects of environmental factors on processes in the life history of cod which affect "net fecundity" (i.e., the number of recruits to the mature population per mature fish in a given year). Indirect effects shown in italics

Life history stage	Process	Environmental factor	Comment	References
Eggs	Buoyancy	Salinity	Baltic, Labrador	Nissling, 1994; Anderson & de Young, 1994
	Respiration	Oxygen	Baltic, Labrador	Nissling, 1994
	Development rate	Temperature	Direct and indirect (predation) effects on mortality.	Thompson & Riley, 1981, Pepin et al. 1997
	Transport	Wind, Freshwater	Vestfjord, Georges Bank	Lough et al., 1994; Adlandsvik & Sundby, 1994
Larvae	Growth	Temperature, light		van der Meeren et al., 1994, Suthers & Sundby, 1997
	Feeding		(part of growth)	van der Meeren et al., 1994
	Encounter rate	Turbulence		
	Food production	*Wind, light, tidal mixing*	*Effects on phytoplankton and copepod production*	Sundby, Ellertsen and Fossum, 1994; *Brander, 1992, 1994.*
	Vertical migration	Mixing, light	Interacts with predation and horizontal transport	Skiftesvik, 1994
	Transport	Wind, Freshwater	Retentive (Georges Bank) and non-retentive (Norwegian shelf) systems.	Lough et al., 1994; Adlandsvik & Sundby, 1994
Juveniles	Settlement	Water depth	Georges Bank	Lough & Potter, 1993
Adults	Growth and maturity	Temperature	Inter-stock comparison	Brander, 1994
	Fecundity		Variable numbers and quality of eggs	Kjesbu et al.
	Migration	Temperature		Rose et al., 1994

(the references cited here are by no means exhaustive and it would be very useful to have additional ones)

Changing Oceans and Changing Fisheries: Environmental Data for Fisheries Research and Management

Executive Summary

Fisheries research and management encompass a broad range of activities directed towards maintaining sustainable fisheries, protected species such as marine mammals, and the marine ecosystems upon which they depend. Fluctuations in the marine environment on varied time and space scales have impacts on the abundance and distribution of populations; exploitation by man superimposed upon environmentally-induced fluctuations creates complex dynamics in marine populations. The demise of the California sardine, the Peruvian anchoveta, and fluctuations in Japanese sardine are important examples of how the environment can affect fisheries, leading to economic and societal consequences. There has thus been an increasing awareness of the importance of environmental variability in managing fishery populations, protected species, and ecosystems.

A workshop was convened at NOAA's Pacific Fisheries Environmental Group in Pacific Grove, California, on 16–18 July 1996, to examine the uses of environmental data for fisheries. The objectives of the workshop were to i) assess the current and future needs for environmental data bases (oceanographic, atmospheric, remote sensing, model output, and geological) in fisheries research and management, ii) identify data sources and formats, and iii) recommend ways to facilitate access to the data. The workshop brought together fisheries scientists, physical scientists, and environmental data specialists to address the following kinds of questions:

- What are the current environmental data needs for research in fisheries and fisheries oceanography?
- What are the shortcomings of existing data and what are likely future data needs for research in fisheries and fisheries oceanography?
- What data sources are available, in what form, and how are they accessed?
- What are new advances in environmental data, including oceanographic model output and remote sensing products, that could be beneficially applied to fisheries?
- What environmental data products, tailored specifically for biological applications, may be appropriate and require further development?
- How have other federal agencies successfully applied environmental data sets to research problems?

Participants represented a wide range of expertise and organizations, including most line offices of NOAA, NASA, the Navy, NSF, Canada, Great Britain, and 7 academic institutions. To provide common ground for subsequent discussions, presentations by fisheries scientists addressed how environmental data are used in fisheries-related investigations; physical and computer scientists described environmental data available, including that from ocean models and geophysical investigations. The workshop also included demonstrations of ocean model output and data management systems and poster presentations describing applications of environmental data to fisheries problems.

This background information provided an ideal backdrop for further discussions and generation of ideas. Five working groups convened during the workshop to address:

- real-time or near real-time environmental data applications to fisheries,
- retrospective environmental data applications to fisheries,
- applications of oceanographic and atmospheric model output to fisheries,
- data delivery systems, data accessibility criteria, and formats, and
- opportunities and mechanisms for partnerships in fisheries oceanography

A total of 48 recommendations were generated by the working groups. These were further evaluated by participant voting to develop a set of twelve priority recommendations from the workshop. The high priority recommendations can be distilled to the following five themes:

Develop baseline time series of the most important parameters: The two highest priority recommendations apply across real-time and retrospective working groups and point out the importance of i) developing the baseline against which perturbations are evaluated for both real time and retrospective aspects of environmental data use and ii) the importance of extending time series of important parameters back in time to evaluate resource fluctuations. These important parameters include ocean and atmospheric data, resource fluctuation data, and integrative time series that may include model output or proxy time series.

Apply new environmental data technologies to fisheries problems: New and emerging technologies have the potential to change the way in which environmental data are applied to fisheries. These techniques, however, require further evaluation and demonstration projects to convince fisheries scientists and managers of their utility. Remote sensing, multi-beam sonar, numerical models, and other techniques are expanding more rapidly than the fisheries community can assimilate them into practical applications for research and management.

Communication and sharing of expertise among disciplines and agencies: Fisheries research and management agencies are under pressure to conduct surveys, produce stock assessments, and conserve resources and habitats with often inadequate staffing. The levels of expertise required to incorporate the new technology into fisheries may need to come from other line offices of NOAA, from other agencies, and from the academic community. Mechanisms should be developed which will promote such communication and collaboration to solve high priority problems, including rotational assignments across agency boundaries and directed funding initiatives.

Demonstration of the benefits of applied environmental data in fisheries: Projects demonstrating how environmental data, model output, or new environmental technologies can be applied to marine fisheries are required in order to promote their future use in the community. Past examples of crises in fisheries exist where environmental data or model output are available. In a retrospective fashion, the scientific community should be able to show how prudent use of these environmental data could have helped understand or predict the situation, thereby assisting in management decisions.

Data accessibility for fisheries scientists: Fisheries scientists and managers are not always able to readily access the data required to do their jobs and to develop new, innovative approaches. More appropriate data bases and integrative time series, available on-line and in near real-time, must be developed.

For further information, contact the convenors:

George Boehlert, NOAA NMFS, Southwest Fisheries Science Center, Pacific Fisheries Environmental Group, 1352 Lighthouse Avenue, Pacific Grove, CA 93950–2097 (gboehlert@pfeg.noaa.gov).

Jim Schumacher, NOAA OAR, Pacific Marine Environmental Lab, 7600 Sand Point Way NE, Seattle, WA 98115–0070 (jdschu@pmel.noaa.gov).

APPENDIX III

TIME TABLE

ICES/GLOBEC Workshop on Application of Environmental Data in Stock Assessment, 23–25 March 1998, Institute of Marine Research, Bergen.

23 March

1000	Welcome. Introduction. Review and interpretation of terms of reference.
	Establishing 3 working groups, one for each term of reference.
1030	Relations to other activities. S. Sundby reported from the ICES/GLOBEC Workshop on Prediction and Decadal-Scale Ocean Climate Fluctuations. K. Brander drew attention to recommendations and suggestions from the working groups on Zooplankton Ecology and Comprehensive Fisheries Evaluation.
1100–1200	Presentations by J.Chr. Holst and P. Fossum.
1300–1700	Presentations by Ø. Ulltang, D.P. Svain, M. Castonguay, C. Fox, S. Skreslet, G. Ottersen and K. Michalsen.

24 March

0900–1030	Presentations by B. Bogstad, J. M. Cabanas and B. Ådlandsvik.
1045–1200	Plenary discussion. Including of tasks for the working groups.
1300–1700	Working groups

25 March

0900–1000	Plenary session. Working groups reporting. E. Svendsen reported from the Working Group on Shelf Seas Oceanography (WGSSO)
1000–1200	Working groups
1300–1400	Final discussion

Daily lunch break at 12–13 hrs.

APPENDIX IV

WORKING DOCUMENTS PRESENTED AT THE WORKSHOP

Note: Not all figures are available in electronic format

Some thoughts on the evaluation of the sensitivity of stock assessment models to environmental data.

Bjarte Bogstad, Institute of Marine Research, Bergen, Norway

This short note is an attempt to address terms of reference b) at the ICES/GLOBEC meeting, based on my somewhat limited experience from ICES Working Groups (Arctic Fisheries, Northern Pelagic).

In this context, stock assessment is taken to mean both to determine the current stock size and to give predictions for how a fish stock will develop given various exploitation rates.

When determining the current stock size, temperature is used when models including predation are used (the stomach evacuation rate is temperature-dependent), and temperature and other oceanographic data may also be used to adjust abundance indices for incomplete spatial coverage (horizontal and vertical).

Working groups now usually give short/medium-term prognosis as well as investigating harvest control rules by performing long-term simulation studies. Risk analyses are carried out, meaning that the uncertainty associated with predictions of e.g., environmental variables can be included in the predictions.

When making projections of stock size, predictions for recruitment R, weight at age W, maturity at age O and natural mortality at age M are needed. These entities have often been predicted simply by taking the mean values from the last years or from an earlier period when the situation for the stock (stock size, size of other stocks, environmental conditions) is thought to have been the same as is expected in the near future.

What one would like from an assessment point of view, are functional relationships where R, W, O and M for a given stock are functions of the abundance of this stock (number at age, size at age) as well as of the abundance of other stocks and of environmental variables. The uncertainty in these relationships should also be quantified.

Below, some examples of such studies for recruitment are listed

Sparholt (1996) gives the following relationship for recruitment (age 0) of Baltic cod as a function of the spawning biomass (SSB) as well as of the spawning volume (GV) (volume of water with salinity > 11 and oxygen content > 2 ml/l): $\text{Log } R = 2.19 + \text{Log SSB} + 0.79 * \text{Log (GV)} - 0.86 * \text{Log (SSB(sprat))}$, i.e., a spawning stock-recruitment relationship which includes both environmental and multispecies effects.

In recruitment predictions, time series of abundance I from prerecruit surveys are frequently used to estimate recruitment R to the fishable part of the stock. The scatter of points in the I-R plot is often quite large, indicating substantial variations in mortality between year classes. The causes of this apparent variability are not well understood. Physical variables may be of importance. For North-East Arctic cod, a large body of data on survey indices as well as environmental variables are available, and a study to track the evolution of year class strength of this cod stock has been initiated (see research proposal below).

Finding functional relationships between environmental variables and recruitment/growth/ maturation/mortality are not enough, however, predictions of environmental variables are also needed in order to improve stock projections.

Reference

Sparholt, H. 1996. Interaktioner mellem torsk, sild og brisling i centrale Østersø. (Interactions between cod, herring and sprat in the central Baltic). Dr scient thesis, University of Copenhagen, 1996. (In Danish).

Research proposal

Tracking the evolution of year class strength in North-East Arctic cod

by Bjarte Bogstad, Kristin Helle, C. Tara Marshall, Kathrine Michalsen, Geir Ottersen and Michael Pennington

Objectives

To identify the life history stage at which year class strength of Northeast Arctic cod is established. To identify the environmental and ecological factors which influence mortality rates during different pre-recruit stages. To develop a mathematical model which generates short-term recruitment predictions which could be used for stock assessment.

Rationale

It has often been stated that year class strength of marine fish populations is determined by mortality during the egg and larval stages (Sundby *et al.* 1989). Other studies claim that year class strength is determined by mortality during the late larval and juvenile stages (Myers and Cadigan 1993). Variation in year class strength has also been attributed to variation in the reproductive potential of the spawners which would influence total egg production (Marshall *et al.* in press; Marshall and Frank submitted ms.; Marteinsdottir and Þorarinsson submitted ms.). Such divergent views about when and how recruitment variation is generated highlight the need to determine whether there is a specific life history stage at which strong year classes become clearly distinguishable from weak ones (ICES 1997). Isolating the stage at which year class strength becomes fixed is a pre-requisite to establishing the relative importance of the factors which influence recruitment (Ulltang 1996).

For Northeast Arctic cod the effects of variation in total egg production (N_0) and pre recruit mortality (Z) on recruitment have been investigated largely in isolation from each other. For example, while N_0 has been shown to be positively correlated with recruitment to age 1 (Marshall *et al.* in press) the analysis did not incorporate inter-annual variation in Z. Both wind speed/direction (presumably influencing Z during egg and larval stages) and spawner biomass (presumably influencing N_0) are significantly related to recruitment (Ottersen and Sundby 1995). However, this empirical relationship could potentially be refined by using N_0 rather than spawner biomass as an index of the reproductive output of the stock. Cannibalism is another important source of Z for this stock (Bogstad *et al.* 1994). The cannibalism seems to increase in periods with low abundance of capelin, the main prey item for cod (Bogstad and Mehl 1997). The influence of cannibalism on recruitment has not been examined in relation to N_0 or other sources of Z. For example, the 1990 year class has evolved into one that is currently dominating the fishery and the spawning stock. It originated from an intermediate value of N_0 but became progressively stronger with age, perhaps because of the lower rates of cannibalism it experienced during first three years (ICES 1998).

An integrated, process-oriented description of the temporal evolution of year class strength for Northeast Arctic cod should also examine how variation in growth during the pre-recruit period affects recruitment. Variation in growth during the pre-recruit stage has the potential to dampen variability in recruitment rather than amplify it (van der Veer *et al.* 1994). A positive correlation between the length of 0-group cod and their abundance ($N_{0\text{-grp}}$) has been observed (Ottersen and Loeng in press). Such correlation is difficult to interpret from a causal perspective because both growth and survival could be influenced by a third variable. Temperature is a likely candidate. The ambient temperature experienced during the pre-recruit stage influences the growth rates of pre-recruit cod (Michalsen *et al.* 1996). Temperature has also been implicated in several recruitment mechanisms for Northeast Arctic cod (Ellertsen *et al.* 1989; Nilssen *et al.* 1994; Kjesbu *et al.* 1996). Effects of water flux seems to be an important factor for the 3–5 months old fish. Effects of fish distribution (horizontally, vertically (bottom settling)) and fish behaviour should also be considered, together with abundance of prey (particularly *Calanus finmarchicus*).

Description of work proposed

This project will track the evolution of year class strength for individual cohorts of Northeast Arctic cod using estimates of absolute abundance obtained from surveys (N_0, $N_{\text{early juvenile}}$, $N_{0\text{-grp}}$, N_1, N_2, N_3) and virtual population analysis (N_3). Mortality rates will be estimated at each life history stage within a cohort. These values will then be compared across cohorts to determine whether stage-specific Z is consistently higher for a specific life history stage. Values of stage-specific z will then be used to test hypotheses related to the mechanistic basis of recruitment variation. For example, the effects of ecological (e.g., cannibalism rates) and environmental (e.g., ambient temperature) variables on stage-specific Z will be determined. The relationship between stage-specific Z and stage-specific growth rates will also be described. A practical goal of the analysis will be to develop a statistical model which can be used to generate short-term recruitment predictions that are required by the assessment.

Hydrographic variability of the Atlantic shelf waters of the Iberian peninsula and their relationship with the recruitment and distribution of coastal pelagic fish

Cabanas J.M., C.Porteiro, Instituto Español de Oceanografía O. de Vigo. Apdo 1552., 36,280 Vigo. Spain

Abstract

The year class strength of the Iberian pelagic fish (as sardine) is regulated by hydroclimatic conditions in the North Atlantic. The low recruitment values of recent years have been caused by reduction of the reproductive stock below the level of biological security. The reproductive strategy of the sardine, with autumn and spring spawning seasons, produces two recruitment periods each year.

This reproductive strategy is adapted to the oceanographic regime in the area, with coastal upwelling between April and September, and with different direction on the alongshore currents in summer and winter. Variations in the intensity and timing of the winter current affect the success of the autumn spawning and can lead to recruitment failure at the end of spring. Variations in the intensity and timing of the northerly wind component, which generates upwelling, control the success of spring spawning.

On the basis of oceanographic data and yearly recruitment from 1975 to 1995, we try to analyze the recruitment variability induced by the marine climate to the Iberian sardine stock.

Introduction

The Iberian sardine has two spawning areas, in the Portuguese coast in winter and in the Cantabrian in spring, with significant interannual variations. Although the sardine has an area and wide period of spawning the survival is generally low, and the population remain due to the years where the recruitment is high because most of the spawn are in periods oceanographically favourable, according to the theory of the optimal environmental window (Cury and Roy, 1987).

For this area Robles, Porteiro and Cabanas (1992) give a description of the biology of the sardine and their relationship with the oceanography. In accordance with these authors, the biology of the sardine, in the periods of reproduction and feeding, seems to be adapted to the conditions of the area; although the sardine is distributed in the whole area, they tend to be distributed by age classes, being the recruits in the coast west, the class I in southern Portugal and the class V and oldest in the Cantabric sea (Pastor *et al.*, 1986).

The study of the influence of the physical environment on biological communities involves introducing its variability into the study and management models for the aquatic ecosystem. Finding an index able to summarise atmospheric and oceanographic variability it would solve the problem.

On a regional oceanic scale, the North Atlantic Oscillation index (NAO), (Rogers, 1984), reflects the changes in North Atlantic oceanic climate. Another index which may be used is the GULF Index (Taylor, 1996), taken from the monthly charts of the situation in the most northerly of the Gulf Stream, in six longitudes between 79°W and 65°W. There is a good correlation between NAO and GULF ($r = 0.73$).

The climatic anomaly called El Niño is monitored by the SOI index (Southern Oscillation Index). To date, the Niño phenomenon was believed only to affect the Pacific, although recent observations have shown its effects in the Atlantic. Both index, NAO and SOI, are teleconnected, and it being observed that although the correlation between the two is low, $r < 0.25$, in pronounced events; as in 1983 and 1987, they show similar anomalies.

In the Atlantic, the fact that the NAO index is high indicates that the Siberian polar winds ease off over northern Europe, while the Arctic winds intensify over the Labrador Sea, which results in an increase in westerly winds (warm and humid) in the mid zones and, consequently, temperate winters over Europe. When the NAO index is low, Europe experiences harsh winters due to the increase in Siberian originated winds and the warm westerly oceanic wind ease off. (Alheith J. and Hagen E., 1997).

Long term changes in temperature and salinity, and therefore in zonal oceanic flow, induce changes in the characteristics of the plankton and in the pelagic trophic chain. This is translated into species migration and replacement by other species which changes catch yield.

Methods

In the case of the Iberoatlantic sardine, when explaining interannual variability, the following must be considered:

1. The stock biomass. With regular oscillations due to fishing, migrations and environmental changes. The stock/recruitment relationship found in the case considered (VPA data) is r = 0.54. Part of the remaining variance may be due to environmental factors, variance which may increase when the stock contracts.

2. The thermohaline variations and dynamics over the shelf due to hydroclimatological changes. This variability can be summarised by an index derived from a set of variables that we have a long temporal series.

For the Iberian sardine, for the period 1976–1996, a preliminary analysis was made considering series of:

a) Eckman transport (43°N 11°W) at various periods of the year, chosen in terms of their influence on the unexploited stage of the resource
b) The NAO, SOI (LDEO) and GULF (Taylor, 1996) climatological indices
c) Temperature of air and sea surface in 43°N 11°W (COADS) and Santander
d) Annual characterization, thermohaline and dynamic, of the Northwest shelf of the peninsula in spring.
e) The abundance of sardine: 0 age recruits and the total biomass (VPA estim.)

Correlations were tested between the series:

TEOC:	Zonal Ekman transport for October-December in the previous year (Polar current strength, winter spawning season).
TEAS:	Zonal Ekman transport for the period April-September (Upwelling season).
TEMA:	Zonal Ekman transport for March-April (Spring Spawning season).
NAO:	Index of the North Atlantic Oscillation
SOI:	Index of the South Pacific Oscillation
SST:	Sea Surface Temperature
GULF:	Index of the Gulf Stream North progression
RECRUIT:	0 aged individuals (sardine recruits).
BIOMA:	Sardine biomass.

Results

The original series show little correlation between them; tests on the average mean (3 years) of the recruitment serie and each environmental variable, Table I, give significative correlation with GULF (-0.82), NAO (-0.56), TEMA (0.52) and SST

(-0.47). With these variables a multiple correlation is tested, achieving a correlation of 0.63 with NAO, SST, TEMA and of 0.76 with GULF, SST, TEMA (smaller than with alone GULF).

The analysis of main components (PCA) of the system gives 86% explanation with three components, of which the first one accumulates 61%. Carrying out the PCA with the system formed by the variables: REC, SST, TOPIC, NAO; with two factors 83% explanation is reached, being the first one the more related with the variables and that he gives 64% explanation.

The negative correlation between recruitment and the NAO index is explained by the fact that in years with a low NAO index (cold winters in northerly latitudes), is when stock concentration is favoured in the mid latitudes (favourable conditions in terms of temperatures and winds).

The positive correlation with transport towards the coast in March-April is related to the continued presence of larvae on the shelf during the planktonic period of the same. The little or insignificant negative correlation with transport in April-September (upwelling) is more linked to adult feeding; even when the sardine has an extensive spawning period, this exerts a double influence: good conditions for producing plankton are bad for larval survival; so that the low lineal correlation found should not be a cause for concern. It is necessary to analyze the influence of the phenomenon from the Optimum Environmental Window theory viewpoint (Cury and Roy, 1989).

The correlation between the NAO and SOI indices is small; likewise the correlation between the SOI and recruitment. In years with a high Niño, however, the SOI is a good forecasting index in terms of recruitment, as can be noted that the best recruitments occurred in 1983, 1987 and 1991, which coincide in years with high El Niño phenomenon. It seems that above a threshold of this climatic anomaly; in the Atlantic, there are oceanographic conditions teleconnected with anomalies produced in other oceans which favour larval survival: extend the optimum environmental window period, and if the NAO is low, moderate winds predominating in the Atlantic ecosystem, making surface temperatures mild.

In terms of this analysis, the importance of the NAO, GULF indexes can be seen as indicative of the climatic conditions of the ocean (surface transport, upwelling, stability, etc.) and its influence in the resources, Ex. the Iberoatlantic sardine. The negative correlation found indicates more favourable conditions for survival in situations of low NAO, the influence of which on the sea is exercised towards more stable situations in the surface layer in European mid latitudes with the presence of moderate westerly winds, which does not occur in northern Europe where easterly winds coming from Siberia intensify which cool down and move the surface layer. Also, in periods of low NAO, the surface waters cool down to the north of the Bay of Biscay, which causes the sardines to move further south, thus increasing their density in the Iberian shelf.

Looking the oceanographic conditions (thermohaline and dynamics) in spring on the Iberoatlantic shelf, an increase in salinity is noted during the 1980's to 1992 (Pérez *et al.*, 1995) where it started to decrease, with a gradual increase in surface water temperatures (Lavín *et al.*, 1996; Afonso-Dias *et al.*, 1996), which may induce too a change in the habitat of the species.

Based on the analysis of the horizontal distributions of salinity and temperature in the spring cruises at 20 and 100 m and to the profile on the 100 m isobath in the corner of Iberia peninsula (Vigo – La Coruña), observing presence of fronts, eddies and tendency of the coastal circulation, we can see, Table 2, that for the period 1987–1997 appeared:

EDDIES	1987,1988,1993,1995,1996,1997
FRONTS	1988,1990,1993,1995,1996
CIRC. S-N	1987,1988,1994,1995,1996,1997

In the whole considered period two action centres are observed, one located to the south/south-west of Galicia and another to the north, in the Cantabrian, that conditioning the characteristics of the water in the shelf. The prevalence of one or another depends on the atmospheric forcing being able to interchanging water, with circulation south-north in the coast and north-south offshore, what also explains the tendency to form eddies in the corner.

The best recruitments take place in the Niño years: 1983, 1987 and 1991. (In 1983 there are good recruitments in general in the whole Atlantic in most of the species) and in 1987 and 1991 there is not front Finisterre/Ortegal, that seems to be the biggest impediment in the viability of the Cantabrian spawn; equal happens in 1992 and 1994, although this last year the recruitment was very bad.

Conclusions

The transport east-west, existence of fronts, characteristic of the upwelling, etc. also impact in the larvae nutrition in their drifting phase (Lasker, 1978); where the food has to be abundant so that the larvae doesn't have to spend energy in getting it; the phytoplankton and the microzooplankton have to be in appropriate concentration and aggregate so that it became useful; relative stability in the photic layer and oceanographic features, as eddies, favour it (Dickson *et al.*, 1988). Winds high to 6 m/s produce water turbulence and food and larvae dispersion, what reduces the possibilities of survival. The concept of «Optimal Environmental Window" (Cury and Roy, 1989) it is very useful to conjugate the turbulence effects and food generation/aggregation; because they synthesise physical and biological processes that condition the larvae survival.

In the case of the Iberoatlantic sardine when having two areas and two spawning times, the best recruitments are given when they are viable both spawns. When one of them fails will be smaller; and it depends on the oceanographic conditions in winter-spring.

As environmental factors that impact in the recruitment, and thus in the stock biomass, we have:

- The presence of winter polar current, the zonal transport in spring and the coastal upwelling.

- The turbulence of the superficial layer
- The superficial coastal currents parallel to the coast and the fronts defined in the capes Finisterre or Ortegal; what allows the communication between the north platform and the west; in both senses according to the distance to the coast.
- The existence of anticyclonic eddies in the corner and other places on the shelf that help to maintain the larvae and their food aggregates (retention larvae areas).

The index NAO, indicative of the climatic conditions of the ocean, together with the transport Ekman in March-April and the superficial temperature explains 75% of the variability due to environmental factors of the total variability in the sardine stock.

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Table I 3 years running mean of selected variables

YEAR	TEOD	TEAS	TEMA	NAO	REC	NMED	GULF	446TA	4311TA	429TA	446TS	4311TS	429TS
1976	-133.00	-472.08	35.75	-0.57	12,009.50	263.38	-0.35	14.60	15.01	15.21	14.88	15.35	15.41
1977	41.44	-432.67	33.83	-0.39	12,596.33	265.58	-0.53	14.59	15.04	15.22	14.93	15.39	15.46
1978	284.22	-379.44	174.17	-1.55	14,001.67	269.67	-0.81	14.59	15.07	15.24	15.09	15.43	15.50
1979	480.11	-294.89	-145.83	-0.68	15,409.33	265.83	-0.87	14.50	15.20	15.32	15.10	15.57	15.62
1980	470.00	-289.33	33.00	-0.08	14,724.67	259.25	-0.75	14.53	15.27	15.38	15.10	15.62	15.62
1981	361.22	-239.39	-17.17	0.90	12,256.00	254.17	-0.61	14.69	15.37	15.53	15.10	15.73	15.74
1982	374.33	-180.83	114.50	2.16	14,533.00	252.33	-0.52	14.90	15.37	15.61	15.23	15.72	15.76
1983	416.22	-220.39	-72.50	2.02	13,615.67	254.42	-0.11	14.87	15.27	15.58	15.24	15.69	15.76
1984	469.11	-195.39	77.67	1.55	12,920.67	258.67	0.72	14.81	15.27	15.57	15.23	15.71	15.79
1985	484.56	-347.89	-64.33	0.27	6851.33	258.67	0.66	14.61	15.11	15.39	15.11	15.59	15.63
1986	363.67	-276.33	7.83	-0.43	7213.33	258.08	0.29	14.70	15.32	15.57	15.16	15.71	15.76
1987	355.00	-318.72	-113.17	0.01	6984.67	257.58	-0.13	14.79	15.35	15.62	15.20	15.67	15.73
1988	350.56	-288.39	24.67	1.49	7071.67	255.67	0.07	15.21	15.70	16.05	15.51	15.93	16.05
1989	565.56	-327.17	-194.83	2.96	5343.00	257.92	0.48	15.39	15.69	16.13	15.76	15.97	16.16
1990	453.56	-376.28	-160.67	3.06	7875.00	256.33	0.88	15.19	15.58	16.02	15.66	15.89	16.08
1991	298.89	-323.11	-292.17	2.27	9250.00	256.33	1.11	14.86	15.38	15.78	15.49	15.76	15.91
1992	92.44	-272.78	-162.67	1.84	8411.00	253.50	1.15	14.60	15.25	15.63	15.13	15.60	15.76
1993	83.22	-224.22	-215.50	2.25	4830.00	253.17	1.20	14.61	15.29	15.70	15.14	15.64	15.82
1994	241.22	-285.06	-171.67	2.59	2051.67	254.33	1.56						
1995	413.44	-299.56	-97.00	2.63	2944.33	263.33	1.25						
1996	592.17	-326.08	-41.00	2.94	3137.00	266.50	1.12						

TEOD: Zonal Ekman transport in the period October-December of the previous year (polar current strength) (m3/s Km)
TEAS: Zonal Ekman transport in the period April-September (upwelling index) (m3/s Km)
TEMA: Zonal Ekman transport in the period March-April (m3/s Km)
REC: Individuals of age 0 (sardine recruits) (E6)
NAO: Oscillation Noratlántic Index
NMED: Sea level in Vigo in the period December - March (cm)
GULF: Gulf Stream north progression (Gulf Index)
xxxTA: Temperatura of the air in the suitable position (xxx)
xxxTS: Temperature of the superficial water in the suitable position (xxx)

Table II

MM-YY	TEMP.	SALINITY	FRONT	EDDY	CIRCULATION
04–1987 *	13.7–12.5	35.30–35.70		Artabro	
**	13.5–12.0	35.75–35.65			ocean-coast/south-north
04–1988 *	13.1–12.4	35.60–35.60	Finisterre	Artabro	south-north
**	12.5–12.0	35.70–35.65			
04–1990 *	14.0–13.2	35.80–35.65	Finisterre		Ocean north-south
**	13.5–12.7	35.80–35.70			north-south
04–1991 *	12.9–12.2	35.80–35.60			
**	12.9–12.0	35.80–35.75			north-south
04–1992 *	13.1–12.2	35.85–35.80			
**	12.6–12.2	35.80–35.75			
04–1993 *	14.1–13.0	35.90–35.70	Finisterre	Artabro	northwest-coast
**	13.3–12.6	35.85–35.75	Ortegal		
04–1994 *	13.3–12.2	35.65–35.60			south-north
**	12.6–12.1	35.75–35.65			
04–1995 *	13.9–12.7	35.80–35.50	Finisterre	Artabro	south-north in coast
**	13.2–12.4	35.90–35.60			north-south in slope
04–1996 *	13.9–12.5	35.85–35.60	Finisterre	Artabro	southwest-north
**	13.5–12.5	35.80–35.65			
03–1997 *	14.7–13.5	35.80–35.65		Artabro	southwest-north
**	14.0–13.0	35.80–35.72			

* temperature and salinity interval at 20 m level

* * temperature and salinity interval at 100 m level

Distribution changes of Atlantic cod (*Gadus morhua*) in the northern Gulf of St. Lawrence in relation to an oceanic cooling.

M. Castonguay[1], C. Rollet[1], A. Fréchet[1], P. Gagnon[1,2], D. Gilbert[1], and J.-C. Brêthes[3]

[1] Pêches et Océans Canada, Institut Maurice-Lamontagne, C.P. 1000, Mont-Joli, Québec, Canada G5H 3Z4 Tel: (418) 775–0634; fax: (418) 775–0740; email: castonguaym@dfo-mpo.gc.ca

[2] Present address: Environnement Canada, 105 McGill, suite 700, Montréal, Québec, Canada H2Y 2E7

[3] Université du Québec à Rimouski, Département d'Océanographie, 300 Allée des Ursulines, Rimouski, Québec, Canada G5L 3A1

Abstract

From data collected on research vessel trawl surveys, we examined distribution changes of Atlantic cod (*Gadus morhua*) with respect to depth, temperature, and latitude in the northern Gulf of St. Lawrence in both winter (1978–1994) and summer (1984–1995) as they relate to a cooling event. We used a cumulative distribution function method that statistically compares distributions of sampled variables with those selected by fish. Major distribution shifts occurred in winter: cod median latitude of geographic distribution in 1993 was 2° (220 km) south of what it was in 1985 and cod were also distributed 200 m deeper in the 1990's. The median latitude of cod distribution in January was correlated with an index of cold intermediate layer temperature anomaly in the previous summer ($r = 0.85$, $p < 0.05$, corrected for autocorrelation). This suggests that cooling of the cold intermediate layer resulted in an earlier wintering migration. However, we did not find evidence that temperatures that cod were exposed to changed with the cooling. On average, cod occupied waters with temperatures of 4.4–5.9°C in winter and of 1.4–3.5°C in summer, with no temporal trend.

Résumé

Nous avons examiné les changements de distribution de la morue selon la profondeur, la température et la latitude et leurs relations avec un refroidissement des eaux à l'aide de relevés de chalutage d'hiver (1978–1994) et d'été (1984–1995) conduits dans le nord du Golfe du St-Laurent à bord de navires de recherche. Pour ce faire, nous avons utilisé une méthode de comparaisons statistiques de fonctions de fréquences cumulatives de variables échantillonnées et de variables sélectionnées par les poissons. Les principaux changements se sont produits en hiver: la latitude médiane de la distribution géographique de la morue en 1993 était 2° (220 km) au sud de ce qu'elle était en 1985 et la profondeur sélectionnée a augmenté de plus de 200 m dans les années 1990. La latitude médiane de distribution hivernale était corrélée à un indice d'anomalie de température de la couche intermédiaire froide de l'été précédent ($r = 0.85$, $p < 0.05$, corrigé pour l'autocorrélation). Cette corrélation suggère que le refroidissement de la couche intermédiaire froide a résulté en une migration d'hivernage plus hâtive de la morue. Cependant la morue ne semble pas avoir été exposée à des eaux plus froides suite au refroidissement de la couche intermédiaire froide. En moyenne, elle a sélectionné des eaux de température de 4.4–5.9°C en hiver et de 1.4–3.5°C en été, sans tendance temporelle.

Introduction

The Gulf of St. Lawrence has been experiencing colder-than-normal water temperatures at mid-depth, in the cold intermediate layer (CIL), since the mid 1980s. The CIL is a layer of cold water sandwiched between warmer and fresher surface waters and warmer and saltier bottom waters. It is a relic of winter cooling typically found in the summer from about 30 to 100 m in the Gulf of St. Lawrence. Water has in fact been so cold in the Gulf of St. Lawrence that seven of the eight coldest years of the 47-year CIL record have occurred since 1986 (Gilbert and Pettigrew 1997; *Figure* 1a). The cold spell is due to the cold winters the NW Atlantic has endured over the same period (Drinkwater 1996). This cooling has also been felt on the Newfoundland Shelf (Colbourne *et al.* 1994; Drinkwater 1996) and the Eastern Scotian Shelf, but not further south (Page and Losier 1994; Drinkwater 1996).

The Gulf of St. Lawrence also experiences interannual temperature fluctuations of its deep waters (200–300 m) (Bugden 1991), but these changes are uncorrelated with CIL temperature variations (Gilbert and Pettigrew 1997). In contrast to CIL temperatures, deep-water temperatures in Cabot Strait (*Figure* 2) were relatively high (5.5–6.5°C) during the late 1980s and early 1990s (Gilbert *et al.* 1997). The uncoupling of temperatures between the Gulf's CIL and its deep water is due to different forcing mechanisms affecting the two layers, the CIL being under the influence of winter atmospheric temperature and flow through the Strait of Belle-Isle (*Figure* 2) (Petrie *et al.* 1988; Gilbert and Pettigrew 1997) while deep water temperatures depend on varying proportions of Labrador and Gulf Stream waters at the shelf edge (Bugden 1991).

Atlantic cod (*Gadus morhua*) from the northern Gulf of St. Lawrence stock (Northwest Atlantic Fisheries Organisation (NAFO) divisions 3Pn4RS) typically overwinter outside the Gulf on the northern side of Cabot Strait, enter the northern Gulf in spring for spawning, and remain there during the post-spawning feeding period when they may be found inshore (*Figure* 2) (Ouellet *et al.* 1997). They migrate back to Cabot Strait in late fall / early winter (Templeman 1978; Chouinard and Fréchet 1994). There is some evidence that the cooling event affected cod distribution in the northern Gulf (Fréchet and Gagnon 1993). Starting in 1989, cod have been distributed deeper in January, as shown by research vessel trawl surveys conducted annually from 1978 to 1994 (*Figure* 2). While the proportion of cod biomass trawled deeper than 360 m was always less than 20% before 1988, it increased up to over 90% in the early 1990's (Fréchet and Gagnon 1993; Chouinard and Fréchet 1994).

The cooling of the NW Atlantic may have impacted on cod stock productivity in the southern Gulf and on the eastern Scotian Shelf through a reduction of somatic growth (Campana *et al.* 1995). An environment-driven condition and growth decline may also have contributed to the demise of the northern Gulf cod stock (Lambert and Dutil 1997; Dutil *et al.*, submitted). However, the role of environmental factors in the collapse of cod stocks is a controversial issue; several recent publications have implicated fishing mortality as the sole significant cause for the collapse of cod stocks in the NW Atlantic (e.g., Hutchings and Myers 1994; Hutchings 1996; Myers *et al.* 1996).

In this study, we relate changes in the winter and summer distribution of juvenile and adult cod from the northern Gulf to the recent cooling of the Gulf. Specifically, our objective is to perform an age-by-age comparison of depth, temperature, and latitude distribution changes that occurred in winter and in summer in relation to the unfolding of the cooling event. We test the null hypothesis that the recent cooling of Gulf CIL waters did not result in exposure of cod to colder water temperatures in winter or summer. Rejection of this null hypothesis would provide a straightforward mechanism to explain declines in condition and growth of cod in the northern Gulf reported by Lambert and Dutil (1997) and Dutil *et al.* (submitted).

Materials and methods

We analysed cod catch data from two stratified random research vessel trawl survey series carried out by the Canadian Department of Fisheries and Oceans in the northern Gulf of St. Lawrence and Cabot Strait (divisions 3Pn4RS). The winter survey was conducted in January on board the MV *Gadus Atlantica* from 1978 to 1994, except that there was no survey in 1982 and that the survey was about 3 weeks later than usual in 1980 (January 27 - February 11) and 1981 (January 29 - February 17). This survey included on average 147 stations (range: 84–207) of 30-min duration. The summer survey was carried out in August/early September from 1984 to 1995 and comprised a mean number of 195 stations (range: 108–233) (ongoing survey), except that in 1984, the survey was in July. This survey was aboard the MV *Lady Hammond* between 1984 and 1989 (30-min tows) and the CSS *Alfred Needler* (24-min tows) thereafter. The winter survey used an Engel-145 bottom trawl with a 30-mm liner while the summer survey employed a Western IIA otter trawl with a 32-mm liner (*Lady Hammond*) and a URI shrimp trawl with a 19-mm liner (*Alfred Needler*). Differences in gear selectivity between the *Lady Hammond* and the *Alfred Needler* will not affect interannual distribution comparisons based on overall catch but they may affect age by age comparisons; results will be examined keeping this caveat in mind.

For both surveys, a depth-stratified design was used whereby sets in a given depth stratum are chosen randomly with the number of sets being approximately proportional to the stratum area (Doubleday 1981), except that since 1992 for the summer survey, an optimal allocation of sets to strata based on variance has been used (Gagnon 1991). Cod catch-at-age, calculated for each tow, was then expanded to the surface area of the various strata using a program (STRAP) developed for analysis of groundfish research trawl survey data (Smith and Somerton 1981). Near-bottom temperatures were measured either with Sippican XBT, Applied STD, Guildline CTD, or Sealogs. Temperature data were quality-controlled by checking every value ≥7°C against mean and SD values for the corresponding month and area from Petrie (1990). We excluded from all analyses tows for which the near-bottom temperature fell outside the range defined by Petrie's mean ± 3SD or was missing. Tows with missing temperatures represented a small proportion (< 30%) of total except for the 1992 winter survey where 52% of tows, mostly from northern stations, had to be excluded due to missing temperatures.

A caveat with this work is that neither survey covered the entire distribution area of the northern Gulf stock in all years. Shallow 37–91 m depths (20–50 fathoms) were not sampled before 1991 during the summer surveys. To analyse the 1984–1995 summer survey data in a standard fashion, we had to exclude tows from depths < 92 m (such tows represented 11% of total, on average). We examined the impact of excluding shallow strata on temperature distribution of cod by comparing from 1991 to 1995 temperatures that cod selected when shallow stations were included or when they were excluded. Moreover, after 1988 in winter, part of the stock was distributed outside the survey area (south and east of 3Pn) (Rollet *et al.* 1994) and hence was not sampled. Finally, two shallow strata in division 4S representing 6% of the total 3Pn4RS area could not be sampled on either survey because of rough bottom.

For both surveys, we compared (ages pooled and disaggregated, ages 2 to 8 and over (8+)) distributions of observed (i.e., as sampled by the trawl) and selected (i.e., observed weighted by number of fish caught) temperatures, depths, and latitudes among years. For every year we plotted 2.5, 50 and 97.5% values of observed (i.e., sampled) and selected (i.e., occupied) cumulative distribution functions (CDF) of temperatures, depths, and latitudes, following Swain and Kramer's (1995) method of graphical representation. We then tested for differences between observed and selected distributions of the above three parameters using a computer program called Habitat developed by one of us (P.G.). Habitat implements a randomisation test developed by Perry and Smith (1994). The test is based on a statistic that is the maximum absolute difference between the CDF of the parameter and the abundance-weighted CDF, which represents the selected distribution (abundance expressed as numbers of fish). This statistic is compared with values typical of a random association between the parameter and the abundance. The program calculates 2000 such values from pseudo-random pairings of observed parameters and abundances. The probability of random association is estimated as the proportion of simulated values greater than the observed one. Details of the method can be found in Perry and Smith (1994).

The above distribution analyses cannot distinguish between shifts in habitat associations of fish and selective disappearance (mortality) of fish from one region of their habitat. For example, a shift to deep water from one winter to the next may reflect a genuine shift in abundance to deep water of fish that previously overwintered in shallow water or it may simply result from the selective disappearance of shallow water fish. To resolve this issue, we compared trawlable numbers of fish per depth stratum among years for the winter survey using the STRAP program (Smith and Somerton 1981). Increases in numbers of fish at depth over time would indicate an actual shift to deep waters of fish that previously frequented shallow waters rather than the disappearance of shallow water fish.

To relate quantitatively environmental change to fish distribution, we calculated a Pearson's coefficient of correlation between the CIL summer temperature anomaly and the median latitude of the geographic distribution of cod in the following winter. The correlation was corrected for autocorrelation (also termed serial correlation) following the effective sample size (n_{eff}) method described in Ebisuzaki (1997, equation 2). Not accounting for autocorrelation would make the statistical tests less stringent. We also calculated correlations corrected for autocorrelation between mean annual temperatures in the northern Gulf at depths of 150–200 and 200–250 m (*Figure* 1b) and cod median January distribution. Although these temperatures were measured in summer, a comparison with fish distributions in winter is valid here because there is no seasonal temperature signal below 150 m (D. Gilbert, unpublished data). In winter, cod do not usually occur within the ice field and large cod catches typically occur in the marginal ice zone (Fréchet 1990). We examined how the median latitude of the cod distribution in winter is correlated (with a correction for autocorrelation) with the percentage of the 3Pn4RS area covered with ice, as determined from the ice map closest in time to the median date of the survey (*Figure* 1c). To calculate the percentage of ice cover, we digitized ice maps corresponding to the median survey date provided by the Atmospheric Environment Service of the Canadian Department of Environment. All the above correlations could be calculated only between 1983 and 1994 because the effective sample size method requires continuous series (1982 latitude is missing).

A length-frequency distribution of juvenile and adult cod in the northern Gulf (Figure 8 of Ouellet *et al.* 1997) and an age-length key (A. Fréchet and P. Schwab, unpublished data) were used to relate ages to maturity stages: ages 2 and 3 are juveniles, age 4 is composed of a mixture of juveniles and adults (but considered as adults here) while ages 5 and over are adults.

Results

Winter changes in cod distribution and the environment.

Adult cod were gradually found deeper in January starting in 1989 for ages 6, 7, and 8+ and in 1990 for ages 4 and 5 (*Figure* 3). Juveniles (ages 2 and 3) also shifted depths but to a lesser extent. Before 1989, the median depth occupied by adults in January varied from 125 to 250 m, with particularly shallow cod distribution from 1978 to 1981. From 1989 to 1991, cod shifted to deeper waters and remained at about 450 m from 1991 to 1994 even though the survey's depth stratification did not change (see available depths of *Figure* 3). The upper (2.5%) and lower (97.5%) bounds of the depth distribution also shifted deeper and the median converged towards the lower bound (*Figure* 3), reflecting that most fish were located within a narrow depth range at the bottom of Cabot Strait. Before 1989, cod selected depths significantly more shallow than sampled depths in five out of 10 years (Habitat, $p < 0.05$). After 1988, selected depths were significantly deeper than sampled ones in four out of six years (Habitat, $p < 0.01$).

The depth shift seemed to involve a genuine movement to deep water of fish that previously overwintered in shallow water rather than the disappearance of fish from shallow waters because the shift produced a sharp increase of trawlable abundance in the deep water (*Figure* 4). This depth shift in abundance occurred in all age groups but was more pronounced in adults than in juveniles. The comparison of estimated numbers of ages 3 and 6 cod among survey depth strata between 1985 and 1991 illustrates this point (*Figure* 4).

The depth distribution change was not accompanied by a corresponding change in median occupied temperature, which remained in the 4.4–5.9°C range throughout the winter survey series except in 1978, when it was only 2.3°C (*Figure* 5). However, the lower (cold) bound of the temperature distribution started to converge towards the median at the time of the depth shift (1989/90), indicating that cod then experienced a more uniform temperature field and remained unexposed to cold water. There was no detectable age-related difference in temperature exposure (*Figure* 5). Interestingly, the small magnitude of the depth shift in juveniles (Figs. 3 and 4) did not result in occupation of colder water after 1988. In most cases (12 out of 16 years), Habitat did not detect significant differences between selected and observed temperatures (ages pooled) even though plots of available and selected temperatures (*Figure* 5) appeared quite different. This is because the test power is weak when most of the abundance comes from a few sets. When fish are highly aggregated, there is not enough proof according to the test to infer that occupation of the habitat is not random.

Cod have also been progressively distributed further south in January starting in 1986, such that the median latitude of their geographic distribution in 1993 was located 2° (220 km) south of their median latitude in 1985 (*Figure* 6). The southerly distribution shift was more pronounced in adults than in juveniles: by 1993, the median latitude of juveniles was still located inside the Gulf (i.e., north of 48°), about 1° to the north of the adult median latitude, which was outside the Gulf (*Figure* 6). The southerly trend was reversed in 1994. It is noteworthy that cod were distributed more to the south in 1980 and 1981, two years when the survey was conducted three weeks later than normal. In 10 out of 16 years, cod (ages pooled) were significantly more abundant in southern latitudes than expected under a uniform distribution hypothesis (Habitat, $p < 0.01$). For the other six years, there was no difference between latitudes "selected" by cod and sampled station latitudes. The southerly upper bound of "selected" latitudes in 1992 represent a sampling artefact caused by the exclusion of many northerly stations with missing near-bottom temperature in that year, as shown by the change in sampled station latitudes for that year (*Figure* 6). The exclusion of these northerly stations in 1992 did not change medians and ranges of observed depths (*Figure* 3) and temperatures (*Figure* 5).

The shift to deeper waters and more southerly latitudes in January could reflect an earlier timing of the wintering migration. To control for a migration timing effect, we compared changes in depth distributions for fish caught only in 3Pn, i.e., those fish whose migration should be mostly completed by the time of the survey (*Figure* 7). Cod median depth in 3Pn shifted from about 200 to 450 m starting in 1990, indicating that the stock's overwintering location shifted to deeper waters (i.e., further offshore and more to the south). Hence results suggest that cod performed the wintering migration earlier and also overwintered in deeper waters. Of notice, the more pronounced depth change of juveniles in 3Pn (*Figure* 7) compared to when the whole stock area is considered (*Figure* 3).

There was a significant positive correlation between the median latitude where cod were found in January and the index of CIL temperature anomaly in the previous summer ($r = 0.85$, $p < 0.05$, $n = 12$, $n_{eff} = 7$, $df = 5$) (*Figure* 1a). Latitude was also correlated with the CIL index of two summers before ($r = 0.85$, $p < 0.05$, $n = 11$, $n_{eff} = 6$, $df = 4$) but not with any other lag of the CIL index. The negative CIL temperature anomalies that started in 1986 (*Figure* 1a) were not felt at typical depths (150–250 m) and locations (4R) occupied by the stock, although temperatures there did become colder in 1991 and 1992 by as much as 1.3°C (*Figure* 1b). Correlations of cod median latitude in January with the 150–200 m or the 200–250 m temperature series or with ice cover were not significant for any lag when accounting for autocorrelation ($P > 0.05$).

Summer changes in cod distribution

We detected little depth, temperature, or latitudinal changes of cod distribution in summer for that portion of the stock surveyed deeper than 91 m. The median occupied depth in August did not exhibit trends and remained in the 144–181 m range (ages pooled), except for 1987 when it was only 119 m (*Figure* 8). There was no apparent age-related difference of depth distribution in summer (*Figure* 8). Excluding 1987, the median occupied temperature in summer fluctuated between 1.4 and 3.5°C without any evidence of a temporal trend (*Figure* 9). As with depth, the cold median temperature of -0.1°C that cod selected in 1987 was atypical. For that year, 47.5% of the fish were caught at the bottom of the CIL in waters having temperatures ranging from -0.3 to -0.1°C (*Figure* 9). The latitudes where fish were found in summer fluctuated little among years or between juveniles and adults (*Figure* 10). The median latitude occupied by the stock varied from 49.4 to 50.1°N. No marked difference in depth, temperature, or latitude distribution was detected for any age in 1990 when the vessel and trawl change took place, suggesting that the change did not affect age by age comparisons. Selected depths were significantly shallower than sampled ones (*Figure* 8), and selected near-bottom temperatures were significantly colder than sampled ones (*Figure* 9) in all years and for all age groups (Habitat, $p< 0.05$). Cod (ages pooled) were significantly more abundant in northern latitudes than expected under a uniform distribution hypothesis in eight out of 12 years (*Figure* 10; Habitat, $p< 0.01$). For the four other years, there was no difference between latitudes where cod occurred and sampled station latitudes.

The most important question regarding the exclusion of waters < 92 m in summer is how it affected cod distribution with respect to temperature. We examined this using results from the 1991 to 1995 surveys, for which shallow waters were sampled. The percentage of fish numbers (adjusted to strata areas with STRAP (Smith and Somerton 1981)) comprised in the 37–91 m depth stratum was 32, 43, 32, 40, and 15 for 1991 to 1995, respectively. Hence, adding the shallow strata to the survey increased the proportion of the stock that was sampled by approximately 50%. However, for those years, the impact of excluding waters < 92 m on the estimation of median temperatures that cod selected was minimal (Table 1). Even though the range of selected temperatures became larger, the median selected temperature was either smaller, equal, or larger when the shallow stratum was included and, on average, it was identical whether shallow stations were included or not. In years when > 30% of the total estimated number of fish were in 37–91 depths (1991 to 1994), the 2.5 percentile of temperature was colder when shallow strata were included than when they were not (Table 1).

Discussion

Our analysis shows that we could not reject the null hypothesis, since we found no evidence that cod were exposed to colder temperatures as a result of the cooling of Gulf waters. However, the significant correlation between the summer CIL temperature anomaly and cod spatial distribution during the following winter suggests a cause-effect relationship between these two variables. The southerly latitudinal shift in winter and the striking depth shift (>200 m) that accompanied it, together with the absence of latitude change in August, suggest that cod performed the overwintering migration earlier and that this change of timing was due to the cooling at mid-depth. Hence cod may have modified their spatial distribution to remain within a range of preferred temperatures. Northern cod (NAFO divisions 2J3KL) were also distributed further south and deeper in the fall in recent years, perhaps in response to the oceanic cooling (Rose *et al.* 1994, Atkinson *et al.* 1997, but see also Hutchings 1996). The offshore shift of overwintering aggregations reported here could be due to cooling of deep (> 150 m) waters. This offshore shift coincided with and presumably explains the failure of the winter (January to March) fixed gear cod fishery off south-western Newfoundland (3Pn) from 1990 on, reported by Fréchet and Gagnon (1993). This fishery took place in depths < 180 m.

The conclusion of absence of difference in temperature exposure is weakened by the caveat that shallow (< 92 m) nearshore waters had to be excluded from the analysis of the summer survey while summer is the season when cod typically forage in nearshore waters. On the basis of the 1991 to 1995 surveys, sampling coverage was increased by about 50% when including the shallow 37–91 m depth stratum. A comparison of temperature distribution of cod for those years shows that median selected temperatures change little whether the shallow stratum is included or not. This would suggest that our acceptance of the null hypothesis is not greatly affected by the exclusion of shallow waters, but we do not know if this conclusion would hold had the above comparison been carried out earlier (1984–1989) when the cooling took place. Landings from the summer fixed-gear fishery in the northern Gulf declined about fourfold between the mid 1980's and 1993 (see Fréchet and Schwab 1995), suggesting that nearshore availability of cod decreased. This decrease could be due in part to the cooling, and by leaving inshore waters, cod may not have been on average exposed to colder water during the cooling event, but this is unknown. Cod use their habitat in three dimensions; there is also the possibility that vertically migrating fish (Beamish 1966) would have been more exposed to the colder and thicker CIL at night as a result of the cooling episode, but there are no data to examine this possible effect.

Changes in size-at-age of both northern and southern Gulf of St. Lawrence cod followed closely changes in the CIL temperature index (Dutil *et al.*, submitted) suggesting that interannual fluctuations of CIL temperature control cod growth. The decline in size-at-age between 1983 and 1988 matched a similar decline in the CIL temperature index between 1981 and 1986. The temperature warming of 1987–1988 resulted in a short increase in size-at-age in 1989–1990, but further cooling of the CIL in 1989–1992 was matched by declining sizes in 1992–1994. Declining sizes-at-age of southern Gulf cod have been attributed to size-selective fishing mortality (Hanson and Chouinard 1992). However back-calculations based on otoliths indicate that cod did not sustain detectable size-selective mortality in the northern Gulf (Dutil *et al.*, submitted). The CIL temperature - growth relationship (Dutil *et al.*, submitted) coupled with this study's finding of a positive correlation between CIL temperature and cod geographic distribution in the following winter points to relationships between CIL temperature, cod distribution, and cod growth. Dutil *et al.* (submitted) proposed a feeding duration hypothesis to account for these relationships: the reduction in the length of the feeding season inferred from the temperature-induced earlier departure to wintering grounds reported in this study was partly or largely responsible for the growth decline of cod in the late 1980's and early 1990's. This hypothesis raises the question of whether the earlier wintering migration and the ensuing growth decline were caused by direct exposure to colder water in the fall (and perhaps also in summer but that we did not detect) or by a diminished availability of preys, or both. Even though survey results indicate that cod median selected depth is below the CIL in summer, it remains that on average 35% of cod were caught above 100 m, in the CIL, when nearshore waters were sampled during the summer survey (1991–1995) (data not shown). There is also evidence that northern Gulf cod shifted from a high-energy, fish-dominated diet (mostly capelin, *Mallotus villosus*) to a low-energy, invertebrate-dominated diet in summer between the 1980s and the 1990s (D. Chabot, Institut Maurice-Lamontagne, unpublished data). Further retrospective work is planned to examine the feeding duration hypothesis.

Even if we were fortunate enough to have both summer and winter surveys available for analysing distribution changes, such surveys are nevertheless only "snapshots" in time. Important distribution changes of northern Gulf cod with respect to temperature may have occurred other than in August and January that could not be detected. To integrate seasonal variability, Colbourne *et al.* (1997) incorporated effects of seasonal cycles on cod migrations over large spatial scales and determined that northern cod migrating along hypothetical circular routes in the early 1990s experienced waters up to 1°C below average, particularly in the inshore zone. An thorough understanding of environmental effects on stock productivity will require modelling representative annual thermal histories of individual fish based on adequate validation. Brander (1995) calculated a growth-temperature relationship across stocks that indicates that a 1°C increase in mean annual temperature that cod are exposed to will produce 30% mass increase. This emphasises the importance of accurately measuring stock-specific annual thermal histories to reliably assess impacts of oceanic variability on fish growth processes. This study, which describes annual variations in thermal exposure of cod in both January and August, is a useful first step. Data storage tags, which measure temperature at frequent and regular intervals (Metcalfe and Arnold 1997), represent a promising tool to derive integrated annual thermal budgets in fishes.

Our result suggesting temporal stability in temperature selection by northern Gulf cod in summer contrasts sharply with cod behaviour in the southern Gulf for the same season, where Swain and Kramer (1995) found that the median selected temperature varied by more than 7°C among years. Comparisons of depth distributions of cod in summer between the northern and southern Gulf surveys must account for differences in sampling coverage: the former samples to a depth of 37 m while the latter extends coverage to 20 m. Nevertheless, results suggest different depth distributions since median selected depths of southern and northern Gulf cod are 40–50 m (Swain 1993) and 143 m, respectively (143 m represents the mean of median selected depths of 1991 to 1995 summer surveys, including 37–91 m depths (data not shown)). These differences in temperature and depth distributions imply very different habitat preferences, although such comparisons have to account for the large differences in bathymetry between the deep northern and the shallow southern Gulf of St. Lawrence. For example, the mean of median depths of tows in the northern Gulf during the 1991–95 summer survey, including stations< 92 m, is 222 m while the mean depth of tows in the southern Gulf averaged from 1971 to 1991 is only 87 m (Swain 1993).

As is the case with southern Gulf cod (Swain *et al.*, submitted), temperatures selected by northern Gulf cod in winter are much warmer than those in summer even though selecting warm water is energetically costly. One possible explanation is that warm temperatures are required in winter for gonad maturation to proceed properly in time for spring spawning. Female cod held at 6°C in the laboratory started spawning 2 mo before females held at 2°C (Y. Lambert and P. Ouellet, Institut Maurice-Lamontagne, unpublished data). By selecting warm waters, cod also avoid a reduction of locomotor activity and swimming speed that exposure to cold water during the overwintering period and the spawning migration will produce (Castonguay and Cyr, submitted).

The distribution changes described in this study occurred concomitantly with a steep decline in abundance of the northern Gulf cod stock that culminated in the closure of the fishery in January 1994 (Anonymous 1994). Even though aforementioned sampling caveats prevented us from adequately measuring this population's range, *Figure* 2 nevertheless strongly suggests that its winter range shrank in the 1990s. Atkinson *et al.* (1997) found that northern cod's range is positively correlated with abundance and suggested that cod exhibited hyperstability during their decline whereby local densities remained relatively constant over a range of abundance levels. Hilborn and Walters (1992) define "hyperstability" to describe stocks with distribution properties such that catch per unit of effort remains high as abundance declines. As suggested for northern cod by Atkinson *et al.* (1997), northern Gulf cod may have exhibited hyperstability during their decline in abundance that led to increased fishing mortality by offshore fleets.

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Table 1. Temperatures (2.5, 50, and 97.5 percentiles, °C) selected by cod on the summer survey when the 37–91 m depth stratum is included (bold) or excluded from the analysis.

Year	**2.5**	2.5	**50**	50	**97.5**	97.5
1991	**-1.7**	-0.6	**2.1**	2.2	**3.7**	3.9
1992	**-0.7**	-0.5	**2.7**	2.2	**5.1**	4.2
1993	**-0.5**	0.5	**1.9**	2.4	**4.1**	4.1
1994	**-1.1**	0	**1.6**	1.6	**6.1**	5.0
1995	**-0.2**	-0.2	**1.4**	1.4	**5.1**	5.1

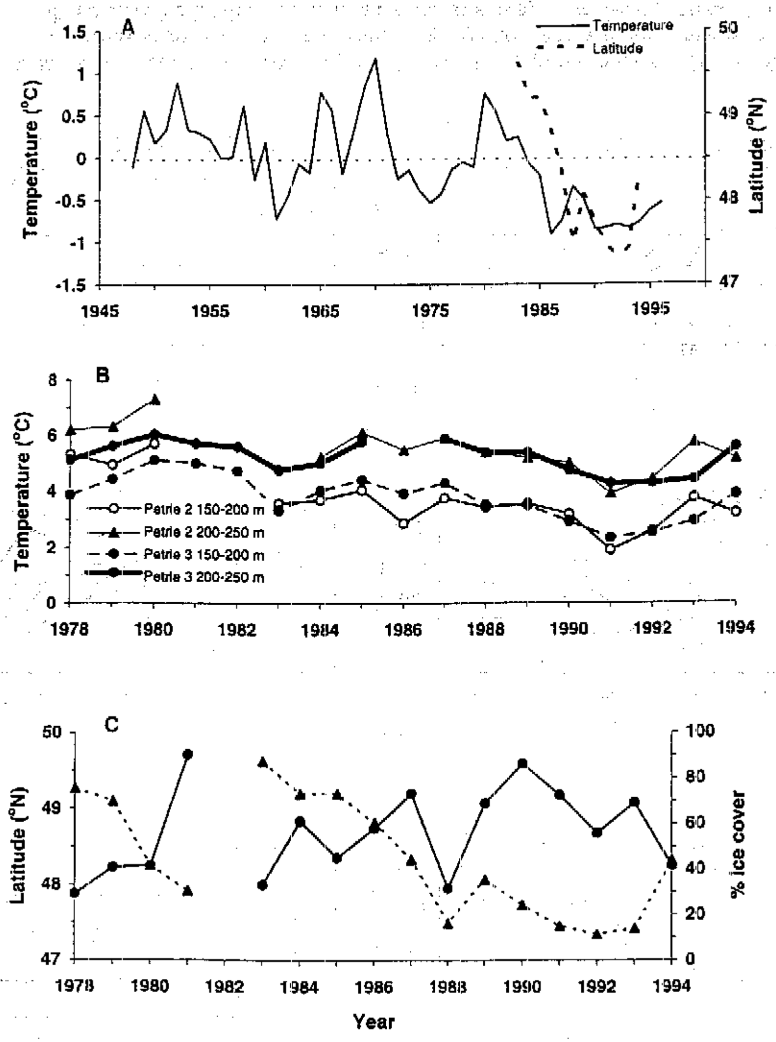

Fig. 1. *(a)* Deviations from the 1948-1994 mean CIL core temperature in the Gulf of St. Lawrence extrapolated to July 15 (redrawn from Fig. 6 of Gilbert and Pettigrew 1997) and median latitude of cod geographic distribution in winter; *(b)* temperature fluctuations at depths of 150-200 m and 200-250 m in Petrie Boxes 2 and 3 (corresponding to southern and northern 4R, respectively) (Petrie 1990) from 1978 to 1994; and *(c)* median latitude of the cod distribution during the winter survey, 1978 to 1994, and corresponding percentage of the 3Pn4RS area covered by ice, as determined from the ice map closest to the median date of the survey.

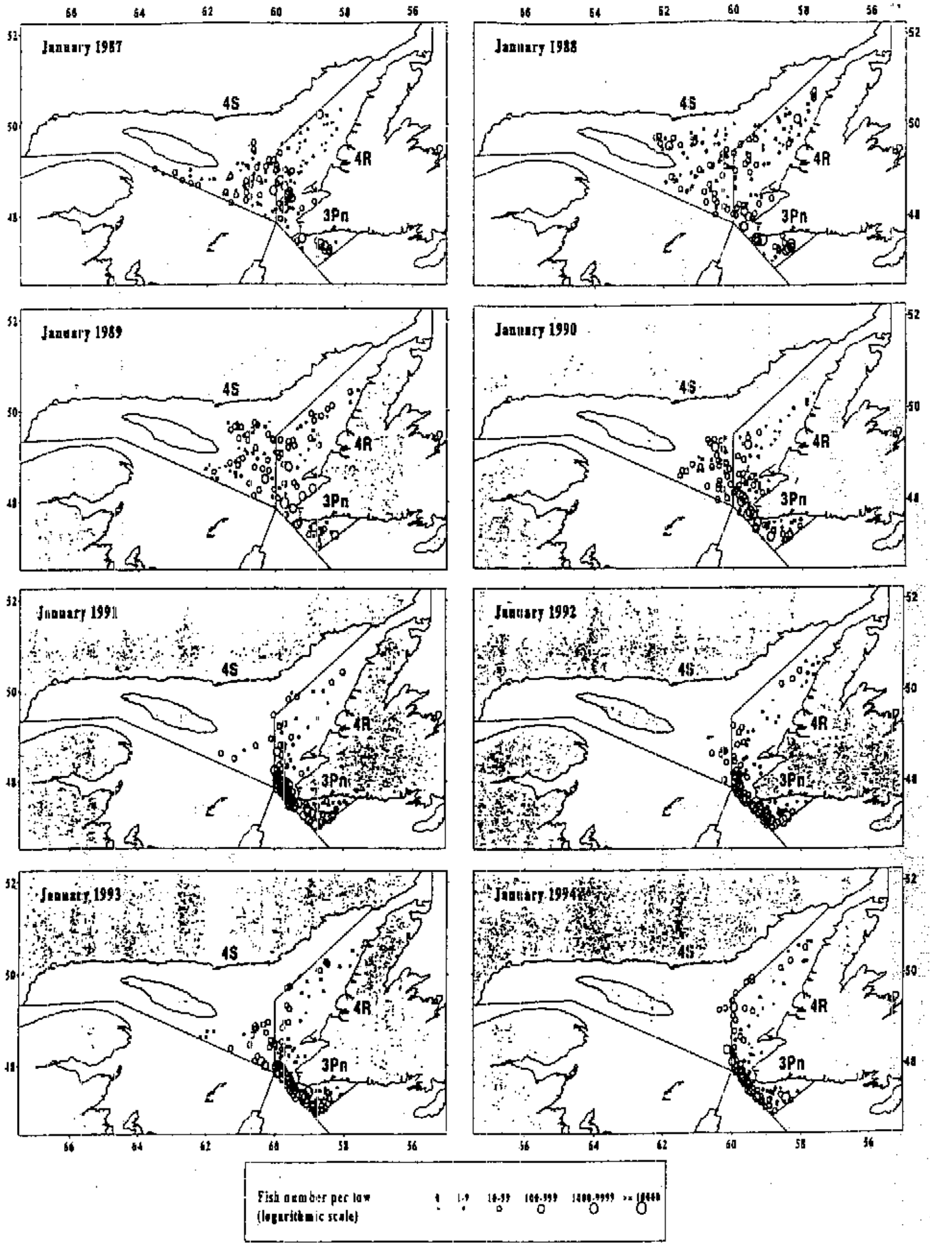

Fig. 2. Spatial distribution of catches (number of cod per tow) during the winter survey in the northern Gulf of St. Lawrence from 1987 to 1994 showing NAFO divisions 3Pn, 4R, and 4S. Sampling coverage differed among years due to variability in weather and ice cover. The southern and northern straits are Cabot and Belle-Isles Straits, respectively. The grey area defines waters >200 m.

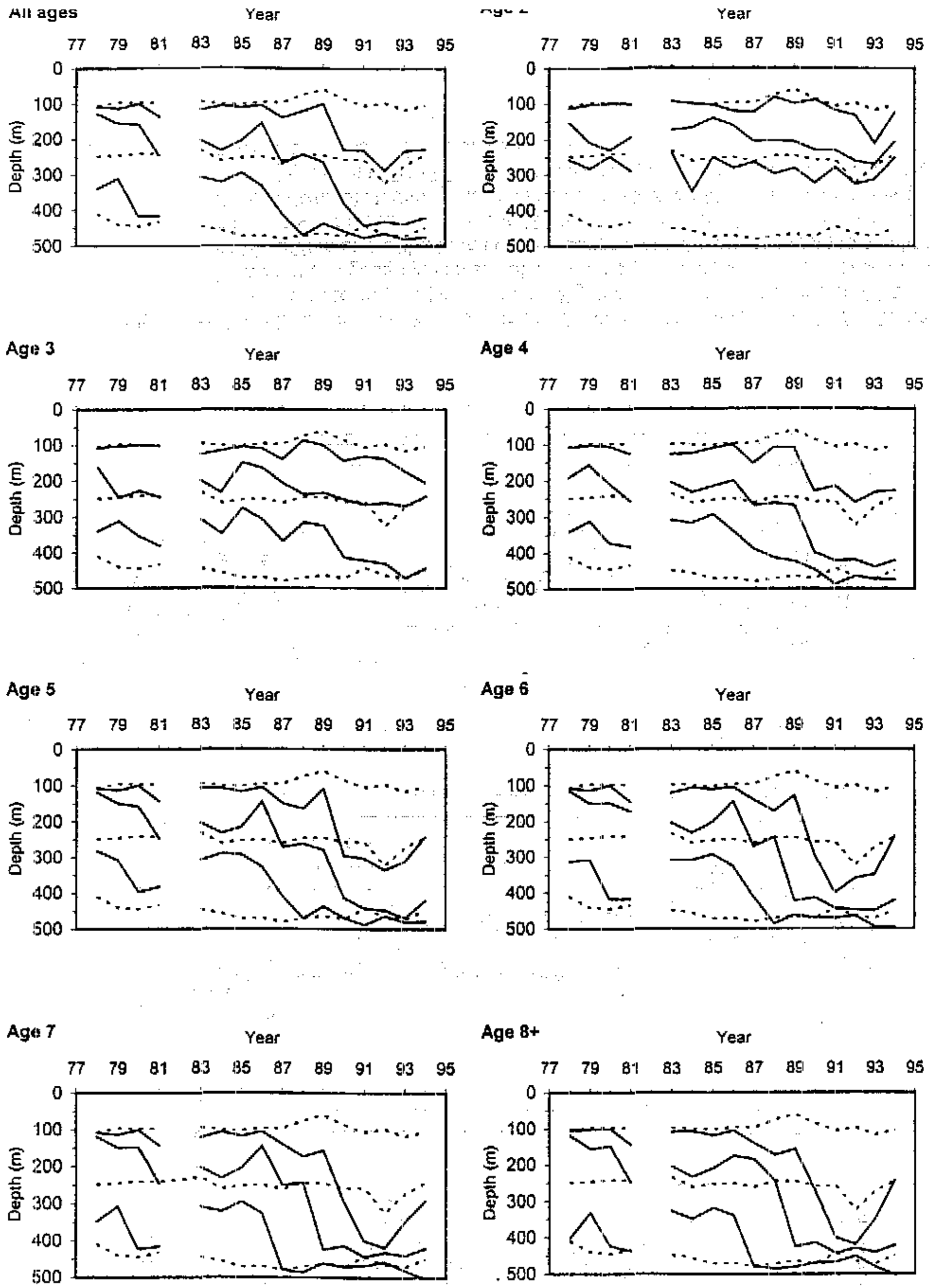

Fig. 3. Cumulative distribution functions (CDFs) of depths (expressed as 2.5, 50, and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the winter survey, from 1978 to 1994. The 2.5, 50, and 97.5 percentiles of selected depth CDFs are represented by the top, middle, and bottom solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled depth CDFs are represented by the top, middle, and bottom dotted lines, respectively.

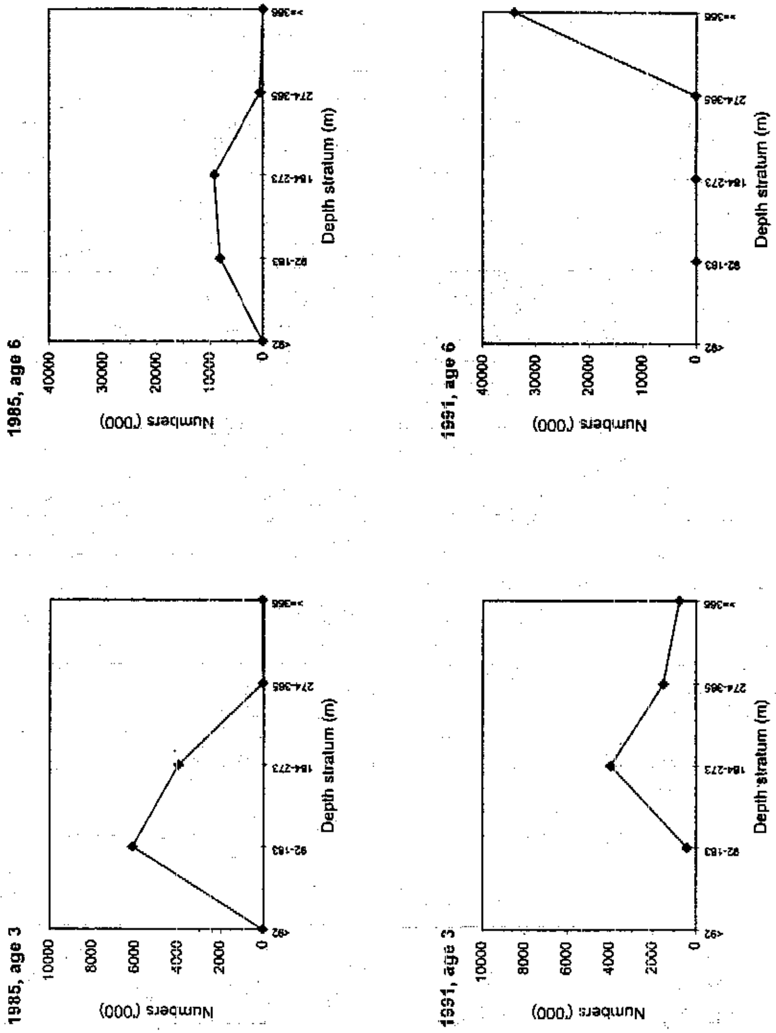

Fig. 4. Comparison between 1985 and 1991 of total numbers (thousands) of age 3 and 6 cod per depth stratum in the 3Pn4RS survey area in winter. Fish numbers are estimated from winter survey data using the STRAP program (Smith and Somerton 1981). Note the scale difference between ages.

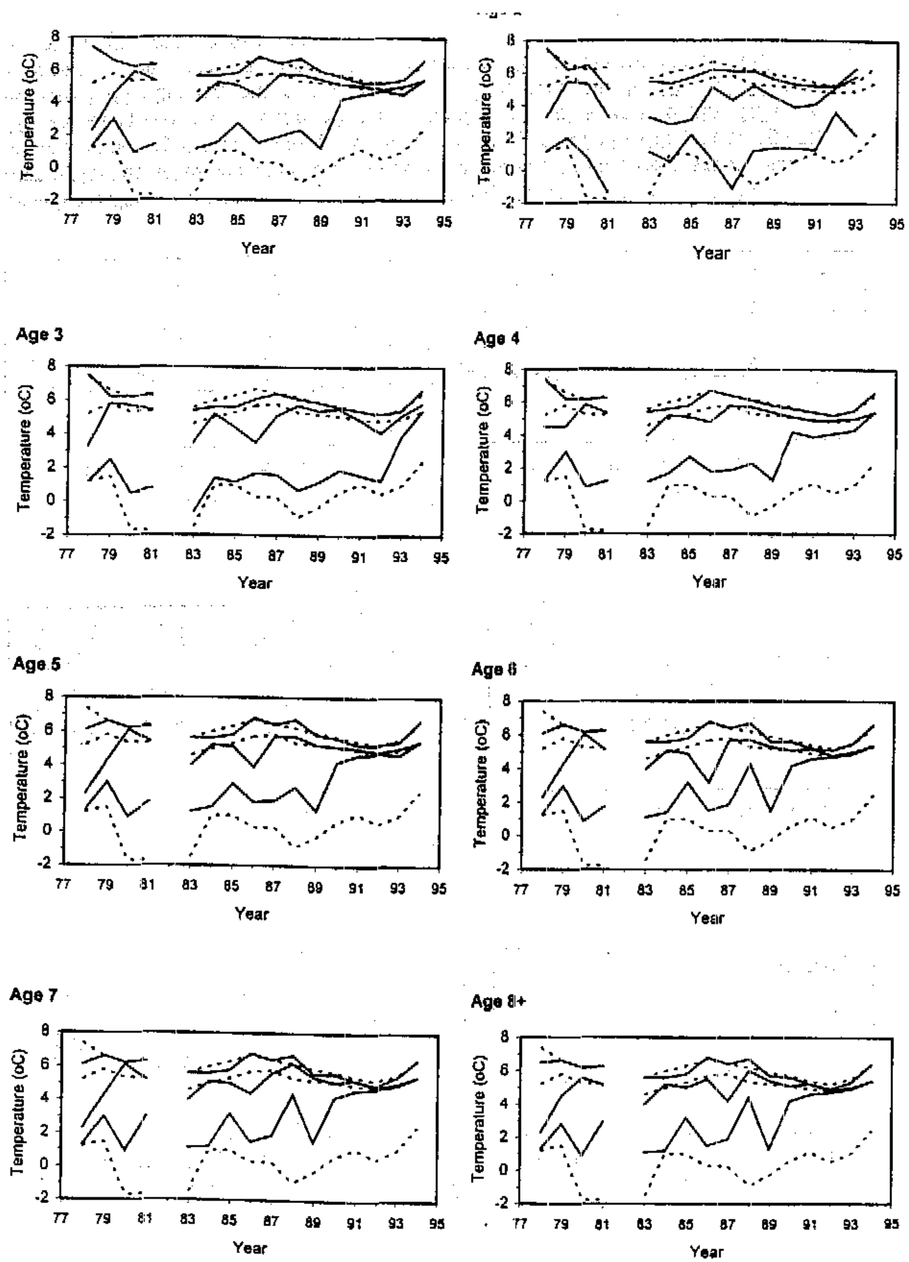

Fig. 5. Cumulative distribution functions (CDFs) of temperatures (expressed as 2.5, 50, and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the winter survey, from 1978 to 1994. The 2.5, 50, and 97.5 percentiles of selected temperature CDFs are represented by the bottom, middle, and top solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled temperature CDFs are represented by the bottom, middle, and top dotted lines, respectively.

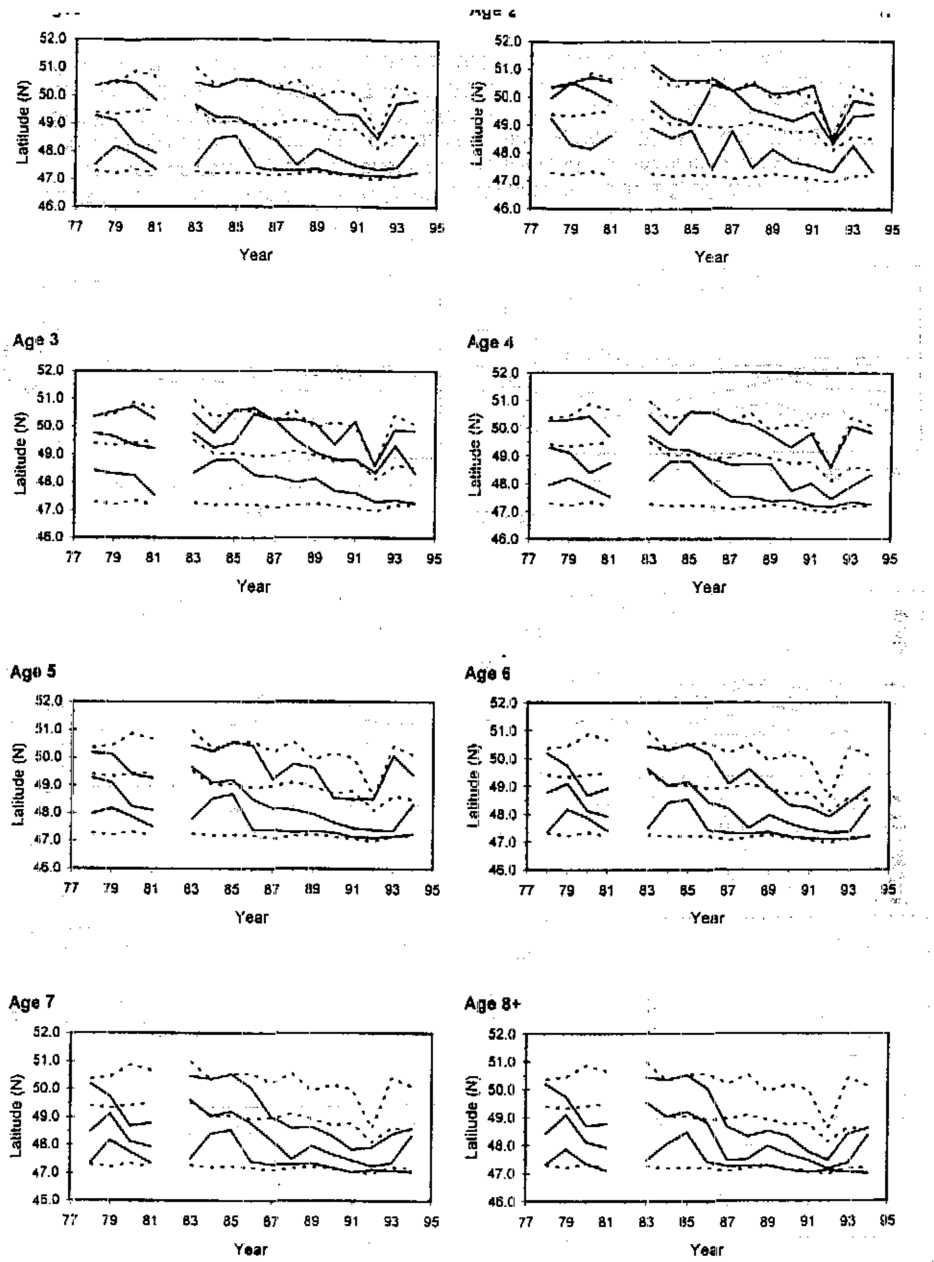

Fig. 6. Cumulative distribution functions (CDFs) of latitudes (expressed as 2.5, 50, and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the winter survey, from 1978 to 1994. The 2.5, 50, and 97.5 percentiles of selected latitude CDFs are represented by the bottom, middle, and top solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled latitude CDFs are represented by the bottom, middle, and top dotted lines, respectively.

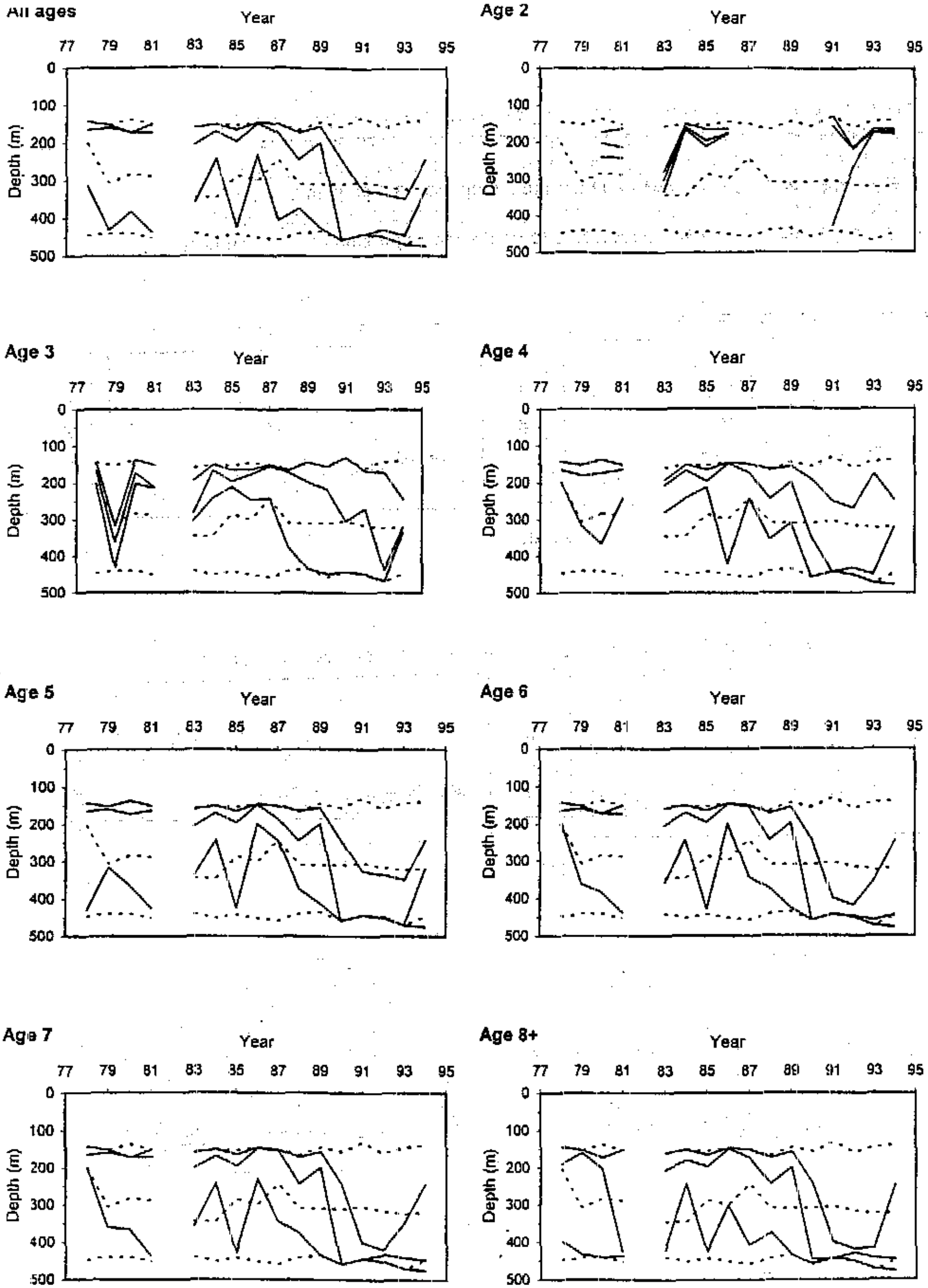

Fig. 7. Cumulative distribution functions (CDFs) of depths (expressed as 2.5, 50, and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the winter survey, from 1978 to 1994, including only 3Pn sampling stations. The 2.5, 50, and 97.5 percentiles of selected depth CDFs are represented by the top, middle, and bottom solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled depth CDFs are represented by the top, middle, and bottom dotted lines, respectively.

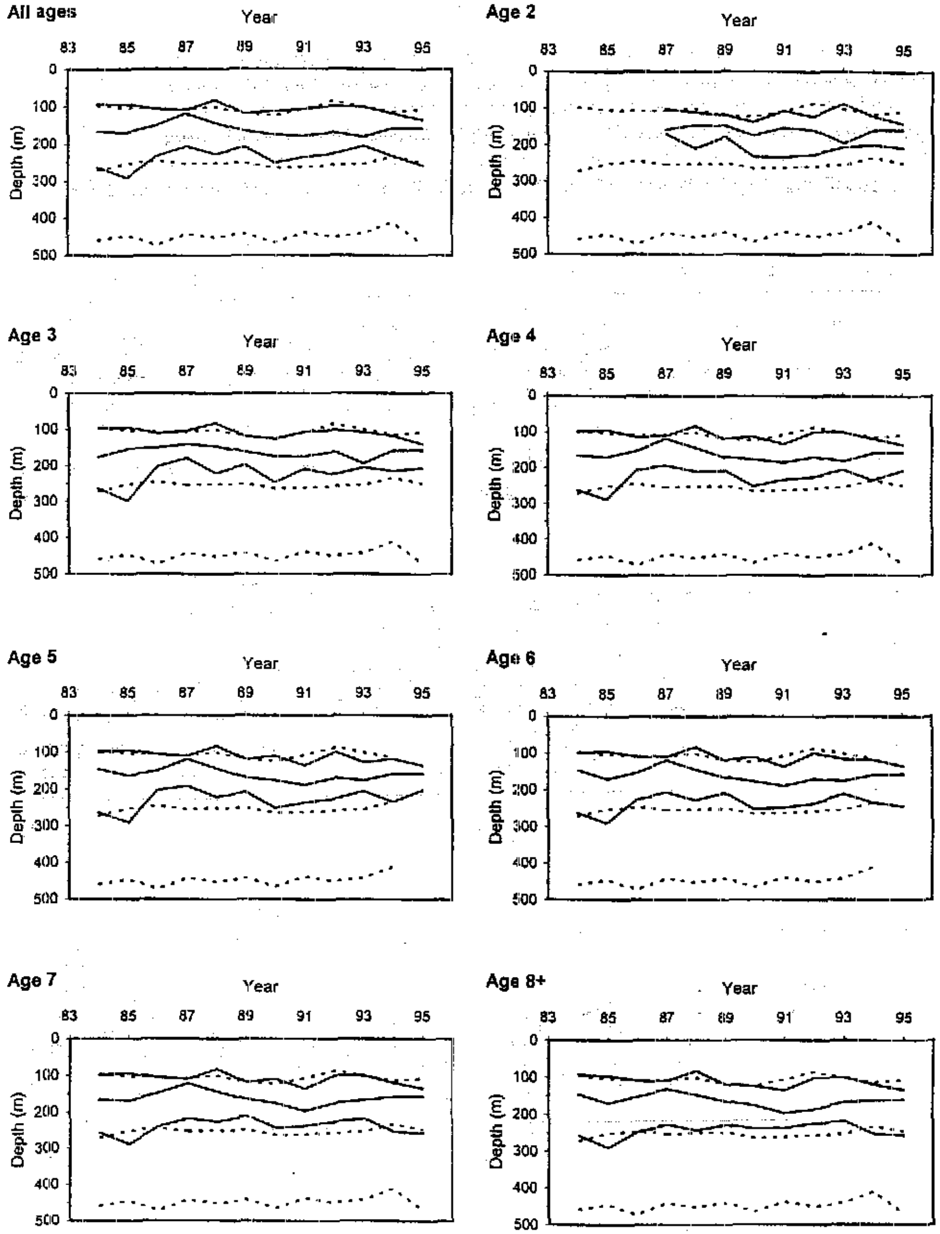

Fig. 8. Cumulative distribution functions (CDFs) of depths (expressed as 2.5, 50, and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the summer survey, from 1984 to 1995. The 2.5, 50, and 97.5 percentiles of selected depth CDFs are represented by the top, middle, and bottom solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled depth CDFs are represented by the top, middle, and bottom dotted lines, respectively.

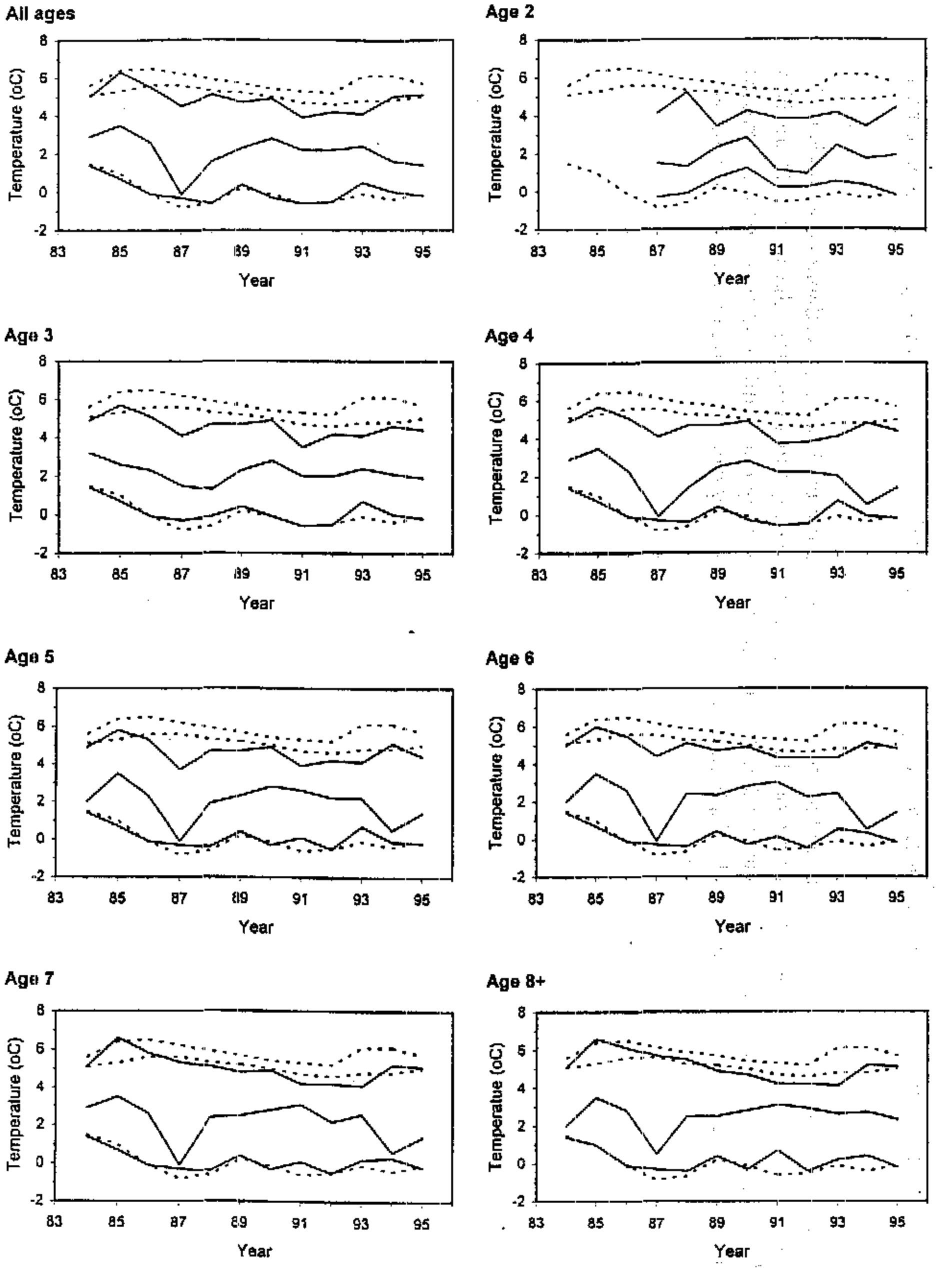

Fig. 9. Cumulative distribution functions (CDFs) of temperatures (expressed as 2.5, 50, and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the summer survey, from 1984 to 1995. The 2.5, 50, and 97.5 percentiles of selected temperature CDFs are represented by the bottom, middle, and top solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled temperature CDFs are represented by the bottom, middle, and top dotted lines, respectively.

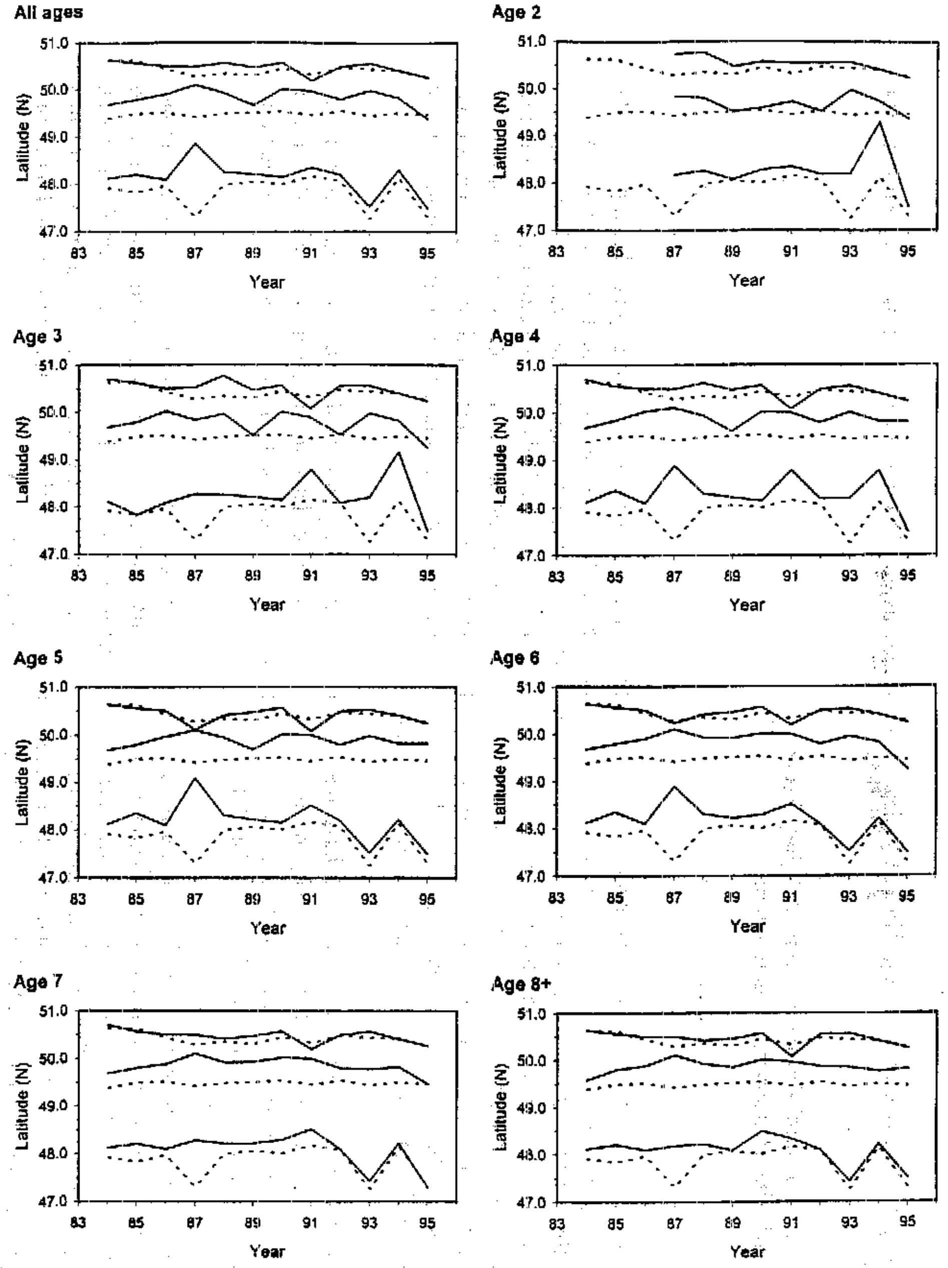

Fig. 10. Cumulative distribution functions (CDFs) of latitudes (expressed as 2.5, 50 and 97.5 percentiles) selected by cod of various age groups (and also for pooled ages) versus those sampled by the trawl during the summer survey, from 1984 to 1995. The 2.5, 50, and 97.5 percentiles of selected latitude CDFs are represented by the bottom, middle, and top solid lines, respectively. The 2.5, 50, and 97.5 percentiles of sampled latitude CDFs are represented by the bottom, middle, and top dotted lines, respectively.

Norwegian spring spawning herring. Recent years development of condition factor in relation to zooplankton availability

Petter Fossum, Padmini Dalpadado and Webjørn Melle
Institute of Marine Research, Bergen, Norway

Abstract

An increased number of spawning sites has been occupied with the concurrent increase in spawning stock. At present the nss herring is spawning from the Sirabank to the Røstbank outside Lofoten. Atresi and condition factor is inversly related and the herring with the highest condition factor is found at the southernmost spawning sites. This year a large proportion of the spawning stock was found over the northernmost spawning areas. This was also expected with the low and variable condition factor found in the overwintering areas this winter. At present there are no strong year class of adolescent herring in the Barents Sea and the last strong year class was the 1992 year class. High larval production has taken place during the 90´ies, however unfavourable conditions in the coastal current and high predation pressure especially in the Barents Sea have been devastating for recruitment.

The physical conditions in the Norwegian sea have been dominated by strong inflow of fresh and cold watermasses through the Denmark Strait since the 60´ies. The inflow of Atlantic watermasses have been strongest through the eastern branch of the Atlantic current. The implication of this is that the nss herring have had a relative restricted feeding area when it re-appeared in the Norwegian Sea in the late 80´ies.

Primary productivity in the Norwegian Sea has been a matter of little concern during the last decades. During the last years investigations have been carried out at Station M. These investigations have shown that stabilisation is indicated through a change in the rate of sea temperature increase, not the temperature level itself. This is important for initiation of the spring bloom. The implication of this for the productivity in the whole sea is not known. The amounts of low pressure systems and thus strong winds that are able to break down the stability and bring nutrients to the euphonic zone during the production season have also strong implication for the overall productivity.

The zooplankton biomass have been relatively stable east of 6V since the last 50´ies. In the western parts, however, the alteration of the physical conditions with both a strong east Island current, strong inflow of Arctic watermasses and a decreased inflow of Atlantic watermasses from the 60´ies, have depressed the zooplankton biomass to a much lower level. During the latest feeding seasons zooplankton production seem to have been reduced. A much higher standing stock of zooplankton was seen in the Norwegian sea during the May coverage in 1996 than in 1997. Later in the season this difference was not significant, however, large grazing pressure from 1 and 2 group blue whiting can also have been an important factor.

Gut content investigation on nss herring in the feeding area has been carried out the last years. Calanoid copepods is the dominant prey item except from the earliest part of the feeding season when krill dominates the menu. There is a stronger diversity of prey items later in the season when the herring is spreading out in different types of watermasses and except from calanoid copepods and krill, amphipods, polychaets, chaetognats, fish, squids and larvaceans was found.

Norwegian spring-spawning herring. Changes in the condition related to environmental factors.

Jens Christian Holst, Institute of Marine Research, Bergen, Norway

Abstract

At high stock levels the Norwegian spring spawning herring performs long range feeding migrations into the Norwegian Sea and in periods also the Icelandic Sea. At low stock levels the migration pattern is coast-near, along the Norwegian coast. A long term study of the growth success of the Norwegian spring spawning herring in its feeding areas, as represented by the length specific weight (condition) of the spawning stock during the period 1935 to 1998, revealed long term trends in the herring growth success (*Figure* 1, 2). The investigation covered spawners from 29 to 36 cm, thus including the majority of the spawning stock. There was a high covariation between the length-groups investigated (*Figure* 1) and the variation in condition was consistent throughout the geographic spawning range. The observed variations in condition of the spawning stock appears not to be density dependent, and high and low condition was observed both at high and low stock levels (*Figure* 3).

A correlation was found between the varying condition of the herring and the climatic conditions in the feeding areas of the herring stock. Under warm climatic periods the condition of the herring was in general high while in colder periods the condition decreased (*Figure* 4, 5). A correlation also seems apparent between the temperature regime and the available amount of plankton within the feeding areas, with lowered densities of plankton present during cold periods. The variation in condition level is accordingly suggested to be a combined effect of changes in both the temperature regime and the level of available food resources in the feeding areas.

In terms of consequences to the biomass of the spawning stock, the variation in condition accounts for very large numbers, and at stock levels at for instance 40 billion spawners, the difference between a stock at the highest condition level observed as compared to the lowest level equals approximately 2 million tonnes. This is not far from the double of the present TAC.

Recent development

Since 1991 the condition of the spawning herring has showed a negative trend with 1998 as the lowest so far. This indicates that the growth success of the herring has steadily decreased with the 1997 feeding season in the Norwegian Sea as the poorest during this recent period. The ocean temperatures (as measured at station M, 66N, 2E) has shown a negative trend during the same period, but in early 1997 the temperatures turned and has been rising since. The rise in temperature during 1997 is among the strongest observed in this part of the Norwegian Sea since the start of the time series in 1948. This indicates that a more favourable regime is on its way and it is expected that the herring condition will rise again from after the 1998 feeding season. The turn in temperatures most probably arrived too late during the winter 1996–1997 to effect the productivity of the Norwegian Sea in the summer of 1997.

It seems that the described cycles in the productivity of the Norwegian Sea appears as waves more than discrete jumps between years. A period of at least 3–4 years is typically needed to move from an ocean characterised by low productivity to high productivity, or the opposite way. The time lag between the shift in oceanographic regime and the shift in biologic regime may be related to the maximum reproduction capability of the plankton within one or two cohorts. Although the oceanographic conditions may shift quickly, and very favourable conditions may appear within the matter of a year, the biologic system cannot take advantage of such a quick shift, and the oceanographic-biologic time-lag appears.

Consequences to the management of the herring stock

These finding represent both a helping hand and present new challenges to the management of the Norwegian spring spawning herring. A helping hand in that it will, first, allow for a better understanding of the variable recruitment process in this herring stock, secondly, it introduces a better basis for forecasting growth success and individual weights and, third, it allows for new ecological aspects to be introduced into the management regime for this herring stock. The challenges will be to include this knowledge into the practical assessments and forecasts. The present study underlines the importance of basic process studies as an important tool for improved fish stock management.

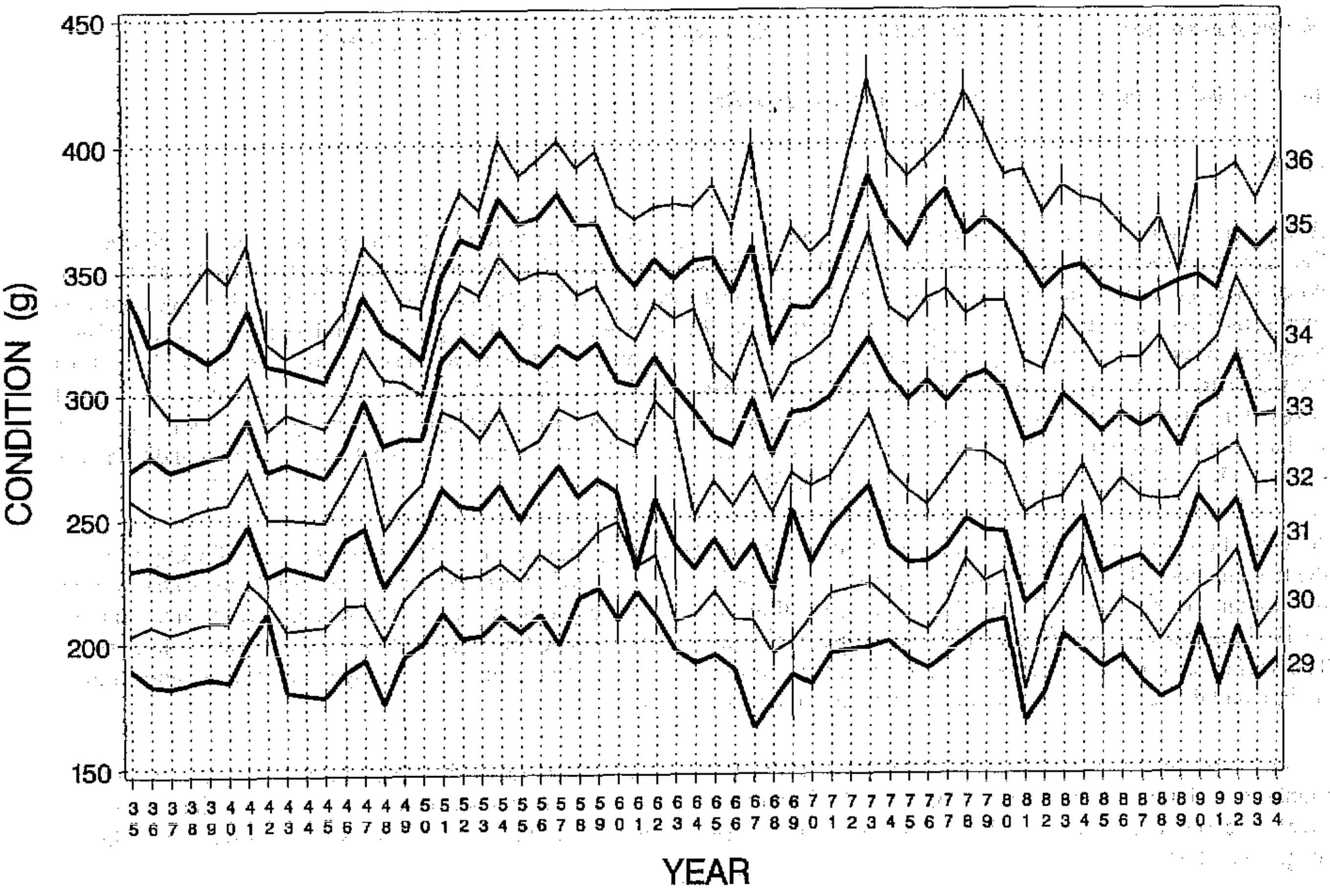

Figure 1. Estimated mean length specific weight (condition) by year for the length groups 29 to 36 cm during the period 1935 to 1994. Includes individuals in the maturity stages 4 and 5 caught at the spawning grounds from 58°N to 70°N during the months January to April. Values given for 1938, 1944 and 1972 are means of the year before and the year after. All mean values ± 1 standard error.

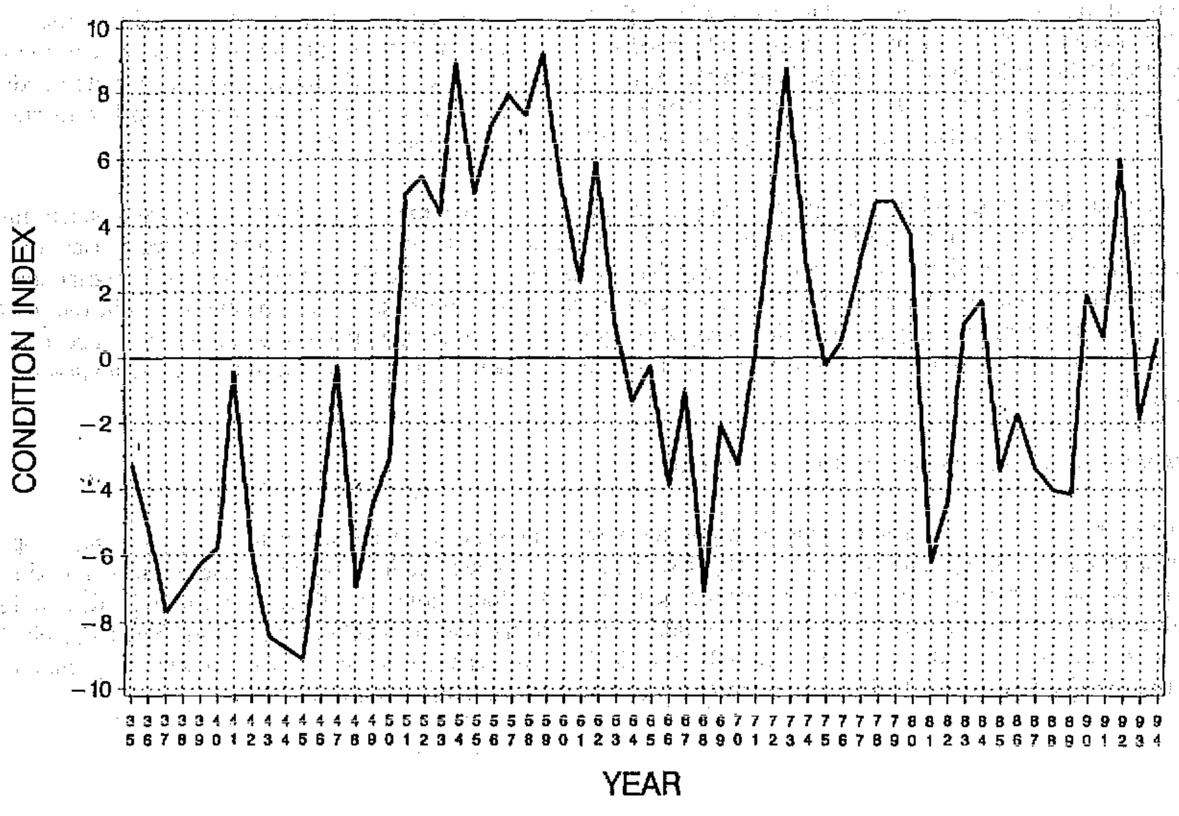

Figure 2. Estimated condition index for the spawning stock (length groups 29-36) by year during the period 1935 to 1994. Values given for 1938, 1944 and 1972 are means of the year before and the year after.

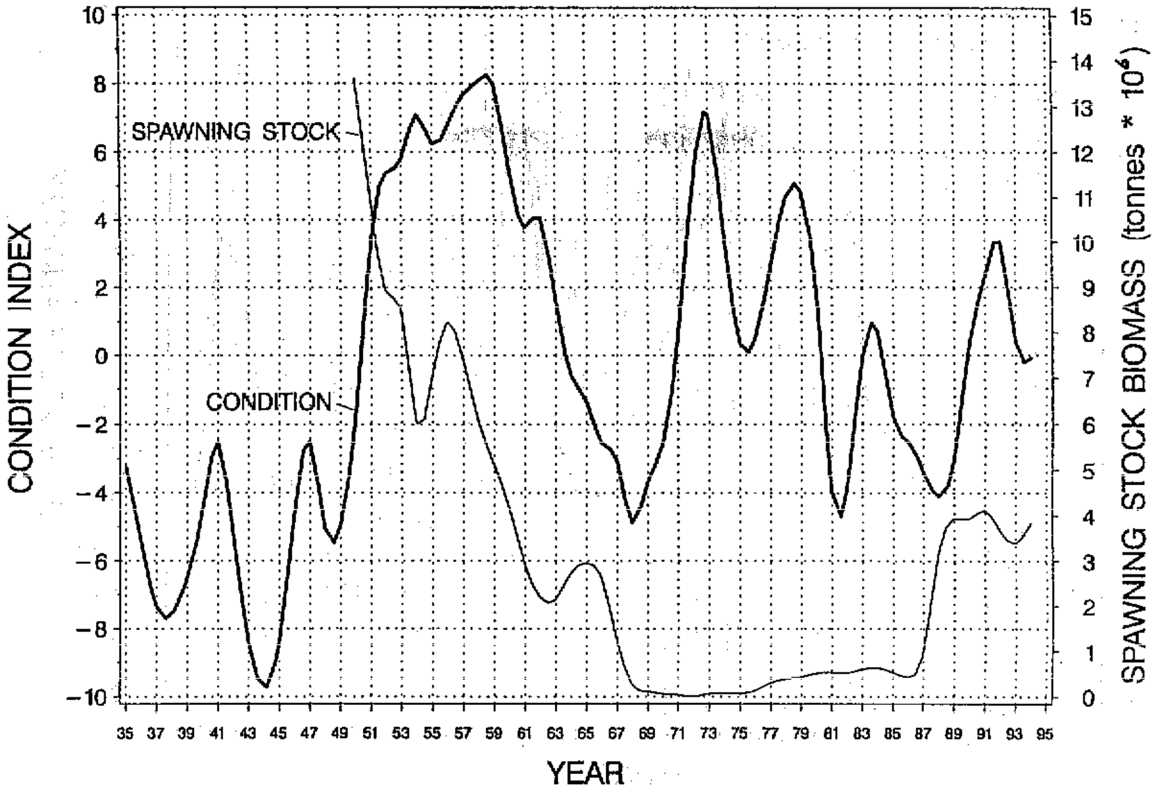

Figure 3. Smoothed herring condition index and estimated NSSH spawning stock biomass. Biomass from Anon., (1995).

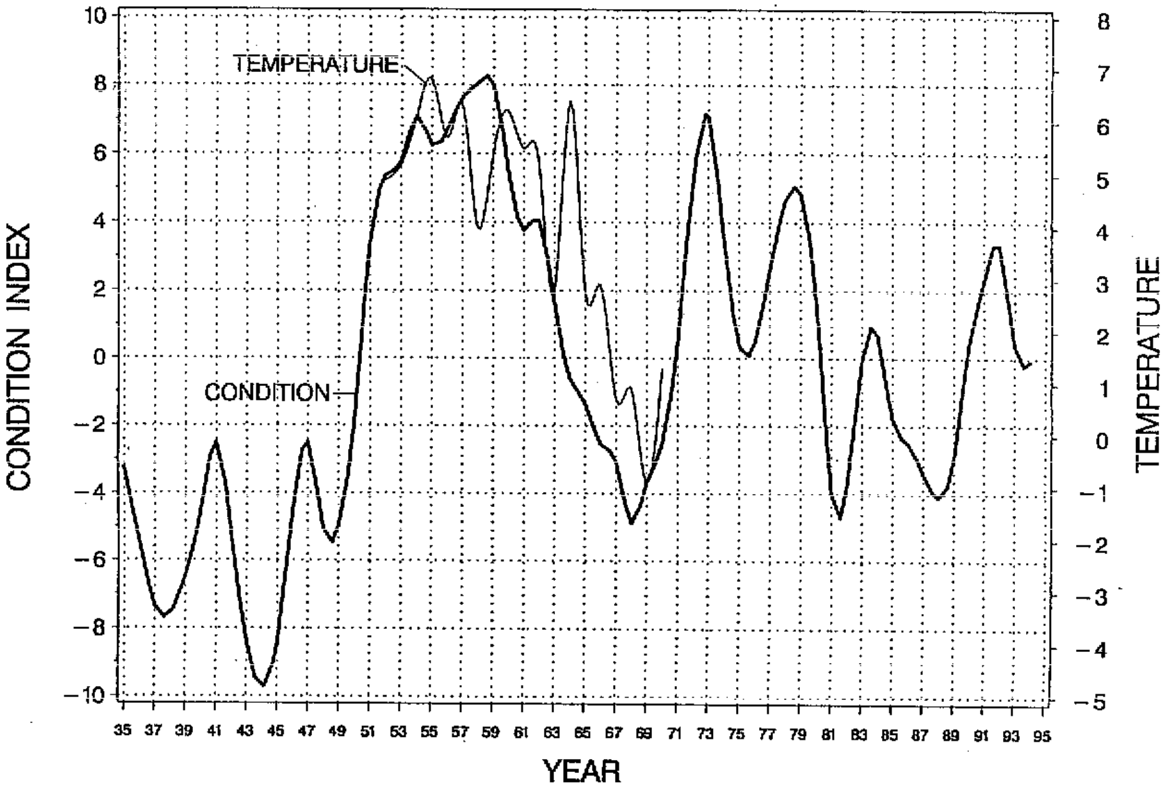

Figure 4. Smoothed herring condition index and temperature at 50 m in May/June at station S-3 (Siglunes section, 66°32'N 18°50'W, Icelandic Sea). Temperatures from Malmberg and Kristmannson (1992).

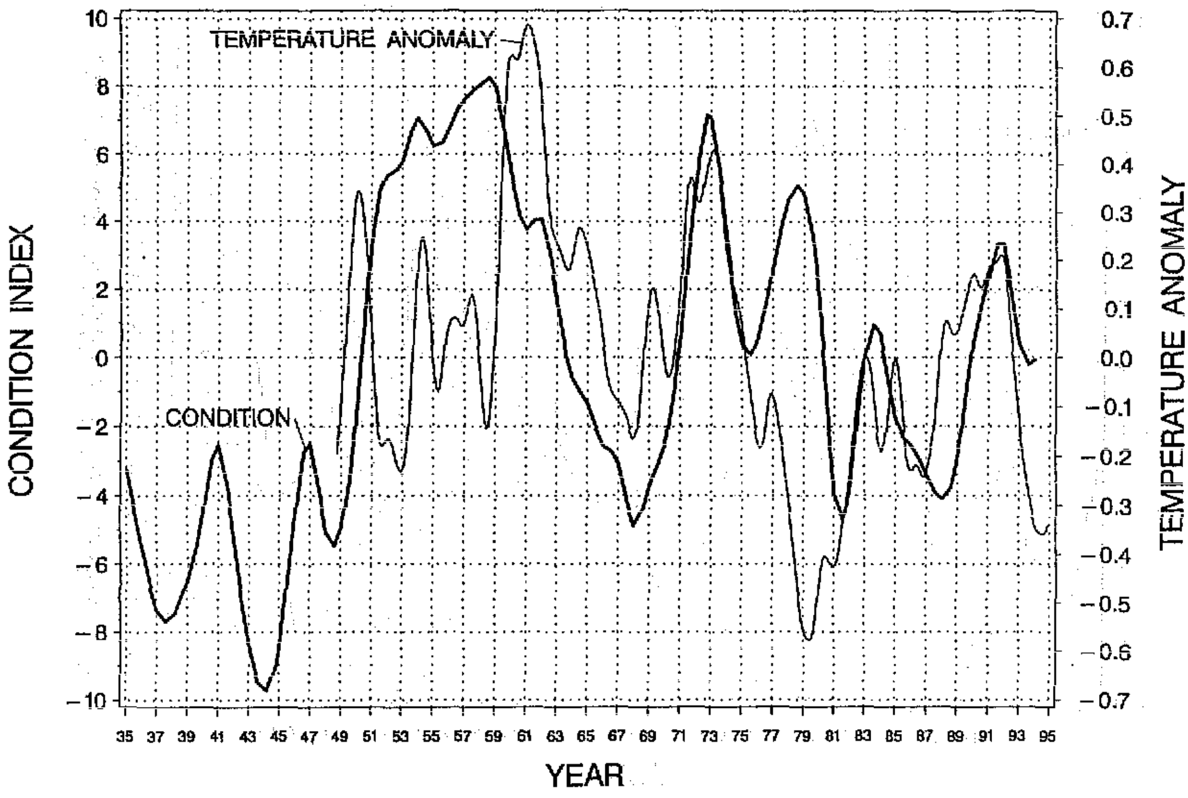

Figure 5. Smoothed condition index and smoothed monthly temperature anomaly at 50 m depth at Station Mike (66°N 2°E, Norwegian Sea). Temperatures most kindly supplied by Svein Østerhus (Nordic WOCE)/Geophysical Institute, University of Bergen, Norway.

Ambient temperature, horizontal distribution and growth of North-East Arctic cod

Kathrine Michalsen, Institute of Marine Research, Bergen, Norway

Most studies on the effects of field temperature on fish distribution and population parameters have considered the temperature and its variability at fixed geographical locations rather than the temperature in the actual surroundings of the fish, the ambient temperature. From spatial distribution of fish density and temperature, estimates of ambient winter temperature have been established for 1–7 year old North-East Arctic cod in the period 1988–1995.

The estimates of ambient temperature were compared with temperature series in the Kola meridian. As expected the interannual variability in ambient winter temperature were found to be larger than in the Kola-section series for all age groups (Figure 1). In addition the ambient temperatures were found to increase with the age of the fish. For the youngest age groups the ambient temperature was found to be lower than in the Kola section. Older age groups were distributed farther west than the younger ones and the reduction in ambient temperatures from 1990 and onwards seems to be related to an extension of the distribution eastwards. In general mean lengths at age increased with increasing temperature for cod of age 2–6. Also mean individual growth (in length and weight) was highest for year classes which experienced high temperatures (Figure 2). We found that increased abundance for young cod was associated with an extension of the distribution area towards east and north into colder water (Figure 3). In the same period the abundance of capelin increased and lead to an increase of individual consumption of capelin by cod. Consequently, the observed reduction in growth rate in this period was not due to a reduction in prey availability. Our interpretation is that high abundance of cod influences the horizontal distribution in a manner that effect the ambient temperature, and thus the growth rates, negatively.

Due to the seasonal migration pattern of cod, they are in the warmest part of their distribution area during winter and in the colder parts of this area during summer. Therefore, we expect that the actual annual means of ambient temperature are lower than the values we have calculated from February. The next step is to calculate the mean ambient autumn temperature, which is possible since we also have survey data from this part of the year. Seasonal variation in ambient temperature have been observed from individual tagged cod (electronic tags, recording depth and temperature every second hour for more than 8 months, Figure 4). Mean temperatures per month indicate that cod experience higher temperatures during early spring (February-March) than in Autumn (September-October). Hopefully, by combining ambient winter temperature, ambient autumn temperature and data from tagging experiments we will be able to create a annual ambient temperature curve which then can be used with the resolution in time needed in consumption analysis.

How to use the results in stock assessment?

The most obvious place to start using ambient temperatures is in the food-consumption calculations of cod. In recent years the consumption by the cod stock has been estimated annually by the Arctic Fisheries Working Group. The temperatures used are monthly climatological temperatures taken from three fixed stations in the Barents Sea. These have been regarded as representative for the western, eastern and northern parts of the distribution area. A comparison of the temperatures calculated by the WG and the ambient temperature estimated by us, show that both the variability between years of each age group and the variation between age groups is larger, while the mean values are lower in our estimates (Figure 5). For the period 1992–1995 the mean ambient winter temperature of age 1–3 years were 1–3 ^{0}C lower than those used by the AF Working group, a difference that would generate an upward error of 10–30% in the consumption estimates.

Since the total consumption of capelin, which is the main prey item for cod, directly affect the estimates of the capelin stock size, an overestimation of the natural mortality will bias the assessment of the capelin stock. In addition, the consumption of cod and haddock by cod would influence the recruitment estimates of these two species. If the consumption is overestimated then we believe that there have been more 3 and 4 year old fish than it was in reality. In 1992, a temperature reduction of 1 ^{0}C would have lead to a overestimation in the consumption of capelin by cod of about 250.000 tonnes, which is ¼ of what was actually caught by the fishing fleet that year.

Further, we have shown that there is a relation between stock size, horizontal distribution and the difference in temperature between the Kola section and the one experienced by the fish. By using this relation, together with temperatures from the Kola section and the converted VPA we can get an idea of the horizontal distribution and ambient temperature even for the years before we started our surveys in the Barents Sea. However, we need to adjust this relation for the fact that the surveys, before 1993, did not always cover the total horizontal distribution area of cod and that we therefore most likely have overestimated the ambient temperature for some years (especially in 1991 and 1992). When we get some more observations (from surveys in the future) where the total horizontal distribution is covered, the slope of the regression line will probably be lower than the one estimated by us.

Also the relation between the survey indices and the converted VPA have to be corrected for lack of horizontal coverage. If we make the plot of the VPA and the survey indices for the recent years we would find a linear relation like this;

N = aI + b, where b is the intercept, a the slope and I the survey index (Figure 6).

But if we split the survey indices into two groups, those taken up to 1992 and those taken from 1993 and up to 1996 we expect to find two different regression lines. This show that; at the same level of abundance the survey indices can be 15% higher when the whole distribution area have been covered. This also indicate that when the "old" relation between survey indices and VPA have been used in the tuning procedures, the stock abundance have been overestimated

Which ambient temperature to use?

There are several methods that can be used to calculate ambient temperatures and all will give different results. As an example; in our study we calculated 4 different estimates of ambient temperature, based on observations from acoustic and swept area densities, and for temperature recordings at the bottom as well as averaged from 100m depth to the bottom. The estimates were all different from each other, but at the same time they were more similar than the temperature series in any fixed geographical location (Figure 7). In our study we did not draw a clear conclusion regarding which temperature to use. Since we know that the vertical distribution of fish varies between years, the choice of sampling method and vertical temperature representation should be defined by availability of the fish for the two sampling methods each year. One way of evaluating this could be to construct a vertical profile showing mean echo density at increasing height above bottom. During 1993–1995 a change in distribution took place; where the cod being closer to the bottom in 1995 than in 1993. Hence we must expect the availability to the bottom trawl increased over the period and that the availability to the acoustics decreased due to more fish in the acoustic dead zone in 1995 than in 1993. Therefore, in years where the fish stays close to bottom, swept area and bottom temperature should be used, while in years where a higher proportion of fish is distributed high up in the water column, swept area or acoustics together with mean temperature from 100m to the bottom should be used.

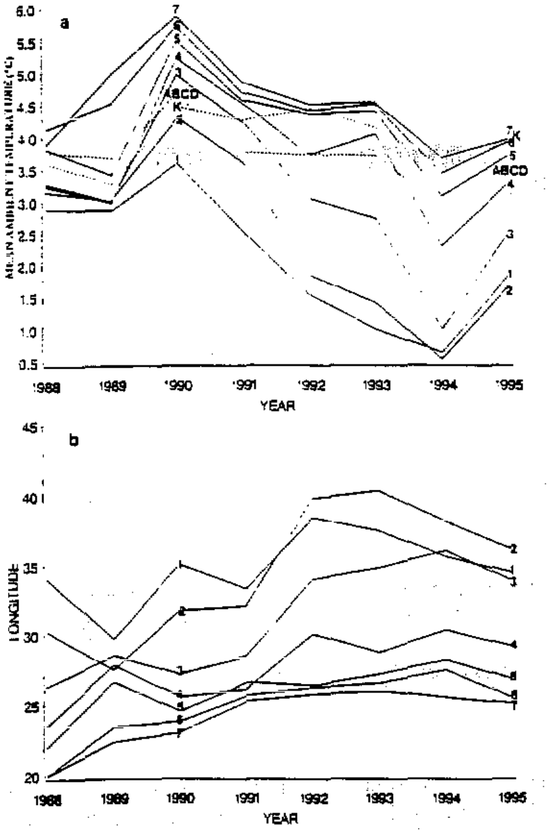

Figure 1 Mean ambient temperatures (a) and centres of mass of distribution (b, in degrees eastern longitude) of Northeast arctic cod 1988-1995 for agegroups 1 to 7. The mean bottom temperature in the ABCD area (ABCD) and the 0-200m December-February temperature mean from the Kola section (K) are shown (stippled lines).

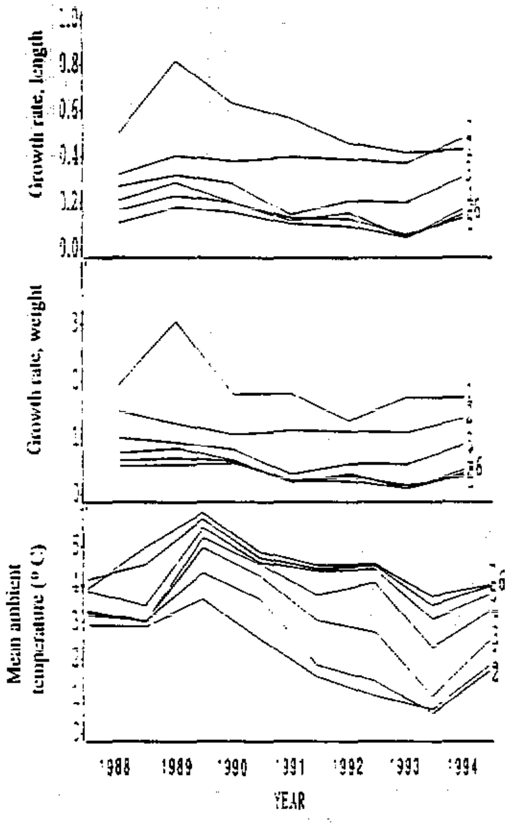

Figure2. Instantaneous annual growth rates in length ($\ln L_{a+1} / \ln L_a$) and weight ($\ln W_{a+1} / \ln W_a$) compared with mean ambient temperature. Numbers to the right indicate age group. Note that growth from age a to age a+1 are taken from February one year to February next year and plotted in the middle of the year the fish was aged a.

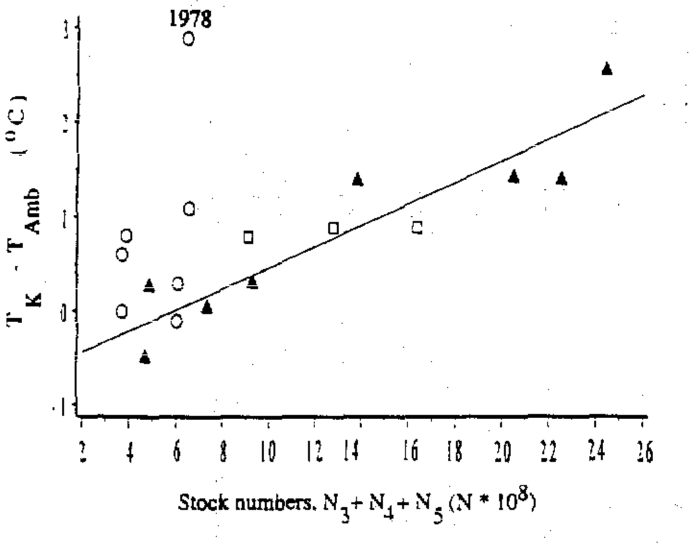

Figure 3. Temperature difference between Kola and mean ambient temperature for 3 year old cod related to stock size in numbers * 10^8 (Anon. 1996). Filled triangles indicate data from 1988-1995, squares indicate data from 1985-1987 and circles indictae data from 1978-1984. The regression line is based on data from 1988-1995 (triangles). The year 1978 is outlined.

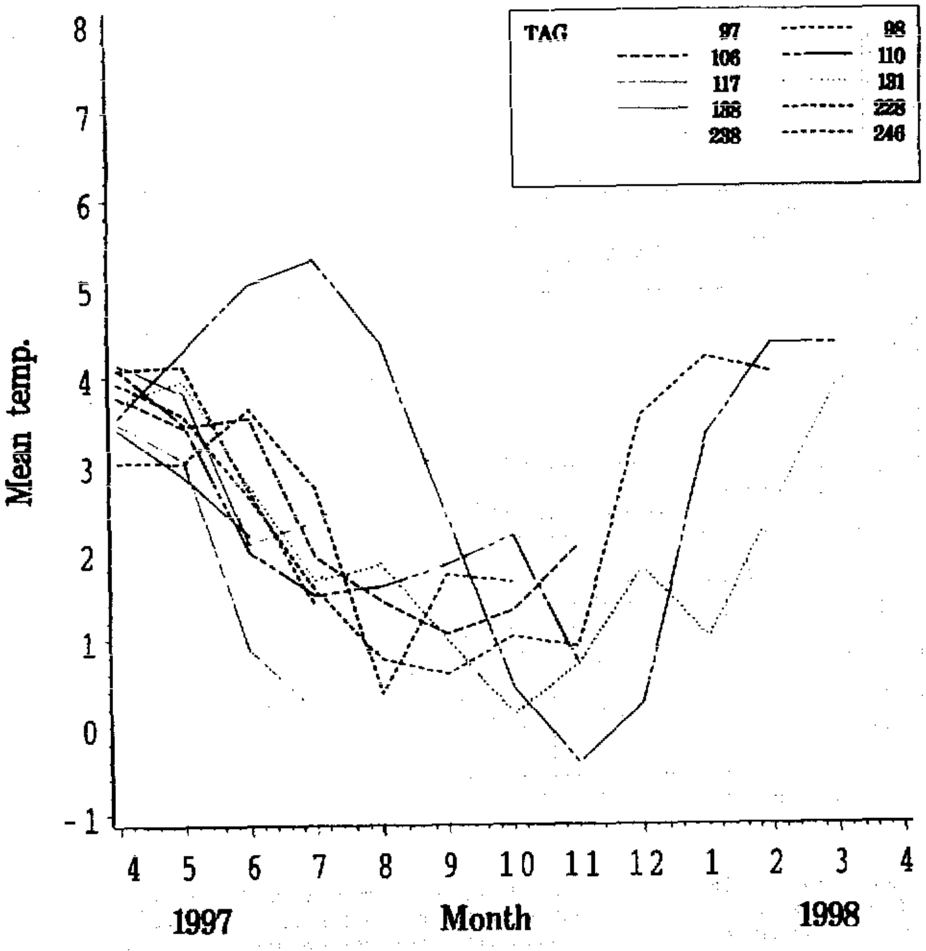

Figure 4. Seasonal changes in mean temperature (per month) from individual tagged cod.

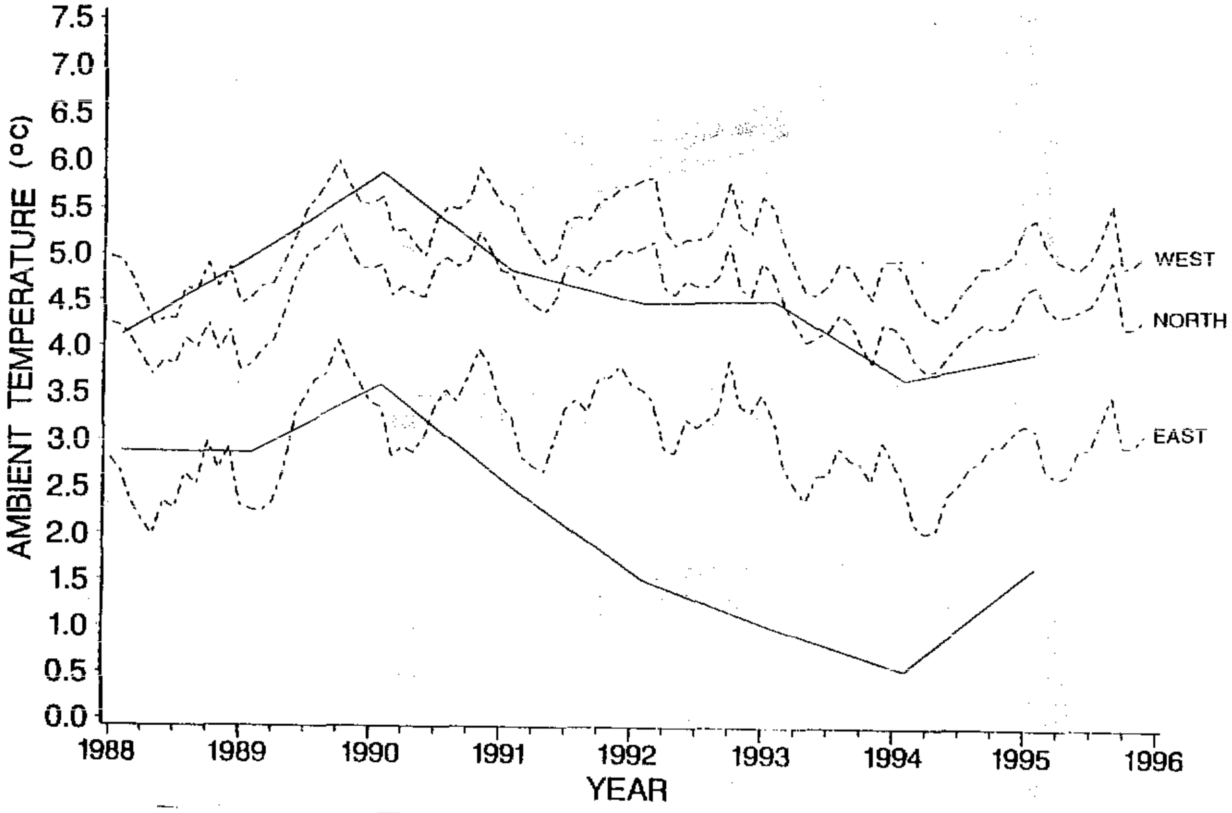

Figure 5. Ambient temperatures and temperatures used for estimation of consumption. Stippled lines show temperatures used by Bogstad and Mehl (in prep.) Full lines show upper and lower limits of mean ambient winter temperatures as estimated by us.

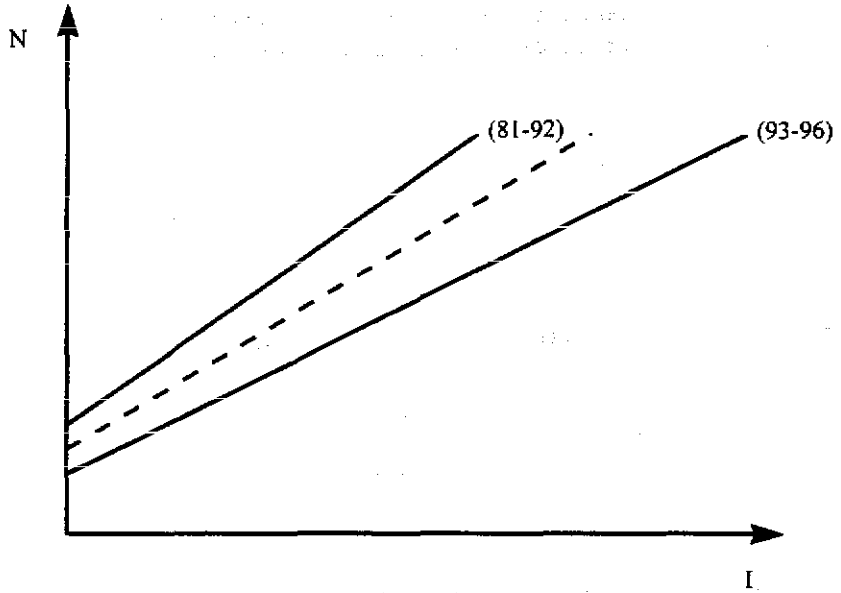

Figure 6. General description of the relation between the converted VPA (N) and the survey index (I) at age. The numbers at right indicate time periods with (93-96) and without (81-92) complete coverage of the horizontal distribution of cod in the survey. The dotted line represent the relationship combined for all years (81-96).

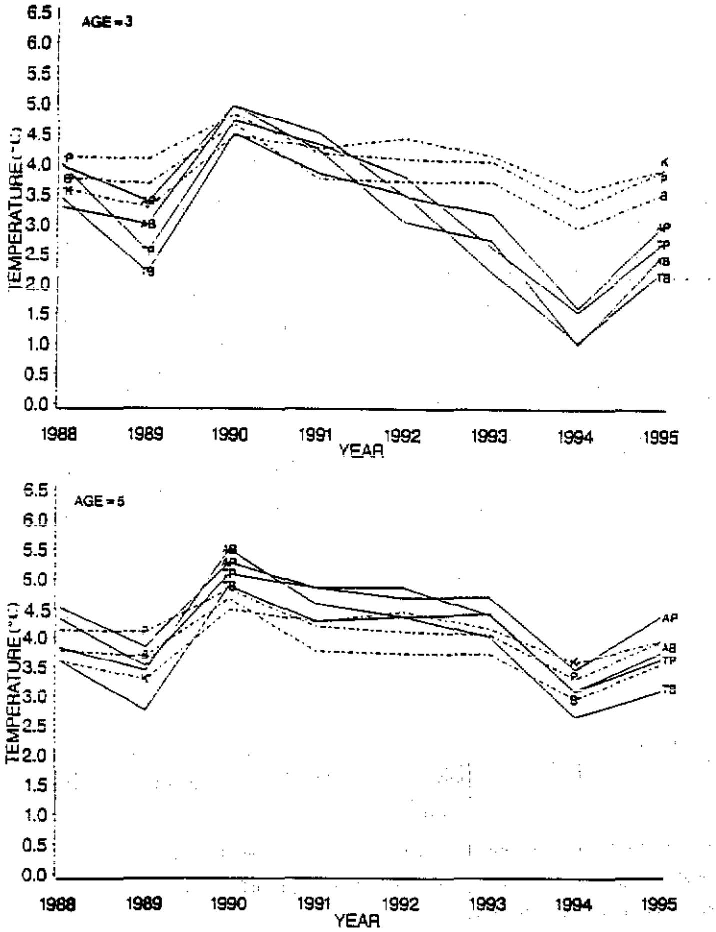

Figure 7. Mean ambient temperatures of 3 year old cod (upper panel) and 5 year old cod (lower panel) in February 1988-1995 based on acoustic estimates and temperatures 100m-bottom (AP), trawl estimates and temperatures 100m-bottom (TP), acoustic estimates and bottom temperatures (AB) and trawl estimates and bottom temperatures (TB). Mean temperatures at 0-200m in the Kola section (K), in area ABCD at the bottom (B) and 100m to bottom (P) are also shown (stippled lines).

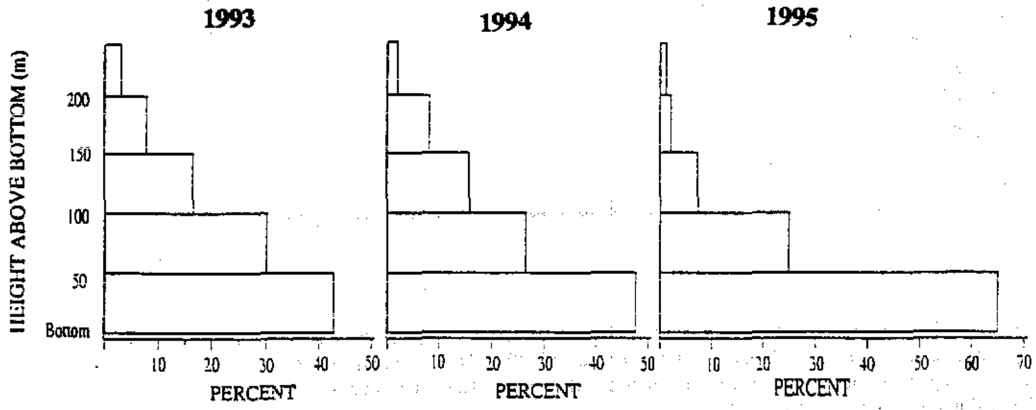

Figure 8. The vertical distribution of cod relative to the bottom in February 1993-1995. Horizontally accumulated s_A-values in 50 m height intervals given as percent of total (from Korsbrekke *et al.* 1995).

Abundance and growth of juveniles in the Barents Sea in relation to environment

Geir Ottersen, Institute of Marine Research

Extended abstract

An important factor in the management of fish stocks is an understanding of the recruitment mechanisms. For many fish stocks, the stock-recruitment relationship is indeterminate, a fact which has lead to focusing on the environmental conditions during the early life stages as regulatory factors of recruitment variability, as for example hypothesized by Hjort (1914).

To be able to use interannual variability in the environmental conditions in fisheries management it is necessary to determine which environmental factors are of importance for the particular stock in question, and to quantify the relationships between the environmental and population parameters.

This presentation will focus on the commercially important stocks of the Barents Sea, particularly Arcto-Norwegian cod. The main spawning areas of this stock are in the Lofoten and Vesterålen areas off the coast of northern Norway. Spawning takes place in the thermocline between cold coastal water and warmer Atlantic water with peak spawning in early April (Ellertsen *et al.*, 1989). The eggs and larvae drift 600–1200 km before they in September, as bottom-settling 0-group, are distributed all over the southern Barents Sea. The year class strength is mainly determined during the first six months of life (Sundby *et al.*, 1989).

Sea temperature affects cod recruitment through many different processes. Stocks near the lower limit of the overall temperature range of the species, like the Arcto-Norwegian, benefit from positive temperature anomalies. Ottersen *et al.* (1994) showed that the mean abundance at the 0-group stage for both cod and haddock for the period 1966–92 was 2.5–3 times higher in warm years than in colder years. The relation between temperature and 0-group strength is however not linear, above average temperature is a necessary but not a sufficient requirement for a strong year class. Wind direction and strength also influence abundance of pre-recruits.

Ottersen and Sundby (1995) found offshore wind stress anomalies in April as well as northerly, alongshore anomalies during the whole period of pelagic drift from April to October, to be favourable for cod recruitment. The mechanisms pointed to were enhanced zooplankton availability and reduced predation risk through increased spreading (offshore anomalies). Examples of simple, statistically derived models explaining pre-recruitment variability by SSB and environmental factors were given.

Sea temperature influences not only the abundance of a year class, but also the size of the early juvenile and 0-group fish. Loeng *et al.* (1995) found that the length of 0-group cod, haddock and herring to a large degree have shown the same fluctuation patterns since the time series were established in the late 1960's. The correlation between cod and haddock lengths was as high as 0.82. Statistically significant correlations between temperature and 0-group length of the three stocks were further found ($r = 0.7$ for cod, 0.6 for haddock and herring. Time series of temperature and length of 0-group cod are shown in Figure 1.

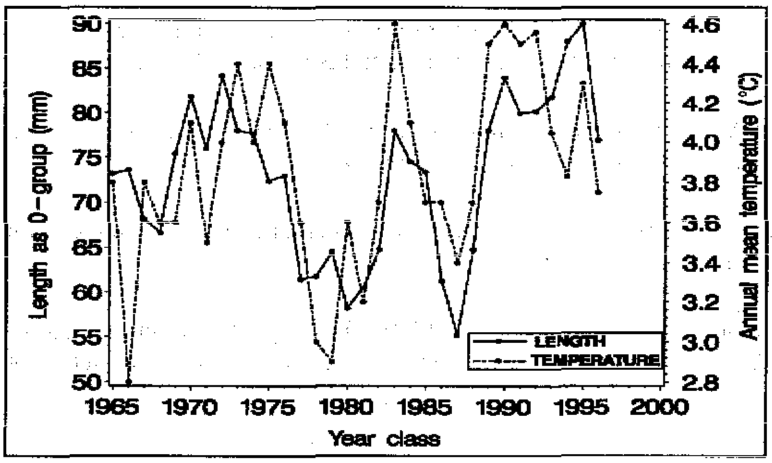

Figure 1. Temporal development 1965–1996 of length of cod at the 0-group stage and annual mean temperature in the Kola section.

New results show that cod length and year class strength as 0-group tend to have a synchronous temporal development. More interesting for assessment is the finding of a relatively close relationship also between length as 0-group and abundance at age 3 as estimated by VPA (Figure 2). The correlations are 0.6 for cod and haddock, 0.7 for herring. This is a closer connection than that between abundance as 0-group and at the three-year stage. Information available in the fishes first autumn thus gives a reasonably good indication of the abundance of the year class at age three.

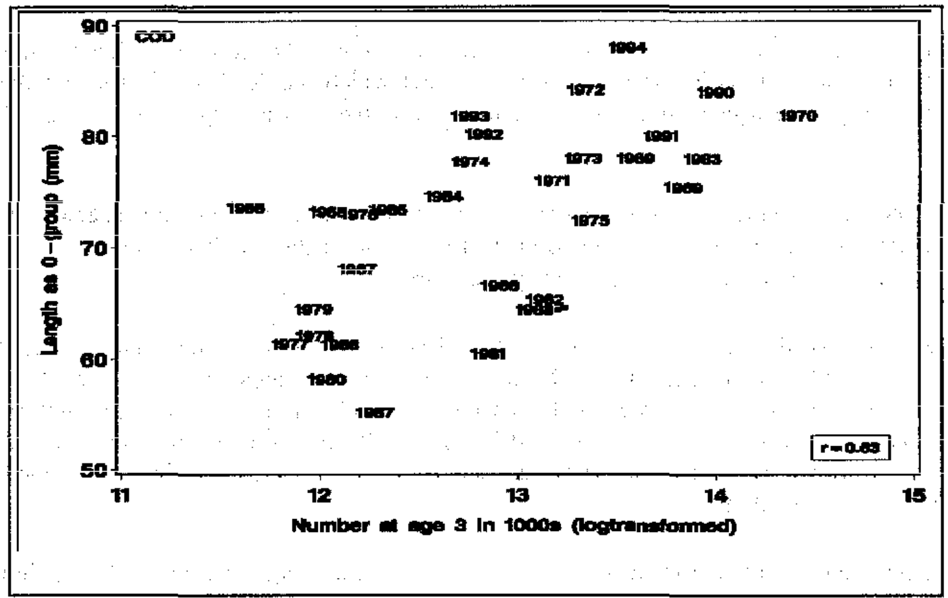

Figure 2. Cod recruitment at age 3 (logtransformed number at age) and length at the 0-group stage. Values are indicated by dots when otherwise difficult to distinguish between years.

The results suggest that interannual temperature variability is the underlying cause of the synchronous variability pattern found in 0-group length and year class strength at both the 0-group and three-year. High temperature will cause a high production of prey items increasing both growth and survival rates through the vulnerable larval and juvenile stages. The duration of the high-mortality and vulnerable stages is also decreased by higher temperature directly increasing the development rate.

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Interannual variability in temperature and the recruitment of Irish Sea cod.

Benjamin Planque and Clive J. Fox

The Centre for Environment Fisheries and Aquaculture Science, Lowestoft Laboratory, Pakefild road, Lowestoft NR33 0HT, UK.

Abstract

A short review shows that in cold, arctic regions of the North Atlantic positive relationships are generally observed between cod recruitment and water temperatures whilst negative relationships are observed in warm-temperate regions. According to this relationship, cod recruitment in the Irish Sea should be negatively related to sea temperatures. Using three independent sources of long-term temperature records we test this hypothesis and show a highly significant connection between the recruitment of cod and temperature signals. We suggest that this relationship should be taken into account in any future attempt at understanding or predicting cod recruitment in this area.

Keywords

cod, temperature, recruitment, Irish Sea, long-term changes

Introduction

Year-to-year variability in temperature has been shown to be linked to changes in fish year class strength for a number of species (Mysak, *et al.* 1982, Murray, *et al.* 1983, Swartzman, *et al.* 1983, Hansen and Buch 1986, Jacobson and MacCall 1995). Atlantic cod (*Gadus morhua*) are widely distributed in the waters of the North Atlantic and surrounding seas and occurs in water temperatures in the range -1 to 12°C. Different stocks show a variety of relationships between recruitment and temperature variations. Three types of response have been reported: firstly a positive link to temperature, this is probably the most widely described relationship (Lablaika, *et al.* 1989, Buch, *et al.* 1994, Malmberg and Blindheim 1994, Ottersen, *et al.* 1994, Ottersen and Sundby 1995, Ottersen 1996); secondly, a negative response which has been reported in a few cases (Martin and Kohler 1965, Dickson, *et al.* 1973) and thirdly an absence of linkage between temperature and recruitment (Serchuk, *et al.* 1993, Hansen, *et al.* 1994, Heessen and Daan 1994). Ottersen (1996) summarised these relationships in relation to different water masses and showed that positive relationships are usually found in cold northern waters, negative relationships in more southerly warm waters and an absence of relationship occurs at intermediate temperatures (Figure 1).

In the Irish Sea, the maximum intensity of cod spawning has been reported from early March to April (Brander 1994) with the highest concentration of eggs being found in the western Irish Sea although significant numbers have also been recorded in the eastern Irish Sea (Nichols, *et al.* 1993, Fox, *et al.* 1997). In the western area, cod larvae hatch in the coastal waters off the Irish coast but are found in deeper offshore regions by late spring and early summer (Dickey-Collas, *et al.* 1996). The offshore circulation in this area is characterised by a density-driven gyre which develops during the spring and persists throughout the summer season. The distribution patterns of young cod in this region are probably linked to the onset of this recurrent hydrographic feature (Hill, *et al.* 1994, Dickey-Collas, *et al.* 1996, Hill, *et al.* 1996, Dickey-Collas, *et al.* 1997). Cod in the Irish Sea are towards the southern boundary of the geographical range of the species although they do occur further south in the Celtic Sea. Based on the concept presented in Figure 1 and linking recruitment and water temperature we should expect a negative relationship for the Irish Sea. Appropriate temperature datasets for the coastal region of the western Irish Sea with which to examine this relationship have not been collected in the past. Hence, in the present paper we study this relationship using available temperature data from three different sources: hindcasts from a physical model driven by local meteorological data, a time-series derived from coarse long-term datasets (the Comprehensive Ocean Atmosphere DataSet and the Reynolds SST dataset) and a local time-series collected by the Port Erin Marine Laboratory (Isle of Man).

Data and method

Cod recruitment

The estimates of cod recruitment at age 0 are from tuned Virtual Population Analysis (VPA) on catch and research data for ICES area VIIa, for the period 1968–1996. VPA tuning data from the commercial fisheries were available for the UK fleet. A total of seven research vessel surveys with four or more years of data were available for inclusion in the tuning procedure, including direct estimates on recruitment (age 0 group). Annual numbers of cod recruits were estimated following the procedure of the ICES Working Group on the Assessment of Northern Shelf Demersal Stocks (Anonymous 1997).

Model hindcast

A hindcast of the sea surface temperature (SST) for the western Irish Sea region (6W-5W and 53.5N-54.5N) was derived from the physical model of Prestidge and Taylor (1995). The one dimension stratification model was implemented on a 5 km grid and forced with hourly meteorological data from Dublin airport and the resulting sea surface temperature estimates output for every four hours. Due to limitations in the accuracy of SST estimates during the summer period in stratified areas, surface temperature were extracted up to mid-May only. Data were averaged over weekly periods from Julian day 42 to 140 for each year from 1966 to 1994.

COADS and Reynolds SST

The Comprehensive Ocean Atmosphere DataSet (COADS, Woodruff, *et al.* 1987) is a global oceanographic dataset which includes a statistical summary of sea surface temperature (SST) for each month of each year using 2° latitude × 2° longitude boxes. The exact positions of samples collected in the Irish Sea could not be derived but samples were more abundant in the eastern and southern parts of the Irish Sea than in the western Irish Sea. The data for each month of each year were interpolated by kriging and the resulting temperature estimates averaged for the period January to December of each year from 1966 to 1992. The Reynolds temperature dataset (Reynolds 1988) is a monthly statistical summary of SST month using 1° latitude × 1° longitude boxes based on similar data as in COADS with additional estimations from satellite imagery. Temperature estimates from the Reynolds dataset were used from January 1981 to December 1996. After checking for bias in the average temperature estimates for the period 1981 to 1992 when the two datasets overlap, the two series were merged to produce a time-series from January 1966 to December 1996.

Port Erin temperature

Data on temperature have been collected weekly since 1954 off Port Erin Bay at Cypris station (54°05'30"N, 4°50'00"W) for 5 depths. Surface temperatures (0m) which allowed comparison with SST derived from the modelled temperature or COADS were extracted for the period 1966 to 1996. A value was derived for each month for the period January to December of each year from 1966 to 1996 using spline interpolation.

Time-series analysis

The three temperature times series relate to different areas in the Irish Sea and the modelled SST is calculated over a short period of the year. Therefore, the average absolute temperature values vary between the series. To correct for these differences, we derived from each temperature time series a series of temperature anomalies calculated as the departure from the mean value for the period of reference 1966–1994. The comparison of temperature anomaly and recruitment time-series was then carried out using correlation analysis. The non-parametric Spearman's rank correlation coefficient was used for all comparisons. No significant ($p > 0.05$) autocorrelation was detected in the series, and hence no correction was made either on the raw data or on the number of degrees of freedom when evaluating the significance of correlation coefficients

Results

Figure 2 shows the year-to-year changes in cod recruitment and anomalies in sea surface temperature (SST) derived from the model, COADS dataset and Port Erin Cypris station data. The three SST time series show similar profiles which are characterised by a period of average temperatures during 1971–1977, two minima in 1979 and 1986 and an increase in temperature in 1989–90, 1992 and 1995. There is a high degree of similarity between all three temperature series as shown by the significant correlation coefficients between them (Table 1). The cod recruitment time series shows high variability with values ranging from 1.8 to 18×10^6 recruits·year^{-1}. The changes in recruitment are opposite to those in the temperature signal with years of negative temperature anomaly generally matching years of high recruitment (e.g., 1979 and 1986) and vice-versa (e.g., 1981–82, 1988–89, 1994). The correlation between temperature and cod recruitment is significant regardless of which temperature time-series is used (Table 1). The highest correlation is found with temperature output from the physical model. This is the only temperature estimate for the western Irish Sea area alone, where cod eggs and larvae are found in high abundance. The negative correlations between changes in temperature and cod recruitment are made clear in Figure 3. This relationship is consistent with results from published studies if they are interpreted as in Figure 1.

Discussion

There are many possible mechanisms which might lead to a link between cod recruitment and temperature. Off Newfoundland, deYoung and Rose (1993) observed that changes in temperature were associated with latitudinal displacement of the cod stock between favourable and less favourable spawning sites. Ellersten *et al.* (1989) and Nakken (1994) observed that the timing of spawning of Arctic cod is fixed while the spawning of *Calanus finmarchicus* (the main prey for cod larvae) can vary by up to six weeks between a cold and a warm year inducing mismatches in extremely cold or warm years. Conversely, Hutchings and Myers (1994) showed that off Newfoundland the spawning time of cod not only varies between regions, but also between years. The differences in peak spawning times were up to 90 days and these variations were partially attributed to year-to-year fluctuations in temperature (-1.7°C to -0.9°C). It was suggested that low winter temperatures have a negative influence on gonad development and delay the onset of spawning in this stock. Similar conclusions were drawn by Kjesbu (1994) who reported that a 1°C drop in temperature during vitellogenesis would delay spawning by about 8–10 days (from results at 9°C). Increased temperatures have also been reported to affect the degree and timing of oocyte maturation and ovulation in the warmwater Pacific cod (Tyler 1995) as well as egg viability and fertility in other species (Howell and Scott 1989, Flett, *et al.* 1996). In the present study, the range of temperatures between the coolest and warmest years was around 3°C. This range should be sufficient to induce similar effects to those reported above. The mechanism linking temperature and cod recruitment in the Irish Sea could therefore be due to direct effects on the reproductive biology of fish, effects on the physiology of eggs and/or larvae, influence of temperature upon food production or a combination of the three. It is not currently possible to define a mechanism for the link between temperature and cod recruitment in the Irish Sea but this previously unreported connection is so strong that it should be included in any future attempts at understanding or forecasting cod recruitment in the Irish Sea.

Acknowledgements

The authors wish to acknowledge the hard work of all those scientists who have contributed to the development of the long-term data series used in this study. The authors are greatly indebted to Richard Nash at Port Erin Laboratory (Liverpool University) for providing the Cypris station temperature data, to Steve Worley (National Center for Atmospheric Research) for providing the COADS data, and Arnold H. Taylor (Plymouth Marine Laboratory) for providing the stratification model output. This work was funded by MAFF under program MF0420, Physical and Biological Controls on Fish Stocks.

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Table 1. Spearman's rank correlation coefficients between the time-series of temperature derived from the model of Prestidge and Taylor (1995), the COADS and Reynolds dataset and Port Erin survey, and cod recruitment from ICES VPA. (** indicates a probability of type 1 error of 1%).

	Modelled temperature	COADS / Reynolds temperature	Cypris station temperature
COADS / Reynolds temperature	0.64** n = 28	–	–
Cypris station temperature	0.70** n = 28	0.64** n = 31	–
cod recruitment	-0.66** n = 26	-0.64** n = 29	-0.63** n = 29

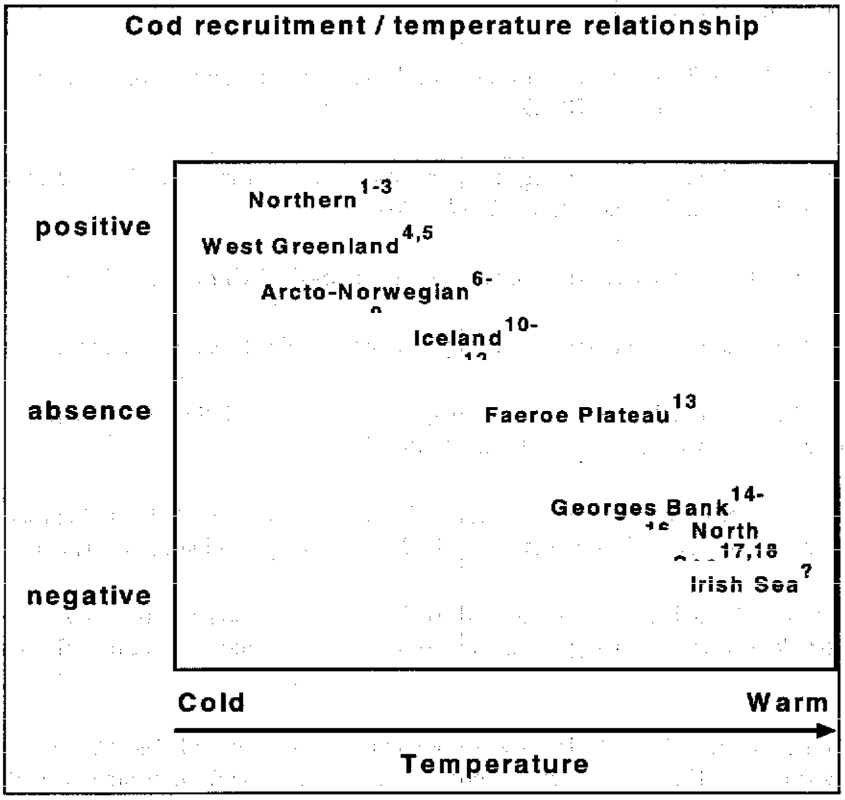

Figure 1. A schematic representation of the nature of the relationship between temperature changes and recruitment for different North Atlantic cod stocks. A positive effect (cod recruitment is favoured during warmer years) is generally observed in cold waters whereas a negative effect (cod recruitment is favoured during colder years) is found in warm waters, drawn from Ottersen (1996). References to each stock are as follows: [1] Elizarov (1963), [2] deYoung and Rose (1993), [3] Taggart *et al.* (1994), [4] Hermann (1953), [5] Buch *et al.* (1994), [6] Izhevskii (1964), [7] Sætersdal and Loeng (1987), [8] Ottersen *et al.* (1994), [9] Ottersen and Sundby (1995), [10] Malmberg (1986), [11] Malmberg and Blindheim (1994), [12] Astthorsson *et al.* (1994), [13] Hansen *et al.* (1994), [14] Martin and Kohler (1965), [15] Holzwarth and Mountain (1992), [16] Serchuk *et al.* (1993), [17] Dickson *et al.* (1973), [18] Svendsen *et al.* (1995).

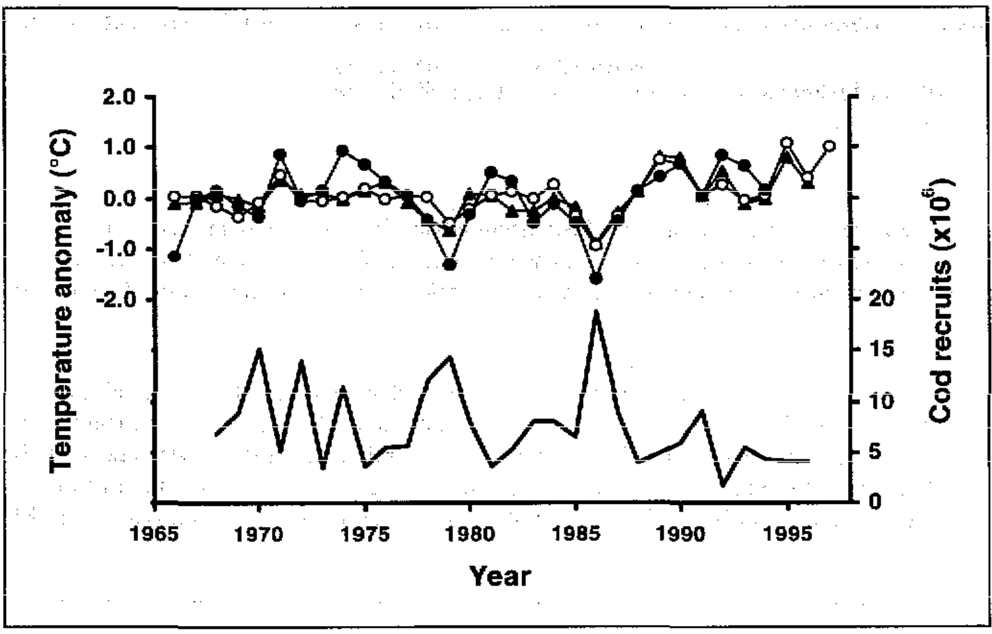

Figure 2. Time-series of cod recruitment (plain line) in the Irish Sea derived from virtual population analysis (VPA), anomalies in sea surface temperature (from mid-February to mid-May) in the western Irish Sea estimated from the model of Prestidge and Taylor (1995) (solid circles), anomalies in mean annual sea surface temperature in the Irish Sea from the COADS and Reynolds SST datasets (open circles) and anomalies in mean annual sea surface temperature at Port Erin Cypris station (triangles).

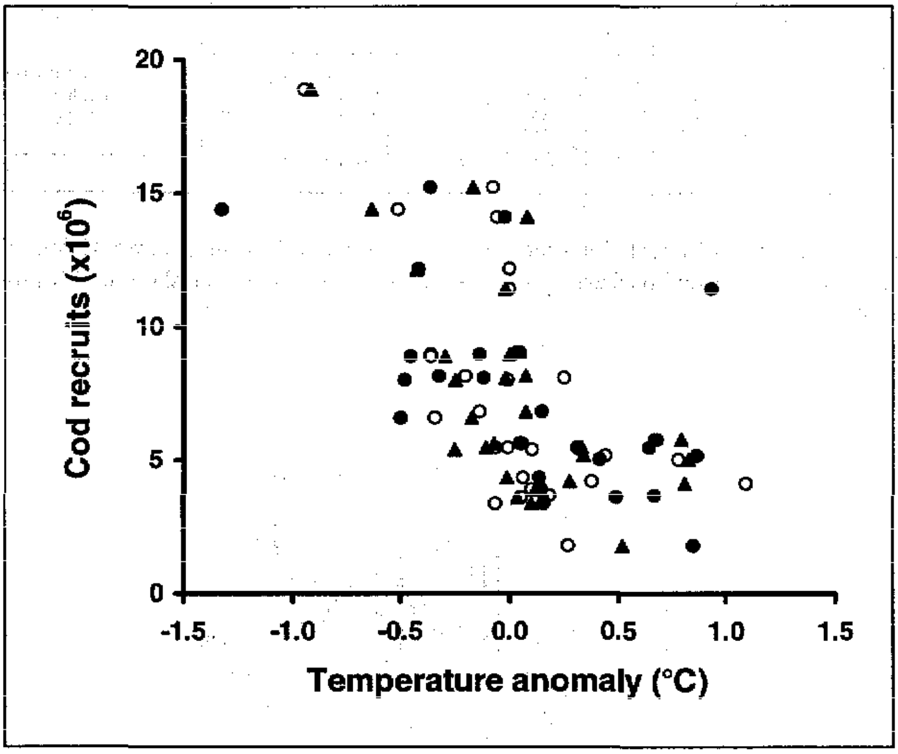

Figure 3. Number of cod recruits plotted against modelled SST (solid circles), COADS/Reynolds SST (open circles), and Port Erin Cypris station SST (triangles).

Abiotic and Biotic Coupling between Climate Forcing and Year-Class Strength in NE Arctic Cod.

Stig Skreslet, Faculty of Fisheries and Science, Bodø College, 8002 Bodø

Extended abstract

Sea-water temperature is easily measured and has been accumulated in extensive data series. It is a proxy for heat that have direct effects on fish metabolism and the geographic distribution of fish stocks, and is much used to study how fish stocks respond to inter-annual climatic change. However, its role as an ecological forcing factor possibly tend to be overestimated.

About 60% of the global energy budget takes place as heat exchange in the hydrological cycle, associated with evaporation and condensation of water. The large seasonal and inter-annual changes in continental run-off express that the energy flow vary considerably, and probably indicate a strong influence on the environment of fish stocks, by its effects on the stratification and mixing of neritic waters. In fact, year class strength and landings of NE Arctic cod has been found to fluctuate in concert with the discharged volume of alpine melt-water from Norway in May-July (*Figure* 1).

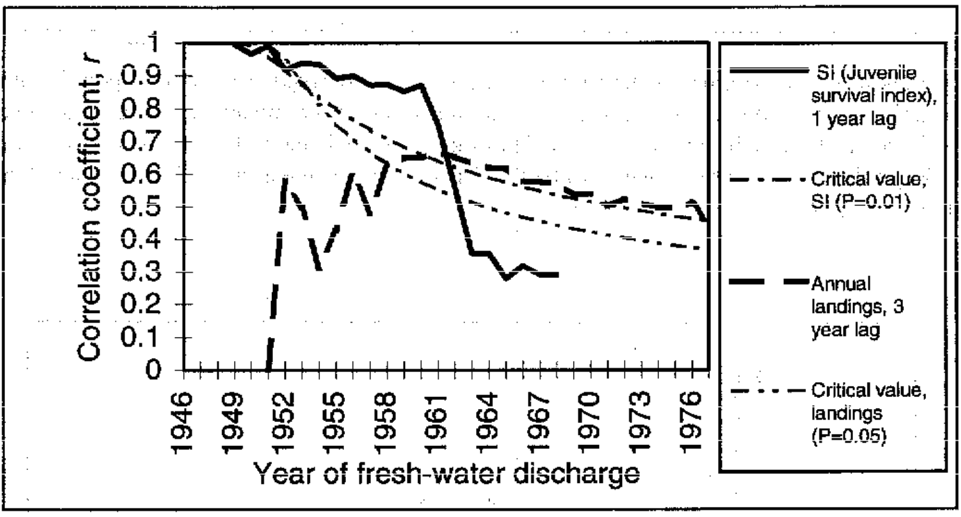

Figure 1. Step-wise correlation coefficients for year class size and landings of immature NE Arctic cod as functions of 30-day maximum melt-water discharge to the southern mid-Norwegian shelf in May-July (Modified from Skreslet 1986).

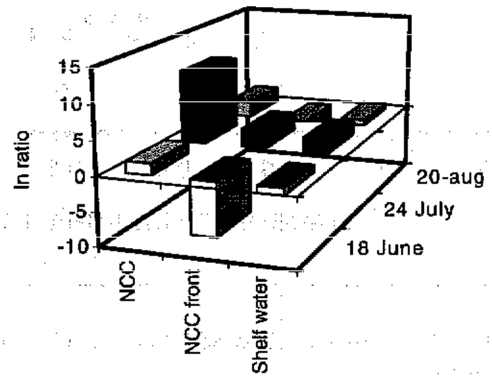

Figure 2 Logarithmic abundance ratio between NI-II and female CVI of *Calanus finmarchicus* under a given sea surface area, in a section across the Norwegian Coastal Current on the inner mid-Norwegian shelf in 1997 (Skreslet, unpubl.).

New field results have established that the copepod *Calanus finmarchicus* spawns in the frontal zone of the Norwegian coastal current over an extended period of time during summer (*Figure* 2). The reproduction rate may be related to the fresh-water discharge, as the abundance of *nauplii* is inversely related to sea surface salinity (*Figure* 3). Parts of this summer generation is probably advected by the NCC into the Vestfjord wintering habitats, from where it emerges as a spawning stock that in April produce nauplii preyed upon by first-feeding NE Arctic cod larvae at the Lofoten Islands. Considering the low fecundity of the copepod, the copepod spawning stock size may be a forcing factor for year class strength in the NE Arctic cod stock.

The processes dealt with here, is thought to be related to the North Atlantic Oscillation that causes variable inflow of warm Atlantic water to the Nordic Seas. In periods with a high positive NAO Index, it may be expected that westerly winds will carry larger than normal quantities of water vapor to the Norwegian coastal mountains, where much of the winter precipitation is stored as snow. I infer that the melt-water discharge rate during early summer forces proportional dynamic processes in the Norwegian Coastal Current front. They probably lift nutrient-rich sea-water into the euphotic zone. There planktonic algae optimizes their demands for light and nutrients at 20–35 m depth, and feed biotic energy to the reproduction of *C. finmarchicus*, at a rate possibly being proportional to the discharged volume. Thus, the organismic system found in the NCC front seems to link the physical forcing by fresh-water outflow to a food web that transfers the climate signal to year class formation in NE Arctic cod.

One physical effect of stratification by melt-water discharge, is an accumulation of solar radiation as heat in the mixed layer, possibly causing the acquired temperature to be proportional to the discharged volume. Thus, the temperature change in the North Atlantic may be mimicked by the Norwegian shelf surface waters, after a time lag of about a year. Therefore, the sea-water temperature in the Kola section and other sampling stations may contain more than one climatic signal. Also, the extensive regulation of fresh-water outflow for hydro-electric production in Norway, may influence the dissipation of heat in the sea, and corrupt the usefulness of temperature as an index for use in fisheries assessment.

In conclusion, there is a need for more sophisticated multi-factorial analyses using both temperature, salinity and/or freshwater outflow, to explain a larger fraction of the observed variance in fish stock features. Eventually, the assessment of fisheries resources will have to apply basin-scale models of an ecosystem that takes account of all dominant driving forces, including anthropogenic regulation of fresh-water flow.

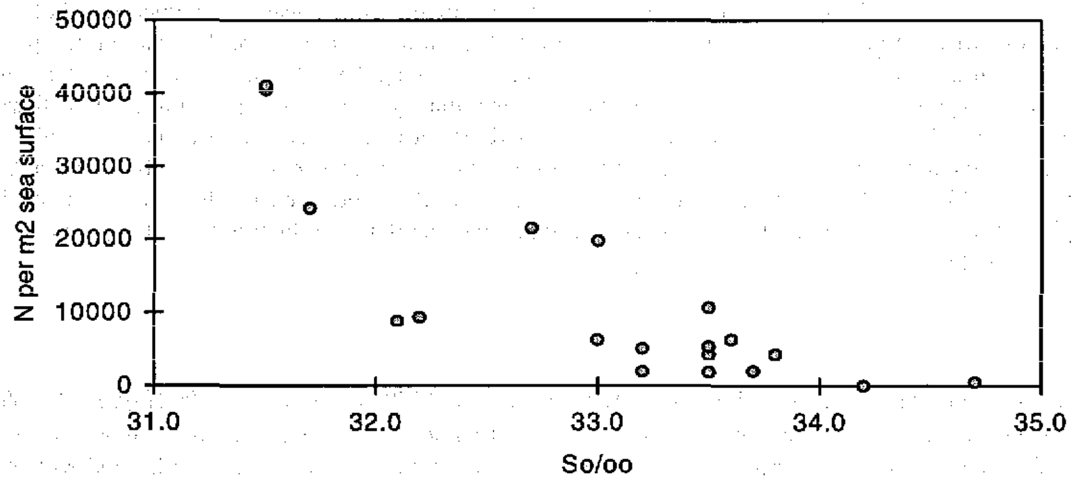

Figure 3 Abundance of Calanus finmarchicus NI-VI as function of sea surface salinity in the Norwegian Coastal Current, on the inner mid-Norwegian shelf from 18 June to 24 August 1997 (Skreslet, unpubl.).

Environmental conditions and stock assessment of southern Gulf of St. Lawrence cod: variation in distribution, growth, recruitment and catchability.

D. P. Swain, A. F. Sinclair, G. A. Poirier and G. A. Chouinard

Environmental conditions are likely to influence the distribution of fish populations and most aspects of their dynamics such as growth and survival. Understanding these influences may provide explanations for interannual variations in distribution and population dynamics and, if environmental conditions can be forecast, may permit more accurate projections of future stock status. Environmental conditions may also influence perceptions of stock status through effects on catchability or availability to research surveys and commercial fisheries, and corrections for these effects may lead to improved indices of abundance. The purpose of this report is to summarize tests for effects of environmental conditions on the distribution, growth, recruitment and catchability of southern Gulf of St. Lawrence cod.

Background

The southern Gulf of St. Lawrence is a shallow shelf with depths mostly less than 100 m bordered by a 500-m trench, the Laurentian Channel (*Figure* 1). Cod migrate into the southern Gulf in spring to spawn, and then disperse throughout the southern Gulf for a feeding period during the summer and early fall. In late fall (November), cod migrate out of the Gulf, overwintering in warm deep water along the slope of the Laurentian Channel. A bottom-trawl survey has been conducted in the southern Gulf during the cod feeding season each September since 1971 (*Figure* 2). Cod abundance has varied widely since 1971 (*Figure* 3), as have environmental conditions (*Figure* 4, 5). Cod abundance was low in the mid-1970s, high in the 1980s, and low in recent years. Bottom temperature was warmest in the early 1980s and coldest in the 1990s. In all years, bottom temperatures are coldest in the central Magdallen Shallows where depths are in the 50–100 m range (*Figure* 1, 4).

Distribution

In the mid-1970s, cod were most concentrated in near-shore areas, with few cod occurring in the central Shallows (*Figure* 6). In the mid-1980s, distribution expanded into the central Shallows, and peak concentrations shifted offshore. In recent years, cod were again most concentrated in near-shore areas and few cod occurred in the central Shallows. These changes in geographic distribution are reflected by changes in the depth distribution of cod, with highest densities in shallow water in the mid-1970s and mid-1990s and at intermediate depths (50–100 m) in the 1980s (*Figure* 7). One hypothesis is that these changes in distribution reflect changes in bottom temperature, with cod moving into intermediate depths in the central Shallows when conditions are warm and out of these zones when conditions are cold. An alternate hypothesis is that these are density-dependent changes, with occupying colder water to reduce metabolic costs when abundance is high (and ration low). These hypotheses were tested using two indices of distribution, the percent of cod occupying the central Shallows and an index giving the strength of the tendency for cod to occupy intermediate depths (*Figure* 8). Both hypotheses were supported in univariate tests that ignored autocorrelation in cod distribution and confounding between the two explanatory variables (Tables 1 & 2). However, tests that accounted for this confounding and/or accommodated autocorrelation in distribution supported an effect of cod abundance on distribution, but provided no support for an effect of changes in environmental conditions on distribution except for age 3 (Tables 1–4). These results emphasise the importance of simultaneously testing alternate explanatory factors when the potential explanatory factors are confounded.

Growth

Length-at-age of southern Gulf cod declined sharply from the late 1970s to the mid-1980s (*Figure* 9). We tested for effects of abundance and temperature on growth using a modification of the von Bertalanffy model in which L_∞ is a function of abundance and/or temperature in each year of life up to the observed year (Millar and Myers 1990). We considered two measures of temperature: Ta, the average bottom temperature available to cod in September (i.e., during the feeding season), and Tc, the average bottom temperature occupied by cod in September.

Relationships among the predictor variables

Tc tended to be warmer when Ta was warmer. Ta tended to be warmer when abundance was high. Despite these relationships, Tc tended to be colder when abundance was high.

Tests of effects of abundance and temperature

The conventional 3-parameter von Bertalanffy model accounted for 58% of the variation in mean length-at-age. Adding a parameter for either temperature or abundance significantly improved the model. *Tc* produced the greatest model improvement, accounting for an additional 22% of the variation in length. Adding a term for abundance (*N*) or *Ta* did not substantially improve the model that already included a term for *Tc* (Table 5). However, the 5-parameter model accounting for the highest percent of the variation in mean length (88.5%) was the model with terms for *N* and *Ta*. Patterns persisted in the residuals, even for models that included terms for both abundance and temperature, with residuals consistently negative after 1990 (*Figure* 10). Thus, while there is evidence for effects of both abundance and temperature on growth of southern Gulf cod, models that incorporate these effects fail to predict the slow growth observed in recent years.

Recruitment

Early survival (recruitment/(spawning stock biomass)) of southern Gulf cod was exceptional in the mid-1970s (1974–1977) (Chouinard and Fréchet 1990; their *Figure* 15). This variation in survival is not concordant with variation in climatic indices (NAO index, air and water temperature indices, freshwater discharge) (Chouinard and Fréchet 1990; their *Figure* 12).

Catchability

Smith and Page (1996) found that cod were associated with the CIL in July on the Eastern Scotian Shelf. They noted that survey catch rates of cod were relatively high in years when the extent of CIL water on the bottom was high. They argued that survey catch rates may overestimate relative abundance of cod when the extent of CIL water on the bottom is high, either because cod are more available when their preferred water mass is in contact with the bottom over a larger area or because catchability of cod is higher when conditions are colder due to reduced swimming speeds in colder water. They suggested that survey abundance indices should be adjusted using their relationship with CIL indices.

Survey catch rates of southern Gulf cod are also correlated with indices of cod distribution and environmental conditions (Table 6). Mean catch rates are negatively correlated with indices of cod temperature distribution. This could reflect an effect on catchability, with catchability reduced when cod are in warm water (due to increased swimming speeds). Alternatively, it could reflect density-dependent temperature preferences of cod, with cod preferring colder temperatures when abundance is high (Swain and Kramer 1995). Mean catch rates are also correlated with an index of depth distribution, with lower catch rates when cod tend to be in shallower water. Again, this could reflect changes in availability of cod or density dependence of cod depth distribution (Swain 1993). Catch rates are less strongly related to indices of environmental conditions, though at the younger ages significant negative correlations do occur with the area of subzero bottom water and significant positive correlations occur with the area of bottom temperature between 1 and 4°C.

Additional information is required to determine whether these correlations reflect bias caused by variation in catchability. We incorporated this additional information using SPA calibration tests and residuals from multiplicative analyses of survey catch rates. Both approaches led to the same conclusions and only results from the former analysis are reported here. In this approach, catchability to the survey was modelled as a linear function of indices of distribution or environmental conditions. These tests provided no support for an effect of cod temperature or depth distribution on catchability (Table 7). There was some indication of an effect of environmental conditions on catchability for older cod (Table 7), but the effect on population estimates was negligible (*Figure* 11). We conclude that the correlations between survey catch rates and indices of cod distribution or environmental conditions do not reflect effects on catchability and that survey abundance indices should *not* be adjusted based on these relationships.

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Table 1. Relationships among P_C, the proportion of cod occupying the central Magdalen Shallows (strata 423 and 424), T_C, mean bottom temperature in the central Shallows, and N, cod abundance. The multivariate model includes both N and T_C as explanatory variables. Partial R^2 values are the Type II Sum of Squares (SS) as a fraction of the Total SS. Unaccounted R^2 values are the model R^2 values minus the two partial R^2 values. All correlations are positive. P gives the significance level.

		Bivariate correlations			Multivariate model			
					Overall Model	Partial R^2		Unaccounted
Age		$P_C \times N$	$P_C \times T_C$	$T_C \times N$		N	T_C	
3	R^2	0.330	0.403	0.270	0.485	0.082	0.155	0.248
	P	0.0027	0.0007	0.0078	0.0007	0.074	0.018	
4	R^2	0.452	0.261	0.285	0.484	0.224	0.032	0.229
	P	0.0002	0.0091	0.0060	0.0007	0.0054	0.25	
5	R^2	0.412	0.178	0.217	0.432	0.254	0.019	0.159
	P	0.0005	0.036	0.019	0.0020	0.0048	0.40	
6	R^2	0.413	0.167	0.221	0.427	0.260	0.015	0.153
	P	0.0005	0.042	0.018	0.0022	0.0045	0.46	
7	R^2	0.182	0.145	0.164	0.234	0.088	0.052	0.093
	P	0.034	0.060	0.045	0.053	0.13	0.23	
8^+	R^2	0.016	0.064	0.087	0.066	0.003	0.051	0.013
	P	0.55	0.12	0.15	0.47	0.80	0.29	
3^+	R^2	0.463	0.299	0.309	0.504	0.205	0.041	0.258
	P	0.0002	0.0047	0.0039	0.0004	0.0064	0.19	

Table 2. Relationships among P_D, an index of cod depth distribution, T_I, mean bottom temperature in the 50–100 m depth zone, and N, cod abundance. The multivariate model includes both N and T_I as explanatory variables. Other symbols as in Table 1. All correlations are positive.

		Bivariate correlations			Multivariate model			
					Overall Model	Partial R^2		Un-accounted
Age		$P_D \times N$	$P_D \times T_I$	$T_I \times N$		N	T_I	
3	R^2	0.400	0.382	0.367	0.487	0.105	0.087	0.295
	P	0.0007	0.0010	0.0013	0.0006	0.045	0.066	
4	R^2	0.524	0.367	0.386	0.564	0.196	0.040	0.327
	P	0.0001	0.0013	0.0009	0.0001	0.0047	0.17	
5	R^2	0.446	0.262	0.288	0.479	0.217	0.033	0.229
	P	0.0003	0.0089	0.0056	0.0008	0.0062	0.25	
6	R^2	0.555	0.207	0.275	0.560	0.354	0.006	0.201
	P	0.0001	0.022	0.0072	0.0001	0.0004	0.60	
7	R^2	0.610	0.185	0.171	0.624	0.438	0.014	0.171
	P	0.0001	0.032	0.040	0.0001	0.0001	0.38	
8^+	R^2	0.522	0.075	0.076	0.528	0.454	0.006	0.069
	P	0.0001	0.19	0.18	0.0003	0.0001	0.61	
3^+	R^2	0.468	0.292	0.409	0.486	0.194	0.018	0.274
	P	0.0002	0.0053	0.0006	0.0007	0.0087	0.39	

Table 3. Likelihood ratio tests of the significance of abundance (N) and temperature (T_C) terms in autoregressive models of the proportion of cod that occupy the central Magdalen Shallows. N and T_C denote terms added to a first-order autoregressive model containing no other terms. $N|T_C$ denotes an abundance term added to a model already including a temperature term. $T_C|N$ denotes a temperature term added to a model already including an abundance term.

Age		χ^2	P
3	N	3.4053	0.065
	T_C	7.9075	0.005
	$N\|T_C$	2.0935	0.15
	$T_C\|N$	6.5958	0.010
4	N	6.4433	0.011
	T_C	1.6331	0.20
	$N\|T_C$	5.6612	0.017
	$T_C\|N$	0.8510	0.36
5	N	8.8176	0.003
	T_C	1.2530	0.26
	$N\|T_C$	8.3231	0.004
	$T_C\|N$	0.7585	0.38
3^+	N	5.8407	0.016
	T_C	2.3781	0.12
	$N\|T_C$	4.7786	0.029
	$T_C\|N$	1.3161	0.25

Table 4. Significance of abundance (N) and temperature (T_I) terms in autoregressive models of the index of cod depth distribution, P_D. Symbols follow the same scheme as in Table 3.

Age		χ^2	P
3	N	8.5889	0.0034
	T_I	7.5827	0.0059
	$N \mid T_I$	5.9984	0.014
	$T_I \mid N$	4.9921	0.025
4	N	8.8493	0.0029
	T_I	3.5100	0.061
	$N \mid T_I$	6.4196	0.011
	$T_I \mid N$	1.0803	0.30
5	N	5.7914	0.016
	T_I	1.6915	0.19
	$N \mid T_I$	4.7559	0.029
	$T_I \mid N$	0.6559	0.42
6	N	14.2004	0.0002
	T_I	1.7680	0.18
	$N \mid T_I$	12.4648	0.0004
	$T_I \mid N$	0.0325	0.86
7	N	17.5158	0.0001
	T_I	1.7680	0.18
	$N \mid T_I$	16.0613	0.0001
	$T_I \mid N$	0.3107	0.58
8	N	10.3278	0.0013
	T_I	0.0699	0.79
	$N \mid T_I$	10.6507	0.0011
	$T_I \mid N$	0.3929	0.53
3^+	N	7.9887	0.0047
	T_I	3.2794	0.070
	$N \mid T_I$	5.0612	0.024
	$T_I \mid N$	0.3519	0.55

Table 5. Sums of squares explained by the addition of abundance and temperature terms to growth models.%TSS is the percent of the corrected total sum of squares explained by the indicated terms. A conventional 3-parameter von Bertalanffy model explains 58% of the TSS.%RSS(age) is the percent of the RSS from the conventional von Bertalanffy model explained by adding the indicated terms. *N* is an index of cod abundance, *TC* the average temperature occupied by cod in September, and *TA* the average bottom temperature available to cod in September.

Explanatory Variables	%TSS	Model R^2	%RSS(age)
N	12.7	0.707	30.3
TC	22.1	0.801	52.5
TA	10.4	0.684	24.7
N, TC	25.4	0.834	60.5
N, TA	30.5	0.885	72.7
TA, TC	22.5	0.805	53.6
N, TA, TC	30.9	0.888	73.4

Table 6. Correlations between log-transformed survey abundance indices for cod and indices of environmental conditions or cod distribution in the southern Gulf of St. Lawrence, 1971–1996. Indices are: T_C, the average temperature occupied by cod; $C_{T>4}$, the percent of cod occurring at bottom temperatures greater than 4°C; P_D, an index of cod depth distribution; T_A, the average temperature available to cod; $A_{T\le0}$, the percent of the survey area with bottom temperatures less than or equal to 0°C; and, $A_{1<T\le4}$, the percent of the survey area with bottom temperatures between 1 and 4°C. *P* is the two-sided probability that *R* differs from 0. Sample sizes were 208 for all ages combined and 26 for each age alone. Survey abundance indices were standardized to a mean of 0 and SD of 1 within ages for the analysis with all ages combined.

Age		T_C	$C_{T>4}$	P_D	T_A	$A_{T\le0}$	$A_{1<T\le4}$
all	*R*	-0.339	-0.314	0.595	0.023	-0.307	0.339
	P	0.0001	0.0001	0.0001	0.74	0.0001	0.0001
3	*R*	-0.211	-0.160	0.424	0.261	-0.509	0.515
	P	0.31	0.44	0.031	0.20	0.0079	0.0071
4	*R*	-0.353	-0.321	0.495	0.173	-0.387	0.391
	P	0.077	0.11	0.010	0.40	0.051	0.048
5	*R*	-0.302	-0.273	0.597	0.273	-0.363	0.215
	P	0.13	0.18	0.0013	0.18	0.068	0.29
6	*R*	-0.389	-0.410	0.620	0.163	-0.450	0.379
	P	0.050	0.037	0.0007	0.43	0.021	0.056
7	*R*	-0.390	-0.380	0.654	0.035	-0.303	0.348
	P	0.049	0.055	0.0003	0.86	0.13	0.081
8	*R*	-0.462	-0.425	0.684	-0.166	-0.149	0.321
	P	0.018	0.030	0.0001	0.42	0.47	0.11
9	*R*	-0.438	-0.440	0.658	-0.226	-0.195	0.342
	P	0.025	0.024	0.0003	0.27	0.34	0.087
10	*R*	-0.491	-0.427	0.692	-0.325	-0.102	0.203
	P	0.011	0.030	0.0001	0.11	0.62	0.32

Table 7. *t*-values for SPA calibration tests of density-dependent catchability and effects of environmental conditions and cod distribution on catchability. *DD* gives values for density dependence. Other variable names are as in Table 6. Boldface indicates significance ($P< 0.05$) according to a two-sided test and italics significance according to a one-sided test (except for *DD* and T_A, for which there is no *a priori* predicted direction of effect).

Age	*DD*	T_C	$C_{T>4}$	P_D	T_A	$A_{T\le0}$	$A_{1<T\le4}$
3	-0.809	-0.959	-0.054	-1.084	0.055	-1.278	1.430
4	-0.436	-0.939	-0.850	-0.378	0.048	-1.375	0.984
5	1.131	-1.002	-1.028	0.509	-0.061	-0.937	0.551
6	**2.224**	-1.184	-1.221	0.899	0.258	*-1.690*	1.319
7	**2.060**	-1.475	-1.221	1.137	-0.049	-1.580	1.226
8	1.781	-0.926	-1.117	1.555	0.215	*-1.816*	0.822
9	0.925	-0.581	-0.986	1.044	0.705	**-2.074**	1.319
10	-0.076	-1.372	**-2.287**	1.677	0.661	**-2.933**	**2.420**

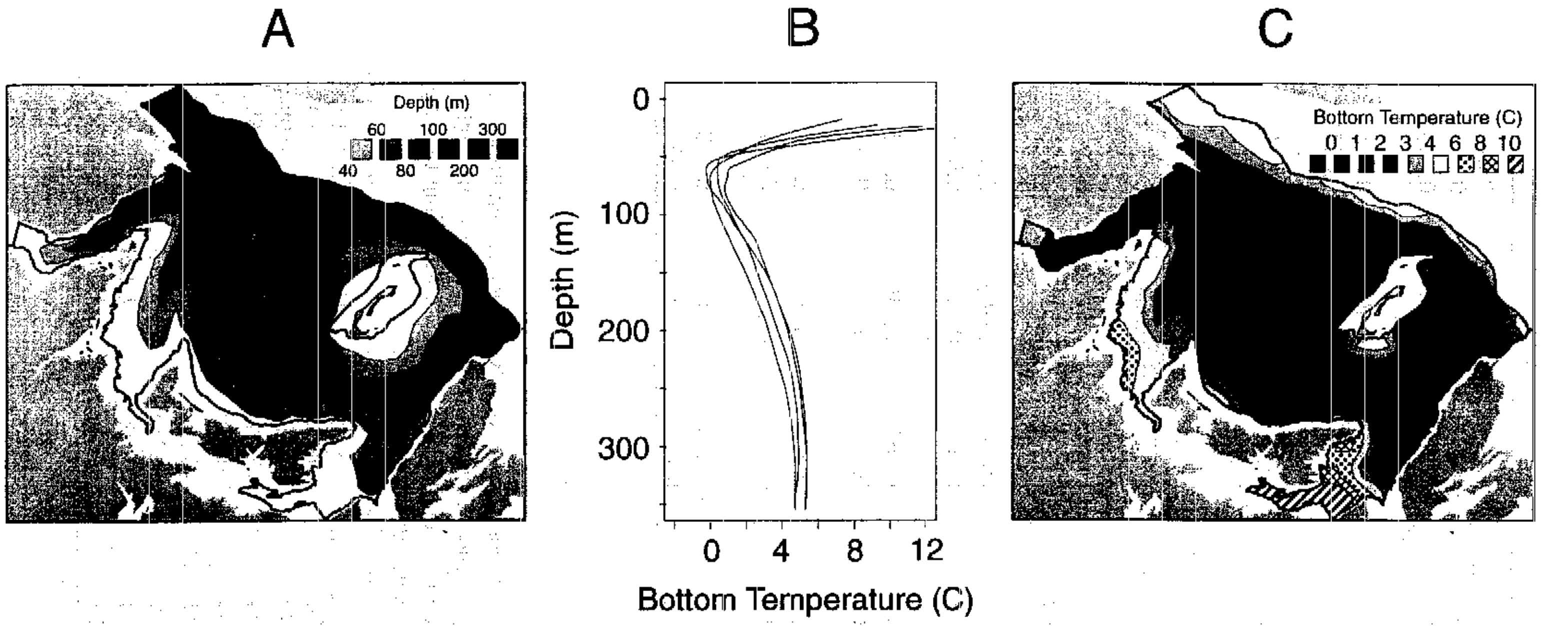


Fig. 1. Bathymetry and bottom temperature in the southern Gulf of St. Lawrence.

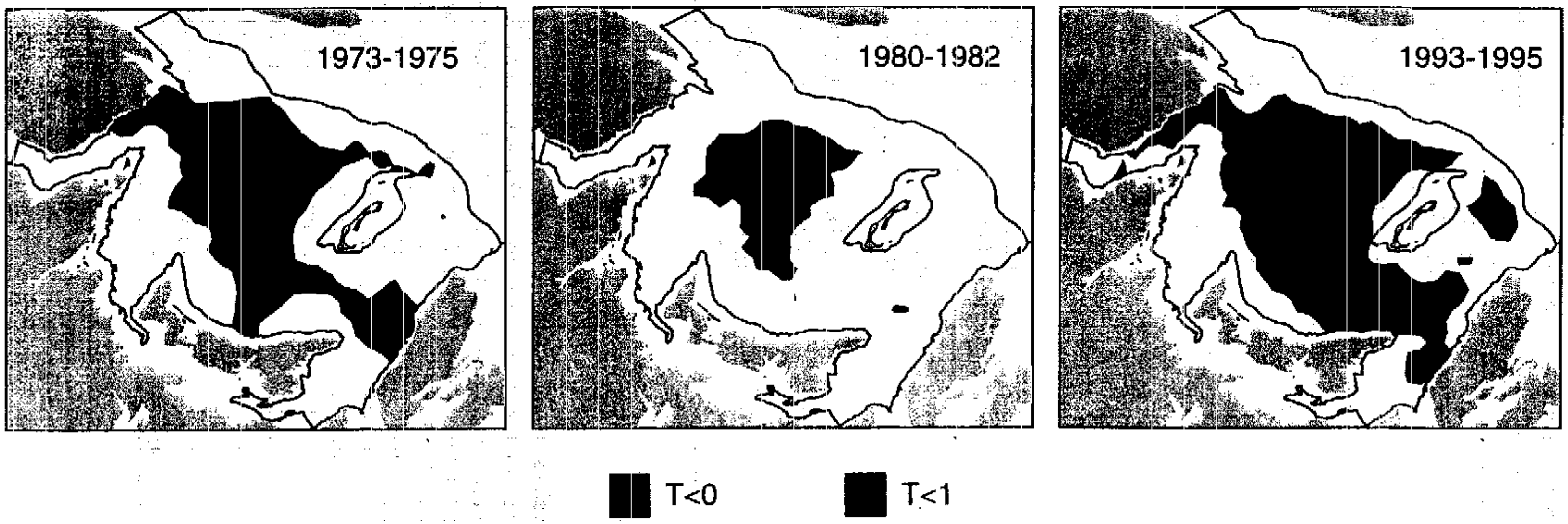


Fig. 4. Variation in the extent of cold bottom water in the southern Gulf of St. Lawrence.

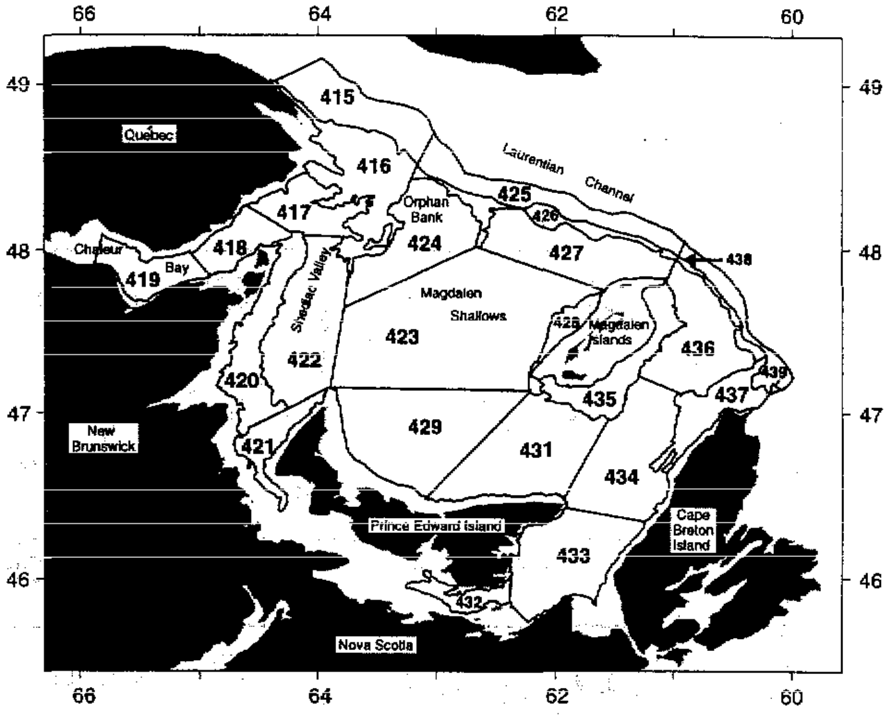


Fig. 2. Strata used in the September bottom trawl survey of the southern Gulf of St. Lawrence.

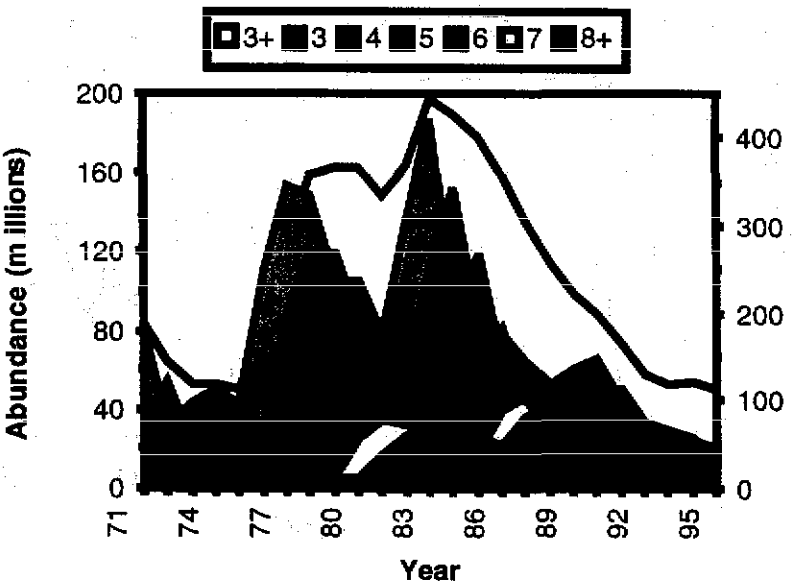


Fig. 3. Abundance of southern Gulf cod.

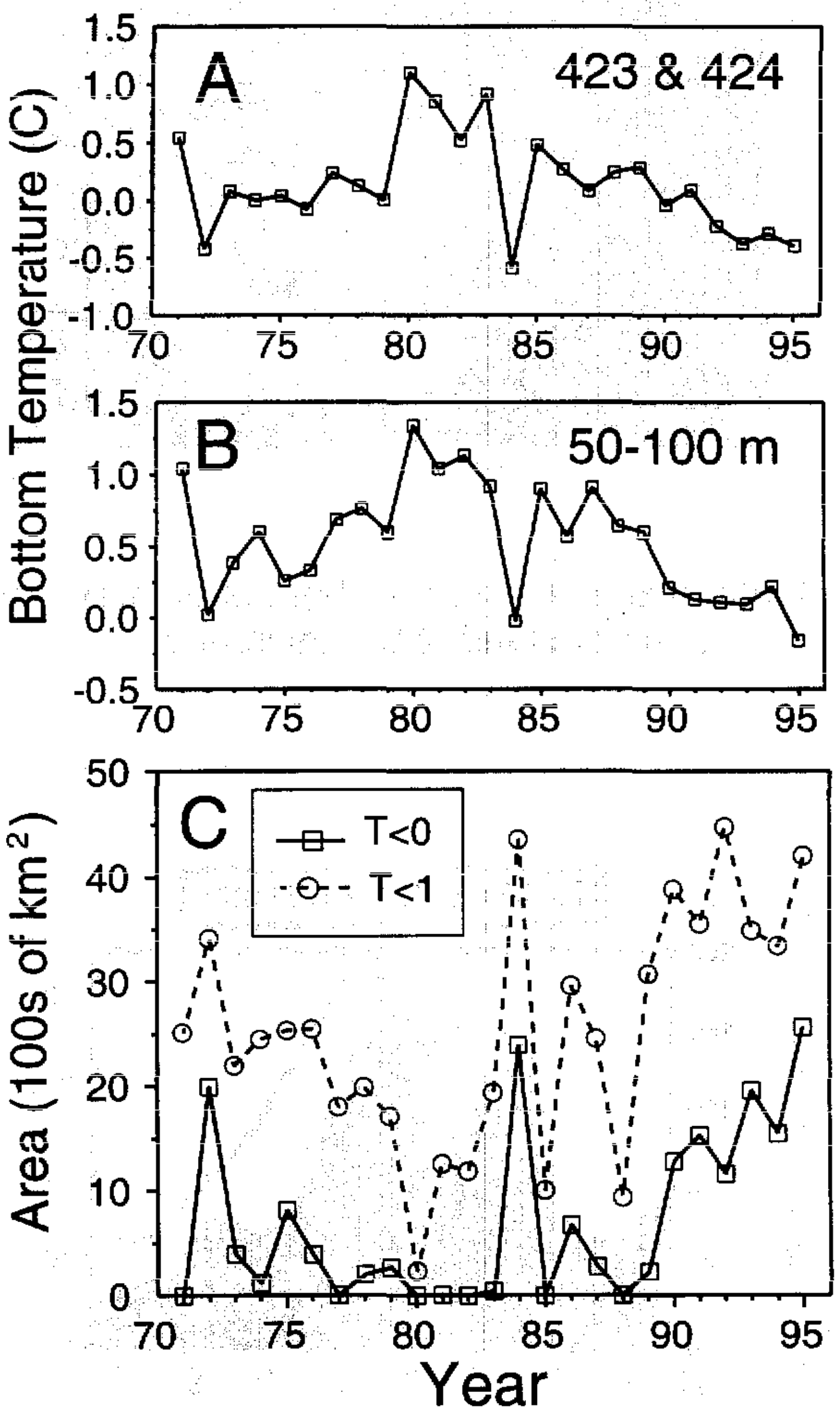


Fig. 5. Indices of bottom temperature in the southern Gulf of St. Lawrence.

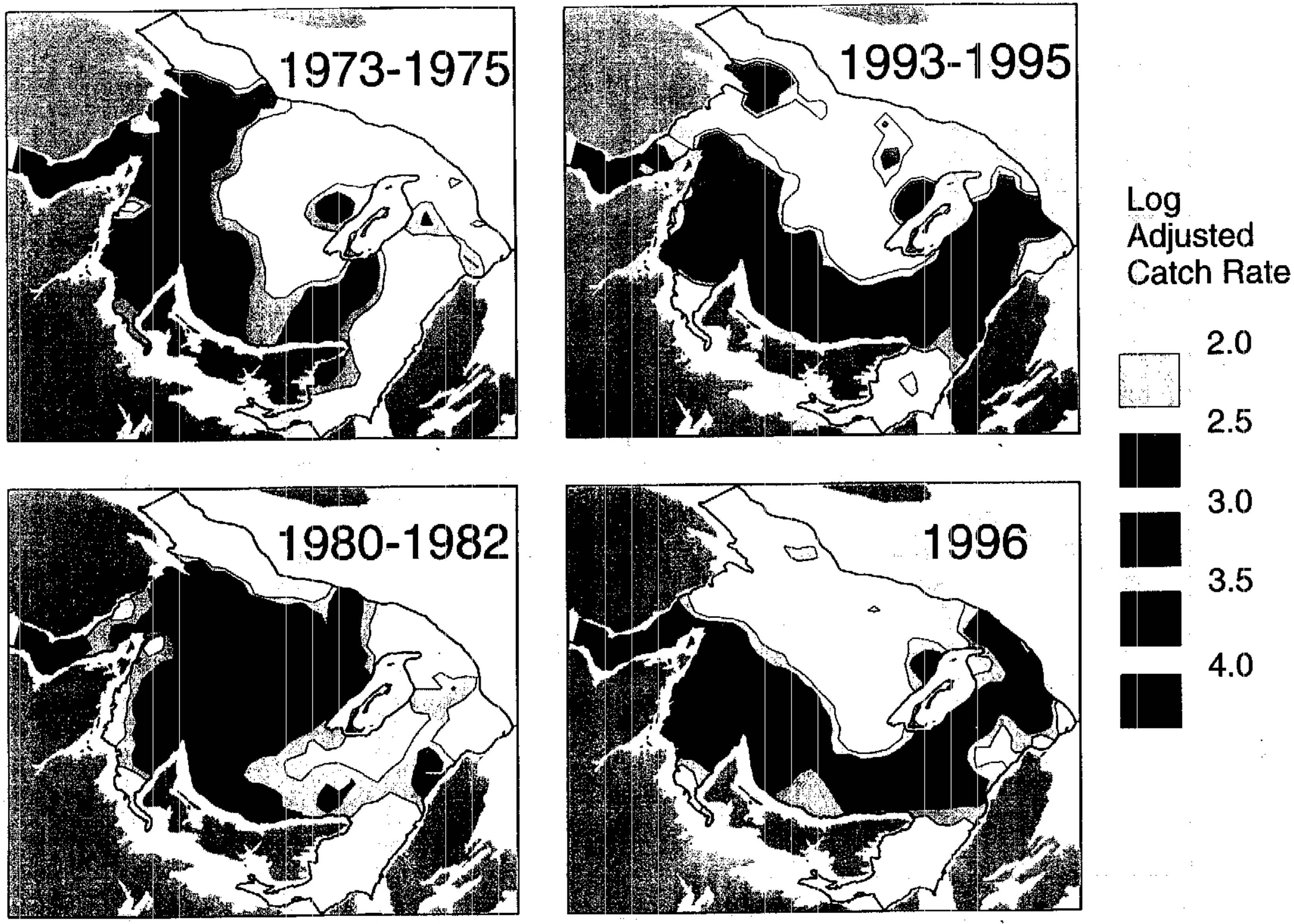
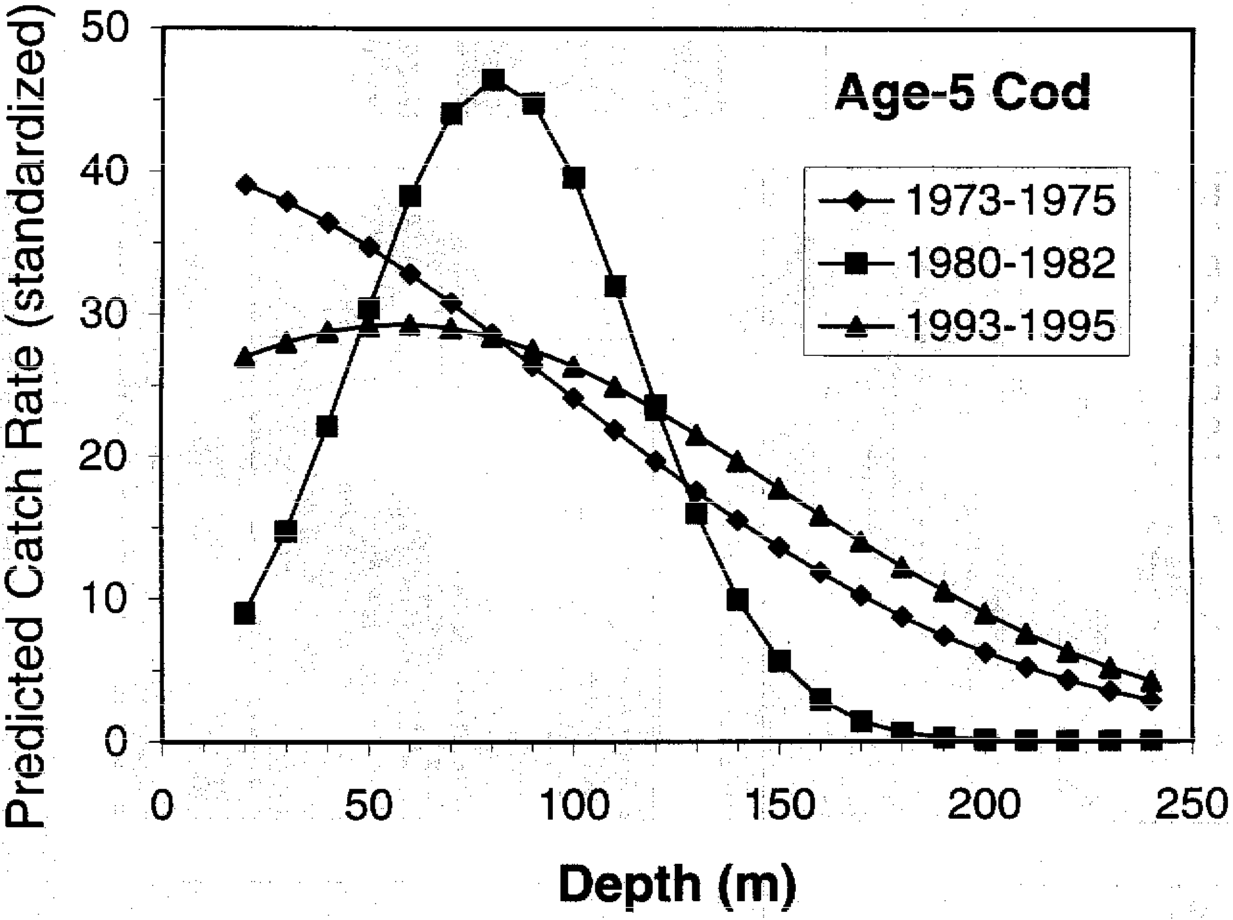


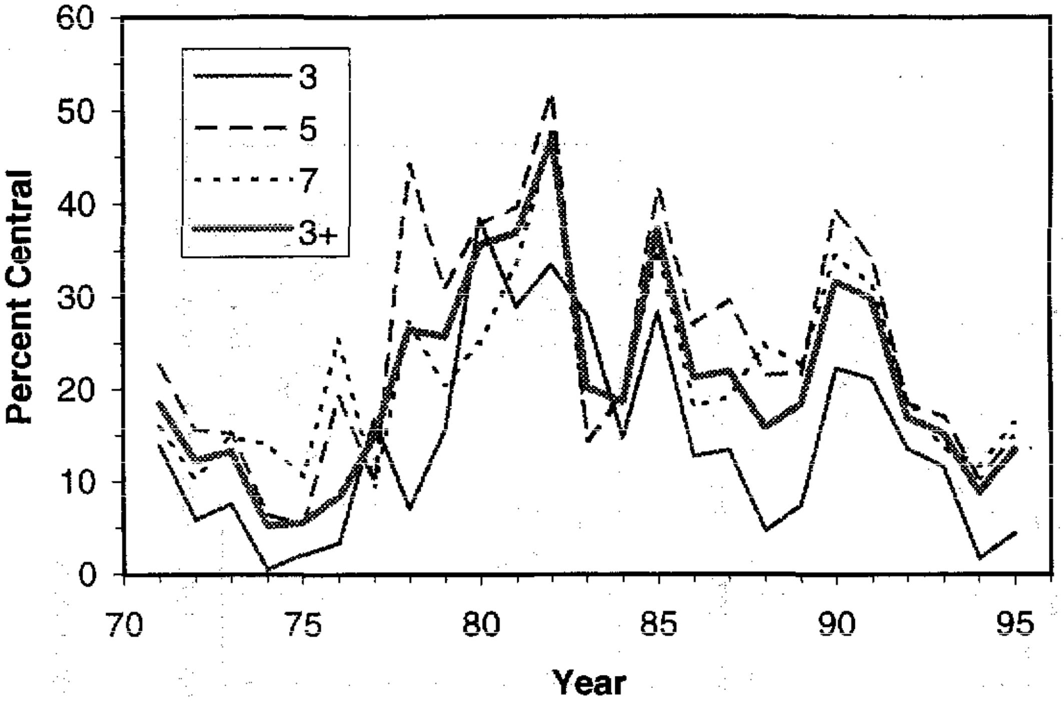
Figure 6. Distribution of age-5 Atlantic cod in September in the southern Gulf of St Lawrence during a low-abundance period in the 1970s, a high-abundance period in the 1980s, and in recent years. Catch rates are adjusted to the same average level (25 fish/tow) in all years.



Poisson regression model

$$E[Y_i] = \exp(\beta_0+\beta_1*\text{depth}+\beta_2*\text{depth}^2]$$

Fig. 7. Depth distribution of southern Gulf of St. Lawrence cod.



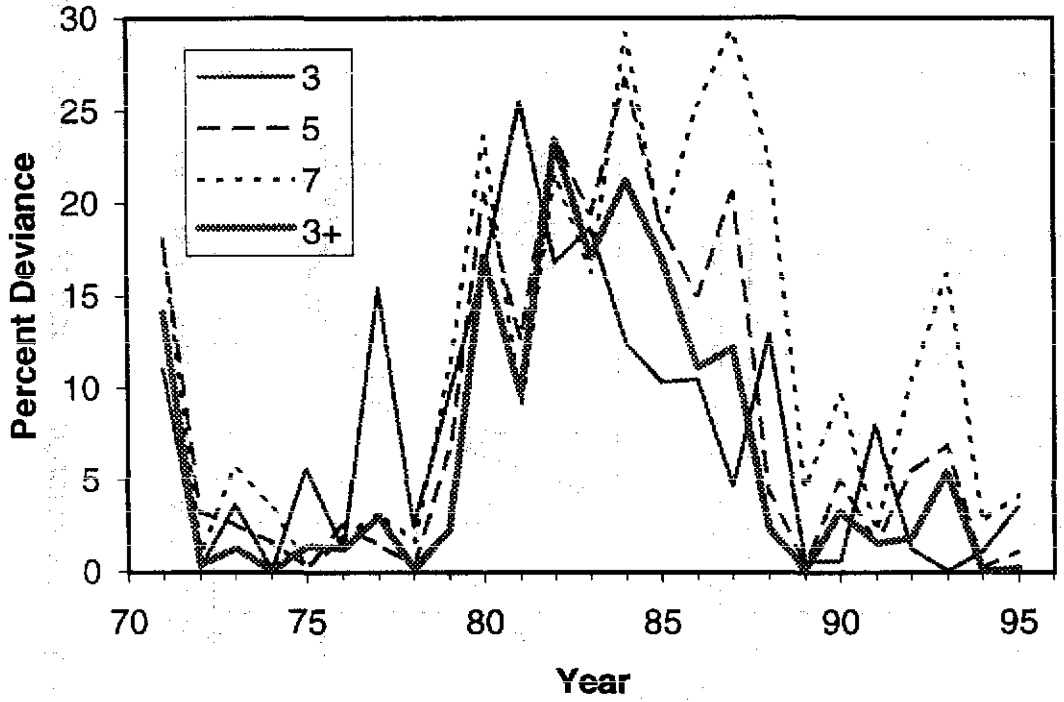


Fig. 8. Indices of distribution for southern Gulf cod. Top: percent of cod occupying the central Magdalen Shallows (survey strata 423 & 424). Bottom: Percent of the total deviance explained by the quadratic term in Poisson regression models relating cod catch rate to depth.

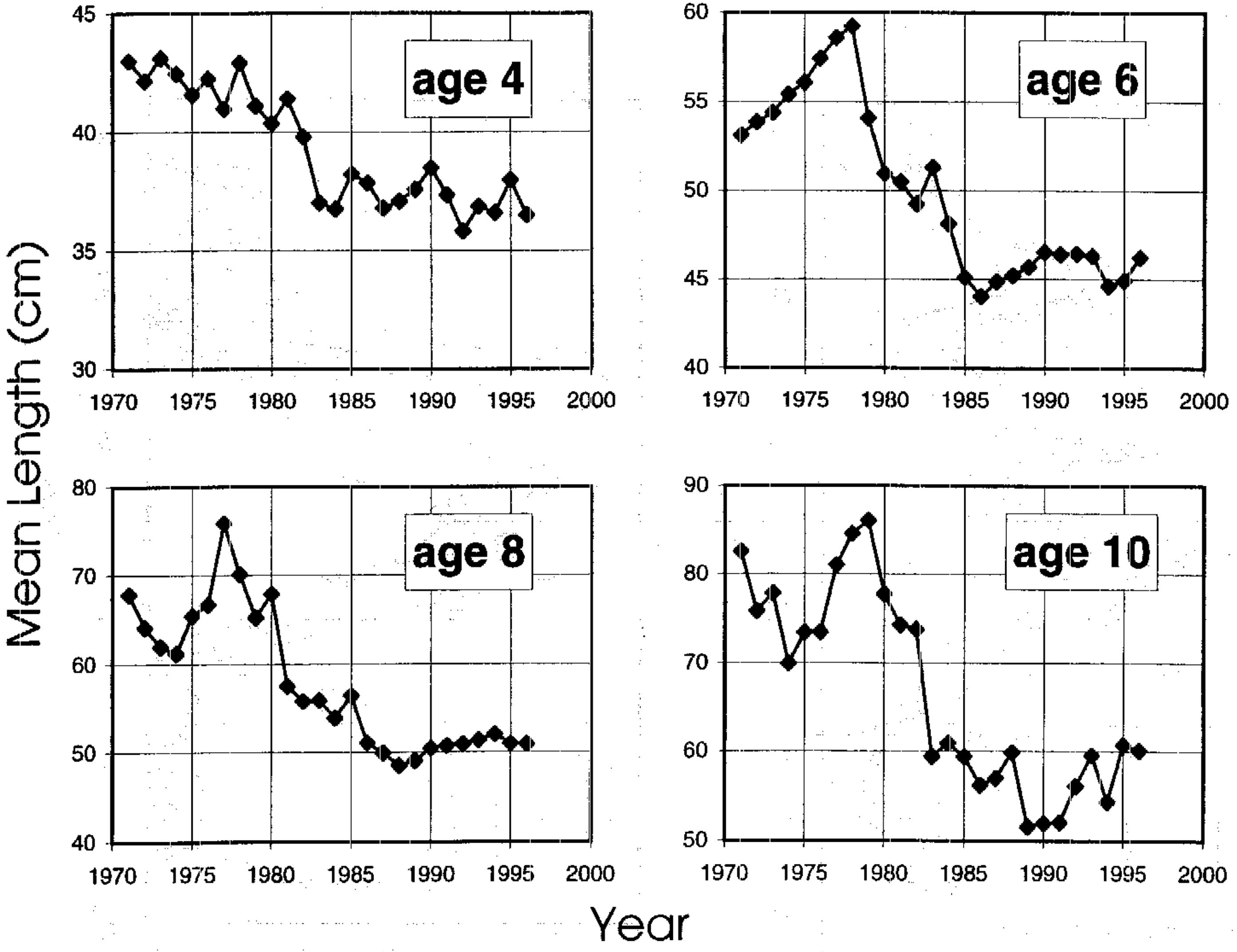


Fig. 9. Mean length-at-age of southern Gulf of St. Lawrence cod.

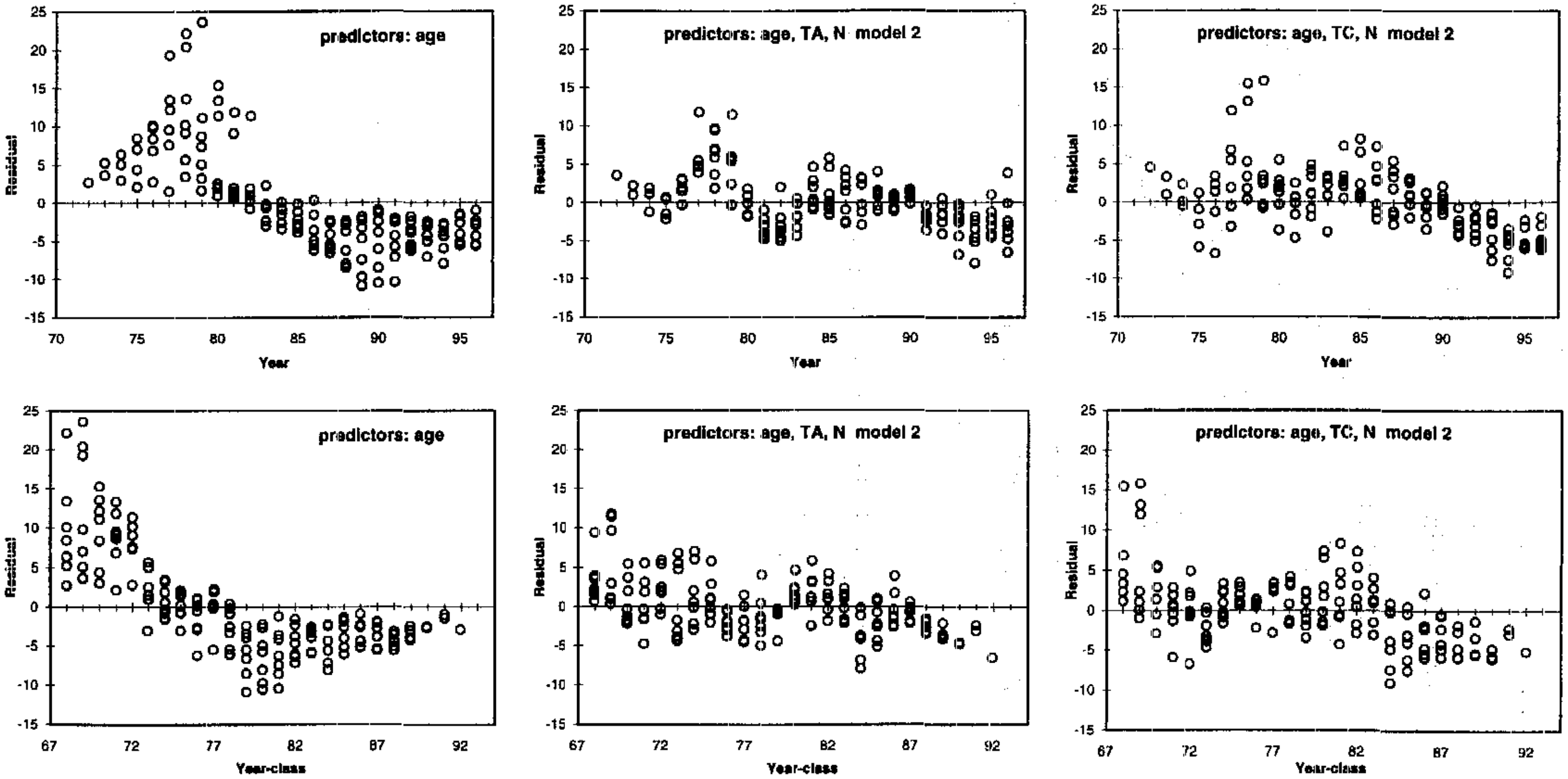


Fig. 10. Residuals from growth models for southern Gulf cod. N is an index of abundance, TC the average temperature occupied by cod in September, and TA the average bottom temperature available to co in September.

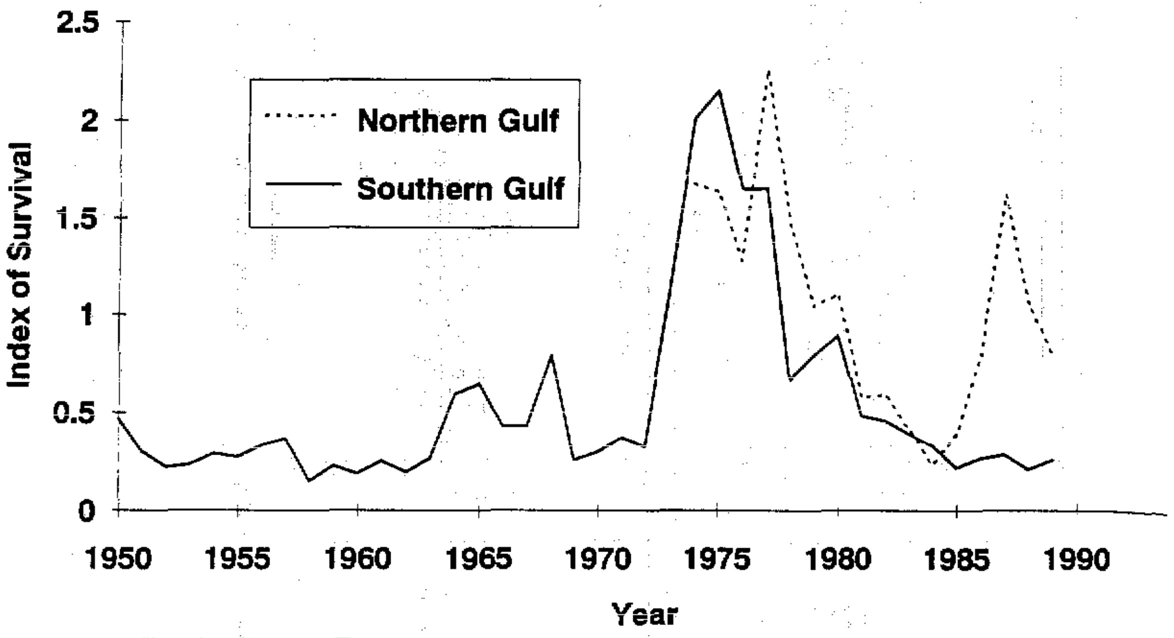


Figure 11. Index of survival (Recruitment/SSB) for the cod stocks of the southern Gulf of St Lawrence.

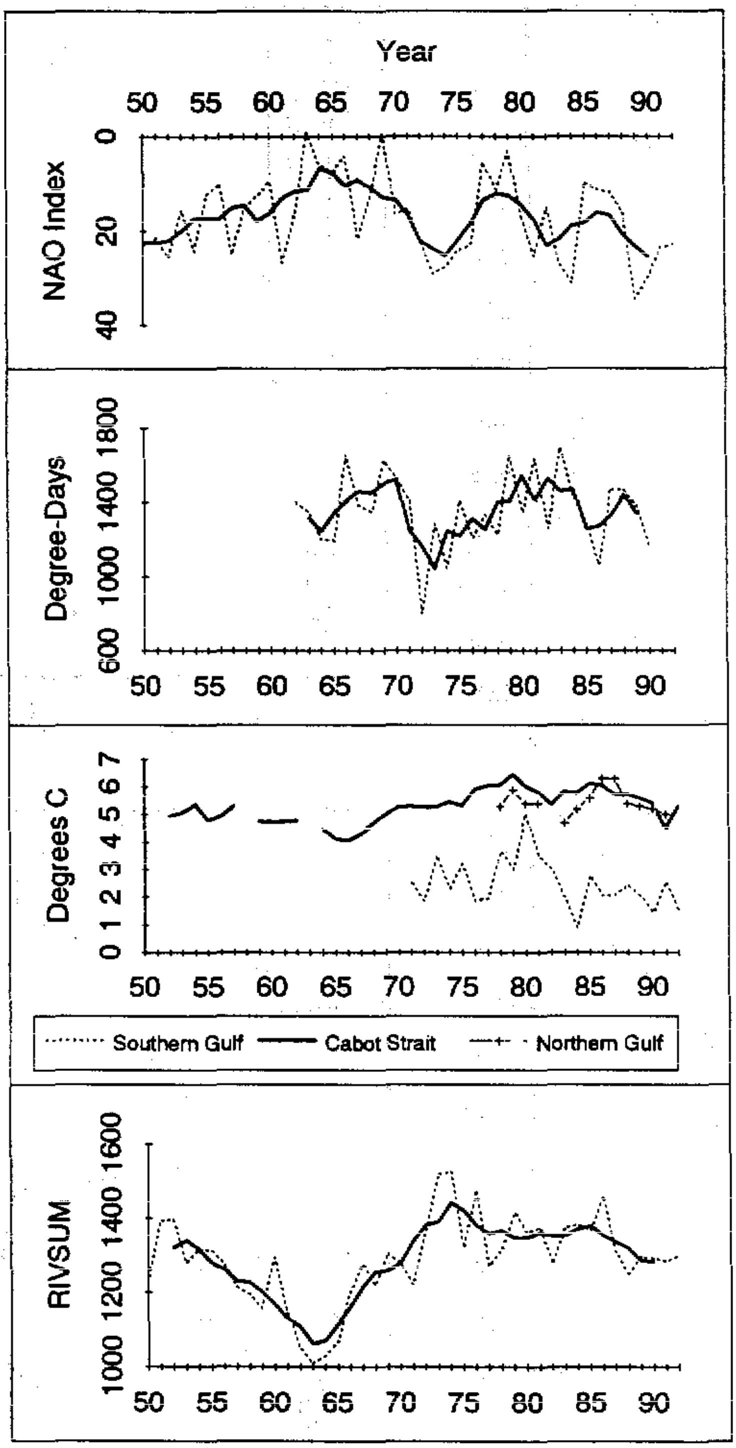


Figure 12. Plot of some environmental variables for the Gulf of St Lawrence. Top panel: Index of the North Atlantic Oscillation (dotted line) and running mean (solid line). Second panel: Mean degree-days of air temperature for six stations in the Gulf of St Lawrence (dotted line) and running mean (solid line). Third panel: Average midwater and bottom temperatures from research surveys conducted in the Gulf of St Lawrence (see text for details). Bottom panel: Index of freshwater discharge (hundreds of m^3/s) from the St Lawrence River (dotted line) and running mean (solid line).

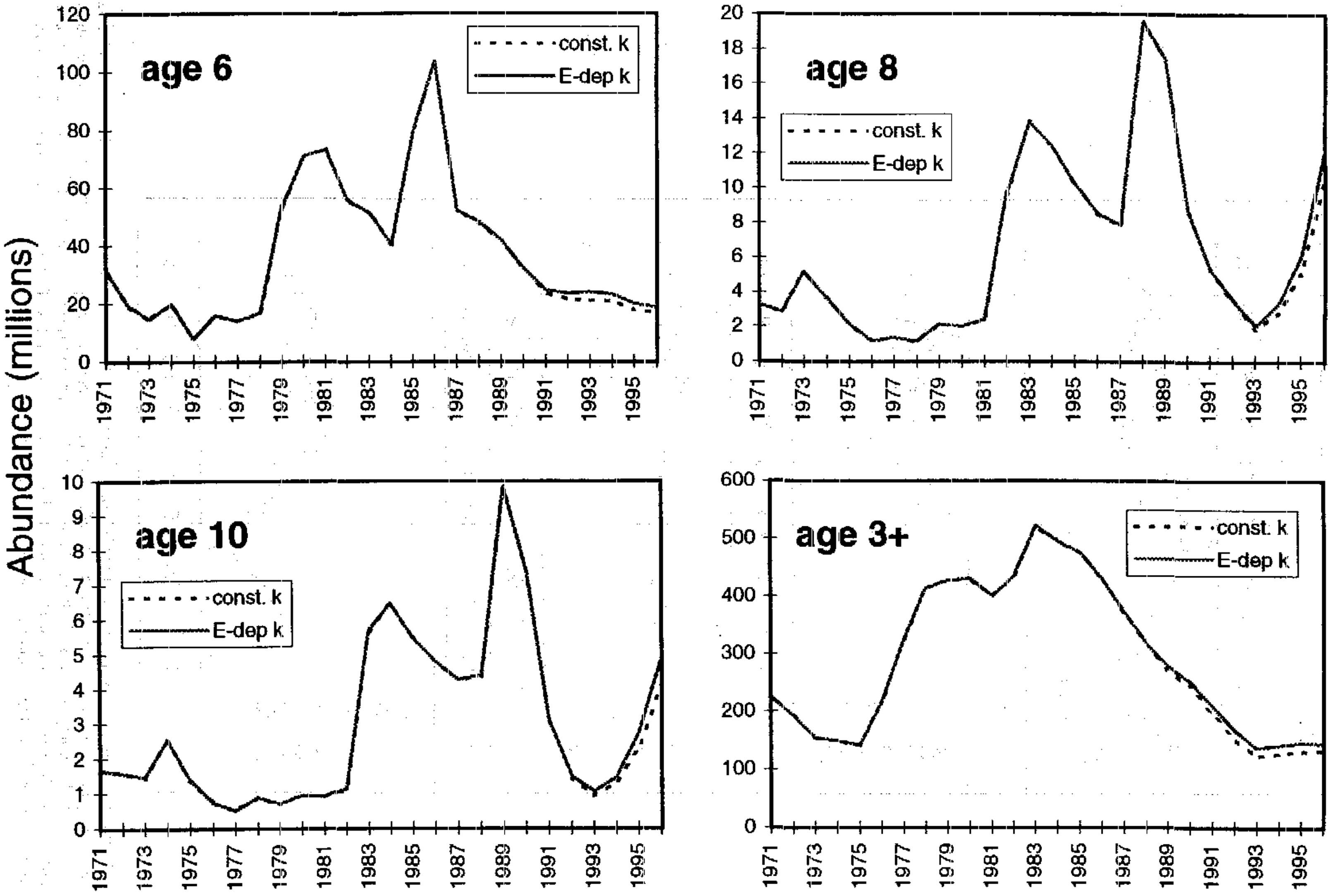


Fig. 13. SPA estimates of population size for southern Gulf cod, assuming either constant (but age-dependent) catchability or temperature dependent catchability. Temperature index is the area of subzero bottom water.

Stock assessment and biological and environmental knowledge: can prediction uncertainty be reduced?

Øyvind Ulltang, Department of Fisheries and Marine Biology, University of Bergen, HIB, N-5020 Bergen, Norway

Introduction

This document consists of two rather separate parts. In the first part, I will comment upon some suggestions I offered in Ulltang (1996) with respect to modelling recruitment of North-East Arctic cod. The second part describes the main tasks of an EU funded Concerted Action which is highly relevant for this workshop and summarises some outcomes of the discussions at the first meeting of the project.

Recruitment of North-East Arctic cod

In 1996 I published a paper (Ulltang, 1996) with a title nearly identical to the title of my introduction here. The only difference is that I have now added the words "and environmental" after "biological". In that paper, repeated references were made to the assessments of North-East Arctic cod stock, suggesting relationships which could be used for predicting short or medium term changes in vital population parameters determining mortality, growth, and recruitment. Ancillary variables in such relationships, with a priori justification for being chosen, could be parameters describing the state of the fish stock in question or the state of its biological or physical environment. In particular, I suggested to incorporate temperature in a Beverton & Holt recruitment function for this cod stock, and used as a first formulation:

$$N_0 = 1 / (\alpha + \beta_0/(T - 1)S) \qquad (1)$$

where N_0 is recruitment as 0-group, T temperature in March-April in Lofoten and S spawning biomass (see Figure 1). I suggested for further development that S should be replaced by egg production E when estimates became available and that α, reflecting both internal and external factors, could tentatively be formulated as a function of egg quality (maternal effects) and temperature. From results in Marshall *et al.* (in press) and on-going research at IMR, it should now be possible to develop this further (not necessarily using the same functional relationship) by incorporating estimates of E and also take account of maternal effects by for example partition E into the number of eggs produced by recruit spawners and the number of eggs produced by repeat spawners.

For the number surviving from 0-group until age 3 I suggested the function:

$$N_3 = N_0 a e^{-bP} \qquad (2)$$

where P is predator stock, giving the following total mortality M_{juv} over the period

$$M_{juv} = \int M(t)dt = \ln(N_0/N_3) = -\ln(a) + bP$$

Figure 2 shows a plot of a mortality index versus index of predator stock taken as the VPA estimated size of the three preceding year classes at age three (for use in predictions this should be replaced by survey estimates of juvenile cod). The figure suggests that cannibalism mortality may be predicted.

In the discussion section of Ulltang (1996) I included the following statement: "The various suggested methods in this paper should be further developed and evaluated by the working group [Arctic Fisheries Working Group] before they are eventually used in the stock assessments". In particular I hoped that the working group would have some look on relationship (2) and eventually develop it further, since it may have some predictive power. The working group has incorporated cannibalism in its VPA, but for the predictions a mean cannibalism mortality as estimated by VPA for some preceding years is used. What Figure 2 and, above all, ***reason*** tell us is that the cannibalism mortality will vary with the amount of predators in the stock (and also with the amount of alternative prey as discussed by the working group).

In Figure 2, the strength of the three preceding year classes was somewhat arbitrarily chosen as the index P of the predator stock. It indicates that it is the amount of older immature cod which determines survival from 0-group to age 3. Bogstad *et al.* (1994) found the same for Icelandic cod using regression techniques. They found that the abundance of older fish did not show a significant effect, and noted that this may be contrasted with results obtained elsewhere from cod stomach sampling programmes. For the Barents Sea, it should now be possible to

a) Compare the mortality index in Figure 2, or an index calculated by similar methods, with cannibalism mortalities as estimated from VPA.

b) Test further the relationship indicated in Figure 2 by extending the time series and eventually redefine the predator stock (or improve the way it is calculated).

With respect to a), conflicting results should not automatically be interpreted to mean that there is something wrong with the mortality index. There may also be problems with diet estimates of cod in different length groups and resulting estimates of cannibalism mortalities.

Concerted action SAP

In Ulltang (1996) I noted that a large amount of scientific knowledge potentially useful in a stock assessment-management context remains unused. I also noted that present fish stock assessment practise is characterised by too sharp a *de facto* separation of fish stock assessment experts and experts within various fields of basic marine sciences. For applying all relevant knowledge in stock assessments, it is important to change this situation both by improving the communication between the groups and by involving experts in the various fields of basic marine sciences in future stock assessments.

Last year I took the initiative to apply for funding of a EU Concerted Action with title *Sustainable fisheries. How can the scientific basis for fish stock assessments and predictions be improved? (SAP)*. We got the funding, and the project started this year with a first meeting in Bergen in February 1998. The project involves 19 fisheries research institutes and universities in Europe, two invited North American experts (Brian Rothschild and Pierre Pepin) and ICES/Keith Brander as subcontractor. Participating scientists are a mixture of fish stock assessment scientists and scientists from the academic community and include the chairman as well as some other members of this ICES/GLOBEC workshop. The project will have a duration of three years with two meetings per year and a symposium at the end of the project.

The main goal of the project is to

Examine how existing scientific knowledge can be better utilised for reducing the uncertainties and increasing the time horizon of fish stock assessments carried out by ICES and other stock assessment agencies/institutions, and evaluate implications for fishery management. Investigate whether existing oceanographic and biological time series, or other available data, can be used for testing theories which would expand the scientific knowledge relevant for fish stock assessments, and propose future coordinated research.

In Appendix A is given extracts from the work programme defining tasks and subtasks.

The problem of communication/co-operation between fish stock assessment scientist and experts within various fields of basic marine sciences is listed as a separate task to be dealt with at the end of the project. However, the main task of the project is to investigate how biological and environmental knowledge can be better utilised in stock assessments, being convinced that the answer to the question in the title of this document is Yes! The effects of the environment is a key question in the project, and there is a great deal of overlap between the tasks of this workshop and the concerted action SAP. I do not see this as a problem, but rather as an advantage. At the next meeting of SAP we will have the report from WKEDSA, hopefully contributing to speeding up the work of SAP.

SAP structure

The project involves experts within the following three broad research areas (topics):

Topic 1: Variability of the marine physical environment and its effects on fish stocks.

Topic 2: Population dynamics including species interactions.

Topic 3: Population dynamics/stock assessment models, including multispecies models.

There is no clear division line between these topics, and most of the experts cover more than one of them. This also reflects the integrated approach which is a key element in the project.

It has also been attempted to involve experts from very different geographical areas. In north-south direction, the following three major areas are represented:

Area 1: Norwegian and Barents Seas and Icelandic waters.

Area 2: North Sea, Skagerrak/Kattegat and Baltic

Area 3: Areas west of the Iberian Peninsula and Mediterranean

The tasks will be dealt with by working groups (WGs) reporting to plenary meetings, the WGs being organised by topic (Topic 1–3) for some tasks and by geographical areas (Area 1–3) for others as shown below:

Task	Breakdown by topic	Breakdown by geographical area
1		x
2	x	
3	x	
4		x

Task 5 will be conducted during the last year of the project involving all participants.

Each participating scientist will be member of one topic and one area WG. By this arrangement, each topic WG will have participants from all areas, and each area WG will have participants from all topics. This will further strengthen the integrated approach.

First SAP meeting

The report from the first SAP meeting is not yet available, but in order to start the process of a mutually beneficial communication with this workshop, I will try to summarise some highly relevant outcomes of the discussions at the meeting with respect to how to deal with the environment.

The meeting started by plenary lectures and discussions addressing topics highly relevant to the main objectives of the project. This part of the agenda was meant as a brainstorming, commenting upon the state of the art, before we proceeded to the various tasks, and was quite open-ended. With respect to environment - fish problems, it was noted that

- Environmental factors are of varying importance in different area, and the importance should be identified for each area evaluating sensitivity of stock assessments to environmental data
- For studying effects of environment, there is need for both working on a much finer time scales than usually used in stock assessments and for studying large scale physical processes and for using aggregated environmental information
- Fish migration is a problem in stock assessments, and migration can be further explained by using environmental information
- Environmental and fishery effects have to be considered together
- Including environment as a third axis in stock - recruitment plots could shed further light on the recruitment problem.

Keith Brander presented in tabular form suggestions on how we might apply environmental data in fisheries assessments and a table of environmental factors on processes in the life history of cod. These tables were found very useful, and revised tables have been circulated by Brander to this workshop.

During the second part of the meeting, the Area WGs started their work on sub-tasks 1.1 - 1.2, scheduled to be finished at the second 1998 meeting in October, while the Topic WGs dealt with sub-tasks 2.1 - 2.2 to be finished at the first 1999 meeting (Topic 3 WG had also a first run on sub-tasks 2.3 - 2.4 to be finished at the second 1999 meeting)

Topic 1 Working Group (Variability of the marine physical environment and its effects on fish stocks) agreed that in depth case studies would be beneficial and that an identification/evaluation scheme of case studies should be established. In Appendix B is given such a scheme in tabular form, extracted from the minutes of the meeting of the working group. The group also related biological production time-series and physical environmental factors (see Appendix B). Brian MacKenzie presented results on estimation of the "Cod spawning volume" (CSV) for Baltic cod.

The volume of water in the Baltic suitable for the development of cod eggs is bounded by an oxygen surface (lower boundary) and a salinity surface (upper boundary). CSV shows considerable interannual variations. The representativity of single stations for the computation of CSV was tested and comparisons of estimates of CSV from various institutes were carried out. It was suggested that fluctuations in CSV could be attempted related to

- westerly winds in the North Atlantic/North Sea, the NAO-index

- the volume of oxygen poor bottom water in the Baltic.

When reviewing assessment problems in the different geographical areas, it became clear that environmental data are used to a very small extent. ***Area 1 Working Group*** noted several examples where biases in cod assessments were related to the lack of including environmental effects, e.g., environmental and fishery mediated increases in catchability in the Newfoundland Northern cod prior to its collapse, changes of distribution resulting in catchability change in the N.E. Arctic cod and a general tendency for the extreme environment in these areas to sometimes modify the behaviour of the stock relative to the usual simple assessment model. Predictions were also jeopardised if attention was not paid to the responses of recruitment to spawning stock size and quality, environmental signals (particularly temperature) and predation effects. For pelagic stocks in the area (e.g., Atlanto-Scandian herring), historic records of catches show a certain pattern of periodicity. Assessment may be less of a problem but a major possible source of error seems to relate to how to manage these through an environmental down turn. This seems to be a problem of loss functions resulting from the interaction between stock size and environmental effects on the slope at the origin of the recruit/stock/environment response surface, and these problems will be further described by the working group.

Area 2 Working Group noted that biological input data to stock assessments were affected by environmental factors on three different scales:

- Specific instantaneous conditions, not to be predicted but easily to be measured, to which species show an immediate reaction, e.g., by emigration or increased mortality (as observed in severe winter conditions for sole in the North Sea). Adaptive approaches would require a flexible management, allowing immediate action to be taken as soon as the specific condition becomes apparent.

- Factors to be measured and available at the time of assessment, influencing biological input data on a short term perspective. Short term predictions could be improved as soon as corresponding relations between the environmental factors and biological input become known and should be considered in these predictions.

- Medium or long term trends in the environmental conditions with effects on biological input data, restricting medium to long term perspectives in fishery management. Improvements could be achieved in case of structured trends that allow reasonable predictions of environmental developments and knowledge about the effects of these trends on biological input data. Important aspects for medium and long term trends relevant for stock projections appear to be especially large scale meteorological fluctuations (e.g., NAO), the predator-prey interactions among species and the effect of changes in stock structure on reproductive success.

Environmental variability relevant for stock predictions including short to long term scales will be reviewed by the working group for the North Sea and the Baltic Sea areas.

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APPENDIX A.

Extracts from Work programme - Project Fair CT97–3805

Sustainable fisheries. How can the scientific basis for fish stock assessments and predictions be improved? (SAP)

Methodology and research tasks

After identifying main causes for shortcomings in present fish stock assessments and predictions, aspects of physical and biological processes which set limits on predictability will be discussed with the aim of investigating whether we now are approaching such limits. The project will then coordinate activities with the aim of conducting critical investigations of possible predictive relationships to be used for improving stock assessments and predictions, making the best possible use of existing scientific knowledge. This will include scrutinising published literature and conducting own investigations, using long time series of physical and biological data as one main source for testing proposed relationships. Simulation studies will be used for evaluating population dynamics models and the consequences of proposed relationships, including implications for fishery management, given the observed past and present behaviour of the environment. For investigating the potential for improvements in fish stock assessments and predictions, case studies for selected fish stocks, or fish stock complexes, in three major geographical areas will be conducted.

Task 1: Shortcomings in fish stock assessments.

Objectives: Identify main causes for shortcomings in present fish stock assessments and predictions.

Methodology: Main causes for shortcomings in present fish stock assessments and predictions will be analysed by reviewing ICES Assessment Working Group Reports and other relevant assessment reports, comparing estimates made in a given year with what later retrospective analyses have shown and analyse causes for discrepancies.

Sub-task 1.1: Sources of errors.

Objectives: Identify main sources of errors in present fish stock assessments

Sub-task 1.2: Limits on time horizon of predictions

Objectives: Identify main factors limiting the time horizon of precise predictions and problems connected to timing and other aspects of the assessment/advice/management implementation process.

Task 2: Limits on predictability.

Objectives: Consider the limits set by nature on predictability of fish stock development.

Methodology: Aspects of physical and biological processes which set limits on predictability will be discussed with the aim of investigating whether we now are approaching such limits, taking into account causes for shortcomings in present fish stock assessments and predictions as analysed under Task 1.

Sub-task 2.1: Variability of fish catches/abundance

Objectives: Consider variability of fish catches/abundance, including changes with length of time interval considered, differences between ecosystems and relations with life history.

Material and methods: Critical review of published literature.

Sub-task 2.2: Probabilistic character of physical and biological processes.

Objectives: Discuss to what extent the probabilistic character of many physical and biological processes will limit the predictability.

Material and methods: Critical review of published literature.

Sub-task 2.3: Role of deterministic predictions.

Objectives: Consider the role of deterministic predictions, given the probabilistic character of many processes.

Material and methods: Critical discussions based on published studies, eventually complemented with own simulation studies.

Sub-task 2.4: Probabilistic predictions.

Objectives: Discuss the interpretation and treatment of probabilistic predictions in fish stock assessments.

Material and methods: Critical discussions based on published studies, eventually complemented with own simulation studies.

Task 3: Scientific knowledge potentially useful in fish stock predictions.

Objectives: Review "the state of the art" within relevant research areas and identify the kind of scientific knowledge potentially useful in fish stock predictions which exists without being effectively used at present. Discuss how such knowledge most effectively could be used and how it could be expanded. Propose future coordinated research.

Methodology: Conduct critical investigations of possible predictive relationships to be used for improving stock assessments and predictions, making the best possible use of existing scientific knowledge. This will include scrutinising of published literature where such relationships are suggested, or where analyses are given which may be used to construct relationships. In addition to evaluating the soundness of proposed relationships from published material and discussions, the project will carry out its own investigations, using long time series of physical and biological data, either from published literature or from available data bases, as one main source for testing proposed relationships.

Sub-task 3.1: Physical environment - plankton and fish.

Objectives: Review the state of knowledge concerning predictability of physical environment and its effects on plankton and fish.

Sub-task 3.2: Fish population dynamics.

Objectives: Review the state of knowledge of fish population dynamics, including reproductive strategies and recruitment functions, density dependent growth and maturation and other responses to exploitation.

Sub-task 3.3: Multispecies effects.

Objectives: Review the state of knowledge of multispecies effects, including plankton - fish interactions and cannibalism, with emphasis on relationships between food supply and growth of fish and relationships determining predation mortalities.

Sub-task 3.4: Population dynamics models.

Objectives: Identify and evaluate predictive relationships and population dynamics models of different types and complexities as tools for predicting stock development, based on the results of 3.1 - 3.3. What will be the main sources of uncertainties, and what will be the time horizon of predictions of acceptable reliability?

Material and methods: Simulation studies will be used for evaluating population dynamics models which differ with respect to complexity, what kind of scientific knowledge relevant to the population dynamics of the stocks which can be directly utilised and to what extent they include assessment of the effects of the various sources of uncertainty.

Sub-task 3.5: Fishery management.

Objectives: Evaluate implications for fishery management.

Material and methods: Implications for fishery management of proposed relationships will be evaluated by simulation studies, given the observed past and present behaviour of the environment.

Sub-task 3.6: Future research.

Objectives: Identify types of oceanographic and biological time series and other data available for further studying effects of environment and fisheries on fish population parameters (recruitment, growth, survival, maturation) and for testing candidates for key explaining variables in predictions. Propose future coordinated research.

Material and methods: Discussions based on the results of sub-tasks 3.1–3.4.

Task 4: Case studies.

Objectives: Carry out case studies for selected areas and stocks with the aim of demonstrating the potential for improvements in quality and time horizon of fish stock predictions.

Methodology: For investigating the potential for improvements in fish stock assessments and predictions, three major geographical areas will be chosen which differ with respect to available knowledge of the fish resources, main driving forces in the ecosystem, complexity of the system and state of exploitation and management problems. For each of these large areas (Barents/Norwegian Sea and Icelandic waters; North Sea, Skagerrak/Kattegat and Baltic; and Areas west of the Iberian Peninsula and the Mediterranean), key fish stocks, or fish stock complexes, on which substantial research has been conducted, will be selected for demonstrating application of results from Task 3.

Sub-task 4.1: Barents/Norwegian Sea and Icelandic waters.

Sub-task 4.2: North Sea, Skagerrak/Kattegat and Baltic.

Sub-task 4.3: Areas west of the Iberian Peninsula and the Mediterranean.

Task 5: Scientific communication/co-operation.

Objectives: Evaluate how communication/co-operation between fish stock assessment experts and experts within various fields of basic marine sciences can be improved. Evaluate how communications between experts working in different geographical regions may improve understanding and quality.

Methodology: Based on experiences from the present organisation of assessment work in ICES and in the different geographical regions, and from the attempts to get discussions across subjects and regions in the present project, recommendations on possible improvements in the way assessment work is organised will be considered.

Sub-task 5.1: Research Agency.

Objectives: Evaluate whether a Research Agency in co-operation with national research centres and ICES, involving both fish stock assessment experts and experts within various fields of basic marine sciences, could strengthen the attempts to improve the scientific basis for fish stock assessments and predictions.

Sub-task 5.2: Cooperation across subjects and regions.

Objectives: Evaluate how communication between fish stock assessment experts and experts working in different zoogeographical areas, e.g., Barents Sea, North Sea, Baltic and Mediterranean, can improve understanding of problems and techniques and raise the quality of assessment and advice.

APPENDIX B.

Extracts from minutes of sap topic 1 working group, Bergen 16 - 20 February 1998

Table of case studies

The purpose of this table is to identify and evaluate case studies which may be useful for retrospective analysis, as examples of 'good practice' in applying environmental data. It can be regarded as an aid to selecting cases for further study, but the tabular format can also be used as a database for classifying, storing and retrieving data, references (and ideas), related to areas, stocks etc. during the SAP programme.

All cases which might be referred to or investigated during the project can be included and participants are encouraged to submit **all such cases.** Since it will be set up as a database the table may be very large in its entirety, but it can be filtered and sorted in many different ways in order to focus on particular requirements. It may also be useful to include literature references and link these with material being maintained in a separate bibliographic database.

The examples shown in the table are for illustration. Suggestions for improving the format and contents would be welcome.

Evaluation

What are the case studies for?

1. To provide retrospective examples of cases where (with the wisdom of hindsight) additional environmental information could have been applied to improve assessment and management.

2. To review cases (anywhere in the world) where environmental information is being applied effectively (i.e., examples of 'best practice')

3. To review existing work in this area (e.g., on Baltic cod) and suggest ways in which it can be supported and improved

4. To identify cases for new work within the lifetime of the SAP project

5. To recommend cases for further work (eventually, by someone else)

Explanation of terms used in the evaluation

- IMPORTANCE There may be several ways of judging importance, but we suggest 'sensitivity of the outcome of the assessment to environmentally induced variability in this parameter'.

- UNDERSTANDING OF PROCESS There may be a number of candidate hypotheses to account for an observed (correlation) relationship, but how well corroborated are they?

- TIMESCALE OF APPLICATION Can we apply this soon (within the lifetime of the SAP project)?

- DATA/METHODS What data and methods need to be procured or developed?

- PREDICTABILITY Can future values of necessary environmental data be predicted?

- COSTS What are the costs of procuring data, doing research and applying the methods to deal with this process?

- NEW/INNOVATIVE Is this case likely to give us new insights and innovative ways of improving assessment and management?

- WHO Who (if anyone) will carry this work forward

TABLE FOR ASSEMBLING DATA ON CASE STUDIES FOR SAP AND FOR EVALUATING THEM

CASE STUDY				EVALUATION OF CASE STUDY							
AREA	STOCK ASSESS PARAM	RANKING HYPOTHESIS/ PROCESS	CLIMATIC CONTEXT	IMPORTANCE	UNDER-STANDING OF PROCESS	TIMESCALE OF APPLICATION	DATA/ METHODS	PREDICT ABILITY	COST	WHO?	NEW/ INNOVATIVE SCIENCE?
Baltic Cod	GROWTH	Food, T									
	MORTALITY										
	RECRUIT	Respiration, buoyancy Oxygen & halocline	West wind/NAO; density of bottom water								
	MIGRATE										
Arcto-Norwegian Cod	GROWTH	Food, T									
	MORTALITY										
	RECRUIT	Direct T effect; C.Fin ascent; distribution at age; food consumption; Atlantic water flux	NAO, past 4–5 decades; slight advective lag?; ice/cold/capelin distribution								
	MIGRATE										
Irish Sea Cod	GROWTH	Food, T									
	MORTALITY										
	RECRUIT	Gonad maturation, match mismatch, plankton production T and recruitment	NAO,effects on Ta, Ts, wind, stability								
	MIGRATE										
Multispp Iberian sardine, anchovy		Upwelling air temp Turbulence, food conc	El Nino, Trades/NAO								
Adriatic sardine		Freshwater/nutrient runoff Phyto production	NAO								
Iceland-Greenland cod	MIGRATE	Transport of larvae & warmth; return migration; survival T at Greenland Advection of larvae	Kushnir U index								
Atlantic Tuna, bigeye, bluefin, albacore		Food, Ts Intensity of equatorial/coastal upwelling	NAO Trade winds								

BIOLOGICAL PRODUCTION SYSTEMS

Relate biological production time-series and physical environmental factors

1. Nutrients

- horizontal currents
- freshwater supply
- upwelling
- North Atlantic Oscillation

2. Primary production/secondary production

- temperature
- freshwater supply
- meteorological index (wind speed, wind direction, air pressure, cloud cover)
- horizontal currents
- upwelling
- North Atlantic Oscillation index

3. Fish recruitment (eggs, larvae, 0-group)

- temperature, salinity and density
- oxygen concentration (particularly Baltic Sea)
- fresh water supply
- meteorological index (wind speed, wind direction, air pressure, cloud cover)
- North Atlantic Oscillation index
- horizontal currents
- upwelling index

BIOLOGICAL PRODUCTION SYSTEMS

Relate biological production time-series and physical environmental factors

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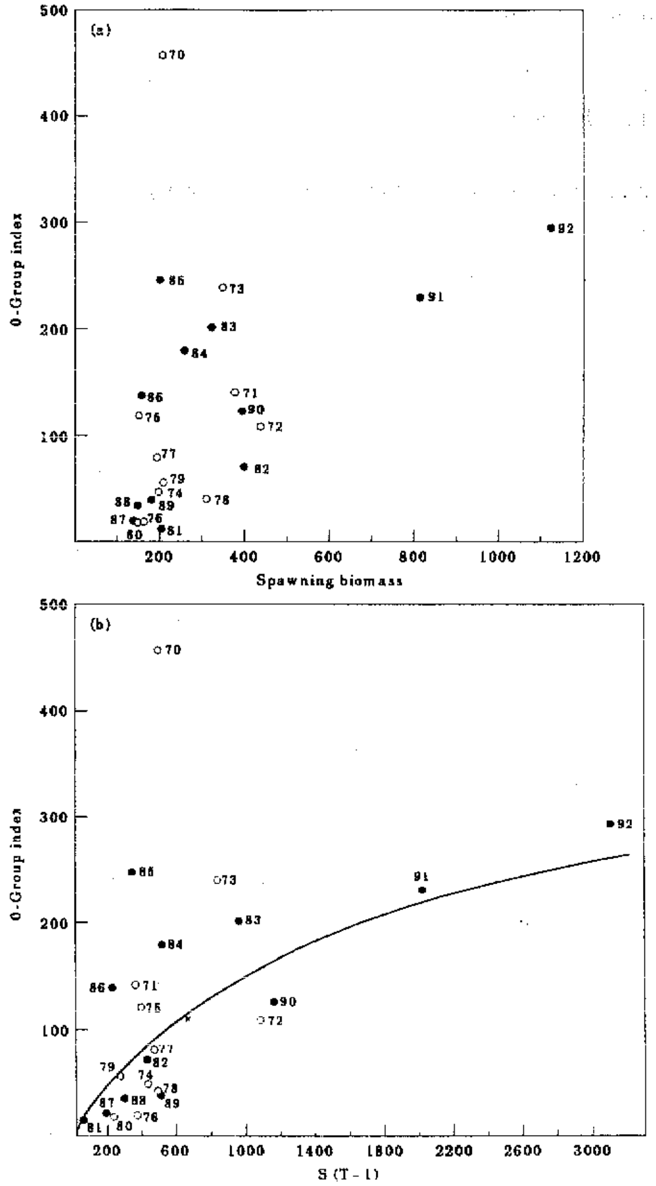
- meteorological index (wind speed, wind direction, air pressure, cloud cover)
- North Atlantic Oscillation index
- horizontal currents
- upwelling index

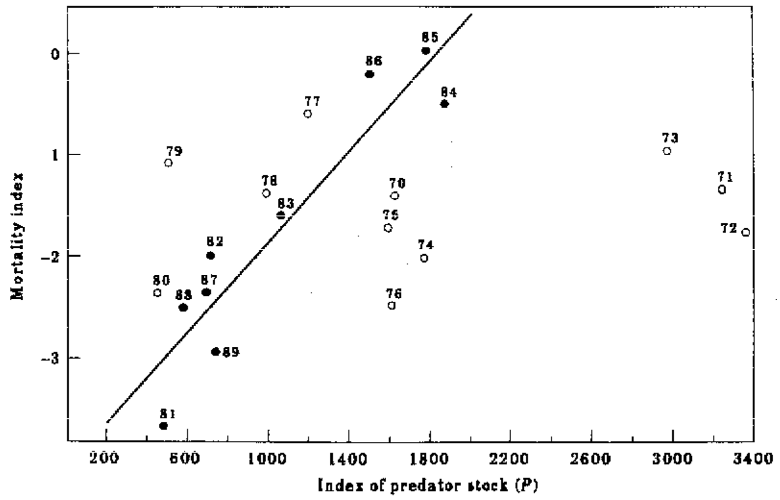
Figure 1. From Ulltang (1996)
Figure 2. From Ulltang (1996)

Figur 1. From Ulltang (1996)



North-east Arctic cod. Revised 0-group index versus (a) spawning biomass S and (b) S(T-1). Beverton and Holt type spawning stock-recruitment curve through mean for 1981–92 in (b). × =mean 1971–92. Spawning biomass in 1000 tonnes.

Figur 2. From Ulltang (1996)



North-east Arctic cod. Mortality index (ln (revised 0-group index/year class size at age 3)) versus index of predator stock (sum of the size of the three preceeding year classes at age 3) for year classes 1970–89. Regression line: Year classes 1981–89.

Prediction Ocean Temperature – Seasonal Prognosis for the Barents Sea

Bjørn Ådlandsvik, Institute of Marine Research, Bergen, Norway

Extended abstract

The objective of this work is to examine the possibility of predicting the yearly mean temperature in Kola section in the Barents Sea, precise enough and early enough to be useful for assessment purposes.

The Kola data are provided by PINRO in Murmansk. The series consist of monthly values from 1921 to present for the averaged temperature for the upper 200 m along the Kola meridian in the Atlantic Water in the Barents Sea. In addition the North Atlantic Oscillation (NAO) winter index is discussed. This is a normalized air pressure difference between Portugal and Iceland, averaged over the months December, January, February, and March.

First two simple forecast procedures are suggested as benchmarks for predictions. They are not meant to be useful predictions. Instead, they are used to define basic preciseness levels that more realistic predictions must improve. The first procedure is simply to issue the last 30 year mean as a prognosis. Figure 1 show the Kola series and the forecasted series. The correlation between the series is almost zero, ae = 0:04, and the root mean square error (RMSE) is 0.46 degree C. The second benchmark, persistence, is to use last years temperature as a prognosis for this year. These results are shown in figure 2. The corresponding error statistics are an improved correlation of 0.39 but slightly worse RMSE of 0.51 degree C.

As observed by Ottersen (Dr Scient. Thesis) and others, the correlation between the spring temperatures and the following autumn in the Barents Sea is much higher than from autumn to spring. This is due to physical processes including wind driven inflow, vertical mixing, heat loss to the atmosphere, sea ice which are stronger and more variable during the winter. Figure 3 shows the correlation between the monthly values of the Kola section and the yearly mean. The correlation increases rapidly to a value of approximately 0.95 in April and stay on that level until September where it drops down again with a minimum in December. From this figure it seems possible to come up with a reliable prognosis for the yearly mean by the end of March, hopefully early enough to be useful for stock assessment purposes. By waiting one more month a more precise prognosis is possible.

The forecast procedure used here, is each year to take the last 30 years of data and make a linear regression between the March temperature and the yearly mean. This regression is used to produce the prognosis that year. Next year, the 30 year window is shifted one position and the procedure repeated. In this way a prognosis series from 1951 is obtained with the following properties. It is a pure prognosis, no future values are used in the regression or elsewhere and it is based on data series of uniform length.

The results of this procedure is presented in figure 4. The correlation between the observed and forcasted series is 0.87 and the RMS error is 0.22 degree C, a clear improvement from the benchmarks.

The temperature in the Kola section is correlated with the modelled inflow to the Barents Sea (Ådlandsvik and Loeng, 1990). Unfortunately, this time series is not long enough to include in the procedure used here. An alternative is the NAO Winter index which has also been shown to be correlated with the Kola temperature. The NAO index is presented in figure 5 from 1864 to 1997. The three tops since 1970 coincide very well with high temperatures in the Kola section. Figure 6 is produced by sliding a 30-year window through the time series and computing correlation coefficients. The correlation between the March and yearly mean values of Kola temperatures is uniformly high, while the correlation with the NAO index is a new phenomena not extending into the past.

A multiple linear 30 years moving regression using the March Kola temperature and the NAO winter index is also tested. The results are shown in figure 7. The correlation is 0.88 and the RMSE is 0.22 degree C, a minimal improvement from the Kola series alone.

As a conclusion, it is possible to give a quite reliable prognosis for the yearly mean Kola temperature by the end of March. Inclusion of other series available at the same time in the same method does not seem to improve the prediction very much and should therefore not be used.

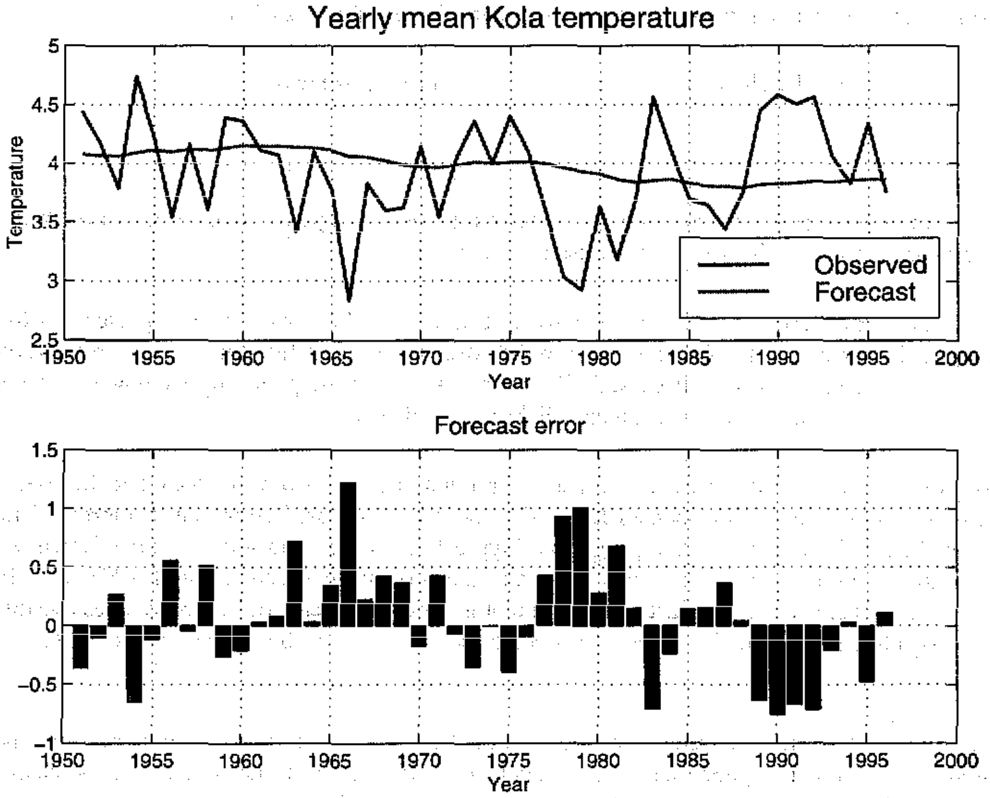


Figure 1. The performance of the mean prognosis. The upper subfigure show the yearly mean Kola temperatures and their mean prognosis, while the lower subfigure shows the prediction error series

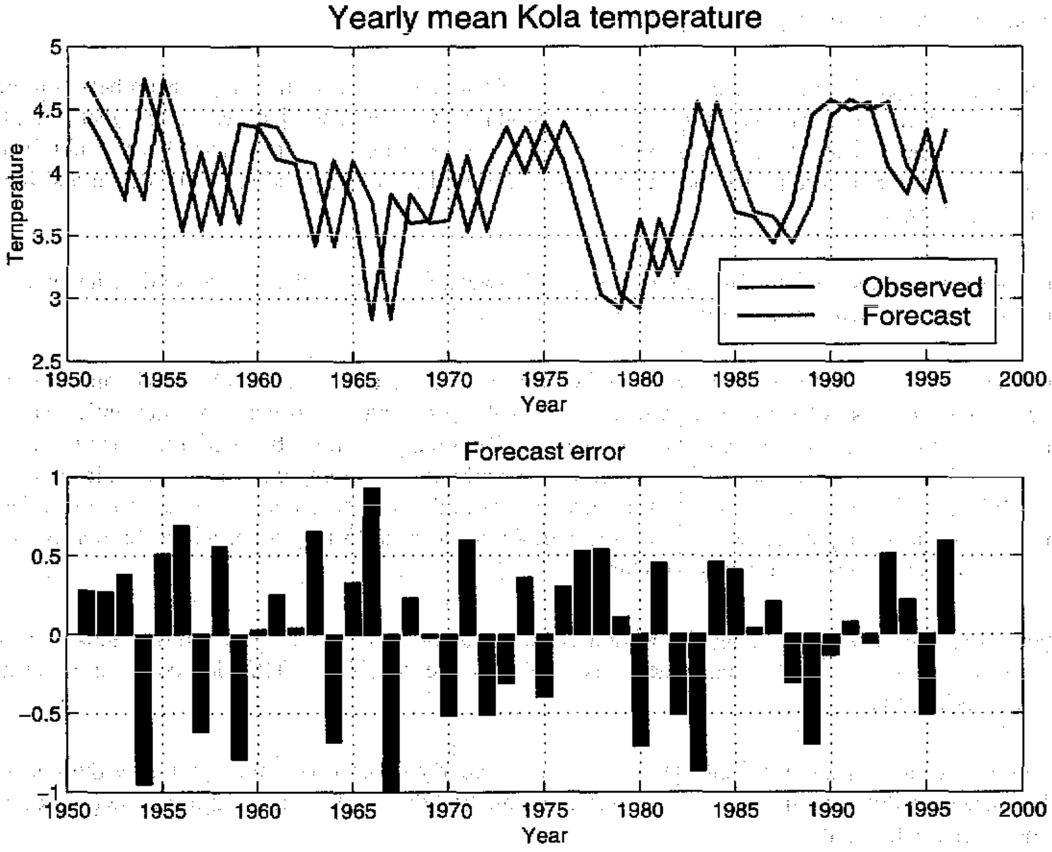


Figure 2. The performance of persistence as prognosis

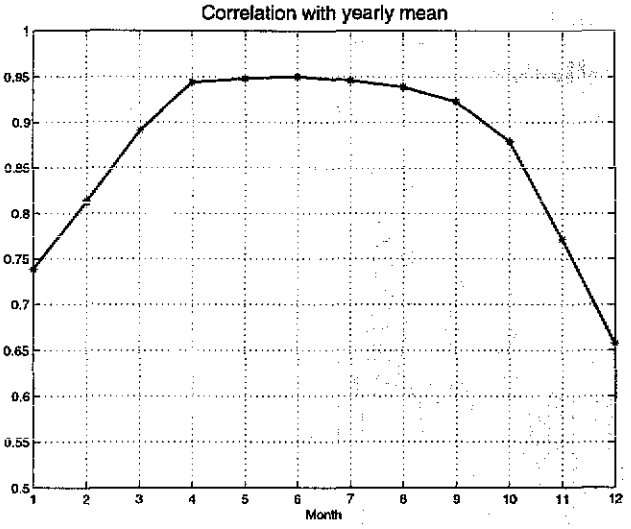


Figure 3. The correlation between monthly and yearly mean values of Kola temperature

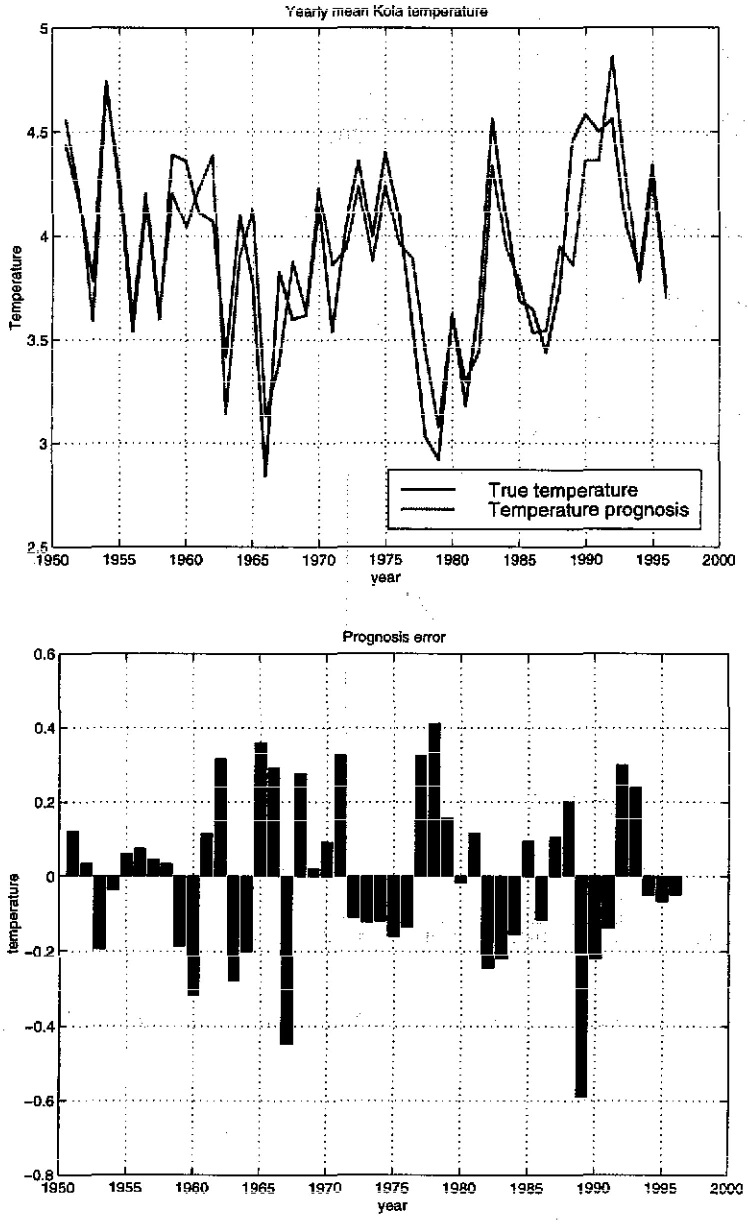


Figure 4. The performance of forecasting based on the March Kola series

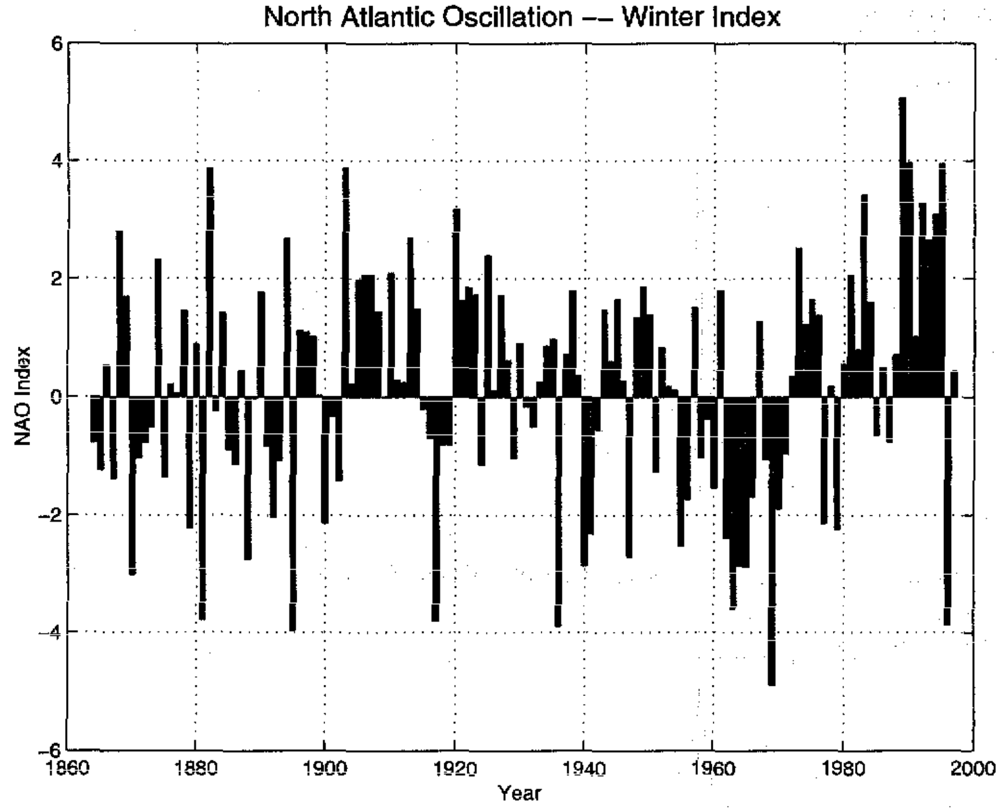


Figure 5. The North Atlantic Oscillation - Winter Index

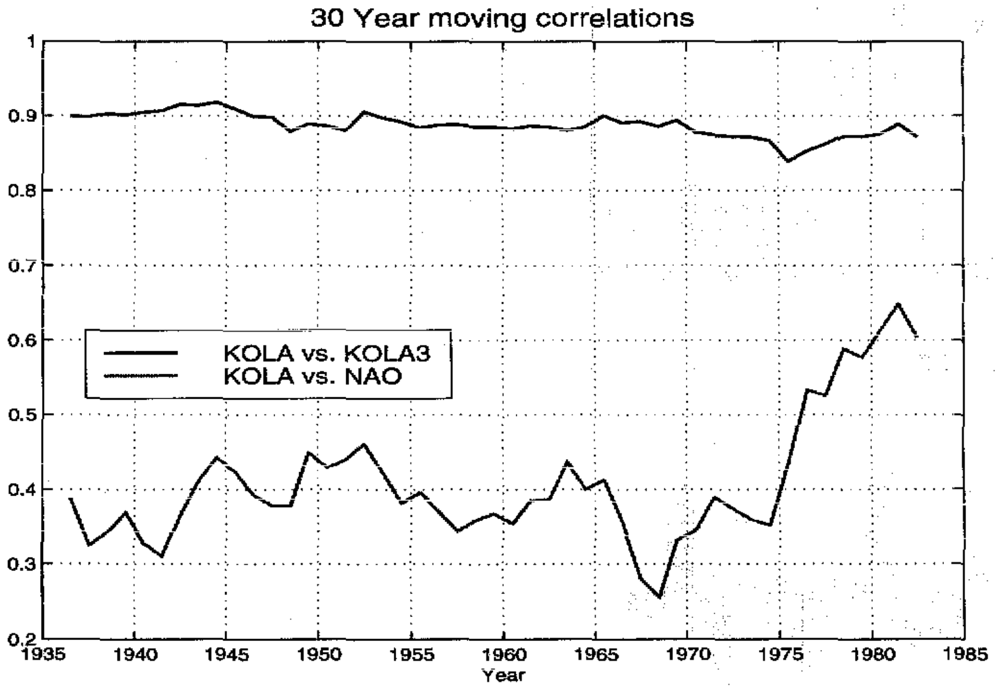
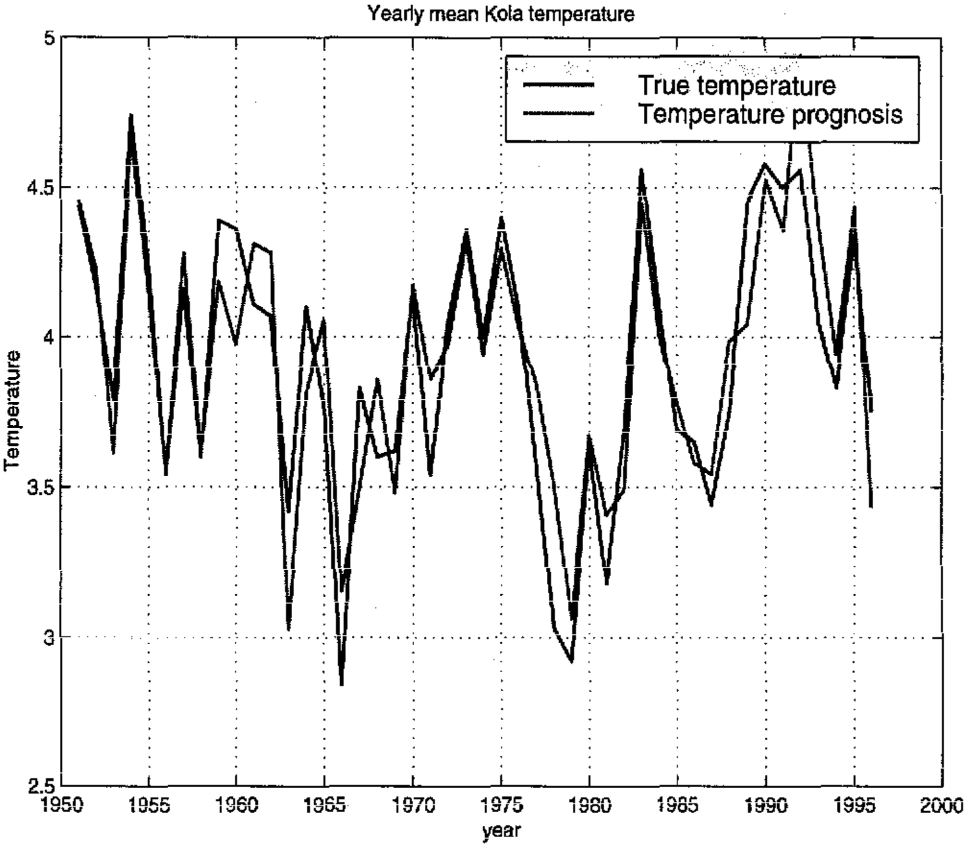


Figure 6. 30 years moving correlations. The timeaxis refers to the midpoint of the 30 year time window



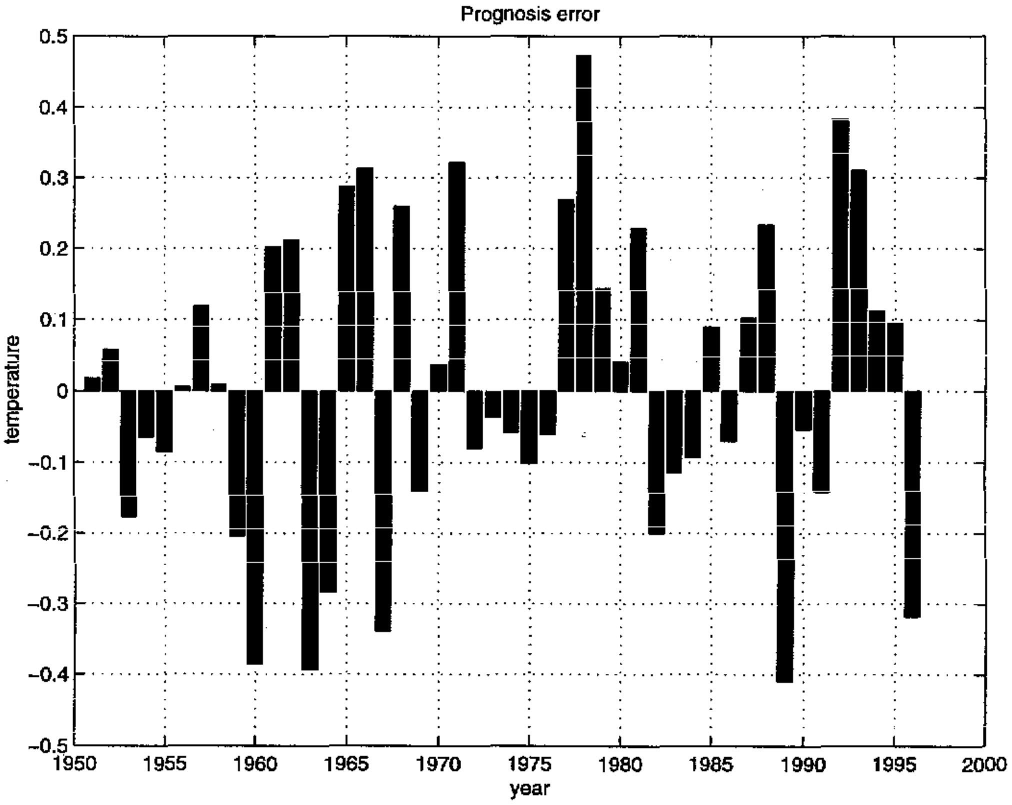
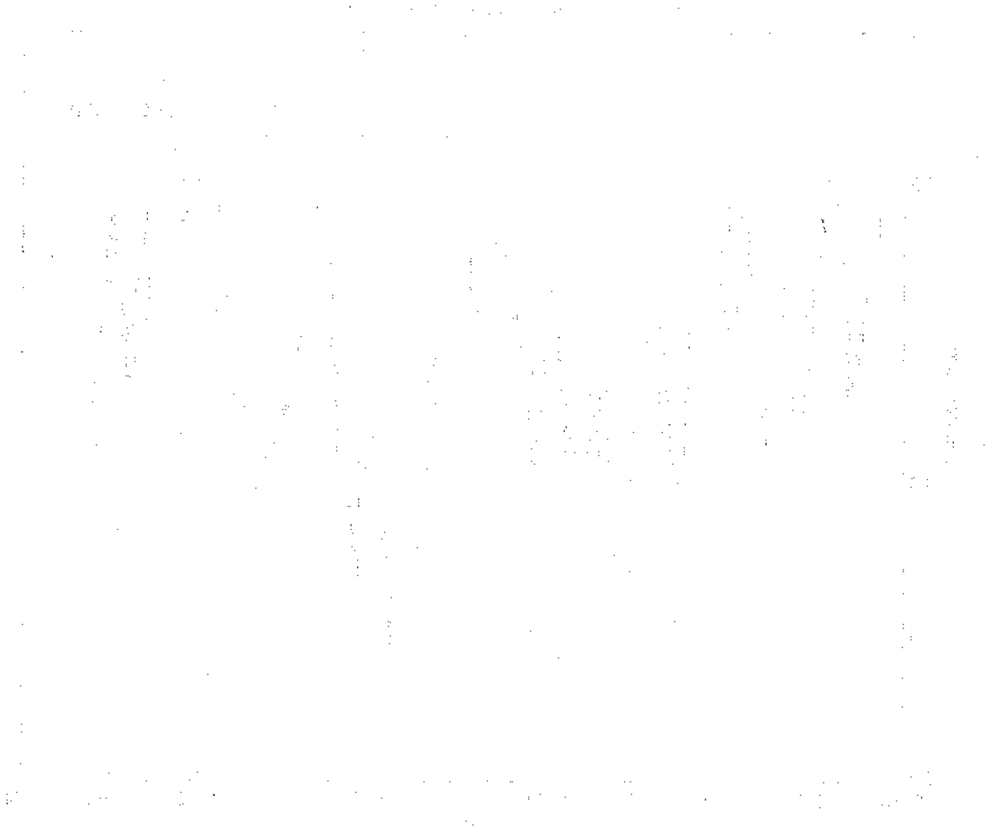
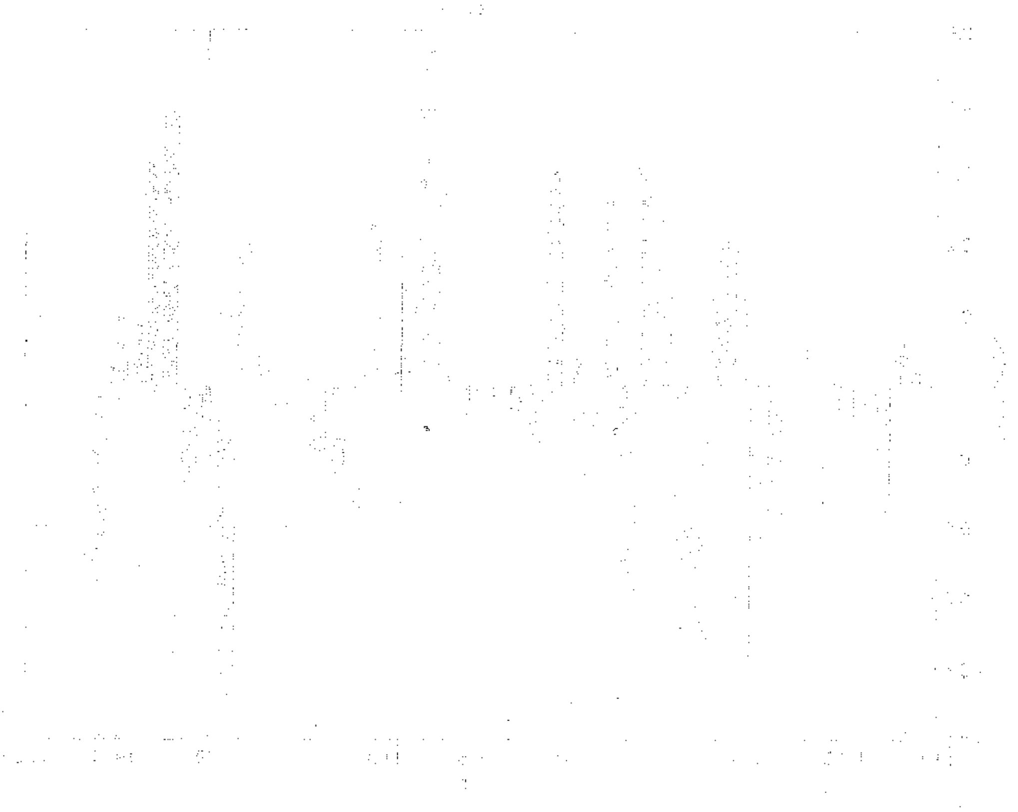


Figure 7. The performance of forecasting based on the March Kola series and the NAO Winter index.





Oceanography Committee

ICES CM 1998/C:2
Ref.: ACME

REPORT OF THE

WORKING GROUP ON SHELF SEAS OCEANOGRAPHY

Gothenburg, Sweden
16–18 March 1998

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK-1261 Copenhagen K Denmark

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1 WELCOME AND OPENING

The chairman Einar Svendsen opened the meeting and welcomed all the participants. Bjorn Sjoberg welcomed the meeting on behalf of the Swedish Meteorological and Hydrographic Institute. The list of participants is given in Appendix II.

2 APPOINTMENT OF RAPPORTEUR

Phil Gillibrand was elected as rapporteur.

3 ADOPTION OF AGENDA

Due to the absence of relevant members, the agenda was modified slightly and approved. Two extra items were added:

12. To consider a change to new units of measurement for oxygen and nutrient data.

13. To discuss a drifter experiment for calibration and evaluation of numerical models.

4 REPORTS OF NATIONAL ACTIVITIES OF SPECIFIC INTEREST TO WG MEMBERS

Roald Saetre described the preparation and publication by The Institute of Marine Research in Bergen of an annual report describing the environmental status of Norwegian waters. The report contains updates of ecosystem and climate indicators from monitoring stations in the seas surrounding Norway. There are also reports on items of interest from the particular year, for example detailing the invasion of jellyfish into several fjords which resulted in major kills of farmed salmon. The final section of the report contained a prognosis for the following year, which is based on analysis of results from monitoring stations and standard sections. So far, in the years since the first prediction for 1995, the prognosis for the ocean climate, production and fish distribution has been reasonably accurate.

Francois-Jacques Saucier described a significant amount of effort in Canada to improve ocean monitoring. A proposal is presently being considered for physical and biological monitoring on the east coast of the country. There has been a big reduction in the Canadian Arctic research programme, but some projects are now being rejuvenated. Climate research is of great importance to Canada because the Kyoto conference stipulated that the country must reduce CO_2 emissions by 20% before 2010. Regional climate models are being developed to focus results from general climate models to improve predictions of climatic events e.g. flooding. It was also noted that very long term environmental monitoring has been maintained in Hudson Bay by the Hudson Bay Company since the 17th century.

Thomas Pohlman reported on two new German projects. The first, named SYKON, is a 2.5 year project with three components: (i) to synthesise the current state of North Sea research, (ii) assess research deficiencies and (iii) to identify new challenges. A series of groups have been established to review the current knowledge of physical, biological and fisheries related oceanography of the North Sea. The project commences in May 1998. The second proposal is entitled "Low pressure systems and the Climate System in the North Atlantic" and will run for 3 years. It also has three parts: a theoretical analysis of climate systems, a modelling component (employing the North Atlantic model at the Max Planck Institute and several regional models) and a field programme. An international conference on "Coastal Ocean and semi-enclosed seas circulation and ecology, modelling and monitoring" in Moscow on 8–12 September is being organised (contact person J. Suundermann).

Einar Svendsen presented some time series showing a strong correlation between modelled transport into the northern North Sea during winter (first quarter) and landings of horse mackerel approximately half a year later. The mechanism behind the correlation was unclear, although it seemed likely that the strong transport into the North Sea would lead to warmer, nutrient- and plankton-rich water in the basin.

Pekka Alenius reported on the present status of Finnish monitoring programmes (including the Baltic Monitoring Programme). An increased use of ships of opportunity has produced projects like Algaline (Kiel - Helsinki) with the data available on the WWW. Ferry companies have provided valuable financial support to the programmes.

Didrik Danielssen presented a long (30+ years) time series of oxygen measurements from a section in the Skagerrak between Denmark and Sweden. Measurements have been made monthly and show that oxygen concentrations are relatively low at present. This is reflected in the low oxygen levels observed in the Oslofjord, where the bottom waters have not been renewed since early 1996. Oxygen consumption in the fjord is estimated to have increased by 50% since the late eighties.

Temperature measurements illustrated the warm summers and winters that have prevailed over the past two years. There was also a report of low nutrient levels in the Skagerrak and eastern North Sea during the past winter.

Martin Schmidt reported on Baltic monitoring, which consisted of three research cruises annually and two permanent stations. However, modelling studies remain event specific, rather than becoming operational.

Hans Dahlin compared the response in Sweden to the Kyoto Conference to that of Canada: in Sweden, CO2 emissions are increasing because at present they are much lower than the specified levels. He also highlighted the latest HELCOM report on the Baltic environment. The series of reports each cover approximately a 5-year period. Dahlin also reported on the present state of BOOS (Baltic Operation Oceanographic Systems), which is using modelling and observational methods to obtain required products (such as physical, chemical and biological parameters).

Bjorn Sjoberg described some modelling and measurement of the Baltic plume. Shortcomings in the modelling and remote sensing data had been identified. The models required improved meteorological forcing, finer vertical resolution and more accurate freshwater input forcing.

5 CONTINUE THE EVALUATION OF THE EFFECTIVENESS IN ENVIRONMENTAL MONITORING PROGRAMMES (WITH FOCUS ON THE NORTH SEA) IN DETERMINING TRENDS AGAINST THE BACKGROUND OF NATURAL SPACE AND TIME FLUCTUATIONS, AND THE POSSIBLE SUPPORT FROM MODELS

The absence of G. Becker, who was mainly responsible for this item, resulted in a shortened discussion. However, Einar Svendsen presented a Norwegian report on eutrophication monitoring and related some of its conclusions about sampling methods. The report's summary included some general points concerning the focus of monitoring programs and emphasised the importance of considering the possibility of detecting changes and the statistical significance of monitoring results. The report also compared the importance of monitoring standard sections, using ship of opportunity and fixed coastal stations.

A general discussion followed about the aims of monitoring and how to focus a sampling strategy. There was some debate over whether monitoring should be justified as part of programs with wider aims or whether it is justified *per se*. It was decided that selected items from the Norwegian report would be adopted as recommendations (Ottersen et al., 1998. "Utarbeidelse av et program for overvåkning av eutrofitilstand og -utvikling i norske kystfarvann basert på både tradisjonelle og høyteknologiske metoder". Fisken og Havet nr.1 - 1998):

1) A main aim for a monitoring program is to detect a slowly developing trend against a background of large natural variations. The statistical basis for allowing a sound answer to this requires at minimum the answer to the following two questions: a) What size of changes in concentration is it important to be able to detect? b) Which probability level is wanted for the conclusion to be right?

2) For most parameters it is difficult to estimate realistic changes in yearly means based on traditional observations. This suggests that a year to year comparison should be made on a seasonal basis, for instance for those seasons when the variability is low compared to the mean value. This indicates that a uniform observation frequency throughout the year for all variables is not advisable.

3) Cruises with good spatial coverage is the form of surveillance giving the most thorough information for a given area and time. This kind of data gathering is most important for characterisation of water masses and spatial distribution. The spatial information from such cruises could be enhanced further by co-ordinating with other methods. Numerical models could be initialised with fields interpolated from cruise data and results from models used to evaluate the degree of representability of measurements from fixed stations.

4) The main purpose of fixed sections is to monitor large scale variability. Station spacing of about 10 km near shore and in frontal regions, and 20–30 km in more homogeneous water seems to be adequate for resolving most of the spatial variance.

5) Measurements from ships of opportunity are a reasonable and effective method for the gathering of many different kinds of data from the marine environment, but the potential of the method is at present far from fully utilised.

6) Fixed coastal stations play a central part in most monitoring programs, and long historical time series exist. It is therefore natural to build future monitoring programs around such stations. Choice of variables, position and number of stations, depths and frequency of observations are important. In the upper layers (such as in the Skagerrak), measuring once a week is recommended to include most of the variance, while further down measurements 1–2 times per months seems suitable. Reducing the number of stations to allow for higher intensity at some selected locations must be considered.

7) Several of the most important environmental parameters have a significant part of their (near surface) variability at frequencies so high that they in practice can not be captured by traditional measurement methods. Automatic buoys can register most of the total variability, however, like fixed stations, the great spatial variability perpendicular to the dominating current pattern, even at short distances, leads to the measurements from single buoys being relevant only for small areas. With the cost of some of today's buoys, they are recommended for monitoring in straits, some fjords and otherwise in situations where single buoys are adequate. To cover larger, more open areas, the use of buoys must be combined with other methods.

8) Satellites are able to give information about the sea surface with a relative high resolution both in space and time. For many years, ocean currents has been estimated from satellite monitoring of the sea surface topography (using altimeter), and wind speed and wave height estimated from the same instrument are regularly used in weather forecasting. Sea surface temperature is the most commonly used remotely sensed parameter, and the sea ice distribution has also been monitored for many years. Even accounting for shortcomings related to cloudiness and low solar altitude (just a restriction for some of the parameters) the remote sensing method has a potential beyond that which is utilised in the current surveillance programs. The potential within coastal monitoring has lately been significantly enhanced by the introduction of the SeaWiFS sensor on one of the NASA satellites. Further advancement follows in the near future when the MERIS is launched and later the ENVISAT. To utilise the large amount of information from satellites it is necessary for some of the parameters to move beyond the usual pictures and make the information available as reliable statistical material.

9) Three dimensional circulation models, some coupled with a chemical-biological component, can give a valuable contribution to surveillance programs. Still such models need refinements and to be properly validated, and so far chemical-biological models are not much used in operational monitoring programs. An important property of models is that they can be used to separate between anthropogenic and natural variability, and that probable effects of future management measures can be simulated.

10) The perhaps least costly area for enhancement relates to the methods currently used for analysing sampled data. Many of the data series are under sampled compared to what is necessary to catch most of the variability. Methods taking this aspect into consideration are presently seldom used.

11) The great differences regarding strength and weaknesses of monitoring programs indicates that a lot can be gained by utilising the best of several methods by a close co-ordination. Numerical models should to a larger degree be used to put scattered data into a spatially and temporally continuous context. The large amount of data from satellites can be made more reliable and valuable by linking them to data from research vessels, ships of opportunity and automatic buoys.

6 CONTINUE TO SUMMARISE THE ROLE OF FLUCTUATIONS IN FRESHWATER INFLOW TO THE MARINE ENVIRONMENT, AND REVIEW THE OUTCOME OF THE THEME SESSION IN THE 1997 ANNUAL SCIENCE CONFERENCE

Again, the absence of T. Osborn who was mainly responsible for this topic, led to a shortened discussion. The group was reminded that the role of freshwater fluctuations had been raised in connection with the occurrence of harmful algal blooms. It was generally agreed that shelf seas oceanography is important to the formation, spread (dispersion) and transport of blooms, but without any expertise in the biological aspects the group felt unable to do justice to the topic.

Instead, Francois Saucier gave a presentation of a field and modelling study of St. Lawrence Estuary. A three-dimensional nested baroclinic model has been developed of the estuary. It is run operationally on a daily basis, using weather forecasts as forcing. The modelling has been calibrated against approximately 50 current meter deployment records and 2000 drifter releases. The model illustrates the freshwater outflow from the estuary, the balance between the freshwater and tidal flows and many other aspects of the oceanography of the estuary.

7 REVIEW THE PROGRESS OF ICES-RELEVANT PRODUCTS ON THE WWW

After some discussion, it became clear that the exact meaning of the topic had been misunderstood by several members of the group, who had looked at only the ICES home page rather than looking for any pages that might be of interest to ICES.

Hans Dahlin suggested that a role model for ICES might be the Swedish Environmental Network, which consists of a homepage with links to relevant pages at all Swedish Institutes. Since several ICES institutes already make data available on the WWW, it may be sufficient for an ICES homepage to establish links to relevant institute pages. It was suggested that the group could recommend to ACME exactly what data products should be included in an ICES "environmental report" web page.

Bjorn Sjoberg suggested that ICES could have a list of the grey literature produced by ICES institutes (e.g. annual environmental reports, eutrophication surveillance reports etc.) could be listed and possibly linked.

8 REVIEW THE CURRENT AND FUTURE APPLICATIONS OF REMOTE SENSING IN SHELF SEAS STUDIES

Because J. Johannessen, an invited guest from the European Space Agency, was unable to attend, this topic was not discussed.

9 CONTINUE THE SENSITIVITY STUDIES OF OPEN BOUNDARIES

Thomas Pohlmann presented results from some sensitivity analysis with the Hamburg North Sea Model. Five numerical experiments had been performed, investigating the impact of changes in boundary salinity on internal conditions in the North Sea. Four simulations, each raising or lowering the boundary salinity at the northern or southern boundary of the model by 1 psu, were compared to a baseline simulation. Each simulation ran for one year with the modified boundary salinity. Time series of salinity from various locations in the North Sea were presented.

The change of +/- 1 psu at the northern boundary propagated into the central North Sea within about 4 months and after 12 months the difference from the baseline was about 0.5 psu. In the German Bight, the changes had less impact, but in the Skagerrak the salinity change was amplified to +/- 5 psu. This was thought to be due to the imbalance between the barotropic and baroclinic forces brought about by the simple boundary modification. Changes to the southern boundary (in the English Channel) had less impact through the general North Sea region, although the difference from the baseline in the southern North Sea (Dover Strait to German Bight) was greater than that caused by the northern boundary. In the German Bight, salinities were modified by about 10% of the boundary effect.

Pohlmann also presented mean velocity difference fields throughout the North Sea between the baseline simulation and a simulation with a salinity change at the northern boundary. In the central and southern North Sea, velocity differences were small. However, in the Skagerrak and northern North Sea, differences were much more significant, in the order of tens of centimetres per second.

Einar Svendsen presented results from the NORWECOM model with a change to salinity of -1 at the open boundary. This model showed much weaker impact on salinities and velocities than the Hamburg model. He suggested that the flow relaxation method applied at the open boundary helped modify the impact of boundary salinity changes.

Following these presentations, there was a general discussion about the sensitivity analyses, and in particular about how the barotropic and baroclinic forcing was modified by the purely baroclinic boundary changes. It seemed likely that at least some of the differences predicted by the simulations were the result of the model re-establishing the equilibrium between barotropic and baroclinic forcing. However, it was also clear that the North Sea is sensitive to its boundaries (at least in terms of salinity) and that a regular sampling strategy at the boundaries would be beneficial to model performances. There was some discussion of possible sampling strategies, including ships of opportunity and fixed buoys. Harry Dooley suggested that more should be attempted with the existing North Sea dataset and the models before embarking on a programme of observations. It was also suggested that GOOS may provide a means of providing salinities at various locations on a regular basis, and these data could then be available for modellers to exploit.

10 COMPILE A COMPLETE SET OF TIME SERIES IN THE SKAGERRAK AREA TO ILLUSTRATE THE USEFULNESS OF THE SAME

Harry Dooley commenced by noting that about 25% of Skagerrak data had been collected during Skagex. He also pointed out that care must be taken when examining the data for trends; there were significant differences between data collected by Swedish institutes and other nations. Harry had collated and distributed Skagerrak times series and there was a general discussion about some of the features in the T, S and nutrient time series presented. In general it was felt that trends were very unclear whereas particular events, such as the cold winters in the sixties and mild winters in the late eighties and nineties, were more noticeable.

Didrik Danielssen presented some long time series (1960–1997) of parameters in the Skagerrak which revealed long periods (i.e. several years) of gradual warming of bottom water interspersed with rapid reductions in temperature. These were interpreted as periods of deep water renewal, while the downward vertical transport of heat was due only to diffusion separated by cascades of colder, denser water.

Einar Svendsen then presented plots showing a correlation between the NAO Index and the surface location of the 35 psu isohaline in the Norwegian Sea. He also presented a time series of the cubed wind speed from Utsira, which shows an increasing trend since the 1960's. Model results (with realistic wind forcing) suggest a very clear relationship between inflow of Atlantic Water to the northern North Sea during the first quarter of the year and horse mackerel catches about half a year later.

There followed a general discussion about other data time series and suggestions as to how to make best use of them. For example, the collation of such time series could allow investigation of particular events, such as the gadoid outburst in the sixties.

Francois Saucier emphasised that it was important to establish mechanisms between the NAO and observed time series if hindcasting and forecasting were to be improved. Simply finding correlations was not sufficient, although it is the first step in identifying relationships.

Finally, it was proposed to gather together all the available long time series in digital format, which could then be made available for distribution on CD-ROM.

11 CONTINUE TO COMPILE INFORMATION ON LONG TIME SERIES IN THE ICES AREA

Harry Dooley presented an inventory of long (> 20 years) time series which he had collated from ICES and other sources (Appendix VI). The inventory had increased slightly from the version presented the previous year (an additional source from the NCAR Climate and Global Dynamics Division) and was to remain available on the groups web page, possibly with links established. It was agreed that other time series known to members of the WG would be forwarded to ICES. Dooley also suggested he may modify the format of the report to improve its accessibility. The meeting recognised the value of Dooley's work.

12 ASSIST THE CONVENOR OF THE FOURTH BACKWARD FACING WORKSHOP (1999) ON THE 1960S AND 1970S ANOMALIES IN THE NORTH SEA IN PREPARING HINDCAST OF DATA ON THE PHYSICAL ENVIRONMENT DURING THIS PERIOD

The meeting decided that the first step in achieving this goal was to collate time series of relevant physical parameters, the aim being to explain large shifts in the North Sea ecosystem. Time series to be included should be at least 20 years long, have a sampling resolution of at least one year and should be presented with a maximum resolution of one month. The list of parameters to be compiled and the person/institute responsible for each is presented in Appendix V. These data should be prepared by the end of 1998.

13 CONSIDER FUTURE WORK PROGRAMME IN RELATION TO REMIT OF OCEANOGRAPHY COMMITTEE AND THE NEED FOR AN ICES FIVE-YEAR PLAN, INCLUDING CO-OPERATION WITH OTHER WORKING GROUPS

Einar Svendsen introduced this topic by relating the letter from Harald Loeng to the chairmen of all the working groups which mentioned two suggested themes for the Oceanography Committee to address. These were (I) climate variability and its effect on the ecosystem and (ii) transport of contaminants in the ocean and in the foodweb and what are the consequences for the foodweb.

There followed a discussion over whether (ii) clashed with the remit of other environment agencies and commissions (e.g. OSPARCOM), and whether it was a suitable topic for ICES. It was felt that the topic opened up the possibility of further developing coupled hydrodynamic-ecosystem numerical models and integrating them and other ecological aspects into fisheries management on a more routine basis.

There was general acceptance about a theme of climate variability and ecosystem impact. There was a suggestion that climate variability should be broken down into three components: climate detection, climate prediction and climate effect.

With the general support of the proposed themes, the meeting discussed the future of the Working Group on Shelf Seas Oceanography and working groups in general. There were suggestions for an "ecological group" with a strong emphasis on ecological numerical model development and use, but there were fears that this would slowly metamorphose into a physical modellers group. More acceptable suggestions were for two new working groups: (I) climate and climate effects, (ii) ecosystem processes and modelling. For the time being, however, until the ICES Five-Year Plan is settled and adopted, the meeting decided the group should continue as it is.

The ideas discussed were summarised by Roald Saetre as follows:

(I) Ocean Climate Variability - causes, effects and prediction

- monitoring; strategies and methods
- dynamic and statistical models
- limits of predictability
- teleconnections
- effects of recruitment, growth and distribution of fish stocks
- operational oceanography on non-meteorological (seasonal) time scales

(ii) Ecosystem Dynamics

- process/system studies
- ecological classification quality objectives and measures
- environmental data and knowledge into fish stock assessment
- ecological coupled models
- ecosystems as unit for management
- integration of fishery and environmental management
- transport and fate of contaminants

14 COMMENT ON THE 1997 ACME STATEMENT CONCERNING THE DEVELOPMENT OF GOOS INITIATIVES IN ICES

This topic was introduced by Roald Saetre who had formulated four possible alternatives for ICES involvement in GOOS. In brief, the four options were as follows:

(i) "Business as usual" i.e. involvement of ICES on all GOOS fora, but no specific ICES activity.

(ii) Establish an official GOOS pilot project within the ICES area, with ICES taken an advisory and service role for the regional GOOS component e.g. data management, quality assurance.

(iii) ICES take responsibility to establish and run a centre for operational fisheries oceanography on a time scale of fish stock assessments (i.e. months) for the whole North Atlantic or a part thereof.

(iv) ICES establish a centre for operational fisheries oceanography on time scales of days to years.

After some discussion, Sartre's personal choice of (iii) was generally favoured. It was suggested in the document that a pilot project area be chosen and the North Sea was duly selected by the group. There was some discussion between the relative merits of the North Sea and the Baltic, but the North Sea has more surrounding active participants and much suitable data are already available. Bjorn Sjoberg suggested that choosing the North Sea would require more resources than the Baltic and also noted that GOOS was missing fishery data which ICES is ideally placed to provide. However, the general feeling was that choosing the North Sea would complement GOOS, and that much could be learned from the Baltic experience.

It was suggested that the eventual aim should be to establish operational oceanography throughout the ICES area (including Canada). A similar collation of North Sea time series as that planned for the Skagerrak (Agenda Item 6) would form the basis of a useful operational dataset provided it was regularly updated as new data became available.

Hans Dahlin presented details of an operational model of the Baltic Sea which predicts (in real time) sea level, currents, ice cover and other parameters. The model is used to forecast given parameters based on predicted atmospheric forcing, and is run daily for the subsequent 24-hour period. Results from the model have been used in search-and-rescue operations.

15 SAMOA/OSPARCOM QUALITY STATUS REPORTS

Einar Svendsen introduced this topic by stating that he was responsible for producing the physical oceanography component of the next North Sea CSR. He wished to include more results from numerical models than has been done in the past, such as time series of transport and other parameters. There were suggestions that it was now important to raise the issues of variability in the ocean rather than concentrate on climatological mean conditions.

16 NUTRIENT/OXYGEN STANDARD UNITS AND USE OF DATA

In a letter from the chairman of the ICES Working Group on Marine Chemistry, the meeting was requested to consider a suggestion that nutrient and oxygen data should be submitted to ICES in terms of mass rather than volume i.e. units would change from $\mu M\ l^{-1}$ to $\mu M\ kg^{-1}$. The reason for this change stems from the adoption by WOCE of the mass-based units. In turn, WOCE have adopted the units for analytical reasons, because the procedure that samples be analysed at 20^0 C (giving a standard sample volume) is not strictly adhered to by institutes. Hence WOCE sees units of $\mu M\ kg^{-1}$ as more reliable and consistent. After some discussion, the meeting decided simply to note the conclusions of WGMC and refer to UNESCO standards at present (which require analysis to be carried out at 20^0 C).

The second part of the request from WGMC concerned the use (and "misuse") of marine chemistry data, in particular the need for spatial and temporal resolution of sampling and the accuracy of analysis. In response, the group agreed that sampling strategy is driven by the requirements of a particular field/monitoring programme and could not be predetermined. In terms of accuracy, it was suggested that WGMC should be asked to provide estimates of accuracy of marine chemistry data, and to demonstrate specific examples of how such data may have been "misused".

17 NORTH SEA DRIFTER EXPERIMENT

Einar Svendsen raised this subject as a possible collaborative exercise between member institutes, with the aim of evaluating the performances of various North Sea models. Given sufficient interest, he plans to submit a proposal for funding to the Nordic Council of Ministers to equip and deploy a number of drifting buoys in the central and southern North Sea. The experiment should last for about 3–6 months, possibly starting early in 1999, and involve about 30 drifters. The results could then be compared to predictions or hindcasts from numerical models in order to evaluate them.

There was general support for the proposal among members and Svendsen agreed to submit a proposal to the Council by May. It was emphasised that the models should be run as normal, and not tuned specifically to improve results from the comparative exercise.

18 ANY OTHER BUSINESS

Einar Svendsen resigned his position as chairman of the working group. Bjorn Sjoberg was elected as the next chairman.

19 PLACE, DATE AND TOPICS FOR NEXT MEETING

It was suggested that a standing invitation was in place for the WG to visit BSH at Hamburg and this was accepted (subject to agreement from G. Becker). The meeting will take place during 15–17 March 1999.

The topics will be:

1. Commence the synthesis of available time series related to the Skagerrak ecosystem variability. (responsibility all)

2. Prepare input to the Fourth Backward Facing Workshop.(resp. all, within 1998)

3. Summarise and review the outcome of the theme session on skill assessment of environmental modelling. (main resp E. Svendsen/B. Sjoberg)

4. Continue the evaluation of the effectiveness in environmental monitoring programmes (with focus on the North Sea) in determining trends against the background of natural space and time fluctuations, and the possible support from models. (main resp. G. Becker)

5. Review the current and future applications of remote sensing in shelf sea studies. (invited guest ?)

6. Review the progress of the North Sea drifter experiment and agree a protocol for evaluating model performances. (main resp. E. Svendsen)

7. Examine the effects on the coastal zone of regulating freshwater runoff (with focus on the Baltic) and the effects of long-term shifts in runoff patterns. (main resp. F. Saucier)

8. Improve estimates of transit times along the Scottish west coast and around the North Sea. (main resp J. Brown)

9. Extend the sensitivity studies of open boundary conditions on model performance. (resp. T. Pohlmann)

The terms of reference and justification for these agenda items are at Appendix I.

20 CLOSING

The meeting closed at 1230 18 March 1998.

APPENDIX

I – RECOMMENDATIONS AND JUSTIFICATIONS

The Oceanography Committee recommends that:

The Working Group on Shelf Seas Oceanography (Chairman Bjorn Sjoberg, Sweden) will meet in Hamburg, Germany from 15–17 March 1999 to:

1. Commence the synthesis of available time series related to the Skagerrak ecosystem variability.
2. Prepare input to the Fourth Backward Facing Workshop.
3. Summarise and review the outcome of the theme session on skill assessment of environmental modelling.
4. Continue the evaluation of the effectiveness in environmental monitoring programmes (with focus on the North Sea) in determining trends against the background of natural space and time fluctuations, and the possible support from models.
5. Review the current and future applications of remote sensing in shelf sea studies.
6. Review the progress of the North Sea drifter experiment and agree a protocol for evaluating model performances.
7. Examine the effects on the coastal zone of regulating freshwater runoff (with focus on the Baltic) and the effects of long-term shifts in runoff patterns.
8. Improve estimates of transit times along the Scottish west coast and around the North Sea.
9. Extend the sensitivity studies of open boundary conditions on model performance.

Justification

1. The previous meeting (this report) prepared a list of parameters related to the Skagerrak which could be compiled to provide a meaningful and useful dataset to investigate ecosystem variability in the region. These data must now be brought together to form a coherent set in a regular format that could be made widely available.

2. The Fourth Backward Facing Workshop takes place during 1999. In order to investigate past anomalies in the North Sea during the 60s and 70s, long time series of relevant parameters covering the period in question are required. A list of suitable available parameters has been drawn up and must be collated into a coherent dataset in preparation for the workshop.

3. A theme session at the ICES Annual Science Conference 1998 was "Skill Assessment of Environmental Modelling". The meeting should summarise the methods of skill assessment that were described at the conference and review the statistical accuracy and reliability of the methods and examine the applicability of the methods to various models.

4. During a discussion on the Baltic Monitoring Program at the WG in 1997, some clear criticism were raised especially with respect to under sampling, weak objectives and general status. Changes in strategy are underway, but before firm conclusions on the general functioning of monitoring programs, the WG wants at least to review the monitoring in the North Sea. Some ongoing monitoring programs have problems with funding and some are heavily criticised. Therefore it is important to evaluate the effectiveness of individual environmental monitoring programs in determining possible trends against the natural variability. Since Bundesamt fur Seeschiffahrt und Hydrographie is responsible for the production of the MURSYS environmental status report for the North Sea and the Baltic, we suggest Dr. G. Becker presents the monitoring behind this to see what general conclusions can be drawn.

5. The basic marine research tools today are observations from ships and fixed (or drifting) platforms/buoys, remote sensing from satellites (and aircraft), numerical modelling and laboratory/mesocosm experiments. The WG therefore feels the need to be updated on the current and future application of remote sensing in shelf areas and will invite an expert in the field to present the topic.

6. At the previous meeting (this report), it was agreed to conduct a drifter experiment in the southern North Sea (subject to funding being forthcoming). The experiment was planned to commence in February, so during the present meeting it should be underway. The meeting should assess the progress of the experiment to date and modify or confirm future plans as required. In addition, the meeting should discuss and agree on a protocol for evaluating the performance of the numerical models which will attempt to simulate the field results.

7. Freshwater runoff plays a vital role in the dynamics of the coastal zone. The regulation of freshwater discharge for hydroelectric schemes is increasing and the impact of such schemes on coastal zone dynamics and ecosystems is presently unknown. On longer time scales, climate change may lead to shifts in runoff patterns with similarly unknown effects on coastal waters.

8. Estimates of transit times from the Irish Sea into the North Sea are still based on tracer experiments and modelling studies (simulated under climatological mean conditions) conducted in the late seventies and early eighties. Recent pulsed discharges into the Irish Sea have been traced round the shelf sea as far as the Norwegian coast and should allow for improved estimates of transit times to and around the North Sea. Recent current meter deployments on the Scottish west coast shelf may confirm estimates of transport rates.

9. Open boundary conditions are a crucial point for numerical models, especially those seeking to simulate nature. Since the North Atlantic exhibits strong variability on different scales, a study on how these variabilities influence the shelf seas and to what extent these variabilities have to be included in the boundary conditions is necessary. A preliminary study has been conducted, but it is proposed to extend the study to increase the realism of the changes to the boundary conditions i.e. to balance the barotropic and baroclinic forces at the boundary.

APPENDIX II – LIST OF PARTICIPANTS

Name and address	E-mail address	Telephone and Telefax
Alenius Pekka Finnish Institute of Marine Research P.O. Box 33 Fin-00931 Helsinki Finland	alenius@fimr.fi	tel#(op) tel#(dir)+358 9613941 fax#+358 961394494
Aure Jan Institute of Marine Research P.O. Box 1870 Nordnes 5024 Bergen Norway	jan.aure@imr.no	tel#+47 55238485 fax#+47 55238584
Brown Juan EG CEFAS	J.BROWN@cefas.co.uk	tel#(op) tel#(dir) fax#
Dahlin Hans SMHI S-601 76 Norrköping Sweden	hdahlin@smhi.se	tel# (op) +46 11 495 8000 tel#(dir)+46 11 495 8305 fax# +46 11 495 8001
Danielssen Didrik Institute of Marine Research 4817 His, Arendal Norway	didrik.danielssen@imr.nor	tel#(op)+47 37059000 tel#(dir) fax#+47 37059001
Dooley Harry ICES	harry@ices.dk	tel#(op)+45 33154225 tel#(dir)+45 33152677 - 210 fax#+45 33934215
Gillibrand Phil Fisheries Research Services Marine Laboratory PO Box 101 Victoria Road Aberdeen AB11 9DB	gillibrandp@marlab.ac.uk	tel#(op)+44 (0)1224 876544 tel#(dir)+44 (0)1224 295313 fax#+44 (0)1224 295511
Pohlmann Thomas Institut fuer Meereskunde Universitaet Hamburg Troplowitzstrasse 7 D-22529 Hamburg	pohlmann@ifm.uni-hamburg.de	tel#(op) tel#(dir)+49 (40) 4123 3547 fax#+49 (40) 560 5926
Saucier Francois-Jacques Dep of Fisheries & Oceans Inst Maurice-Lamontange 850 route de la Mer C.P. 1000 Mon-Joli, Quebec G5H 3Z4 Canada	saucierf@dfo-mpo.gc.ca	tel#(op) tel#(dir)+1 418 775 08 53 fax#+1 418 775 05 42

Name and address	**E-mail address**	**Telephone and Telefax**
Sætre Roald Institute of Marine Research P.O. Box 1870 Nordnes 5024 Bergen Norway	roald.saetre@imr.no	tel#(op)+47 55238500 tel#(dir)+47 55238602 fax#+47 55238584
Schmidt Martin Baltic Sea Res. Inst. Seestraβe 15 D-18 119 Rostock Germany	martin.schmidt@io-warnemuende.de	tel#(op) tel#(dir)+49 381 5197 121 fax#+49 381 5197 400
Sjöberg Björn SMHI Göteborg S-426 71 Västra Frölunda Sweden	bsjoberg@smhi.se	tel#(op)+46 11 495 8000 tel#(dir)+46 31 751 8960 fax#+46 31 751 8980
Svendsen Einar Institute of Marine Research P.O. Box 1870 Nordnes 5024 Bergen Norway	einar@imr.nor	tel#(op)+47 55238500 tel#(dir)+47 55238458 fax#+47 55238584

APPENDIX IIIA - AGENDA (1998)

i) Welcome and opening (Monday 10 March, 0900 am)
ii) Appointment of rapporteur
iii) Approval of the agenda
iv) Reports on national activities of specific interest to WG members

1. continue the evaluation of the effectiveness in environmental monitoring programmes (with focus on the North Sea) in determining trends against the background of natural space and time fluctuations, and the poss. support from models. (Becker)

2. continue to summarise the role of fluctuations in freshwater inflow to the marine environment, and review the outcome of the theme session in the 1997 Annual Science Conference. (main resp. T. Osborn)

3. review the progress of ICES-relevant products on the WWW. (resp. all)

4. review the current and future applications of remote sensing in Shelf Seas studies. (J. Johannessen from ESA is invited)

5. continue the sensitivity studies of open boundaries (resp. Pohlman/Svendsen)

6. compile a complete set of time series in the Skagerrak area as to illustrate the usefulness of the same. (main resp. D. Danielssen/ H. Dooley)

7. continue to compile information on long time series in the ICES area. (Dooley)

8. assist the Convenor of the Fourth Backward Facing Workshop (1999) on the 1960s and 1970s anomalies in the North Sea in preparing hindcast of data on the physical environment during this period. (main resp. E. Svendsen)

9. consider future work programme in relation to remit of Oceanography Committee and the need for an ICES Five-Year Plan, including co-operation with other Working Groups. (resp. all)

10. comment on the 1997 ACME statement (Agenda Item 21.3) concerning the development of GOOS initiatives in ICES (resp. H. Dahlin ? / R. Sætre)

11. If time permits, I will also have a discussion on input to the new ASMO/OSPARCOM Quality Status Reports to be written.

12. Nutrient/Oxygen standard units and use of data

v) Any other business (election of new chairman etc.)
vi) Place, date and topics for the next meeting
vii) Closing of the meeting (Wednesday 12 March, 1600)
As we suggested last year, a theme session for ASC-1998 will be:

"Skill assessment of Environmental Modelling"
Convenor Einar Svendsen, Co-convener Björn Sjöberg

We should also decide if we want to keep our suggested theme session for ASC-1999 (together with WGCC and WGOH) on "Long time series".

APPENDIX IV – TERMS OF REFERENCE AND JUSTIFICATIONS (1998)

The Working Group on Shelf Seas Oceanography [WGSSO] (chairman: Einar Svendsen, Norway) will meet in Gothenburg, Sweden from 16–18 March 1998 to:

1. continue the evaluation of the effectiveness in environmental monitoring programmes (with focus on the North Sea) in determining trends against the background of natural space and time fluctuations, and the possible support from models. (main resp. G. Becker)
2. continue to summarise the role of fluctuations in freshwater inflow to the marine environment, and review the outcome of the theme session in the 1997 Annual Science Conference. (main resp. T. Osborn)
3. review the progress of ICES-relevant products on the WWW. (resp. all)
4. review the current and future applications of remote sensing in Shelf Seas studies. (J. Johannessen from ESA is invited)
5. continue the sensitivity studies of open boundaries (main resp. T. Pohlman/E. Svendsen)
6. compile a complete set of time series in the Skagerrak area as to illustrate the usefulness of the same. (main resp. D. Danielssen/ H. Dooley)
7. continue to compile information on long time series in the ICES area. (resp. H. Dooley)
8. assist the Convenor of the Fourth Backward Facing Workshop (1999) on the 1960s and 1970s anomalies in the North Sea in preparing hindcast of data on the physical environment during this period. (main resp. E. Svendsen)
9. consider future work programme in relation to remit of Oceanography Committee and the need for an ICES Five-Year Plan, including co-operation with other Working Groups. (resp. all)
10. comment on the 1997 ACME statement (Agenda Item 21.3) concerning the development of GOOS initiatives in ICES (resp. H. Dahlin ? / R. Sætre ?)

As we suggested last year, a theme session for ASC-1998 will be

"Skill assessment of Environmental Modelling"

Convenor Einar Svendsen, Co-convener Björn Sjöberg

We should also decide if we want to keep our suggested theme session for ASC-1999 (together with WGCC and WGOH) on "Long time series"

Justification

1. From last meeting discussion on the Baltic Monitoring Program, some clear criticism were raised especially with respect to under sampling, weak objectives and general status. Changes in strategy are underway, but before firm conclusions on the general functioning of monitoring programs, the WG wants at least also to review the monitoring in the North Sea. Some ongoing monitoring programs have problems with funding and some are heavily criticised. Therefore it is important to evaluate the effectiveness of individual environmental monitoring programs in determining possible trends against the natural variability. Since Bundesamt fur Seeschiffahrt und Hyrographie is responsible for the production of the MURSYS environmental status report for the North Sea and the Baltic, we suggest Dr. G. Becker to present the monitoring behind this to see what general conclusions can be drawn.
2. The frontal dynamics and variability of coastal plumes and processes over very sharp pycnoclines typical for estuaries are generally not resolved by standard measurement programs and large scale numerical models. Estuaries and coastal zones are also areas where harmful algal blooms occur, thus it is important to increase our knowledge on how these finer scale processes influence the environment and how this influence varies with varying amounts of freshwater input.

3. In the ACME discussion on the feasibility of an ICES Environmental Status Report, it was concluded that relevant oceanographic and environmental information should be readily available to potential users (including fisheries biologists) in a timely way, and this could best be achieved by making use of WWW capabilities. ACME also noted that electronic dissemination of data is quicker and more economical than the production of a printed report. Products to be put on the web pages were clearly suggested on the last WG meeting.

4. The basic marine research tools today are observations from ships and fixed (or drifting) platforms/buoys, remote sensing from satellites (and aircraft), numerical modelling, and laboratory/ mesocosm experiments The WG therefore feel the need to be updated on the current and future application of remote sensing in shelf areas and will invite an expert in the field to present the topic.

5. Open boundary conditions are a crucial point for numerical models, especially those claiming to simulate nature. Since the North Atlantic exhibits strong variability on different scales, a study on how these variabilities influence the shelf seas and to what extent these variabilities have to be included in the boundary conditions is necessary. Due to the severe results presented in the last meeting, modellers are urged to make similar studies to check the sensitivity in different model set-ups. This study can also give advice for the configuration of monitoring stations that are able to provide the necessary boundary data.

6. A first overview of long time-series have been collated, and it was decided as an example to compile a complete set of oceanographical, meteorological and fisheries data (+ model results) for the Skagerrak (in many ways also representing much of the North Sea) to see the usefulness of such integrated information.

7. From the first compilation of available time-series, it was suggested to include not only measurements, but also indexes (e.g. the NAO) and info on how to get the data. In order to predict possible changes in regional seas due to climate change, the understanding of large scale long-term climate variability and its affects to the physical, chemical, biological and geological system of shelf seas are of fundamental interest. The answers to questions arising in this context (see report from 1996) are of fundamental importance to management activities, as well as to sustainable development. The understanding of interannual and interdecadal variability and the functioning of the system is a great challenge in marine science and important for human society living in coastal areas.

The justification for the theme sessions was:

The need for better quantified knowledge (within reasonable costs) of the marine environment has strengthened the need for numerical simulations. Results from such simulations are increasingly being used by management. So far there is a grate lack of evaluation, or "quality assurance" of model results claiming to reproduce nature.

Numerical models can also be used for estimating the typical scales and magnitude of natural environmental variability, which is a crucial factor to know for evaluating ongoing or planned monitoring activities. Therefor we suggest a theme session on this topic for the ASC 1998.

For the reasons stated under 7) above, a theme session on the use of long time series for ecological and climatological research is suggested for the ASC 1999.

APPENDIX V – LIST OF TIME SERIES PARAMETERS TO BE COLLATED FOR THE FOURTH BACKWARD FACING WORKSHOP

A list of long time series parameters to be collated (and those responsible for preparation) for the Fourth Backward Facing Workshop, 1999.

Modelled Time Series(Pohlmann/Svendsen)

Modelled monthly volume transports
Turbulent kinetic energy in mixed layer
Mixed layer temperature, salinity and thickness
Freshwater content

Observed Time Series

River Flows (Baltic, SMHI; Glomana, IMR; Gota, SMHI)
Cloud cover (SMHI)
Wind data (wind cubed + E & N stress) at outer Skagerrak (Svendsen)
Air temperature, humidity, ice index at Vinga (SMHI)
NAO + local pressure index (SMHI)
SST at Toringen (Svendsen)
Skagerrak S, T, O_2 at 600 m (Danielssen)
Sea level at Hanstrom (?) and Mandal (Saetre)
Atlantic inflow (approx 200 m) (Danielssen)
Deep nutrients (Dooley)
Benthos (SMHI)
Fish, shrimp, herring, cod (ICES/SMHI)
CPR (Brown)
JONSIS temperature and salinity (Gillibrand)

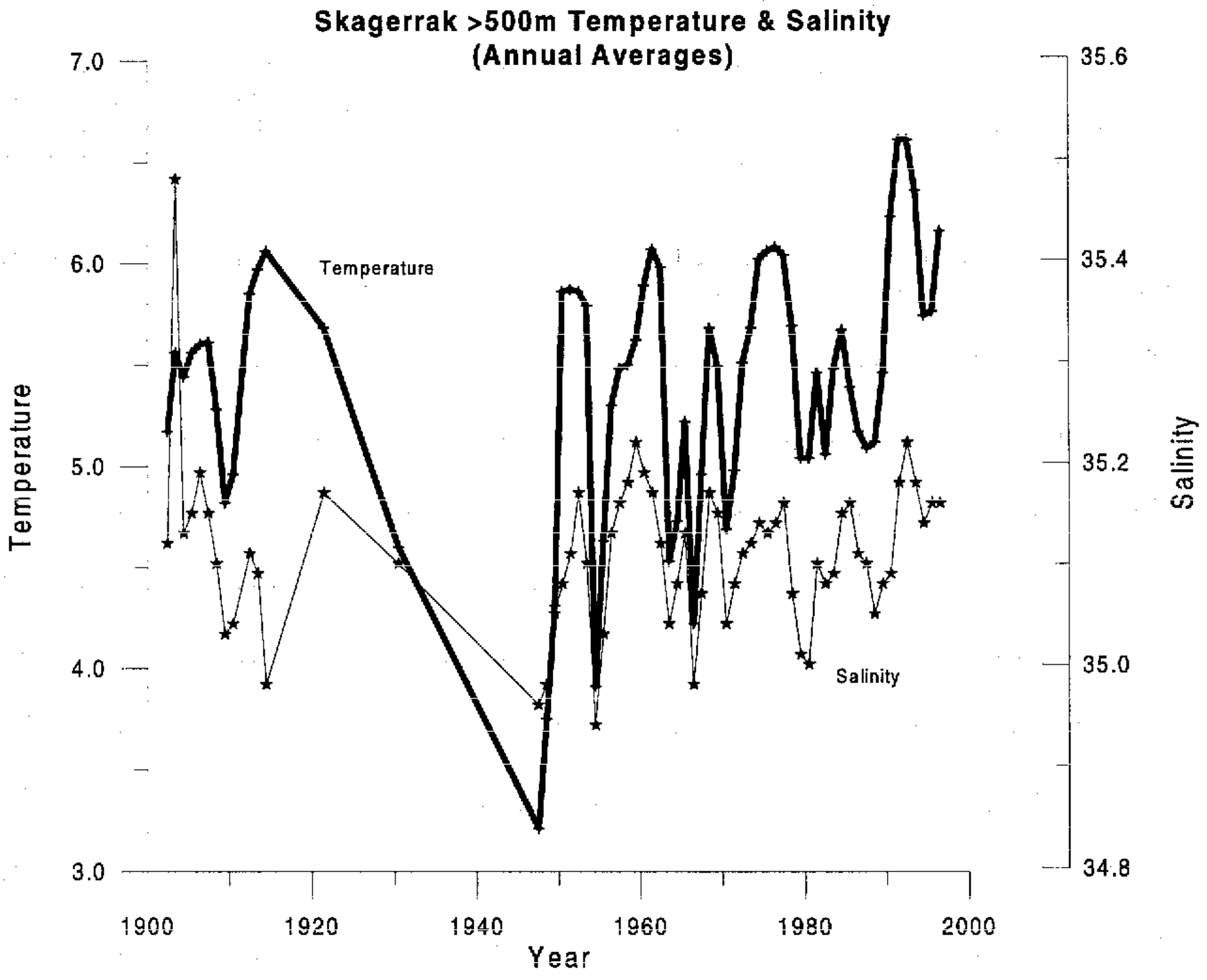
V – INVENTORY OF LONG TIME SERIES

Inventory of long (>20 years) time series

of

Oceanographic, meteorological, fisheries and astronomical observations and model results

A Second Compilation (1998)



Background

The Working Group decided to develop an inventory of time series of observations and model data during its 1996 meeting. The decision followed from its discussion on how to set up a programme of work in the North Sea to establish the ecological effects of cold "Ice" winters in the North Sea. According to the background justification for this compilation, the working group believed that, in order to predict changes in regional seas due to climate change, the understanding of large-scale, long term, climate variability and its effects on the physical, chemical, biological and geological systems of shelf seas are of fundamental interest, especially in the coastal zone where the vast majority of the human population resides.

Sources of Information

For this first compilation, information on time series was collated from a circular email to the three Hydrography Committee Working Groups, and also by a cursory search on the World Wide Web. In addition, time series available from within the ICES Data Centres were also surveyed and summarised.

There was a low number of responses from the Working Groups, nevertheless the following pages probably provides a useful first attempt at identifying those time series that do exist. Emphasis has been put on those time series that are readily available free of charge. For example, amongst the many time series that are not included are much of the light vessel data from around the North Sea which is only available at considerable cost from respective meteorological agencies.

For this initial compilation, no attempt is made to sort the time series by discipline. Instead the listings are provided by "Source" but with a clear identification of the type of time series.

SOURCE : WORLD WIDE WEB

Meteorology:

Climate data for ADVANCE-10K

Source of Information: http://www.cru.uea.ac.uk/advance10k/climdata.htm

Unix	MS-DOS	Size	Description
cuwld.all02.Z	cruwlda2.zip	3.6MB	monthly temperature station data up to 1990
glform9196b.dat.Z	glf9196b.zip	120KB	above updated to 1996
gridbox.f		1KB	Fortran code to read the above file format
Average temperature anomaly (relative to 1950–79) in each 5°x 5° box from a variable number of stations. Not normalised. See: *The Holocene*, vol. 2 no. 2 (1992)			
globalnew91.Z	glonew91.zip	3.3MB	5°x5° gridded monthly temperature data 1854–1991
globjandec92.dat.Z	globjd92.zip	76KB	above updated for 92/93
globjandec94.dat.Z	globjd94.zip"	35KB	above updated for 94
globjandec95.dat.Z	globjd95.zip	36KB	above updated for 95
sstcoads.f		2KB	Fortran code to read the above file format
presmslpup.dat.Z	prmslpup.zip	1.3MB	mean monthly SLP 1873–1991. For millibar divide by 100 and add 1000 (eg. 555 = 1005.55mb)
PRES.FOR		1KB	Fortran code to read presmslpup.dat

MET-OCEAN

Comprehensive Ocean-Atmosphere Data Set (COADS)

SOURCE: http://www.scd.ucar.edu/dss/pub/COADS.html

Overview of COADS

The Comprehensive Ocean-Atmosphere Data Set (COADS)* has been created by combining, editing, and summarising global in situ marine data from many different sources. Merchant ship observations back to 1854 have been supplemented in more recent years by automated measurements, e.g., from drifting and moored buoys. COADS currently covers the period 1854–1992. Two COADS products are most often requested by users (decadal summaries and other products are also available):

I) Marine reports: These contain the basic individual observations (e.g., of air and sea surface temperatures, winds, atmospheric pressure, cloudiness, and humidity) taken from the ocean-atmosphere boundary layer.

II) Global monthly summaries for 2-degree latitude x 2-degree longitude boxes. Fourteen statistics, such as the median and mean, were calculated for each of 19 observed and derived variables. The statistics are global only to the extent that observations were actually recorded at a given time and place (i.e., statistics were calculated for each year, month, and 2-degree box containing "acceptable" data). Due to data volume, statistics are often requested in the form of group files, each group containing eight selected statistics for four variables.

Ordering COADS products

COADS products for Release 1 (1854–1979) and Release 1a (1980–92) are available from:

Steve Worley
Data Support Section

e-mail: worley@ncar.ucar.edu
National Center for Atmospheric Research
P.O. Box 3000
Boulder, CO 80307
Phone: 303–497–1248, Fax: -1298 USA

Data requests are filled by NCAR at a one-for-one copy cost (currently $6 per 10 Mbytes) plus additional cost for tape media and overseas shipping if required. Any subsetting not part of the general storage file structure is subject to an additional charge (individual marine reports are generally available in global monthly files, while the 2-degree monthly summaries are normally distributed in global annual files).

In addition, Release 1 individual marine reports can be obtained from:

Director
National Climatic Data Center
NOAA, Federal Building
Asheville, NC 28801
USA

Selected Data for Oceanographic Research

SOURCE: http://www.scd.ucar.edu/dss/catalogs/odl.html

1. Definitions
2. Ship Observations
    - COADS Documentation, ASCII (version, 6 April 1994)
    - COADS Documentation, Hypertext (version, 6 April 1994)
3. Sea Surface Temperature
4. Surface Wind and Wind Stress
5. Air-sea Heat Budgets
6. Ocean Depth and Land Elevation
7. Moored and Drifting Buoys
8. Sea Ice
9. Data Derived from Satellite Sensors
10. Subsurface Climatology / Model Input and Output
11. Datasets from Operational Atmospheric Analyses
12. Miscellaneous
13. Data Requests and Further Information

2 Ship Observations

DS540.0 :>Comprehensive Ocean-Atmosphere Data Set (COADS), Marine Observations

Geographic Coverage :
global oceans
Temporal Coverage :
1854 - 1993
Product Type:
CMR, Compressed Marine Reports (1854–1979), 71 million observations - 29 most used parameters, 1.7 GB.

DS540.1 :>Comprehensive Ocean-Atmosphere Data Set (COADS), Statistical summaries of DS540.0

DS535.0 :>Observations from Ocean Weather Ships

Geographic Coverage :
approx. 14 locations
Temporal Coverage :
1945 - 1992

Dataset Size :
470 MBytes

DS285.0 :>Levitus' World Ocean Atlas, 1994

Geographic Coverage :
global analyzed 1 x 1 grids and observed profiles
Temporal Coverage :
based on data approx. 1900 - 1992
Dataset Size :
928 MB analyzed, 2278 MB observed

DS533.0 :>USSR Marine Ship Archive

Geographic Coverage :
global oceans
Temporal Coverage :
1888 - 1990
Dataset Size :
2.7 GB

DS277.0 :>Global SST from Natl. Centers for Environ. Prediction (formerly NMC), by Reynolds, Stokes, and Smith

ProductType:

In situ and global blended analyses. These were the first developed SST analyses. Work on this time series has been discontinued. The OI and Reconstructed SST products supersede these products.

DS289.1 :>Global Ocean Surface Temperature Atlas (GOSTA) March 1990, by Bottomley et. al.; UK Met. Office and MIT

Geographic Coverage :
global, 5 and 1 degree resolution
Temporal Coverage :
longterm climatology
Dataset Size :
68 Mbytes

DS277.2 :>GISST.1 UK Met. Office Global Ice an SST

Geographic Coverage :
global, 1x1 degree resolution
Temporal Coverage :
1948–1993, yr-mo
Dataset Size :

150 MB Description : SST observations for ship have been analysed by Parker to form a monthly time series. This is a proprietary dataset and special permission is required for data access.

DS552.0 :>UNESCO: Flow Rates of Selected World Rivers

Geographic Coverage :
global
Temporal Coverage :
approx. 1800 - 1972
Dataset Size :

2.1 MBytes

Free datasets available via ftp (ftp://ncardata.ucar.edu/pub/)

Data files for the following sets may be compressed (.Z) and groups of files may be combined with tar (.tar). If you are unable to use the files in this form, the data can be provided in other forms using our standard pricing. For some datasets, only certain files or subsets are available for free.Some data files are also available via our special projects page, which points to our ftp "pub" directory.

ds010.1 Monthly mean NH Sea Level Pressure grids
ds090.1 NMC Global Reanalysis Anals, 6-hrly, monthly files only
ds085.1 Monthly mean 700- 500- mb heights/temperatures
ds195.5 NH Time Series Grids monthly only
ds205.0 NCDC/NCAR Climatology
ds207.0 Rand's global climatology
ds209.0 Esbensen - Kushnir, Global Ocean Heat and Wind
ds209.3 Hastenrath's Tropical Atlantic heat budget, monthly
ds215.0 Jones long period gridded temp anomalies
ds232.0 Hellerman, GFDL Monthly Global Wind Stress
ds233.0 Walsh's Arctic Ice Anals, monthly 1953–1988
ds234.0 Ropelewski's CAC Antarctic Ice Anals, monthly 1973–1990
ds237.0 Willmott's Terrestrial Water Budget, monthly
ds270.2 Monthly SST and Ice-Pack Limits (Alexander &)
ds277.0 Parts of the monthly SST set
ds280.0 Seasonal World Ocean Surface Currents
ds289.0 Global Monthly SST Climatology (D. Shea)
ds290.0 Climatology by D. Shea, NCAR
ds315.0 Dewey&Heim's Snow Cover, wkly monthly 1966 Nov-1988 monthly files only
ds318.1 GFDL Climate Model Outputs for CO2 Studies
ds318.2 UK Climate Model Outputs for CO2 Studies
ds318.3 CCC Climate Model Outputs for CO2 Studies
ds318.4 GISS Climate Model Outputs for CO2 Studies
ds318.6 German Climate Model Tropo Anals for EPA CO2 studies
ds474.0 Univ Washington Russian Ice Station Obs, daily 1950–1990
ds483.0 Indonesian monthly data from Asian Station set
ds552.0 River discharge from UNESCO publications
ds564.0 Global Historical Climatology Net (GHCN) Temp, Precip, Pressure
ds570.0 World Monthly Sfc Station Climatology, 1738-cont US stations only
ds572.0 So. American Monthly Precip (Harnack)
ds578.1 China monthly temp and precip
ds582.0 Univ Wisconsin Antarctica Sfc Obs, monthly 1980–1989
ds718.5 Arkin's 1/2 Monthly Outgo LW Radia, 1974Jun-con
ds728.1 Xie and Arkin Merged Monthly Precipitation Estimates
ds740.1 Highly Reflective Clouds Longterm Means/Std.Dev
ds750.1 One degree global elevation values
ds754.0 Navy 10 minute Elevation
ds756.1 Defense Mapping Agency (DMA) US 30-Sec Elevations
ds757.0 2.5 degree global elevation and land-sea mask
ds759.1 NGDC ETOPO5 Global Ocean Depth & Land Elevation, 5-Min
ds759.2 TerrainBase Global 5-minute Ocean Depth and Land Elevation
ds765.0 Vegetation, Land Use, and Albedo (Matthews)
ds765.5 Matthew's GSFC Global Wetlands & Methane Emission, 1-Degr
ds766.0 Argonne Land-use & Deposition Data, 0.2-Degr
ds767.0 Vegetation, Soils (Wilson, Henderson-Sellers)
ds768.0 Global Precip Climatology & Topography (Cogley&Briggs)
ds769.0 World Ecosystems (Olson)
ds770.0 Staub & Rosenweig's GISS Soil & Sfc Slope, 1-Degr
ds780.0 Continental Outline Data Set
ds808.0 NSSFC Severe Local Storms Log (SELSLOG), 1955–1972 June
ds816.0 Wind Energy at Global Stations, Battelle PNL

ds824.0 NCDC Global Tropical Cyclone Position Data, 1886–1991
ds825.0 Central England Temperatures, Manley, 1659-con
ds834.0 Sunspot Numbers from NGDC
ds863.0 SPECMAP Ocean Core Data, 400,000 yr record
ds866.0 GISS Methane & Livestock Distribution, 1-Degr
ds867.0 Matthew's GISS Methane from Rice Cultivation
ds885.1 NCDC TD9640 US Palmer Drought Indices, monthly 1895–1987
Basic station dictionary info
    ds900.0 WMO station library from USAF
    ds900.1 WBAN station library
    ds901.0 COOP station library

SOURCE : ICES and its Secretariat

Ocean Time Series at ICES (including working groups)

ICES Standard Stations (Oceanic Hydrography WG (OHYD))

Location	Position	Depth	Period at ICES	No at ICES (Hyd/Che)
Greenland Sea	75°00N 05°00W 71°00N 04°00E			
West Greenland	63°53N 53°22W	900 to 1300	1934–1994	157(82)
Norwegian Sea	64°30N 06°00W	3250	1953–1993	9(3)
Iceland Basin	60°00N 20°00W	2730	1977–1991	1(0)
Faroe-Shetland Channel	61°28N 03°42W	860	1905–1995	156 (9)
Faroe Bank Channel	61°16N 08°00E	1260	1959–1972	2(1)
Porcupine Abyssal Plain	50°00N 17°00W	2700	1976–1990	11(8)
Weathership A	62°00N 33°00W		1954–1974	1444(0)
Weathership B	55°47N 51°53W		1928–1974	2234(0)
Weathership C	52°45N 35°30W		1910–1990	10393(2974)
Weathership D	44°00N 41°00W		1962–1984	1668(3)
Weathership E	35°00N 48°00W		1910–1979	2116(24)
Weathership H	38°00N 71°00W		1927–1982	730(98)
Weathership I	59°00N 19°00W		1955–1975	708(0)
Weathership J	52°30N 20°00W		1950–1975	994(0)
Weathership K	45°00N 16°00W		1949–1973	505(0)
Weathership L	57°00N 20°00W		1975–1989	454(0)
Weathership M	66°00N 02°00E		1948–1990	8011(46)
Weathership R	47°00N 17°00W		-	0(0)
Canadian Eastcoast				
Prince 5	44°57N 66°49W		-	0(0)
Station 27	47°33N 52°35W		-	0(0)

OHYD List of Standard Sections in the North Atlantic

COUNTRY/NAME	STARTPOINT	ENDPOINT	NO at ICES	PERIOD
CANADA				
Flemish Cap	47°00N 52°02W	47°00N 42°00W	1191 (49)	1913–1991
Bonavista	48°44N 52°58W	50°00N 49°00W	199 (4)	1931–1989
White Bay	50°40N 55°00W	52°07N 49°45W	134 (1)	1950–1989
Seal Island	53°14N 55°39W	59°38N 44°09W	302 (4)	1931–1994
DENMARK				
C. Farewell	59°38N 44°09W	58°46N 45°50W	46 (19)	1952–1988
C. Desolation	60°50N 48°45W	60°02N 51°27W	26 (9)	1928–1988
Frederikshaab	61°57N 50°00W	61°34N 52°30W	110 (53)	1924–1987
Fylla Bank	63°57N 52°22W	63°48N 53°56W	669 (276)	1908–1988
Sukkertop	65°06N 52°55W	65°06N 54°58W	294 (134)	1908–1988
Holsteinsborg	66°53N 54°10W	66°41N 56°38W	308 (133)	1908–1988
FAROES				
Northern Section	62°20N 06°05W	64°30N 06°05W	366 (20)	1904–1989
Nolsey-Shetland	62°00N 06°12W	61°01N 01°36W	2099 (746)	1902–1993
Troellhoevdi - Faro Bank	61°50N 07°00W	60°28N 09°20W	159 (18)	1904–1989
GERMANY				
Dohrn Bank I	65°27N 28°38W	65°53N 30°53W	56 (11)	1903–1988
Dohrn Bank II	65°58N 29°24W	65°21N 30°06W	38 (4)	1955–1988
Gauss Bank	65°22N 34°30W	64°50N 33°33W	12 (1)	1933–1988
Heimland Ridge	64°09N 37°12W	63°33N 36°33W	7 (0)	1932–1988
Cape Moesting	63°38N 40°05W	63°04N 39°12W	13 (2)	1933–1988
Cape Bille	62°10N 41°24W	61°56N 40°27W	42 (16)	1933–1988
Discord Bank	60°57N 42°17W	60°48N 40°18W	14 (2)	1958–1988
ICELAND				
Faxafloi	64°20N 22°25W	64°20N 28°00W	627 (342)	1903–1991
Latrabjerg	65°30N 24°34W	66°09N 27°15W	680 (255)	1904–1990
Kogur	66°30N 23°00W	67°20N 23°40W	829 (293)	1904–1990
Siglunes	66°16N 18°50W	68°00N 18°50W	1066 (448)	1908–1990
Langan N	66°37N 14°16W	68°00N 12°40W	508 (239)	1929–1990
Langan A	66°22N 14°22W	66°22N 09°00W	813 (308)	1904–1990
Krossan	65°00N 13°30W	65°00N 09°00W	468 (187)	1902–1990
Stokksn	64°12N 14.50W	63°40N 13°40W	414 (204)	1933–1990
Selv.B.	63°41N 20°41W	63°00N 21°28W	820 (495)	1934–1990
Iceland Sea	68°15N 16°32W	70°35N 13°25W	29 (3)	1958–1986
NORWAY				
Torungen	58°24N 08°46E	57°38N 09°52E	4489 (1993)	1902–1993
Oksø	58°03N 08°05E	74°14N 08°33E	1596 (742)	1906–1994
Hansth.-Aberdeen	57°00N 07°57E	57°00N 01°28W	3208 (1010)	1903–1995
Utsira	59°17N 05°02E	59°17N 02°14W	5159 (1642)	1902–1994
Feie	60°45N 04°37E	60°45N 00°40W	3356 (612)	1902–1994
Svinøy	62°22N 05°12E	64°40N 00°00E	1315 (158)	1901–1990
Gimsøy	68°24N 14°05E	70°24N 08°12E	883 (24)	1923–1990
Bjørnøy	70°30N 20°00E	74°15N 19°10E	1963 (49)	1926–1995
Vardø	70°30N 31°13E	76°30N 31°13E	1356 (79)	1913–1995
Sem Islands	69°05N 37°20E	76°30N 37°20E	691 (40)	1904–1990
Bjørnøya-W	74°30N 18°30E	74°30N 07°00E	1104 (108)	1929–1993
SCOTLAND				
FIM	60°10N 03°44W	61°12N 06°22W	651 (322)	1902–1993
FS (see Faroe)	62°00N 06°12W	60°56N 01°00W	1827 (635)	1902–1993
MR	56°40N 06°08W	57°35N 13°38W	597 (48)	1908–1993
JONSIS (see Norway)	59°17N 05°02E	59°17N 02°14W	Utsira	
SPAIN				
Vigo	42°08N 09°18W	42°13N 08°51W	28 (13)	1952–1992

COUNTRY/NAME	STARTPOINT	ENDPOINT	NO at ICES	PERIOD
La Coruna	43°25N 08°26W	43°21N 08°22W	2 (0)	1987–1992
Santander	43°30N 03°47W	43°42N 03°47W	6(1)	1952–1994
Cudillero	43°36N 06°08W	43°46N 06°10W	5 (0)	1992–1993

FIXED North Sea Stations for surface temperature and salinity at ICES

(not exhaustive list)

LIGHT VESSELS

Platform	Name	Position	Year	Nos. of Stations
06HR	Helgoland Reede	5410N ; 750E	1933–1937	456
11WH	West-Hinder	5122N ; 228E 5123N ; 226E	1905–1961 1961–1979	6194
64GE	Goeree	5156N ; 340E	1955–1993	3072
64NH	Noordhinder	5139N ; 234E	1955–1982	19.932
64TB	Terschellingerbank	5328N ; 508E	1950–1970	4630
64TE	Texel	5301N ; 422E	1952–1975	9860
74BY	L.H. Bardsey*	5245N ; 448W	1957–1985	3199
74GA	Galloper	5144N ; 158E	1920–1977	2715
74LP	Liverpool*	5245N ; 448W	1934–1956	3318
74LV	Liverpool Bar	5332N ; 319W	1957–1973	1489
74MB	Morecombe Bay	5355N ; 329W	1957–1965	1215
74SK	Smith's Knoll	5243N ; 217E 5244N ; 218E	1920–1951 1952–1971	4395
74SS	Seven Stones	5003/5004N ; 604/605 W	1906–1987	5990
74VA	Varne	5056N;116/117W 5104N ; 124E	1905–1967 1967–1985	6771

Examples of Other Time Series at ICES - fixed Profile data

Name of Station	Location	Number of Stations	Period	Parameters
E1	50 02N 4 22W	454	1903–1992	t, s, nutrients
Cypris (IOM)	54 05N 4 50W	1014 (996)	1954–1982	t, s, nutrients
Breakwater (IOM)	54 05N 4 46W	28810	1904–1982	t
Norwegian coastal stations	various	1770	1927–1994	t,s,oxygen
Skagerrak >600m includ-ing M6	58 08 -58 12N;9 10 - 9 32E	659 (357)	1902–1996	t,s,oxygen,nutrients, etc

SOURCE: EDMED

Time Series referred to in EDMED (European Directory for Marine Environmental Data)

Rockall Channel CTD section time series (1975-)
Rockall Channel surface temperature and salinity time series (1948-)
Hunterston Power Station, Clyde sea area, temperature time series (1960–1985)
Hunterston Power Station, Clyde sea area, biological time series (1960–1985)
A long time series of meteorological data from Genova, Italy
French national archive of time series data, particularly current meter and thermistor data
LPO Current meter and temperature time series in the North Atlantic
LPO Subsurface Lagrangian floats time series from the Atlantic
Sea level time series in the Indian Ocean
Sea level time series in the Tropical Atlantic
Lagrangian time series from drifting buoys in the Tropical Global Ocean
ORSTOM current meter and time series data from the global tropical ocean
Sea surface temperature time series from German Baltic Sea coastal stations (1953–90)
Sea surface salinity time series from German Baltic Sea coastal stations (1953–90)
Meteorological and sea surface hydrography time series from KIEL Lightship, Baltic Sea (1936–39,47–67)
Hydrographic station time series at UFS KIEL Lighthouse, Baltic Sea (1985–90)
Meteorological, sea surface hydrography and hydrographic station time series from ELBE 1 Lightship, German Bight (1920–39,47–88)
Meteorological, sea surface hydrography and hydrographic station time series from ELBE 2 Lightship, German Bight (1935–39)
Meteorological, sea surface hydrography and hydrographic station time series from ELBE 3 Lightship, German Bight (1935–39)
Meteorological, sea surface hydrography and hydrographic station time series from FEHMARN BELT Lightship, NE Germany (1922–9,47–84)
Hydrographic station time series from FEHMARN BELT Buoy, NE Germany (1985–89)
Meteorological, sea surface hydrography and hydrographic station time series from ELBE 4 Lightship, German Bight (1920–39)
Meteorological, sea surface hydrography and hydrographic station time series from AUSSEN JADE Lightship, German Bight (1935–39)
Meteorological, sea surface hydrography and hydrographic station time series from MINSENERSAND Lightship, German Bight (1921–39)
Meteorological, sea surface hydrography and hydrographic station time series from NORDERNEY Lightship, German Bight (1935–39)
Meteorological, sea surface hydrography and hydrographic station time series from S2 Lightship, German Bight (1947–53)
Meteorological, sea surface hydrography and hydrographic station time series from DEUTSCHE BUCHT Lightship, German Bight (1948–86)
Temperature and salinity depth profile time series at UFS DEUTSCHE BUCHT Automatic Lightship, German Bight (1989–90)
Meteorological, sea surface hydrography and hydrographic station time series from TW EMS Lightship, German Bight (1947–78)
Temperature and salinity depth profile time series at UFS TW EMS Automatic Lightship, German Bight (1989–90)

Meteorological, sea surface hydrography and hydrographic station time series from BORKUMRIFF Lightship, German Bight (1921–39,47–88)
Temperature and salinity depth profile time series at UFS ELBE Automatic Lightship, German Bight (1989–90)
Meteorological, sea surface hydrography and hydrographic station time series from WESER Lightship, German Bight (1921–39,47–81)
Meteorological, sea surface hydrography and hydrographic station time series from BREMEN Lightship, German Bight (1922–39)
Meteorological, sea surface hydrography and hydrographic station time series from AUSSEN EIDER Lightship, German Bight (1921–39)
Meteorological, sea surface hydrography and hydrographic station time series from AMRUMBANK Lightship, German Bight (1921–39)
Meteorological and sea surface hydrography time series from ADLERGRUND Lightship, Baltic Sea (1921–39)
Meteorological and sea surface hydrography time series from FLENSBURG Lightship, Belts (1936–39)

SOURCE: Einar Svendsen

IMR Bergen, The Norwegian Met. Inst., Oslo, Norway

OCEANOGRAPHY

Fixed stations (50 +/-20 years)

9 hydrographic stations (vertical profiles) along the Norw. coast
20 surface T,S along the Norw. coast and across the North Sea
20 fjords (hydrography, nutrients and oxygen)
Station M-Norwegian Sea (hydrography)

Fixed sections (20–30 ++ years)

12 hydrographic sections normal to the Norwegian coast into deep water (one with oxygen)
Russian Kola section since 1901

Regional Observations (20–30 years)

Hydrography in the "whole" ice-free Barents Sea 3 times a year.
Norwegian Coast (hydrography) twice a year
North Sea (northern & central) twice a year
Lofoten once a year

METEOROLOGY

Standard coastal weather stations:
40–50 standard weather stations at the coast/islands of Norway, including
Jan Mayen,
Svalbard,
Bear Island and
Hopen.

This "covers" an area from 58 to 79 degrees northern latitude, and from 11 degrees east to 8 degrees west. Some of these includes sea state and sea surface temperature. Most of the monitoring started in the early 1900.

Gridded (75x75 km) wind, atmospheric pressure and wave parameters every 6 hour since 1955 over parts of the North Atlantic and Arctic ocean and the total Nordic, North and Barents seas. (3000 grid-points/ time-series).

Gridded sea ice coverage and ice type once a week since 1966

Gridded SST once a week since 1972

FISHERIES (ICES/IMR, Bergen, Norway/other Many long time-series from the commercial fish stocks on recruitment, individual age classes and spawning stock biomass are available at ICES, together with catch distributions.

Indexes of the amount and maps of distribution of Atlantô Scandian Herring and Norwegian Arctic Cod larvae/ 0-group from IMR and russian research cruises.

ASTRONOMICAL

The main astronomical periods which also are found in measured time-series (in addition to the standard short term tidal and yearly cycles) is the: 11.2 years (mean) solar activity cycle

- 18.61 years nodal tide
- 8.85 years
- 2.3 years
-

The solar activity cycle (from the average number of sunspots and the mean area) fluctuate over time in a more or less regular manner with a mean period of about 11.2 years.

The Nodal tide, Mn: 18.61 yr tidal component. From Burroughs (1992): "The 18.61 yr period in the regression of the longitude of the node - the line joining the points were the Moon's orbit crosses the ecliptic".

8.85 yrs: Tidal component connected to the variation in the alignment of the Moon's perigree and the Earth's perihelion. From Burroughs (1992): "The 8.85 yr period in the advance of the longitude of the Moon's peri gee which determines the times of the alignment of the perigee with the Earth's perihelion"

SOURCE: H Van Aken, NIOZ, Texel

Timeseries of Sea Surface Temperature and Salinity from the Marsdiep estuary.

Samples are taken daily at 08:00 local time. In order to remove oscillations due to the interference of tides and sample time these daily values are reduced to monthly mean values. The time series started in July 1860 in Den Helder and was continued there until 1962. From 1947 onwards a similar timeseries is collected from the Texel side of the Marsdiep, near 't Horntje, the present location of NIOZ. From the 16 years overlap monthly mean correction have been determined to transform the monthly mean values from 't Horntje to Den Helder.

The data from 1860 to 1981 have been described by P.C.T. van der Hoeven in "Observations of surface water temperature and salinity, State Office of Fishery Research (RIVO): 1860–1981" KNMI Scientific Report W.R. 82–8, KNMI, De Bilt, 1982

This report also contains time series from several other positions in the Wadden Sea and in the former Zuiderzee, as well as from Dutch light vessels. KNMI owns even more timeseries of sea surface temperature along the whole Dutch coast, but colleagues of NIOZ who tried to obtain these data from KNMI did so in vain. Possibly they were lost some time. Perhaps you can put some pressure on KNMI to uncover these data.

Only the Marsdiep data are available from H. Van Aken (aken@nioz.nl) as computer files (Excel).

Algal timeseries from the Marsdiep estuary

Dr. G. Cadee from NIOZ maintains this time series.

Timeseries of shellfish from plates in the Wadden Sea of at least 25 years.

Beukema of NIOZ maintains this time series .

SOURCE: Finnish Institute for Marine Research (Ari Seina)

Baltic Sea:

1) **Maximum extent of ice cover 1719/20-**

In Seina and Palosuo 1996: the classification of the maximum annual extent of ice cover in the Baltic Sea 1720–1995.- MERI-report series of the Finnish Institute of Marine Research No 27.

2) **Ice seasons 1830–1996.**

Further information from http://ice.fmi.fi

3) **Freezing, maximum annual ice thickness and breakup of ice on the Finnish Coast 1830–1984**

Published in Geophysica 21(2) by Lepparanta and Seina, 1985. Data used in the paper is published in FIMR Internal report 1985(2), email: parkkonen@fimr.fi.

SOURCE: NERC, UK (L Rickards - The "Environment in Time")

Marine Biology

- **Zooplankton and fish larvae densities, 1924–1988**

Western Approaches of English Channel. Maintained by MBA, Plymouth

- **Pelagic zooplankton and phytplankton, since 1931**

NE Atlantic and North Sea, funded largely under CPR programme. Regular work along 20W by SOC (to 100m and 10 degree intervals)

- **Littoral-sublittoral communities, 1963–1986**

In Firth of Clyde, by DML, Oban.

- **Pup production of grey seals, since 1959**

All major UK seal colonies by SMRU.

Physical Oceanography

- **Mean Sea Level, since 1806**

Worldwide, POL coordinates data for IOC, 400 stations in GLOSS.

- **Tidal Changes since 1950s (some since mid-19th century)**

- **Wave Height, 1954–1988**

North Atlantic. Data from OWS. UK wave climate atlas in press.

SOURCE: J Dippner (DKRZ, Germany)

Various links concerning time series are available from:

http://www.dkrz.de/forschung/project/klimadatenkatalog.html

Including:

Climate Data Catalog - Germany

A list of climate research centers in Germany and available datasets.

Climate Data Catalog - Europe

Information on European centers for climate, atmospheric and oceanographic research.

Climate Data Catalog - Worldwide

Climate data centers with online accesable data and informations all over the world.

Climate Models and Diagnostics

Links to technical reports on climate models and diagnostic programs.

SOURCE: PICES Inventory of Long Term Series relevant to the North Pacific

http://pices.ios.bc.ca/data/longterm/lttsintr.htm

The Technical Committee on Data Exchange (TCODE) has undertaken the task of assembling a list of important datasets that are relevant to the study of long term trends in the physical, chemical and biological environment of the North Pacific. These datasets are particularly important for the retrospective analyses that are to be carried out in the PICES Climate Change and Carrying Capacity (CCCC) studies.

The primary objective of TCODE in assembling this inventory was to provide short descriptions and "pointers" to the locations of the datasets, to assist researchers in selecting and accessing a diverse set of long term data. The criteria for inclusion were loose - we were interested in any data that was considered to be relevant to the PICES area that spanned (or will eventually span) a period of 10 years or more. We have included references to some global datasets, as well as references to some observations in equatorial waters which are know to

have impacts on the North Pacific.

For convenience, we have classified the datasets into four types: 1. Biological Oceanographic Data 2. Fisheries data 3. Meteorological data 4. Physical and Chemical Oceanographic data

1 Biological Oceanographic Time Series

TINRO Biological Oceanographic Profile data - Russia
OWS Papa - Chlorophyll and primary production
OWS Papa - zooplankton biomass and composition
HOTS- Hawaii Ocean Time Series

2 Fisheries Time Series

Auke Creek- Salmon escapement and environmental conditions

North Pacific Salmonid Coded Wire Tag (CWT) Database
Pink Salmon escapement and env. factors - Sashin Creek
US/Japan Fisheries Resource Assessment Surveys
NMFS Longline Survey
Pacific Coast Acoustic/Trawl Hake Survey
Standard Trawl surveys - West Coast of US to BC
US Commercial Fishery Landing Statistics
Standard Trawl surveys - West Coast of US to BC
Groundfish catch and Composition - US Observer Program
Standard Trawl Surveys - Gulf of Alaska and Aleutians
Standard trawl surveys - Eastern Bering Sea (US)
Northern Fur seals - Pribilof Islands
Groundfish stomach contents - US Waters
TINRO - fish biomass and composition from trawls- Russia
Aboriginal Catch Database (Canada)
Recreational Catch Database (Canada)
Groundfish Catch Database (Canada)
Herring Catch Landings (Canada)
Herring Spawn Data (Canada)
Herring Biological Sample Data (Canada)
Mark Recovery Program (Canada)
Groundfish Biological Database (Canada)
Eastern Bering Sea Acoustic/Trawl Pollock Survey
Bogoslof Island Acoustic/Trawl Pollock Survey
Commercial Catch Database (Canada)
Salmonid Enhancement Program (Canada)
Mark Recovery Program Commercial Biological Sampling (Canada)
Mark Recovery Program Multiple Finclip Database (Canada)
Gulf of Alaska Acoustic/Trawl Pollock Survey
Shellfish Harvest Log Databases (Canada)

3 Meteorological Time Series

COADS SST and surface met. data - NODC CDROM-56/57
NOAA Climate Prediction Center-Teleconnection Indices (See entry below)
Canada-Regional air temperature anomalies 1895 - present
FNMOC SLP, winds and upwelling indices
Global air temp anomalies - with and without ENSO
NOAA Marine Environmental Buoy Database
Offshore meteorological.oceanographic buoys (Canada)
global and hemispheric air temperature anomalies

4 Physical and Chemical Oceanographic Time Series

OWS Papa - Nutrient profiles
OWS Papa - Temp, Salinity and Oxygen profiles (WOCE PR6)
JODC Temp, Salinity, Oxygen and nutrient profiles
JODC Currents (includes ADCP)
Sea Level Heights - Japan - 1961 to present
Offshore meteorological/oceanographic buoys - Canada
JODC Moored Current Meter data
Sea Level heights (Canada -West Coast)
World Ocean Atlas 1994
Canada-MEDS Sea Level Height database
Canada - MEDS oceanographic data profiles
NODC/WDC-A Oceanographic Station Profile Time Series
NOAA/NODC Sea Level Height CD-ROM

FNMOC Sea Level Pressure and Ocean flow fields
Arctic and Southern Ocean Sea Ice Concentration
T&S profiles - NW Pacific, Bering, Okhotsk (Russia)
Joint Archive for Shipboard ADCP (JASADCP) at the UH
Lighthouse SST and SSS - (Canada-West Coast)
TINRO Temperature and Salinity Profiles - Russia
Canada- MEDS world archive for drifting buoy data (DRIBU)
Monthly SST and anomalies - WC US, Alaska, Eastern Pacific
Temperature and Salinity profiles - Gulf of Alaska (GAK 1)
CALCOFI Temp, salinity and nutrient profiles (US-Calif)
NODC Ocean Current Drifter Data
NOAA Climate Prediction Center-Teleconnection Indices
http://nic.fb4.noaa.gov/data/cddb/

CPC - Data: Current Monthly Atmospheric and SST Index Values Updated around the 10th of each month. Also available through anonymous ftp to nic.fb4.noaa.gov:/pub/cac/cddb/indices

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Winds
•200 MB Zonal Winds Equator (165W-110W): Data, Graphic
•850 MB Trade Wind Index(135E-180W) 5N-5S West Pacific: Data, Graphic
•850 MB Trade Wind Index(175W-140W) 5N-5S Central Pacific: Data, Graphic
•850 MB Trade Wind Index(135W-120W) 5N-5S East Pacific: Data, Graphic
•QBO.U30.Index (replaces 30 MB Singapore Winds [see FAQ]: Data, Graphic
•QBO.U50.Index (replaces 50 MB Singapore Winds [see FAQ]: Data, Graphic

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Sea Level Pressure
•Darwin Sea Level Pressure: Data, Graphic
•Tahiti Sea Level Pressure:Data, Graphic
•Darwin (SLP) 1882 - 1950: Data
•Tahiti (SLP) 1882 - 1950: Data

Southern Oscillation Index (SOI)
•(Stand Tahiti - Stand Darwin) Sea Level Pressure: Data, Graphic
•(Stand Tahiti - Stand Darwin) SLP 1882 - 1950: Data

Sea Surface Temperature
•Nino 1+2 (0–10S)(90W-80W) Nino 3 (5N-5S)(150W-90W) Nino 4 (5N-5S) (160E-150W) Nino 3.4 (5N-5S)(170–120W): Data, Graphic
•North Atlantic (5–20N, 60–30W), South Atlantic (0–20S, 30W-10E), Global Tropics (10S-10N, 0–360): Data
•West Coast of Americas SST (Known as Ship Track 1): Data
•Hawaii Fiji SST (Known as Ship Track 6): Data
•West Coast of Americas SST 1921 - 1950 (Ship Track 1): Data
•West Coast of Americas SST 1921 - 1950 (Ship Track 6): Data

Temperatures
•Zonally Average 500 MB Temperature Anomalies: Data, Graphic

Outgoing Long Wave Radiation
•Outgoing Long Wave Radiation Equator (160E-160W): Data, Graphic

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Northern Hemisphere Teleconnection pattern indices
•Standardized Amplitudes of NH teleconnection patterns

SOURCE - CPC: STANDARDIZED NORTHERN HEMISPHERE TELECONNECTION INDICES

http://nic.fb4.noaa.gov/data/cddb/

column 1: Year (yy)
column 2: Month (mm)
column 3: North Atlantic Oscillation (NAO)
column 4: East Atlantic Pattern (EA)
column 5: East Atlantic Jet Pattern (EA-JET)
column 6: West Pacific Pattern (WP)
column 7: East Pacific Pattern (EP)
column 8: North Pacific Pattern (NP)
column 9: Pacific/ North American Pattern (PNA)
column 10: East Atlantic/West Russia Pattern (EA/WR)
column 11: Scandinavia Pattern (SCA)
column 12: Tropical/ Northern Hemisphere Pattern (TNH)
column 13: Polar/ Eurasia Pattern (POL)
column 14: Pacific Transition Pattern (PT)
column 15: Subtropical Zonal Pattern (SZ)
column 16: Asia Summer Pattern (ASU)
Documentation for teleconnection patterns

SOURCE: NCAR Climate and Global Dynamics Division (CGD)

http://www.cgd.ucar.edu/

CGD is broken into a number of sections, and each section may be working on a number of projects. This page consists mainly of links to individual sections and projects.

- Search CGD's Web.
- Visit also our Anonymous FTP site.
- CGD Seminar information

Research Sections

- Climate Modeling
- Climate Analysis (see below) (CAS)
- Global Dynamics •Climate Change Research •Oceanography •Ecosystem Dynamics and the Atmosphere

http://www.cgd.ucar.edu/cas/

The CAS Mission

The mission of the Climate Analysis Section is to increase understanding of the atmosphere through empirical studies and diagnostic analyses of the atmosphere and its interactions with the earth's surface and oceans

on a wide range of time scales. Emphasis is on the atmospheric general circulation, meteorological phenomena, and climatc variations over several time scales, such as those in blocking events; 40- to 50-day tropical oscillations; interannual variations, such as the El Niño-Southern Oscillation phenomenon; the 1988 North American drought;

solar-weather relationships; and longer-period trends.

Publications

- ONLINE Papers •Abstracts of Current Works •CAS Tech Notes
- An Introduction to Atmospheric and Oceanographic Datasets

Dataset Activities and Holdings

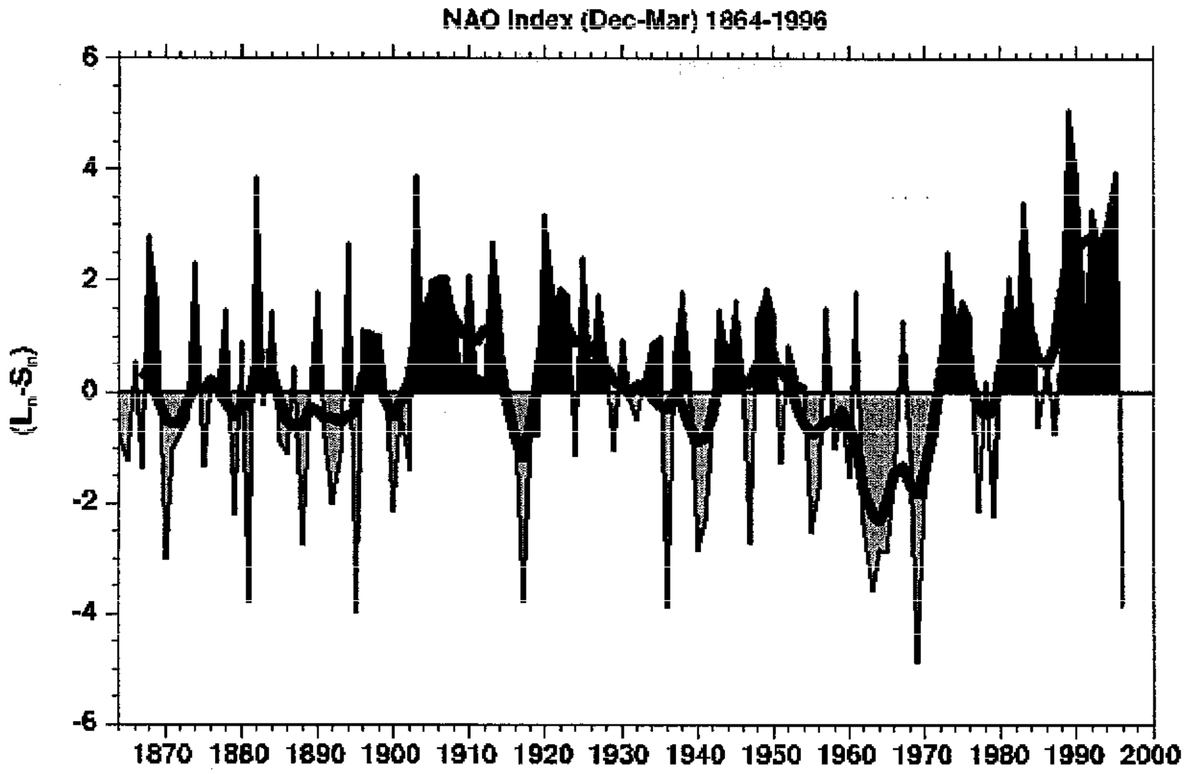
- CAS Data Catalog •Climate Indices •Atlantic Climate Variability

Model Validation

- Community Climate Model, version 3 (CCM3)

Software

- RD2CFM/CIRCE: For putting data into CCM history tape format (for local use)
- EZPLOT: For Publication-Quality Plots (for local use)


NAO Index (Dec-Mar) 1864-1996
6
4
2
0
-2
-4
-6
(L_n-S_n)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Oceanography Committee

ICES CM 1998/C:3
Ref.: ACME

REPORT OF THE

WORKING GROUP ON PHYTOPLANKTON ECOLOGY

Lisbon, Portugal
19–24 March 1998

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK-1261 Copenhagen K Denmark

TABLE OF CONTENTS

1 OPENING OF THE MEETING

The meeting was opened by the chairman, Prof. Franciscus Colijn at 10.00 hrs on 19 March 1998. The chairman welcomed the members and participants of the Working Group meeting and thanked the local organiser Dr Maria-Antonia Sampayo for her help in making hotel reservations, guiding the participants to the hotel and to the IPIMAR facilities. Then the chairman passed to Dr Carmen Lima, the director of IPIMAR, who welcomed the participants on behalf of the institute. In her address she stressed the importance of phytoplankton for the productivity of the sea, and the problems of some phytoplankton species because they affect the quality of seafood for human consumption. She wished the participants a fruitful meeting and mentioned the Annual Science Conference later this year at Estoril hosted by Portugal.

The chairman started the meeting with a series of announcements mainly regarding ICES business and new questions for the Working Group on Phytoplankton Ecology which came up recently, and which will be dealt with in the agenda.

A few members have informed the chairman that they were unable to attend the meeting: Sakshaug (Norway), Richardson (Denmark), Bode (Spain); no members are attending from the Netherlands, Belgium, the Baltic States, Poland, Ireland and France. Still effort should be given to try to get more scientists involved in the work of the Working Group on Phytoplankton Ecology, mainly because a series of interesting scientific and applied problems are discussed (eutrophication, marine food web structure and regulation, global change etc.).

The chairman mentioned that the following papers are available for discussion:

Check list of phytoplankton species of the Northwestern Iberian Atlantic (1948–1996) by M. Varela, A. Bode and J. Lorenzo (Annex 4)

Phytoplankton species composition in the Southern Iberian coast, by A. Bode and M. Varela (Annex 5)

Working manual on the use of a standard incubator-technique for primary production measurements, by F. Colijn and L: Edler; (Annex 7)

Flowcytometry as a tool for counting and identification of phytoplankton (groups) and other applications by G. Dubelaar and R. Jonker; (Annex 8)

Extract from the 1998 Draft Report of the marine Chemistry Working Group, Stockholm, 2–6 March 1998, 8.3.3.d. Quality assurance aspects in the determination of chlorophyll a in sea water (Annex 9)

Determination of chlorophyll a by spectroscopic methods: overview and recommendations for quality assurance by A. Aminot (this paper originates from the Marine Chemistry Working Group and will be available through Marine Chemistry Working Group or ICES; it will not be annexed to this report)

The chairman then informs the members on the status of the proceedings of the Kiel 1997 Variability Symposium, held just one year ago. The physical problems of the chairman after a second Achilles tendon rupture, have caused a delay in the acceptation procedure of many manuscripts. However about 15 have been accepted and are with the final editor of the ICES J. of Marine Science, Niels Daan in the Netherlands. Another 15 are on its way of being accepted or rejected. It will take another 2 months to finalise all manuscripts. There is good hope that the volume can be printed this year.

The chairman shortly informed about a recent study at his institute in commission for the German Environmental Ministry on the preparation of phytoplankton samples for intercomparison studies between institutes and companies which like to be involved in phytoplankton monitoring studies. The high degree of homogeneity of samples to be counted and identified by participants is a prerequisite for an intercomparison.

An ICES/HELCOM workshop/training course on phytoplankton (WPHYT) will be held under the chairmanship of A. Andersson-Nordström in Klaipeda (Lithuania) from 24 to 28 August 1998.

During the meeting the chairman will insert an agenda item (TOR i) on (EURO)GOOS and its role in ICES and the ideas of the Working Group on Phytoplankton Ecology on this item. (the terms of reference on this item can be found under the steering group on GOOS, chairman R. Saetre, stating that the chairmen under the newly formed Oceanography committee have to comment and support R. Saetre by correspondence).

Another item which needs to be discussed is the 5- year plan of the newly formed Oceanography Committee (Chairman Harald Loeng, IMR, Bergen, Norway), to which the Working Group on Phytoplankton Ecology will report. We need to come up with a plan what we are actually going to do in the next years. Moreover we should discuss the possibility to build stronger links to other WG's under the Oceanography committee like Working Group on Zooplankton Ecology, Working Group on Shelf Seas Oceanography, ICES/IOC Working Group on Harmful Algal Bloom Dynamics etc. A first step will be the joint meeting with the ICES/IOC Working Group on Harmful Algal Bloom Dynamics during the meeting in Lisbon on the 24th of March.

The contents of the 2001 ICES variability symposium was asked for. Apart from the Convenors and the venue no official information is yet available. The symposium will have structure comparable to the one held in Mariehamm in 1991 on decadal variability. New results of plankton long term variability studies could well be presented there.

After these announcements a short introduction round was made because a few new members and colleagues of IPIMAR and the University of Algarve were attending the meeting.

After adoption of the agenda (Annex 1), Dave Mills was appointed as rapporteur. A few final arrangements about coffee/tea and lunch breaks were settled. Then a coffee break was held before the discussion on the TORs started.

2 TORS

a) review progress in the preparation of a practical check-list of all phytoplankton occurring in the ICES area, with special emphasis on toxic species and species known to cause harm;

b) propose a mesocosm experiment to investigate new approaches in phytoplankton ecology, in a joint meeting with the ICES/IOC ICES/IOC Working Group on Harmful Algal Bloom Dynamics;

c) identify and discuss methods for the measurement of phytoplankton biomass, production and growth rate in situ, and its identification, including QA procedures;

d) discuss and exemplify effects of anthropogenic inputs of nutrients including changed nutrient ratios over time on the phytoplankton community, with special emphasis on phytoplankton bloom development and phytoplankton community changes;

e) assess monitoring strategies of the pelagic ecosystem and their practical outcome in monitoring programmes within the ICES area;

f) review in a joint session with ICES/IOC Working Group on Harmful Algal Bloom Dynamics on 24 March the results of the Workshop on Development of in situ growth rate measurements of Dinoflagellates held in Kristineberg;

g) review in a joint session with the ICES/IOC Working Group on Harmful Algal Bloom Dynamics on 24 March the status of taxonomic coding systems with a view to recommend the adoption of a single coding system for use in ICES;

h) consider the future work programme in relation to the remit of the Oceanography Committee and the development of the ICES five year plan, including cooperation with other working groups.

i) (new/added) discuss the role of ICES in (EURO)GOOS and report suggestions to the chairman of Steering Group on the Global Ocean Observing System, R. Saetre inter alia to prepare an action plan for how ICES should take an active and leading role in the further development and implementation of GOOS at a North-Atlantic regional level with special emphasis on operational fisheries oceanography.

3 DISCUSSION OF TOR'S

a) review progress in the preparation of a practical check-list of all phytoplankton occurring in the ICES area, with special emphasis on toxic species and species known to cause harm;

This TOR was discussed in a general sense. The chairman opened the discussion by stating that he had tried to prepare this TOR through a discussion with M. Elbrächter. The result of this discussion was a proposal to be discussed with the ICES/IOC Working Group on Harmful Algal Bloom Dynamics on setting up a meeting of a few days with taxonomic experts to check available checklists for most of the ICES subregions.

A list of known checklists and phytoplankton identification literature was produced during last years meeting of the Working Group on Phytoplankton Ecology. This list was extended further (Annex 10). The WG decided that also species lists of phytoplankton that are not published, but in use in different laboratories should be made available, as they are of great value in the development of lists covering the entire ICES area. In case these lists were not yet available they could be before the experts meeting in winter 1998–1999. A discussion with Henrik Enevoldsen (IOC) showed that

IOC is also interested in this activity and might be willing to support it. The checklists however should be available before the experts convene. Speed is needed for this activity because some experts will be retired soon (e.g., Drebes) and working up material later is difficult and not guaranteed. The chairman will ask permission from the RIKZ in the Netherlands to use their material to compile a Dutch checklist with the help of TRIPOS.

The Working Group on Phytoplankton Ecology then discussed possible ways of preparing a practical „ICES Checklist of Phytoplankton" and its contents. It was agreed that *practical* in this case means - what is possible to produce now. When having made the „ICES Checklist of Phytoplankton" several smaller checklists, covering regions should be extracted. Examples of such regions are: the Baltic Sea, the Kattegat and Skagerrak, the North Sea, the waters around the British Isles, the French waters, Iberian-Atlantic waters, Icelandic waters, St. Lawrence Estuary, Canadian Atlantic waters, north-east USA waters, south-east USA waters.

The possible role of the ETI in Amsterdam (Expert Taxonomic Institute) which had been involved in setting up the former Linnaeus CD Rom was mentioned several times. Upgrading and extension of the work done would be very appreciated. Several members suggested to try to encompass much more than before electronic media for exchange purposes (electronic www checklist; transmission of electronic/ video pictures etc.). Accreditation of phytoplankton analysis requires reference material. This is accomplished by saving computerised pictures which may be checked by taxonomic experts regularly. A further suggestion was to add to the electronic species list eco-physiological details on species. However this would certainly enhance the amount of work considerably.

The work of compiling, adding synonyms and checking the validity of the checklist is a heavy workload, the idea of applying for an EU project was therefore discussed. As several bodies, such as IOC/UNESCO, ICES, OSPAR and HELCOM have a considerable interest in a useful checklist support from these bodies can be anticipated.

It was further agreed that the coding of species is a technical and not a taxonomic problem and should be solved by computer experts in consultation with phytoplanktologists.

Lars Edler will try to compile during the meeting any further extensions to the list given in last year report (see Annex 10). That should be the basis for the material to be checked by the experts. Several members reported about lists which were under construction. Finally publication of the list in the ICES Journal of Marine Science was strongly supported.

All members will give input to this TOR. Recommendations on the proposed meeting were formulated and are given in Section 6.

b) propose a mesocosm experiment to investigate new approaches in phytoplankton ecology, in a joint meeting with the ICES/IOC ICES/IOC Working Group on Harmful Algal Bloom Dynamics (see report section under 4);

Before discussing this item with the ICES/IOC Working Group on Harmful Algal Bloom Dynamics the chairman invited the members to come up with suggestions to formulate such a mesoscosm experiment, which not necessarily needs to be performed together with the ICES/IOC Working Group on Harmful Algal Bloom Dynamics. However to improve cooperation and use expertise from both groups it would be useful to discuss it together. Several suggestions were made on the principal questions to be raised and which could function as a hypothesis to be tested. One of the possibilities which obtained a lot of support was to test the causes and meaning of diel variability in phytoplankton processes. By setting up this experiment with a species relevant for the ICES/IOC Working Group on Harmful Algal Bloom Dynamics it might well be possible to perform this together. The outline of a possible experiment were set by T. Smayda. His suggestions are the following:

Proposal for an experiment

Diel periodicity in flagellates - causes and consequences

Background

The periodicity observed in natural populations of phytoplankton is largely a result of entrained signals which have both a biological and a physical component. Diel periodicity in diatom dominated population results primarily from the interaction between fluctuation at the cellular level and physical forcing. Periodicity in flagellate dominated populations are further complicated because of the additional behavioural component and our understanding of flagellate bloom dynamics is therefore limited.

Objectives

- to identify the sources of variability in observed diel periodicity in flagellates
- to determine critical rate processes and activities
- to determine and critically evaluate the role of physical forcing with special emphasis on light

Rationale and approach

Observed diel variability with a biological cause include motility and migration, circadian rhythms in cell divisions, photosynthetic parameters, cell cycle (e.g., C:chl), changes in specific gravity and grazing. Physical forcing likely to impact upon short term changes include, light, and mixing and also nutrient regime.

In particular, the role of light is seen as critical with a particular advantage of mesocosm approach being natural irradiance. The natural light field has a number of elements, intensity, photo-period and quality (wavelength). Irradiance level is critical for photosynthesis, photo-period for cell division and light quality impacts upon both. Light also has other unique attributes in contrast to all other physical factors. It cannot be mixed, it is the only variable to fall to zero (excluding moonlight) and it is 'recharged' daily but not always to the same level.

An important aspect of this study will be to ensure that a sufficiently intense vertical gradient in light and nutrient (macro and micro) concentration are developed to allow development of a range of growth conditions (niches). This will allow the major behavioural component (vertical migration) to be studied.

A key element of our approach will be to ensure that sampling frequency is sufficient to resolve the variability of critical parameter in time and space. This implies some measurements will have time scales of < 1 minute and vertical resolution of < 10 cm.

Benefits

Such a study would benefit both observational and modelling studies of flagellate (possibly harmful) bloom dynamics. Many observational programmes rely upon simple, low frequency measurements to characterise the state of growth and the associated physical-chemical environment of phytoplankton populations. Our confidence in such measurements is limited by our awareness of rapid change in some of these parameters in space (depth) and time (sub-daily). Future observational programmes could, therefore, be better designed in terms of sample frequency (both in space and time) and choice of parameters.

Better understanding of rate processes and activity would lead to improved diagnostic models of flagellate bloom dynamics with 'fingerprinting' (identifying external conditions which select for a particular species) contributing to the development of prognostic models with the potential to predict development of flagellate blooms.

A spin-off of this work is that we will use the opportunity to evaluate a range of newly emerging (bio-optical) techniques to provide information on state (e.g., chlorophyll biomass, accessory pigment concentration) and rate (ϕ, α, Pb) variables. These techniques also have the advantage of providing the high frequency (spatial and temporal) measurements already identified as of particular interest in this study.

Problems to be addressed

Based on initial feedback from the Working Group on Phytoplankton Ecology members a number of issues have been raised and are outlined below.

- how do you collect large samples with out disrupting vertical structure
- how do we ensure the development of a population of flagellates (natural vs cultured)
- the presence of a nutrient rich aphotic zone is desirable
- dimensions of the mesocosm are critical if naturally generated turbulence is desired
- how will the work be funded and where will it be carried out

A table is attached outlining the possible sites for such an experiment. The list is not exhaustive and will be completed later. Funding for travel and subsistence could be secured by opting to use a mesocosm designated as a Large Scale Facility by the EU.

Although an exhaustive literature search is still outstanding it is clear that new developments in technology for making measurements in the sea (and therefore mesocosms) and emergence of new disciplines (e.g., molecular biology) will enable us to carry out our investigation with advantages over previous work. These developments are particularly significant in biology and chemistry where through the use of novel sampling (intelligent′ water samplers), high frequency electronic sensors and (bio-) optical techniques (e.g., FRRF, UV nitrate sensors) we can resolve differences in the vertical of < 10 cm. These technologies, in particular, bring us into the same realm as physicists in being able to resolve very small vertical differences. Furthermore, these fine scale measurements will include rate and state variables, critical in the approach to this study. A further advantage of such techniques is there ability to resolve rapid changes in time when used at a fixed point. Judicious use of such techniques in this proposed work will provide detailed and matching spatial and temporal variability of physical, biological and chemical parameters within our mesocosm. It is unlikely that such an approach has been taken elsewhere.

Although many questions remain to be addressed the nature of the mesocosm and its potential vertical physical structure are crucial. Clearly we envisage a mesocosm with vertical gradients that allow the development of specific niches for flagellates. Dimensions of the mesocosm are likely to be critical in facilitating the development of such gradients and we can learn from previous work. Although, we would wish to allow the natural development of vertical gradients we may have to consider intervening to artificially generate such conditions. These considerations will play an important part in determining the feasibility of the mesocosm approach and require attention at an early stage in the design of the experiment.

In deciding what constitutes a successful outcome to the proposed work we need to consider whether we require specific information about targeted species or whether we are more interested in a generic approach. Perhaps the answer to this question will reflect the interests of the two working groups. There are obvious advantages and disadvantages for both approaches. Generic conclusions may have wider significance although interpretation with respect to particular species is likely to be more difficult. In contrast, targeted work may yield valuable insights on particular species but may be of limited value to the wider community. Clearly, our strategy need to be thought through carefully. Finally, it is worth noting that a successful experiment could be carried out with either a toxic or non-toxic species.

Another suggestion made by Wolfgang Hickel was to use a mesocosm to control growth conditions in such a way that potential toxic species do form toxins. *Chrysochromulina* would be a good candidate for such a study.

Before making recommendations on a repeated mesocosm experiment under ICES responsibility/flag our ideas were discussed in a joint session with the ICES/IOC Working Group on Harmful Algal Bloom Dynamics, where several comments on the mesocosm experiment were made (see Report on Joint Meeting including Agenda, Topic 4, and Annex 12).

c) identify and discuss methods for the measurement of phytoplankton biomass, production and growth rate in situ, and its identification, including QA procedures;

The Working Group on Phytoplankton Ecology has been active in this field over the last years. The chairman had listed in the annotated agenda the main items on which the WG had worked: the standardisation of the ^{14}C method for monitoring purposes; the standardisation of the chlorophyll a measurement and introduction of new promising techniques in phytoplankton ecology like fluorescence methods to study photosynthesis and flowcytometry to study phytoplankton species identification.

-1. Measurement of phytoplankton biomass: chlorophyll a.

The Working Group on Phytoplankton Ecology has again discussed the matters related to the development of a standard procedure for the measurement of chlorophyll *a* in seawater, although it was not on the meeting's terms of references. This was due to a communication from the ICES Marine Chemistry Working Group, including a document on the measurement of chlorophyll *a* prepared by Alan Aminot from IFREMER, that was made available to the Working Group on Phytoplankton Ecology for comments,. The document agreed in most part with the recommendations from the Working Group on Phytoplankton Ecology report form 1997, except on the subject of storage of the filters. The Working Group on Phytoplankton Ecology recognised the fact that storage at -20 ° C is indeed a good storage procedure easily to recommend when only chlorophyll *a* is being measured since no phaeopigments were produced during the different forms of storage. This fact was already recognised in the 1997 Working Group on Phytoplankton Ecology meeting but it did not come clearly forward in the report. Some others comments were also made, mainly regarding different suggestions on the Quality Assurance procedures.

At the meeting it was also reported that contact have been made with Dr Shirley Jeffrey from the SCOR WG 78, who was the main scientist behind the UNESCO book (Phytoplankton pigments in Oceanography, 1997) on which most of the information that leaded to the recommendations of both ICES WG was based on. Dr Jeffrey has promised to continue her work on the development of an equation for chlorophyll *c* in methanol. This together with recently improved equations for chlorophyll *a* and *b* will make it possible to develop the same kind of trichromatic equation as for 90 % acetone and provide the means to carry out a thorough comparison of both extract solvents as suggested by the 1997 meeting.

The Working Group on Phytoplankton Ecology recommends also to establish contact with the Marine Chemistry Working Group in order to propose working together by mail in producing a common document that includes the recommendations and opinions of both groups, specially regarding QA procedures. This work should start as soon as possible in order to have the document ready for the Oceanography Committee well ahead of the Annual Science Meeting to be held in September in Portugal. After approval by ICES, the document will also be made available for other scientific communities as OSPARCOM and HELCOM.

-2. Measurement of primary production: a standard incubator protocol and device.

Within the ICES community there is a very strong interest in ^{14}C production measurements with the newly developed incubator and standard measuring protocol. The protocol has once more been distributed and a few additional remarks were made for improvement. However, the manual was not meant for further additions in the procedure because it would bring us away from the 'simple and inexpensive incubator`. However Lars Edler and the chairman were willing to incorporate some of the remarks as alternative options in the manual. Also a few other details will be reconsidered. Together with the Annexes the manual will go to ICES for publication; a strong plea was held to combine the procedure with a standard calculation based on software available for everyone using the method. Addresses of interest for users of the method will be made available by the editors of the method. Drafts of the Manual and annexes will be made available through photocopies and if possible through the FTZ website, as long as the procedure has not been published officially (The Manual and Protocol are printed as Annex 7)

-3. Measurement of species composition: identification by flowcytometry.

Based on last years report the chairman had invited two Dutch colleagues (Dubelaar and Jonker) to write a state of the art paper on the possibilities of flowcytometry in the identification of phytoplankton. The paper is presented as Annex 8.

-4. Advanced plankton monitoring and smart moorings.

Dave Mills presented information on attempts to improve the monitoring of plankton, by updating the continuous plankton recorder with new sensors, and by using smart moorings. The information is copied as Annex 11 (two pages).

Finally it was decided to prepare for next years meeting a document on the state of the art of fluorescence measurements (F. Colijn) and on the growth of phytoplankton (T. Smayda).

d) discuss and exemplify effects of anthropogenic inputs of nutrients including changed nutrient ratios over time on the phytoplankton community, with special emphasis on phytoplankton bloom development and phytoplankton community changes;

The American East coast

A clear linkage between increased algal bloom events and nutrient enrichment has not been established for the coastal waters of the eastern United States. Certainly, novel blooms and harmful and benign species have occurred, just as nutrient-enriched coastal waters are recognisable. But these blooms and nutrification sites are not identical. There is currently growing concern, however, over a possible linkage between agriculturally derived nutrification and blooms and the notorious ichthyotoxic, and associated hazard to public health, species, *Pfiesteria piscicida* in Chesapeake Bay and North Carolinean estuaries. However, the evidence at best, is anecdotal and awaits verification in the form of a quantitative, year-round study in representative nutrient enriched and pristine habitats within the known geographical range of bloom events of *Pfiesteria.* (e.g., Burkholder & Glasgow, 1997).

The Baltic Sea

In spite of all protection measures taken by all countries around the Baltic Sea, the sea reflects the changes very slowly. Based on the results of the Third Periodic Assessment of the State of the Marine Environment of the Baltic Sea, some improvement of the environmental situation was observed.

In the beginning of the 1970s a strong increase in phosphorus and nitrogen concentrations was observed. By the early 1980s the results of rapid nutrient increase became a problem in many areas around the Baltic Sea. Intensive algal blooms indicating increasing eutrophication appeared to occur more frequently. There was evidence that phytoplankton primary production had doubled in the area from the Kattegat to the Baltic Proper, with a similar doubling of phytoplankton biomass and its subsequent sedimentation. Consequently, low oxygen concentrations in late summer and autumn were often observed in the southern Kattegat, the Belt Sea, the Sound and the Arkona Basin in the 1980s, resulting in increased mortality of demersal fish and benthic organisms.

Nitrogen inputs display considerable year-to-year variations since they depend on river run-off and atmospheric deposition. The land-based inputs are assumed to have decreased slightly since the 1980s while the atmospheric inputs are still increasing. The phosphorus inputs have decreased significantly during the past decade and this tendency is continuing in most areas of the Baltic Sea.

However, despite first indications of decreasing winter nutrient concentrations in the Arkona and Bornholm Seas, in the Gulf of Riga and, in particular, in several coastal regions, the drastic reduction in fertiliser usage since 1989/1990 has not yet been significantly reflected in the Baltic Proper. The symptoms of eutrophication have decreased in some coastal areas where the reduction of nutrient inputs has been substantial. However, in the open sea areas no clear changes have so far been observed.

With respect to long-term variations, there were no major differences in the dominance of phytoplankton species between the three assessment periods 1979–1983, 1984–1988 and 1989–1993. There are indications that the frequency and spatial coverage of harmful blooms in the Baltic Sea may have increased. This may be partly due to changes in the seasonal availability and relative proportions of nutrients.

Nitrogen or nitrogen and phosphorus together are proved to be the limiting nutrients for the phytoplankton production in the Baltic Sea except the Bothian Bay, where phosphorus is the main limiting nutrient. Silicate limitation is also reported. this is expected to be the main reason for the observed dominance of diniflagellates in spring. Low N:P ratios are promoting the development of nitrogen fixing blue-green algal blooms.

Model calculations and experimental studies in laboratory and in the sea show that both nitrogen and phosphorus inputs are to be reduced in order to counteract eutrophicatioin in the Baltic Sea.

The Swedish coast - Baltic Sea

In the Archipelago south of Stockholm (Himmerfjärden) in the Baltic, large scale and long-term experiments have been carried out studying the effects of changing nutrient loadings and ratios on the ecosystem (Elmgren and Larsson, 1997). The results on the phytoplankton community demonstrated that some of the dominating species reacted with a large increase in abundance when nutrients were increased. Further, the species diversity was affected so that the occurrence of rare species became much more variable compared to the occurrence of the dominating species. The main result of the input of nutrients was an increased phytoplankton biomass. The Himmerfjärden study also demonstrated very clearly the importance of the weather on the variability of the phytoplankton community. Several of the observed changes in the phytopankton variability were observed both on the nutrient impacted and the control station, supporting the idea that weather can pose much on the variability. Therefore the importance of long time series with frequent sampling including reference areas is stressed. Only in this way effects of weather variability and anthropogenic effects on phytoplankton communities can be separated.

The Sweden coast - Kattegat/Skagerrak

In autumn 1997 – winter 1998 the worst situation regarding the deep oxygen concentration and the negative effects on the benthic fauna was observed in the archipelago along the north western coast. This situation was probably the result of a high organic load in combination with the unusual warm and nice summer of 1997. As a result, there is an ongoing debate on how important the anthropogenic input described above has been in relation to the weather and long term climatological variability. The long term decline in oxygen concentrations in the deep water (Rosenberg, 1990) in combination with the results on increasing annual primary production during the period 1985 – 1995 (Lindahl, 1995) most likely indicates that the input of anthropogenic compounds is too large, at least during periods of negative influence of weather conditions and/or long term climatological variability. However, at present there are no results on the phytoplankton biomass and the species variability/occurrence which directly can support the effects of the anthropogenic nutrient inputs.

The German Bight

From long term time series in the German Bight (Helgoland) carried out since 1962, it appears that:

- eutrophication could be clearly measured, in the way as summarised in the 1997 Working Group on Phytoplankton Ecology report. The main features were a 3–4 times increase in nitrate concentrations at Helgoland (inner German Bight) but only a doubling of phosphate concentrations. While phosphate decreased again since 1984, nitrate is still on the rise. A large increase in N:P ratio resulted.

- the effects of increasing levels and N:P ratios on phytoplankton could not be shown at Helgoland to the expected level, however. Diatoms did not increase, only flagellates did. When separating size classes, only nannoplankton < 20 micron, mainly < 10 micron, was responsible for the increase.

- large phytoplankton blooms in the outer German Bight suggested that a large impact of eutrophication was found there, because of improved light conditions in the water column. These locations however, are outside the reach of the daily sampling scheme at Helgoland.

- this leads to the recommendation that a more efficient monitoring program must be based on the hydrographical structure of the German Bight, not only on the appropriate sampling frequency in time. This is particularly true considering the sites of the other German monitoring stations, which are in the narrow coastal strip which receives the river water and is permanently mixed due to tidal currents.

Waters around the UK

A 3 year programme assessing the offshore effect of anthropogenic nutrient input to UK coastal waters (JONUS II) will be completed in April 1999. The work focuses upon the Thames and Southern Bight of the North Sea and the Irish Sea and will examine the response of the pelagic ecosystem to nutrient input.

In the Irish Sea 3 areas have been sampled during 1996 - 97 which differ in their nutrient loading, Liverpool Bay, Dundalk Bay and a deep seasonally stratified site in the north western Irish Sea. Highest biomass and productivity during the spring bloom were associated with the highest winter input of nutrients (approx. 30 µM) in Liverpool Bay. Next highest biomass levels were found in Dundalk Bay (15.0 µM). Copepod abundance showed an inverse relationship with peak biomass such that lowest numbers were found in Liverpool Bay. Size fractionated biomass and production measurements showed that large cells (> 5.0 µm) dominated biomass (> 95 %) and productivity in Liverpool Bay. Diatoms and later Phaeocystis sp. dominated the spring bloom in Liverpool Bay, whilst diatoms dominated in Dundalk Bay. At the stratified site silicoflagellates appeared to dominate the spring bloom in 1997.

In the southern North Sea our 3 sample sites lay along a gradient of dissolved inorganic nutrient loading (about 30 - 15 µM) from the mouth of the R. Thames to the southern Bight. There is a clear decline in chlorophyll biomass and production along this gradient with small (< 5.0 µm) phytoplankon contributing < 30 % of the productivity at the most inshore site and > 70 % at the most offshore site. We also made measurements during the winter and demonstrated the presence of viable photosynthesising populations at our most turbid and cold (< 1.0°C) inshore site that were capable of gross photosynthesis. We were unable to detect respiration raising the interesting possibility of net production occurring under some circumstances in the winter.

Dutch coastal waters

Based on the manuscript for the ICES J. Mar. Science (Plankton Variability Symposium Kiel, March 1997) a summary of the most recent findings for the Dutch coastal zone are included (by courtesy of de Vries *et al.*).

In the Dutch coastal zone, nutrient and chlorophyll concentrations show gradients up to one order of magnitude perpendicular to the coast within a zone of 0 km to 30–50 km offshore. Time series analysis reveals significant decreasing trends for dissolved inorganic phosphorus (40 %) and total-phosphorus (35 %) and an increase of the dissolved inorganic N/P -ratio from 25–30 to 40–55 mol/mol in the period 1988–1995. Other trends, e.g., nitrogen (-15 %), silicate (stable), and chlorophyll are smaller and mostly not statistically significant. The trends in phosphorus reflect a proportional and immediate response to decreasing riverine inputs.