ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES

NO. 244

Report of the
Workshop on Gadoid Stocks in the North Sea during the 1960s and 1970s
The Fourth ICES/GLOBEC Backward-Facing Workshop

Aberdeen, UK
11–13 March 1999

M. R. Heath and K. Brander (Editors)

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

Palægade 2–4 DK-1261 Copenhagen K Denmark

April 2001

ICES Cooperative Research Report No. 244

ISSN 2707-7144
ISBN 978-87-7482-420-6

https://doi.org/10.17895/ices.pub.5382

TABLE OF CONTENTS

Section **Page**

TABLE OF CONTENTS

Section **Page**

ABSTRACT

The Fourth ICES/GLOBEC Backward-Facing Workshop was held in Aberdeen, UK during 11–13 March 1999. The Workshop was commissioned by the ICES Working Group on Cod and Climate Change to examine the possible causes of the ‘gadoid outburst’ in the North Sea during the 1960s and early 1970s.

The Workshop assembled an inventory of data on climate, physical oceanography, plankton and fisheries during the latter half of the 20th century, and conducted a preliminary analysis of trends and patterns.

A set of hypotheses to account for the gadoid outburst in the North Sea was formulated, and each was examined with reference to the available data.

The main conclusions of the Workshop were:

- All four of the major gadoids in the North Sea showed extremes of recruitment in the 1960s and increased catch rates.
- A number of oceanographic characteristics distinguish the 1960s decade from the periods before and after, and appear to be related to the North Atlantic Oscillation (NAO).
- There is some correlation between what happened to the gadoid stocks in the 1960s, the NAO and sea temperatures, but no causal processes could be identified.
- There is a lack of comprehensive understanding of the functioning of the North Sea ecosystem under different climatic conditions and very few systematically collected data on fish early life stages from the relevant periods. Nevertheless, there is a clear holistic relationship between recruitment of cod, in particular, and the NAO.

1 Overview

1.1 Background to the workshop

The Fourth ICES/GLOBEC Backward-Facing Workshop was held in Aberdeen, UK during 11–13 March 1999. The Workshop was commissioned by the ICES Working Group on Cod and Climate Change, with terms of reference set out in ICES Council Resolution 2.22 (C.Res.1998/2.22) (Appendix 1).

The objective of the Workshop was to examine the causes of the increases in abundance of gadoid fishes in the North Sea which occurred during the 1960s and early 1970s, an event which has been referred to as the 'gadoid outburst'. The Workshop followed the pattern established by previous Backward-Facing Workshops by using a combination of retrospective analysis, new process studies and modelling in order to interpret the causes of past population events. Previous workshops have investigated the tilefish kill during 1881/82 in the Northwest Atlantic (Backward-Facing I; ICES CM 1995/A:7), the changes brought about by a cold period in the Barents Sea and Baltic (Backward-Facing II; ICES CM 1996/A:9), and the gadoid outburst in the Northwest Atlantic (Backward-Facing III; ICES CM 1998/C:9 and ICES Cooperative Research Report 234).

The Workshop reported to the Working Group on Cod and Climate Change (WGCCC), to the Oceanography, Resources Management, and Living Resources Committees at the 1999 Annual Science Conference, and to the Advisory Committee on Fisheries Management (ACFM) at its May 1999 meeting.

1.2 Preparations for the meeting

In the lead up to the meeting an electronic bulletin board was set up on the ICES Internet site (www.ices.dk/globec) to disseminate data sets of interest and establish some exchange of ideas on possible causes on the gadoid outburst. A number of individuals who were unable to attend the workshop in Aberdeen were able to contribute to the discussions in this way.

The layout and content of the bulletin board as at the start of the Workshop was as follows:

- **Data Inventory and Analysis**
  - North Sea fish data and analysis – Keith Brander
    - North Sea Catch data from the 1997 ACFM report
    - Annual recruitment, biomasses, fishing mortality etc. for the four gadoid species and others
    - Age structured data on weight, numbers etc. for the four gadoid species and others
  - Data on the NAO and other climate information – Bob Dickson
  - Hydrographic data and products – Harry Dooley
  - Haddock and stratification, temperature and salinity – Beth Scott
  - CPR data 1948–1997 – Andy Warner SAHFOS
  - Cod, haddock and whiting since 1920 – John Pope

- **Discussion of Hypotheses**
  - Small effect on shelf export of sedimentation loss-rate as independent forcing – Soren Floderus
  - Match-mismatch and spring bloom timing – Keith Brander
  - Calanus transport and effects of variable inflow – Keith Brander
  - Correlations with climate, NAO, temperature etc. – Keith Brander
  - Temperature during gonadal maturation – Uwe Lange
  - Cod recruitment and temperature – Keith Brander
  - Interactions with pelagic fish stocks – Keith Brander
  - Comment on causes – Niels Daan
  - Fisheries and Multispecies Interactions – Keith Brander
  - Trophic cascading and the gadoid outburst – Chris Reid

- **Notices about the meeting**

A total of 20 participants attended the Workshop (Appendix II) and a further 6 contributed by correspondence on the bulletin board.

1.3 Summary of the outcome of the workshop

- All four of the major gadoids in the North Sea showed extremes of recruitment in the 1960s and increased catch rates.
- A number of oceanographic characteristics distinguish the 1960s decade from the period before and after, and appear to be related to the North Atlantic Oscillation (NAO).
- There is some correlation between what happened to the gadoid stocks in the 1960s, the NAO and sea temperatures, but no causal processes could be identified.
- There is a lack of comprehensive understanding of the functioning of the North Sea ecosystem under different climatic conditions, and very few systematically collected data on fish early life stages from the relevant periods. Nevertheless, there is a clear holistic relationship between recruitment of cod, in particular, and the NAO.

The full report from the Workshop was produced as a document at the ICES Annual Science Conference in 1999 (ICES CM 1999/C:15). Those aspects concerned with the North Sea have been further collated and are presented in this Cooperative Research Report.

2 What was the gadoid outburst and why is it important?

Catches of the four main gadoid species, particularly haddock, increased during the 1960s to by far the highest levels ever taken (Figure 2.1). The increased catches were due to increased fishing pressure, but also to increased stock levels (Figures 2.2–2.5). An increase in stock during a period of rising fishing pressure is extraordinary and it came about in this case because of good recruitment over a number of years. The aim of the workshop was to determine the processes, which may have governed the observed high levels of gadoid recruitment.

The years in which good recruitment took place are not the same for all four species of gadoid, nor is the period of years during which recruitment was high. It is therefore not possible to demarcate the beginning and end of the "gadoid outburst" clearly. Since it is difficult to demarcate the time period of the event, the question of whether it makes sense to talk about a "gadoid outburst" at all was discussed. In relation to the catch history, it certainly makes sense to talk about a gadoid outburst. In relation to the time series of recruitment the evidence that something different was happening is also reasonably convincing (Figure. 2.6), although the picture is by no means uniform for the four species. If one considers recruitment/spawning stock biomass to be an index of survival, then the evidence for something different happening during the gadoid outburst is not good. In fact this index has remained high or even increased ever since.

There are several reasons why it is important to continue to study the “gadoid outburst". Even though it happened thirty years ago it continues to play an important part in the scientific basis for current advice on the strategy for managing North Sea fisheries, because the strategies are based on interpretations of the causes of the recruitment observed during this period. The high levels of recruitment in the 1960s and 1970s took place during a period when spawning biomass was higher than it is now and some stock - recruit models predict that recruitment would increase if spawning biomass increases. However, if part of the reason for the high recruitment during the "gadoid outburst" was because other conditions were particularly favourable, then the prediction is faulty. So a task for the workshop was to explore whether “other conditions” may have contributed to the high recruitment and whether any of these “other conditions” are susceptible to control or can themselves be explained and predicted.

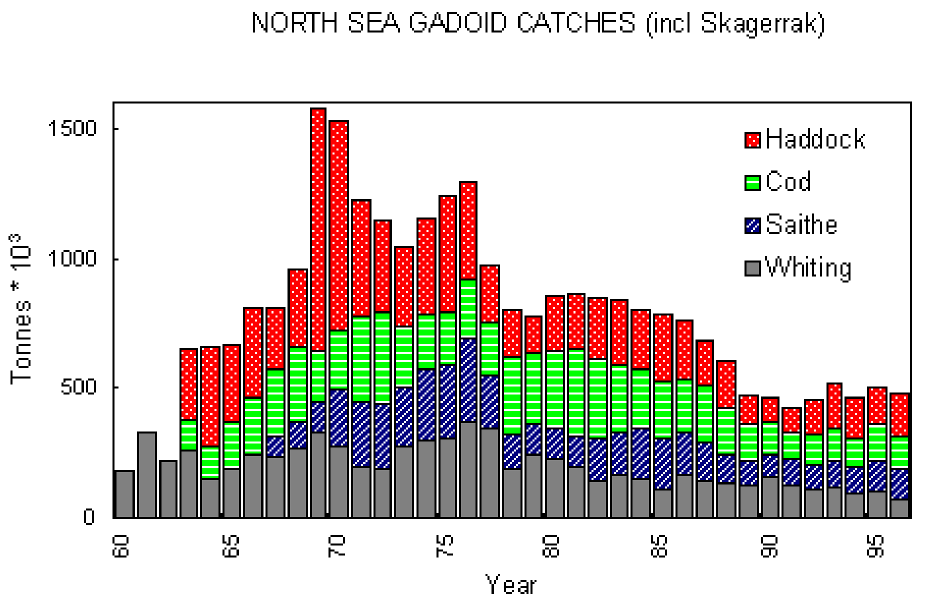

Figure 2.1. Landings of the four main commercially exploited gadoid species in the North Sea.

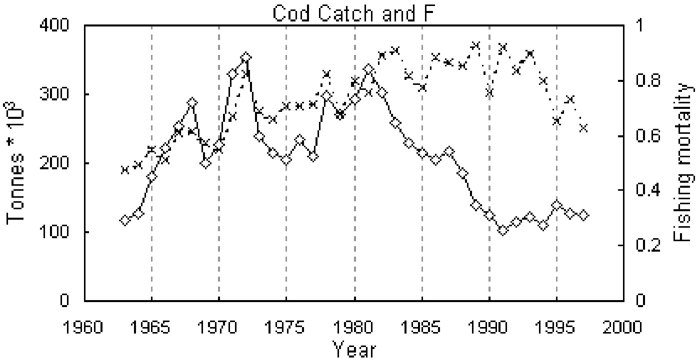

Figure 2.2.a

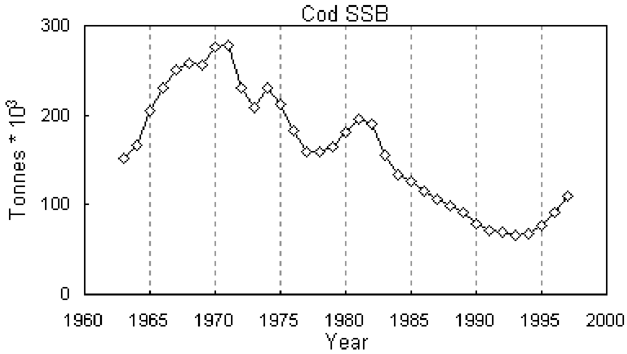

Figure 2.2.b

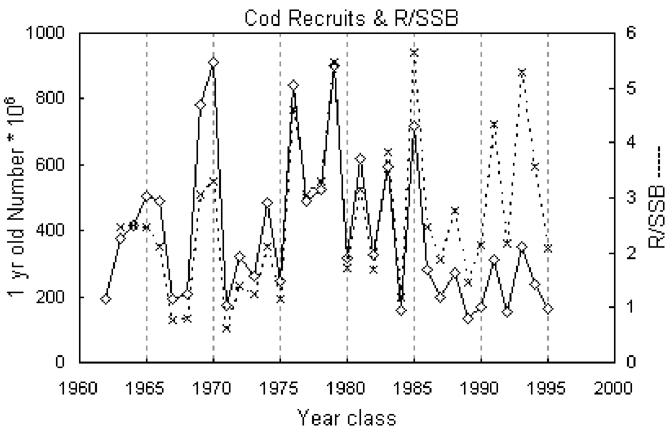

Figure 2.2.c

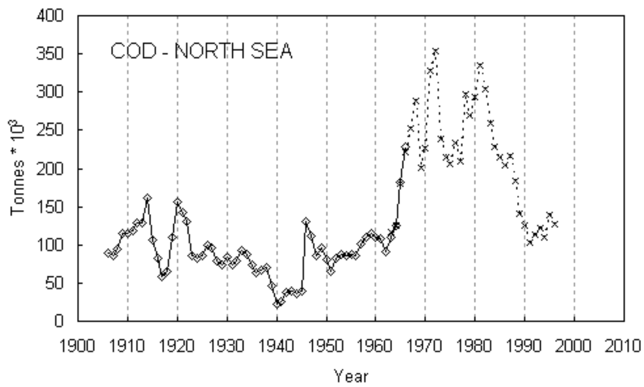

Figure 2.2.d

Figure 2.2. North Sea cod stock histories. a) landings and fishing mortality (dashed line), b) spawning stock biomass estimated from Virtual Population Analysis, c) recruitment and an index of early life stage survival (recruitment/spawning biomass), d) extended time series of landings data from various sources.

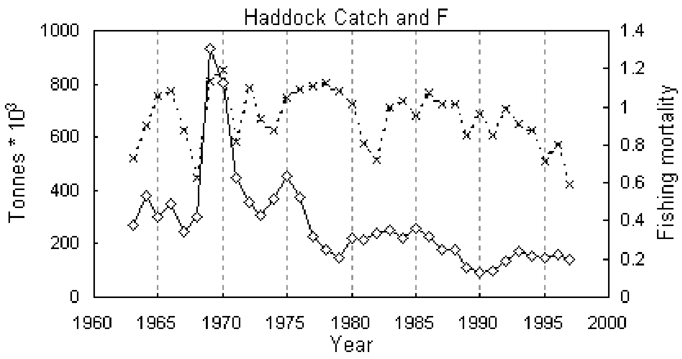

Figure 2.3a

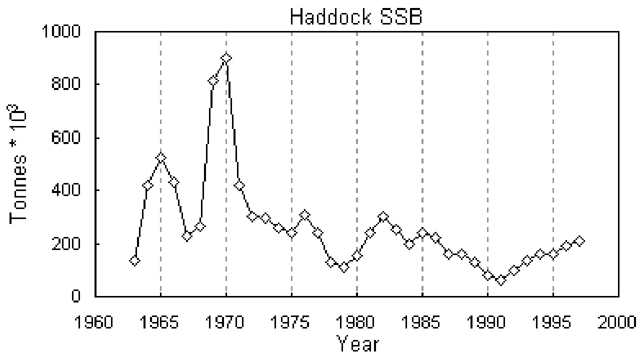

Figure 2.3.b

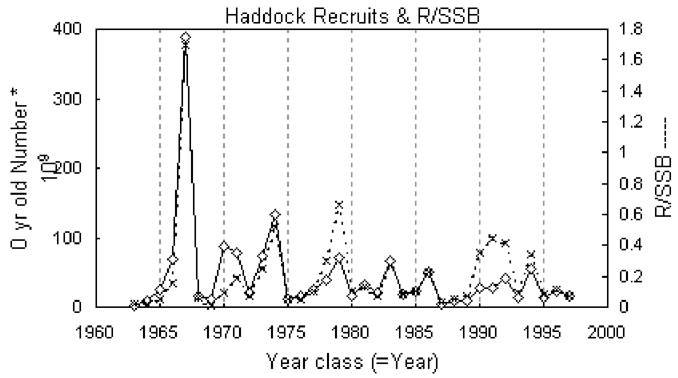

Figure 2.3.c

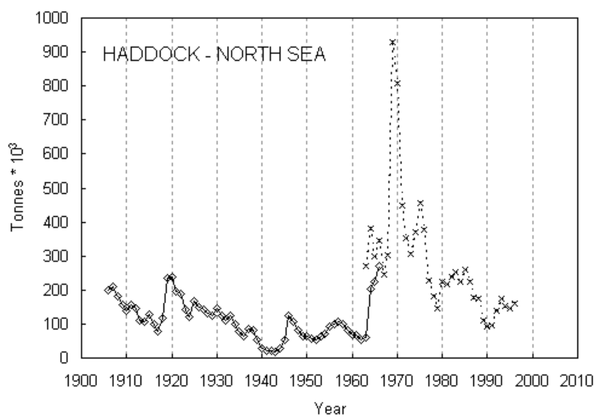

Figure 2.3.d

Figure 2.3. North Sea haddock stock histories. a) landings and fishing mortality (dashed line), b) spawning stock biomass estimated from Virtual Population Analysis, c) recruitment and an index of early life stage survival (recruitment/spawning biomass), d) extended time series of landings data from various sources.

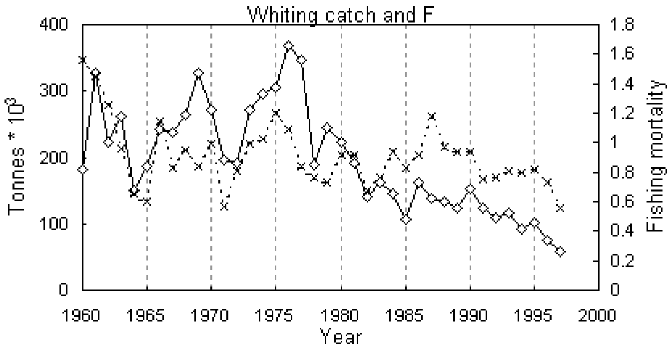

Figure 2.4.a

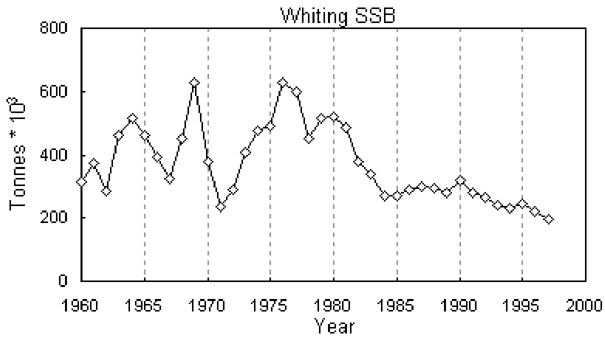

Figure 2.4.b

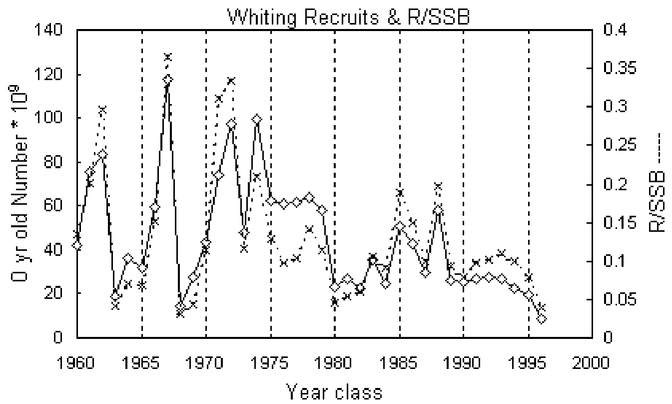

Figure 2.4.c

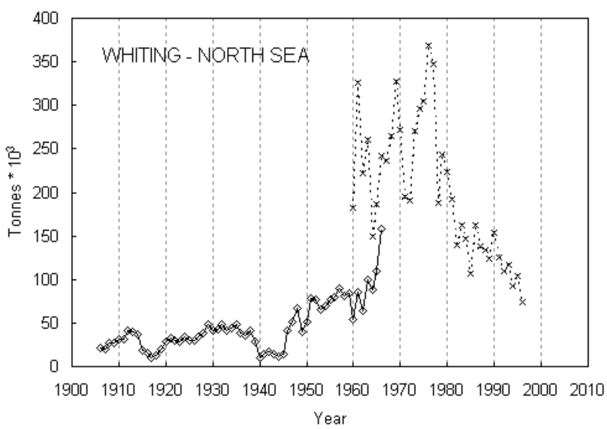

Figure 2.4.d

Figure 2.4. North Sea whiting stock histories. a) landings and fishing mortality (dashed line), b) spawning stock biomass estimated from Virtual Population Analysis, c) recruitment and an index of early life stage survival (recruitment/spawning biomass), d) extended time series of landings data from various sources.

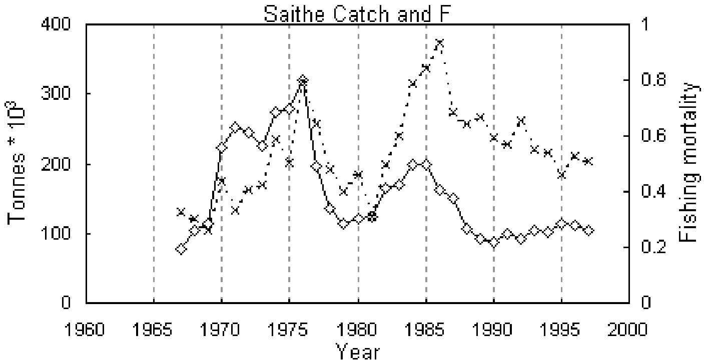

Figure 2.5.a

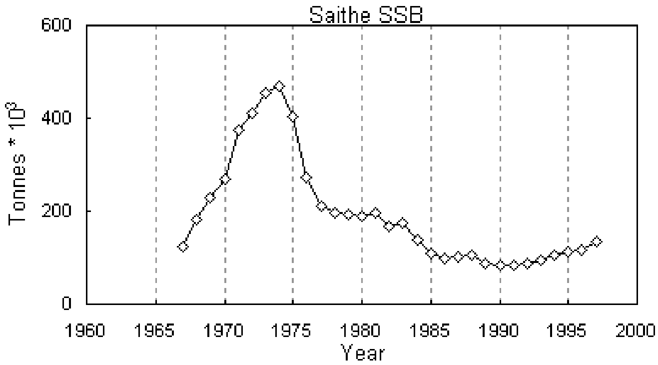

Figure 2.5.b

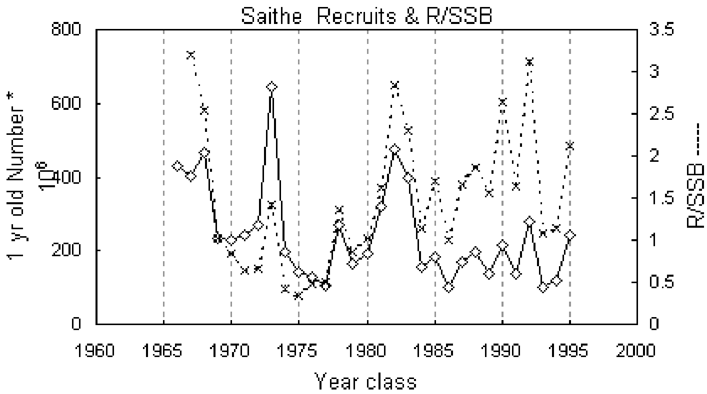

Figure 2.5.c

Figure 2.5. North Sea saithe stock histories. a) landings and fishing mortality (dashed line), b) spawning stock biomass estimated from Virtual Population Analysis, c) recruitment and an index of early life stage survival (recruitment/spawning biomass).

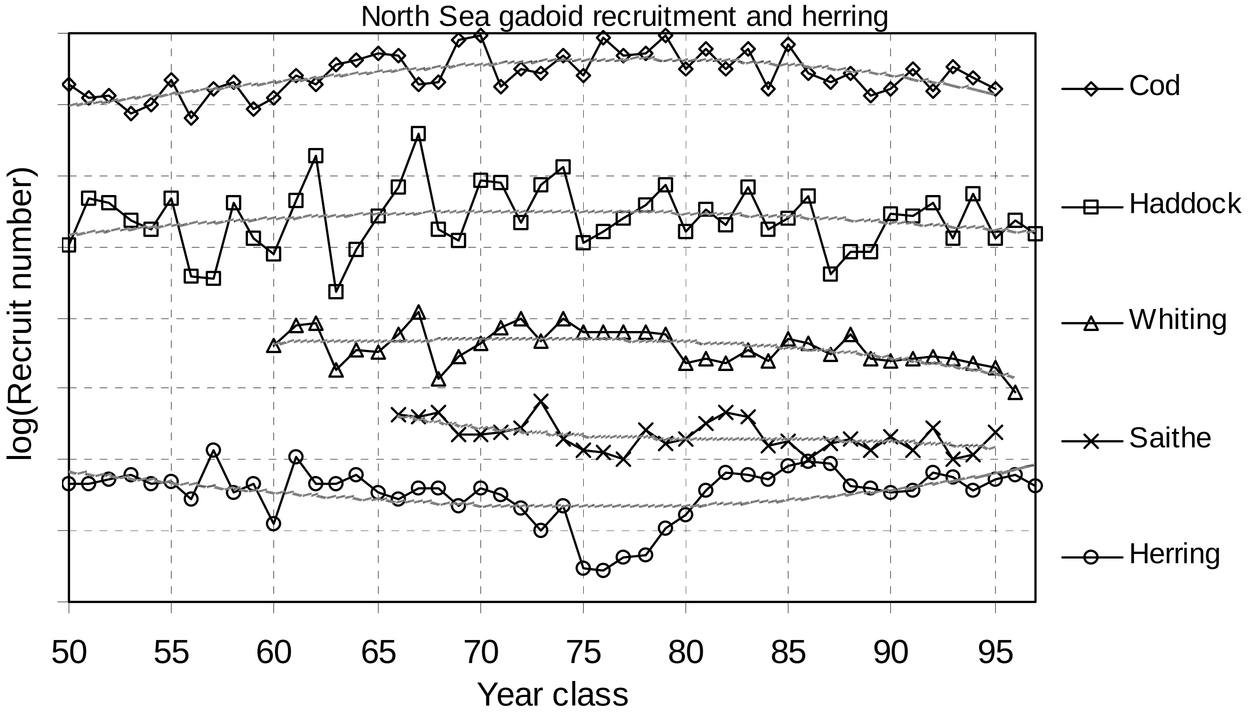

Figure 2.6. Recruitment data from 1950 onwards, for the North Sea gadoid species.

3 Summary of the biology of gadoid fish in the North Sea

At least eighteen species of gadoid fish occur in the North Sea. However, fisheries scientists tend to concentrate on five species (cod, haddock, whiting, saithe, and Norway pout) all of which are commercially exploited and, perhaps more importantly, are subjected to an analytical stock assessment (VPA) which means that estimates of their absolute abundance in the entire North Sea are available.

These species have a number of life history traits in common:

- They produce relatively small pelagic eggs.
- Their fecundity is high.
- They are serial (batch) spawners.
- The spawning season, both of individual fish and the species as a whole, is prolonged.
- There is an initial pelagic phase that lasts for several weeks.

However, there are several major differences between the five species. These differences must be taken into account when attempting to relate environmental events to the atypical patterns of recruitment that characterised the “gadoid outburst”, i.e. a given event will not affect all gadoids in the same way.

3.1 Area of distribution (including spawning areas)

Cod and whiting are distributed over the whole North Sea. The populations in the southern North Sea are probably distinct from those north of the Dogger Bank. In contrast, haddock and Norway pout are more or less absent from the southern North Sea. There may be distinct spawning groups of cod, haddock and whiting within the northern and central North Sea. Juvenile and adolescent saithe occur in the northern and central North Sea, but the spawning adults are found mainly near the shelf slope, i.e. the northern perimeter of the North Sea. Although North Sea saithe are treated as a separate stock management unit, they should be regarded as a component of a larger population whose distribution extends along the western and northern seaboard of the British Isles. Source: Knijn *et al.*, 1993. There is a marked lack of detailed information on the location of the spawning grounds of gadoids in the northern North Sea.

3.2 Spawning season

Although there is considerable overlap between the spawning seasons of each species, the peak spawning periods differ (see Table below, derived from Hislop, 1984). For each species, spawning generally commences earlier in the southern part of its range, but the timing of cod spawning is probably related to the seasonal plankton production cycle and not to latitude or temperature (Brander, 1994).

	Jan	Feb	Mar	Apr	May	Jun	Jul
Saithe		--------------					
Cod	---						
Norway pout			--------------------------				
Haddock		---					
Whiting			--				

3.3 Nursery areas

0-group and 1-group cod and saithe occur mainly in shallow water, often close inshore. Haddock and Norway pout do not have nursery areas. The 0-groups recruit directly to the grounds occupied by the adults, in relatively deep water. 0-group whiting are widely distributed in shallower depths than those occupied by haddock and Norway pout.

3.4 Food

3.4.1 Pelagic juveniles

There is very considerable overlap in the diets of the five species in areas where they coexist. All feed mainly on crustaceans (particularly copepods), but there is evidence that different predators may exploit different prey species (e.g. *Anomalocera* were found only in the stomachs of saithe). Fish larvae are consumed by cod, whiting, haddock, and saithe, and cannibalism is known to occur during this stage in the life cycle. Haddock appear to prefer slower-moving prey such as *Oikopleura*. Sources: Robb and Hislop, 1980; Bromley *et al.*, 1997.

3.4.2 Adults

Cod and whiting feed mainly on crustaceans and fish (including haddock and Norway pout), the proportion of fish in the diet increasing with the size of the predator. Both species are cannibals. Haddock of all sizes and ages feed mainly on relatively small benthic organisms, although fish, mainly sandeels and Norway pout, are seasonally and locally important prey. Cannibalism is infrequent in haddock. Norway pout feed mainly on planktonic crustaceans. Saithe eat planktonic crustaceans and fish, including Norway pout. Sources: Daan, 1989; Hislop 1997.

Maximum size (cm)		Age at which 50% of females are mature	
Norway pout	25	Norway pout	2
Whiting	60	Whiting	3
Haddock	80	Haddock	4
Cod	>100	Cod	4
Saithe	>100	Saithe	5?

4 Summary of Northeast Atlantic climate history and environmental consequences for the North Sea

With the high gadoid yields of the 1960s and the low gadoid yields of today coinciding, approximately, with contrasting climatic states in the North Atlantic, it is relevant to consider whether some aspect of environmental change is an underlying cause. The obvious candidate for investigation is the recent behaviour of the North Atlantic Oscillation (NAO) which is the dominant recurrent mode of atmospheric behaviour in the North Atlantic sector, accounting for more than one-third of the total variance in winter sea-level pressure. The NAO is characterised by a two-cell pattern in the pressure-anomaly field with centres of action near the Icelandic Low and the Azores High. Taking the pressure difference between these two main cells as an index of its activity, the NAO is found to alternate between a "high-index" pattern, characterised by an intense Iceland Low with a strong Azores Ridge to its south, (hence strong midlatitude westerlies), and a "low-index" pattern in which the signs of these anomaly-cells are approximately reversed.

Various pressure pairs are used in calculating versions of the NAO Index. Hurrell (1995a, 1996) uses the Lisbon-Stykkisholmur winter (DJFM) index, while Jones *et al.* (1997) employ the longer instrumental records from Gibraltar and SW Iceland to extend the time-series back to 1823 (Figure 4.1). However, the pattern of NAO variability shown in Figure 4.1 will be common to any version of the index: noisy interannual variations during the 19th century and early 20th century; the development of a more-extreme and more-decadal tendency thereafter (Hurrell and van Loon, 1997), with the NAO swinging from its most extreme and persistent negative phase in the 1960s to its most extreme and persistent positive phase during the late 1980s and early 1990s; the rapid, record interannual decrease in the index between the winters of 1994–1995 and 1995–1996; the recovery to positive values since then.

Thus the period (1960s to present), contrasted by the Working Group from the viewpoint of cod yield, is also the period in which the principal atmospheric forcing mode in the North Atlantic has exhibited its most sustained low frequency change in a 176-year instrumental record. We can extend that context if we rely on proxy records of NAO behaviour. Currently, the only available proxy record of the *winter* NAO is a 555-year series derived from tree ring analysis of cedars from the Atlas Mountains of Morocco (Stockton and Glueck, 1999), whose basis is the control of Mediterranean winter rainfall by the NAO, and the effect of that rainfall on tree-growth. That proxy record suggests that values of the NAO index as low as those observed in the 1960s have occurred only two or three times previously since 1420 (Figure 4.2). If such a proxy proves valid — and it does appear to capture the recent amplification of the winter NAO over the last 4 decades — it would seem to demonstrate that climatic conditions at the time of the gadoid outburst were indeed extreme.

The specific mechanism which might affect the North Sea yield of gadoids is unclear and may be difficult to determine due to the wide range of responses in the sea that are attributed to the changing NAO. These include effects on wind speed, latent and sensible heat flux, (Cayan, 1992 a,b,c), evaporation/precipitation (Cayan and Reverdin, 1994; Hurrell, 1995a), sea surface temperature (Cayan, 1992c), the ocean circulation (Myers, Helbig and Holland, 1989; Marsh, 2000; McCartney, Curry and Bezdek, 1996, 1997; Curry and McCartney, 1999), the distribution, prevalence and intensity of Atlantic storms (Rogers, 1990, 1994, 1997; Hurrell, 1995b; Alexandersson, 1998), the wave climate (Bacon and Carter, 1993; Kushnir *et al.*, 1997; Cotton *et al.*, 1997; WASA Group, 1997), the intensity of deep convection at the main Atlantic sites (Greenland Sea, Labrador Sea and Sargasso: Dickson *et al.*, 1996; Dickson, 1997 and effects on both zooplankton production (Fromentin and Planque, 1996) and the recruitment of cod (Planque and Fox, 1998; Planque and Fredou, 1999).

Certain of these responses seem more critical than others. Since the work of Gran and Braarud (1935) and Sverdrup (1953) it has been known that the initiation of marine primary production in temperate waters and its subsequent rate of development are both functions of the depth of wind mixing in spring. Alexandersson *et al.* (1998) calculate a storm index for the northern North Sea/southern Norwegian Sea since 1880, and their conclusion that the storminess of the 1960s (1990s) was at a century-long minimum (maximum) is borne out by many detailed studies of the North Sea wind and wave climate.

The SW wind component seems to have been especially amplified with the amplifying NAO. Thus, in addition to evidence of an increase in the transport of the North Atlantic Current and Faroe-Shetland through-flow, we also suspect a major increase in the oceanic inflow to the northern North Sea between the low-index 1960s and the high-index 1990s. Conforming with the changing patterns of Atlantic sensible and latent heat flux under extreme NAO forcing, we expect a cooler (warmer) North Sea during the 1960s (1990s) and, by and large, our time series confirm this too (see discussion under Section 6.3 below).

It is as important to remember the converse, of course: that the circulation field associated with the NAO is not the only driver of environmental change in the North Sea; that the NAO is much less effective outside the winter period; that sustained, decadal trends in NAO behaviour belie an apparent lack of "memory" in NAO behaviour from autumn to winter or winter to spring; that there have been periods earlier in the 20th century when the ocean seems to have been much less responsive to NAO variability. Nonetheless, since our instrument and proxy measures suggest that the behaviour of the NAO over the past 4 decades has been extreme, it seems sensible to consider it as a possible, or even a likely cause of extreme changes in North Sea fish yield over the same period. Much of the discussion in Section 6.3 below will therefore center on NAO variability and the adequacy or otherwise of our biophysical data sets to detect and assess these effects.

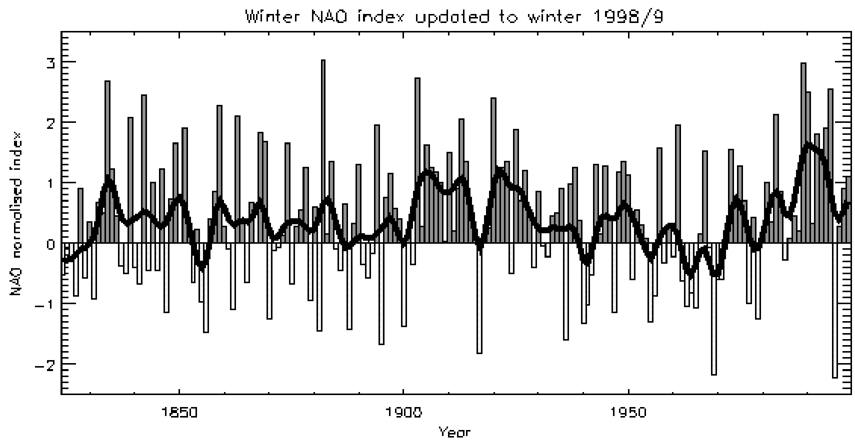

Figure 4.1. North Atlantic Oscillation winter index from 1825 to the present day.

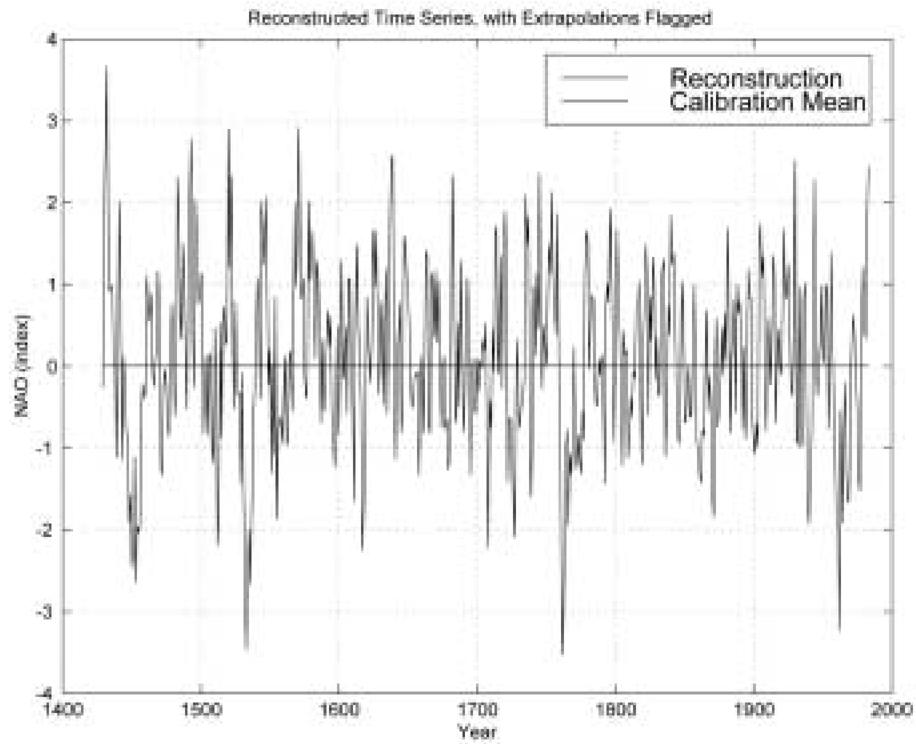

Figure 4.2. Reconstructed time series of the North Atlantic Oscillation index from the mid-15th century onwards.

5 Data inventory

The following sets of data were brought to the meeting and introduced by the participants. Details of some of the data are presented in Section 12.

Category	Holder	Data
Meteorology	ICES	Processed meteorological data from Utsira
Meteorology	ICES	NAO
Meteorology	Hamburg (Schrumm)	Meteorological data 58–97
Meteorology	MLA (Turrell)	Lerwick 1960>
Oceanography	ICES	Surface and bottom temperature and salinity by 1^o x 1^o x month
Oceanography	IMR (Ottersen)	Temperature on Kola section
Oceanography	MLA (Scott)	Stratification by month 1960 –1997
Oceanography	Hamburg (Schrumm)	HAMSOM output
Oceanography	IMR (Ottersen)	Volume fluxes North Sea 55–98 from NORWECOM
Oceanography	IMR (Ottersen)	Hydrographic data from Arendal-Hirtshals section 1952–1998
Oceanography	MLA (Turrell)	FS channel hydrographic data
Oceanography	MLA (Turrell)	Coastal temperature data
Oceanography	MLA (Turrell)	COADS data
Oceanography	U St Andrews (Beare)	NAO/SST/sea level pressure 50–92
Oceanography	CEFAS (Dickson)	Felixstowe/Rotterdam hydrographic data
Plankton	Brander	Prestige and Taylor spring bloom timing
Plankton	ICES/SAHFOS	CPR DATA 1950–1998 Green + zooplankton
Plankton	IfM Hamburg (Moll)	ECOHAM1 model output
Plankton	U St Andrews (Beare)	CPR spatial temporal changes in C.fin and C.hel
Plankton	U St Andrews (Beare)	Arctic and NAO index
Stock	MLA (Wright)	IOGS length at data pelagic 0-group
Stock	MLA (Wright)	IOGS distribution data on pelagic 0-group
Stock	ICES	IYFS data on juvenile abundance and distribution
Stock	ICES	VPA 1960–1996: cod, haddock, whiting, saithe, herring, plaice, sole
Stock	ICES (Pope)	Stock and recruitment to 1920
Stock	IMR (Ottersen)	Lengths of Barent Sea 0-group cod 1965–1996
Stock	MLA (Gallego)	Larval fish abundance data
Stock	IMR (Ottersen)	Coastal cod recruitment 1919–1998 beach seine

6 Assessment of data available to the workshop

6.1 Fish population data

A large array of data on fish stock properties are available from assessment and survey sources in ICES and elsewhere. However, it is often difficult to locate a definitive series of data for any one stock and considerable prior knowledge is required in order to be able to confidently use the data. All the recent Virtual Population Analysis (VPA) outputs of stock abundances at age, biomass and fishing mortalities are available from the ICES web-site, but it is important to realise that in general these only extend back to 1960 or later, and that they are subject to update on an annual basis as new data are incorporated. Other one-off, longer VPA series are available for some stocks, but combining these with contemporary outputs should be done with caution.

The situation is more difficult still with respect to results from the various fishery independent surveys of fish stocks. There are a variety of data series from ongoing and extinct periodic surveys. Some of these cover the whole stock distribution whilst some are targeted on smaller geographical domains. Locating and assembling these data presents considerable difficulty as in many cases the data are published only in grey literature ICES reports. Some are in current usage as part of the annual stock assessment process, and historical series are listed in the Assessment Working Group Reports.

The participants in the Workshop identified a clear need to consolidate the disparate data on fish stock abundances into a coherent form in a single worksheet for each species, in order to make significant progress with diagnosing the history and causes of the North Sea gadoid outburst. The group drafted a layout for a spreadsheet database to hold all of these data. Many of the entries required in this database are available at ICES, either electronically or in manuscript form, and K Brander (ICES) offered to take the initiative in assembling the necessary material. A preliminary collation for cod and haddock was carried out during the Workshop specifically in order to address the hypotheses posed in Section 7. The collation was based on data from the following sources:

VPA output, 1920 – 1993	Pope and Macer 1996, available on the ICES web-site
VPA output, 1963 –	Most recent ICES assessment WG
Historical abundances of larvae, 1956 – 1992	Gallego, unpublished, as supplied to the Workshop
International 0-group Gadoid Survey data, 1975 – 1983	Report of the Working Group on the International 0-group Gadoid Surveys in the North Sea (ICES, 1984)
English Ground Fish Surveys (August)	Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES, 1999)
Scottish Ground Fish Surveys (August)	Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES, 1999)
International Bottom Trawl Surveys (Quarter 1)	ICES Demersal Fish Assessment WG report (ICES, 1999)

6.2 Planktonic food production and timing

There is a lack of data on plankton within the North Sea. The Continuous Plankton Recorder data (CPR) are the only long-term data source for comprehensive spatial and temporal changes in zooplankton abundance. The CPR also provides a ‘greenness’ index which is a measure of the amount of chlorophyll. Sampling of chlorophyll by various national institutes has been carried out and the data are archived at ICES. However, the coverage is not systematic and has been very patchy both spatially and temporally.

There is a great deal of temperature and salinity data for the North Sea at reasonable temporal and spatial scales, and physical water characteristics can be used to infer possible changes in primary production. This can be done indirectly using differences in density (referred to here as a stratification index) or as driving forces for models of chlorophyll and primary production.

6.2.1 Datasets on trends in timing and abundance of zooplankton and phytoplankton

6.2.1.1 CPR– Northern North Sea and Atlantic

Continuous plankton recorder data (processed) used during the TASC (Trans-Atlantic Study of *Calanus finmarchicus*) project are available. They extend from 56˚N to 64˚N and from 30˚W to 10˚E between 1958 and 1996. Spatial patterns and time-series from specific locations can be supplied from the output of statistical models. There are many potential sources of bias in CPR data such as data voids in space and time and non-random sampling effort, and the models go some way towards accounting for these problems. In spite of the problems of bias and non-random sampling it is clear from examination of time-series and spatial patterns of abundance that *C. finmarchicus* abundance has fallen very dramatically since the 1960s and that the declines are associated with pan-oceanic distribution changes, viz. lower numbers in the North Sea accompanied by increases south of Iceland. The abundance of *C. helgolandicus* also fell in the 1960s, were low during the 1970s and 1980s and have subsequently increased steadily during the 1990s.

6.2.1.2 Icelandic zooplankton data

Data for many zooplankton species are also available from the Icelandic Spring Surveys (ISS) which are done around the coast of Iceland in May and June every year. The ISS data available cover the period between 1960 and 1996 and the spatial coverage varies. These data suggest that the abundance of *Calanus finmarchicus* was particularly high around Iceland in the 1960s, but since then numbers have declined while those of *C. hyperboreus*, which tends to characterise Arctic water, have increased rapidly, mainly to the north-east of Iceland. The fixed time of sampling each year makes these data difficult to interpret because of the potential for changing annual cycles of population abundance in zooplankton populations.

6.2.1.3 Stratification Index – indirect index of the timing of the spring phytoplankton bloom

The ICES archive of temperature and salinity data has been used to derive a stratification index (the difference between the bottom and surface density). Values between 0.3–0.4 are the dividing line between completely mixed and very slightly stratified water with the beginnings of a thermohalocline. The data are derived from ICES hydrographic data (courtesy of Harry Dooley). The data set which was used to calculate the stratification index contains the monthly means for temperature and salinity, surface and bottom in each ICES rectangle ($1^0 * 1^0$) from 51˚–62˚N, 4.5˚W–8.5˚E, from 1960 to 1997.

The onset / breakdown of stratification possibly indicates the timing of the spring and autumn bloom (in the North Sea). To analyse long-term trends the data were de-seasonalised by taking a 12-month running mean. The North Sea was broken into 3 regions: 1) Western North Sea (Orkney, Shetland and east Scottish Coast), which is a mixed region due to strong tidal currents; 2) Northern/Central North Sea, which is a region that is predictably stratified; and 3) Southern North Sea, a mixed region of the North Sea due to its shallowness (< 70 metres in depth). In general across all 3 regions the trend was low levels of stratification in the very early 1960s with higher levels occurring from 1963–1970. Between 1970 and 1980 the stratification index is low and from 1980 to 1985 stratification is high across the whole North Sea. From 1985 to 1997 the trend flips back and forth (every 2.5 years) but is no longer coherent across all 3 regions.

To investigate seasonal differences, quarterly means (winter=JFM, spring=AMJ, summer=JAS, fall=OND) were produced for each of the 3 regions. The 1960s are unusual because there are high winter and spring values for all 3 regions. After 1970 there are only the occasional year with high winter stratification values. Further details are given in Section 12.1.3.

6.2.2 Model output data

6.2.2.1 Ecological North Sea Model, Hamburg, Version 1 (ECOHAM1)

The chlorophyll and net primary production data from the Ecological North Sea Model, Hamburg, Version 1 (ECOHAM1) are for the whole North Sea (49˚–62˚N, 4˚W–9˚E) on a daily basis from 1985 to 1994 within a grid size of 0.2° latitude and 0.33° longitude (nearly 20 * 20 km) with a five-metre depth resolution. The model is described in detail in Moll (1998, Journal of Marine Systems 16:150/171).

6.2.2.2 Assessment of model data CHL, NPP, stratification

The ECOHAM1 simulations are forced with data from a prognostic baroclinic circulation model. Therefore, when the temperature and salinity fields are validated, the onset of the stratification is temporarily and regionally resolved on a very fine grid. The model includes high resolution solar radiation forcing (every 30 minutes) for every surface grid point. We believe that the onset of the spring bloom in the North Sea is quite well predicted and the annual net primary production as well.

6.2.3 Summary of plankton data sets:

Observations	**Spatial coverage**	**Temporal coverage**
Continuous Plankton Recorder (zooplankton and greenness index)	North Atlantic, North Sea and southern Norwegian Sea. Raw data at 10km resolution.	1958 onwards, essentially monthly resolution
Icelandic Spring Surveys (zooplankton and chlorophyll)	Icelandic shelf with a series of transects	1960 onwards, essentially a single standard survey each year.
Chlorophyll concentration from ICES database	40°N – 70°N, 20°W – 15E, 1° x 1° resolution	Monthly averages, 1950 onwards

Derived data	**Spatial coverage**	**Temporal coverage**
Timing of stratification. Stratification index derived from ICES temperature and salinity data	51°N – 62°N, 4.5°W – 8.5°E, 1° x 1° resolution	1960–1997, monthly averages

Model	**Spatial coverage**	**Temporal coverage**
ECOHAM-1, Simulated chlorophyll and net primary production	North Sea, 49°N – 62°N, 4°W – 9°E, 0.2° latitude x 0.33° longitude horizontal resolution and 5m vertical resolution.	Simulated 1985 – 1994 daily resolution

6.3 Dispersal and temperature

The approach taken by this group was first to consider changes on the scale of the North Atlantic, then progressively to reduce the scale under consideration by focussing in on the NW European Shelf, and then the North Sea. While no direct correlations with any biological parameters were attempted, the group's aim was to highlight the major environmental differences between the decade of good gadoid recruitment (1960s) and the decades of poorer recruitment, both more recently and earlier in the century, when records permit. The North Atlantic Oscillation (NAO) has been identified by many studies to be a key index of environmental change in the North Atlantic area, and a brief introduction to this phenomenon is given above in Section 4.

6.3.1 Decadal changes in transport

1. *North Atlantic Current:* The NAC flows along the boundary between the subtropical and subpolar gyres, carrying the principal trans-ocean transport of warm, Atlantic water to the margins of the NW European shelf. In the period of the 1960s, when the NAO was in its most persistent and extreme negative phase this century, the coordinated but opposite changes in the production of mode waters in the Sargasso and Labrador Seas resulted in a 30% lower NAC transport in the 0–2000db layer compared with the transport in the 1990s, when the NAO was in a persistently positive phase (see Figure 6.1).

2. *Northern Boundary of NW European Shelf:* The net transport of oceanic water from the Atlantic into the Nordic Seas through the Faroe-Shetland Channel also appeared to change in synchrony with the NAO Index. Evidence from two standard hydrographic sections across the Faroe-Shetland Channel indicate that the net baroclinic Atlantic water transport reduced to its lowest (highest) value this century during the 1960s (1990s) (Figure 6.2).

3. *The North Sea:* When considering changes within the North Sea itself, the group first considered possible changes in wind stress as the primary forcing both of North Sea inflow and the North Sea internal circulation. In hourly wind observations at Lerwick (Shetland), at the northern entrance to the North Sea, wind stress reached a multi-decadal minimum between 1965 and 1970, and rose to a general maximum in the 1990s in keeping with what we know of the NAO effects on winter storm climate (track, frequency and intensity). These long-term changes were particularly

evident in the SW quadrant, which is the optimum quadrant for driving inflow to the North Sea from the west, and driving the cyclonic circulation within the northern North Sea (Figure 6.3). An empirical model relating transport into the North Sea through the Fair Isle Passage showed that net warm water inflow was lower during the 1960s compared to the 1990s. The NCEP reanalysis data-set, combining observations and model output, confirmed that similar changes applied in the North Sea as a whole.

The products of numerical hydrodynamic models were then considered. When run with mean January winds, the HamSOM model (IFMH; Schrum 1997) revealed a lower net exchange with the North Atlantic across the northern boundary (i.e. lower net inflow and lower net outflow) in the decade 1958–1967 compared with 1988–1997:

Calculated volume flux from the HamSOM *model forced by constant January winds. Units are Sv (10^6 m^3s^{-1}). Schrum, (pers comm.)*

	I: Mean January wind field 1958–1967	**II: Mean January wind field 1968–1977**	**III: Mean January wind field 1988–1997**	**II–I**	**III–1**
N.boundary (W, inflow)	1.023	1.023	1.1	0.	0.077
N.boundary (E, outflow)	–1.012	–1.1	–1.163	–0.088	–0.151
N.boundary (net)	0.011	–0.077	–0.063	–0.088	–0.074
Skagerrak (N, inflow)	0.1678	0.1019	0.1052	–0.0659	0.0033
Skagerrak (S, outflow)	–0.1364	–0.1279	–0.2089	0.0085	–0.081
Skagerrak (net)	0.0314	–0.0260	–0.1037	–0.0574	–0.1684
Channel	–0.1678	–0.1019	–0.1052	0.0659	–0.0033

It was also evident, however that there was a lengthening of the period of strong winter windspeeds with time and, in detail, a change in the timing of the winter windspeed maximum so that the total effect of a changing winter windfield on inflow has yet to be made using this model.

Differences of the internal North Sea circulation between these decades were evident, particularly in the exchange-area between the North Sea and the Skagerrak. The NORWECOM model has been run monthly (Iversen, Skogen and Svendsen 1997) and does appear to confirm lower winter inflow across the northern boundary in the 1960s to late 1980s compared with subsequently, apparently supported by an increase in the horse mackerel catch (Figure 6.4).

Questions which arose during these discussions were:

- *Calanus*: If oceanic inflow to the North Sea increased between the 1960s to the 1990s, why has *Calanus* abundance not also increased?
- Skagerrak: The major internal change was an increased inflow to the Skagerrak. Do variations in the North Sea / Skagerrak exchange have any biological significance?
- Problems are known to persist in the reanalysis data. Are there obvious flaws in the reanalysis wind data for our region that we should be aware of?

6.3.2 Decadal changes of temperature

1. North Atlantic: The correlation between SST and the NAO is negative in a broad area of the Atlantic west of the Scottish shelf but is generally positive over the western shelf, North Sea, English Channel and Western Approaches (Figure 6.5). Thus in the North Sea, the negative NAO would result in a general cooling (warming) during the 1960s (1990s).

2. Northern Boundary of the NW European Shelf: Waters lying at the northern boundary of the North Sea underwent a prolonged cooling event during the 1960s and warming during the 1990s. The cooling was the greatest and most persistent observed this century. A comparison between mean temperature sections across the Faroe-Shetland Channel in 1965–1969 and 1990–1995 confirmed that the Atlantic waters against the Scottish Slope were warmer by up to 3.5°C

(Figure 6.6) and saltier during the later period, (the NAO+ phase). Thus, the temperature of the long-slope Atlantic current as well as its transport appear to have contributed to the warming of the northern North Sea under the amplifying NAO.

3. North Sea: A detailed study of the response of SST within the North Sea to the NAO revealed two dominant modes of response (Becker and Pauly 1996; Dippner 1997). The deeper northern North Sea appears to be dominated by advective processes, so that the correlation with the NAO is positive, but of relatively low magnitude. The shallower southern North Sea is dominated by direct atmospheric forcing, and in this area the correlation is greatest (e.g. the Felixstowe-Rotterdam SST series, Figure 6.7).

Many different sea-temperature data sets, interpretations of the same data sets and combinations of data sets exist, possibly all showing different aspects of change within the North Sea. It was generally concluded by the group that (at least in the case of annual mean or filtered data) negative temperature anomalies compared to a long-term mean were more prevalent in the 1960s than in the 1990s. In investigating gadoid recruitment in the North Sea, there is a real question of which is the optimum temperature time-series in time, space and depth to apply to the problem. No one full-depth comprehensive set is available, or indeed possible. The locations and times of biological significance are a prerequisite to this type of analysis, but may not be identifiable from the poor biological data available. There is a good case for keeping individual section or station data separate from the amalgamated ICES/COADS-type data and using these series as more homogeneous indices of wider environmental change within the North Sea. This is particularly true for full-depth observations. The standard Hirtshals-Arendal Section across the entrance to the Skagerrak in particular will be further examined for evidence of environmental temperature change during the 1960s cf 1990s.

Questions which arose during these discussions were:

- What is driving the inflow/outflow through the English Channel, an area where large changes in imported fauna, for example, have been observed?
- Where in space and time is the best (data duration, data density, etc.) and most biologically-significant temperature data set in the North Sea from the viewpoint of gadoid recruitment?
- Is the heat flux to the North Sea determined by changes in the magnitude of the inflow, or the temperature of the inflowing waters, or both?

6.3.3 Salinity

The comparison of Faroe-Shetland mean sections for the 1960s and 1990s, representing contrasting phases of the NAO (Figure 6.6, lower panel) suggests that a more saline Atlantic-water core lay against the upper slope west of Britain during NAO-positive conditions, and the group is undertaking the analysis of salinity data from the Hirtshals-Arendal transect of the Skagerrak to investigate if these saltier conditions have also characterised the main deep inflow to the North Sea. Elsewhere, although there is some evidence of a correlation with the NAO index, the surface salinity data of the North Sea appears much more noisy than for SST, and its time-dependence much less clear-cut. It was acknowledged to have a potential importance to the discussion of gadoid recruitment, acting e.g. through changes in near-surface stability.

A question which arose during these discussions was:

- What is the net effect of Atlantic inflow, Baltic outflow and direct precipitation on North Sea near-surface salinity under NAO+ and NAO- conditions, and how might any resulting change in vertical stability affect production-timing?

6.3.4 Summary

Taking a large scale view in both space and time, the decade of strong gadoid recruitment in the 1960s also appears to be extreme from the viewpoint of environmental change; the NAO was at its most persistent and extreme negative phase, the transport of the North Atlantic current, the slope current through the Faroe-Shetland Channel and the inflow to the North Sea were all at long-term extremes of weakness, storminess, windiness, and especially the SW wind component over the North Sea was at minimum strength, affecting both transport and mixing processes. The oceanic waters in the inflowing slope current and its extension around the northern boundary of the North Sea were at their coolest this century, and sea surface temperatures within the North Sea were also cool, in response to NAO forcing. In the 1990s when recruitment to the North Sea gadoid stocks was generally weak, these environmental tendencies were at their opposite extreme state.

The above is a generalised statement. If we focus on single years or seasons or in particular sub-areas of importance to gadoid recruitment, the sparsity of data becomes more apparent, and the broad scale picture of change becomes far more complex and confused. The most promising way forward appears to be the integration of the patchy oceanographic observations with the more coherent meteorological data using numerical hydrodynamic models. The proposed 40-year model run of the HamSOM model in particular should produce very relevant results for future consideration in terms of gadoid recruitment processes.

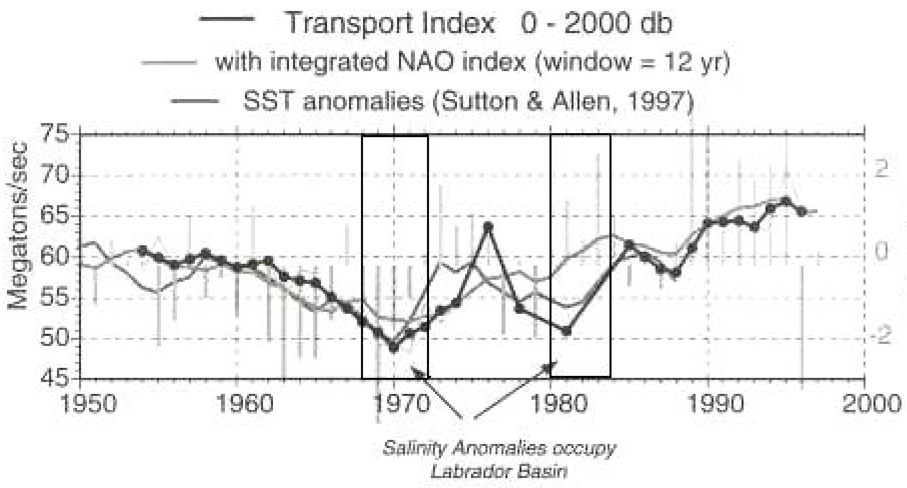

Figure 6.1. Transport of the North Atlantic Current in the 0–2000db layer, compared to the North Atlantic Oscillation index.

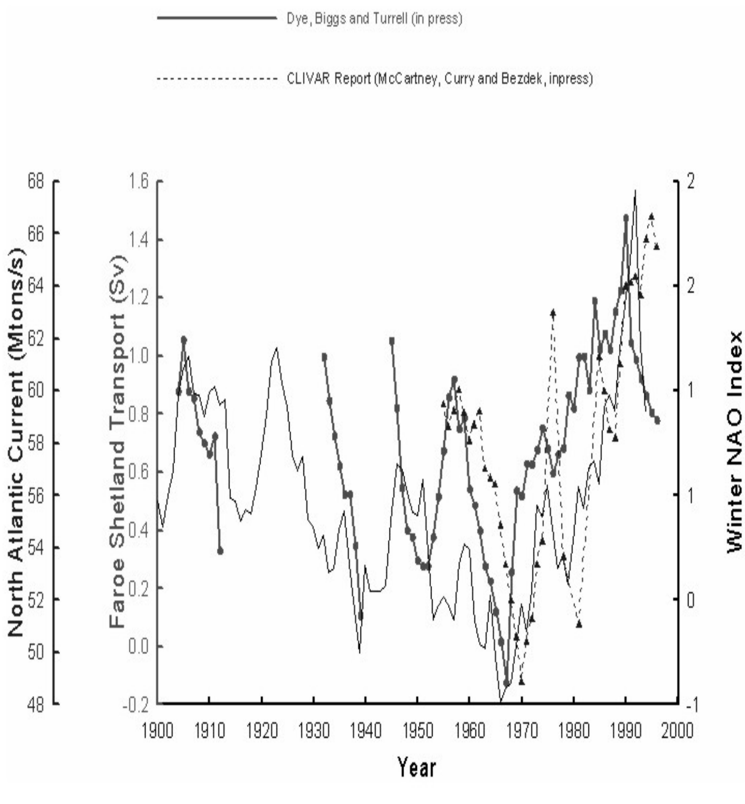

Figure 6.2. Transport in the North Atlantic Current and through the Faroe-Shetland Channel, compared to the North Atlantic Oscillation index from 1900 onwards.

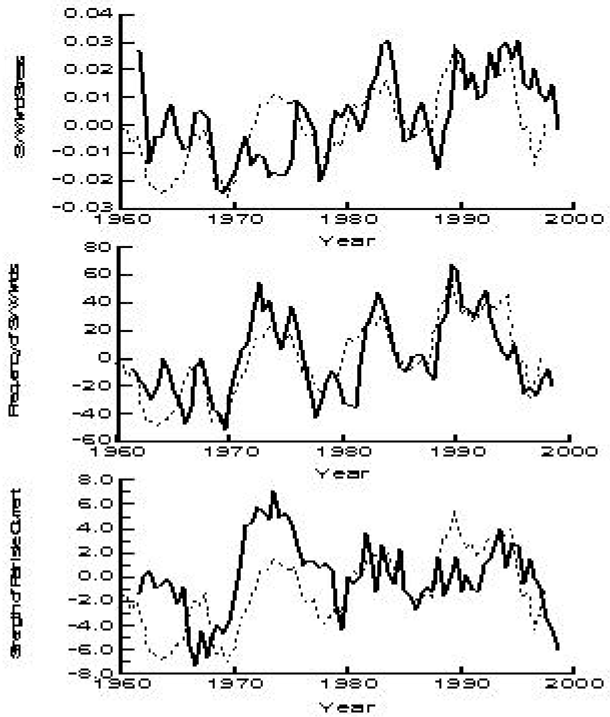

Figure 6.3. Wind stress, frequency of southwesterly winds, and the strength of the Fair Isle Current in the North Sea, from 1960 onwards.

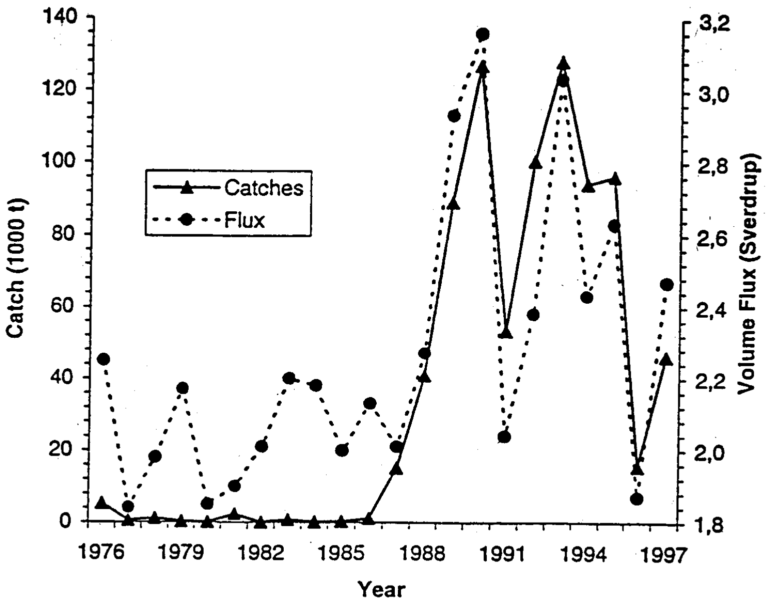

Figure 6.4. Modelled transport into the northern North Sea (from NORWECOM), compared to horse mackerel in the North Sea.

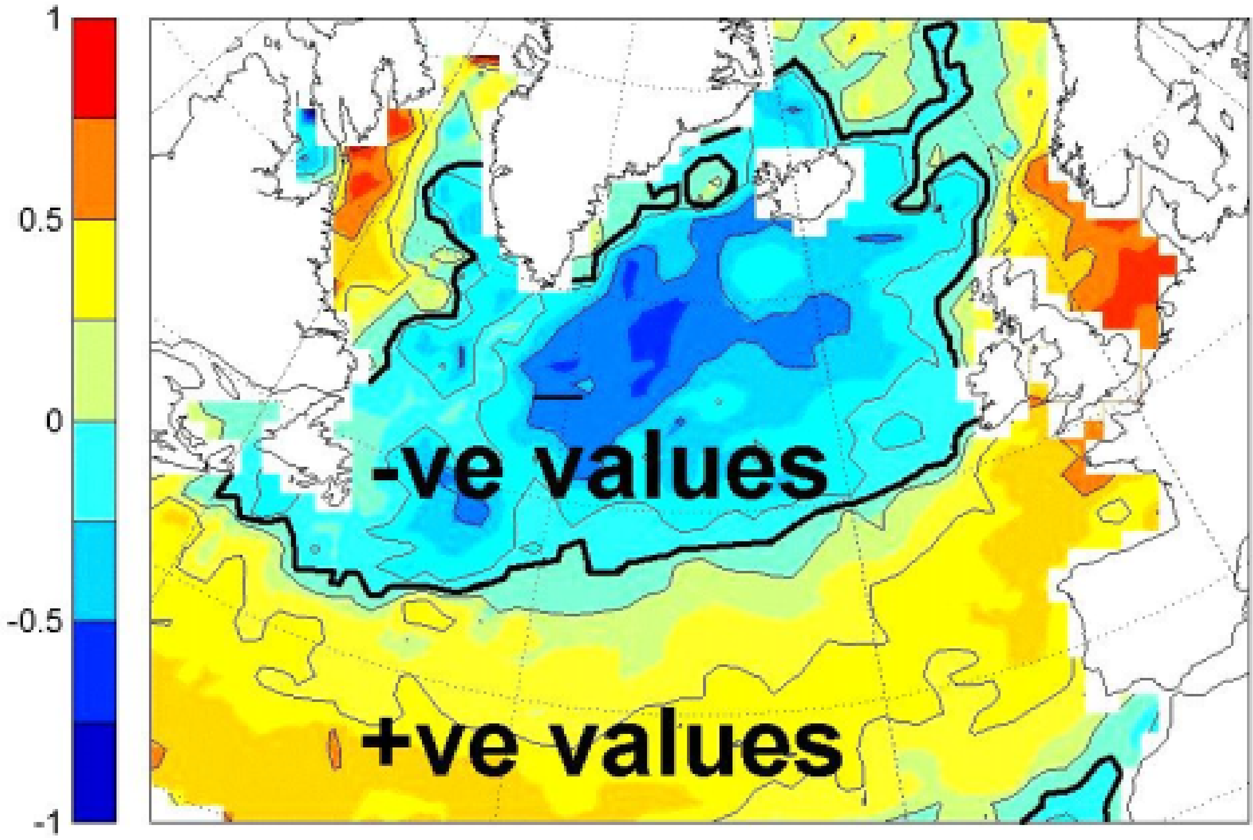

Figure 6.5. Spatial variation in the correlation between time series of sea surface temperature and the North Atlantic Oscillation index.

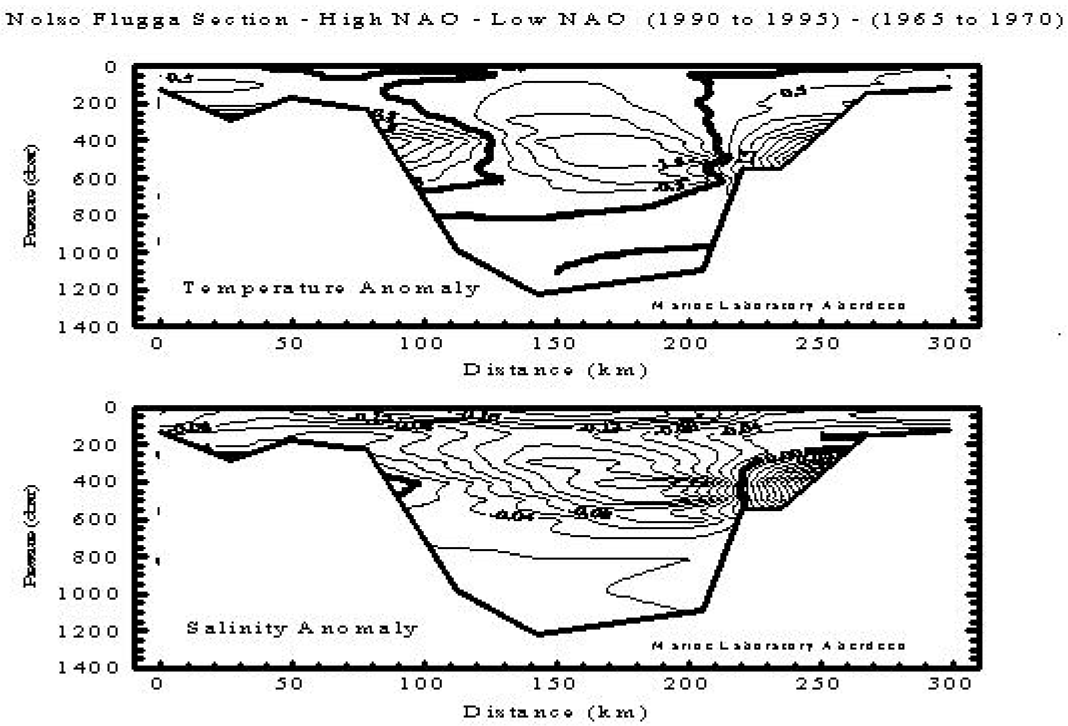

Figure 6.6. Differences in temperature and salinity along a section across the Faroe-Shetland Channel, between years exhibiting high and low values of the North Atantic Oscillation index.

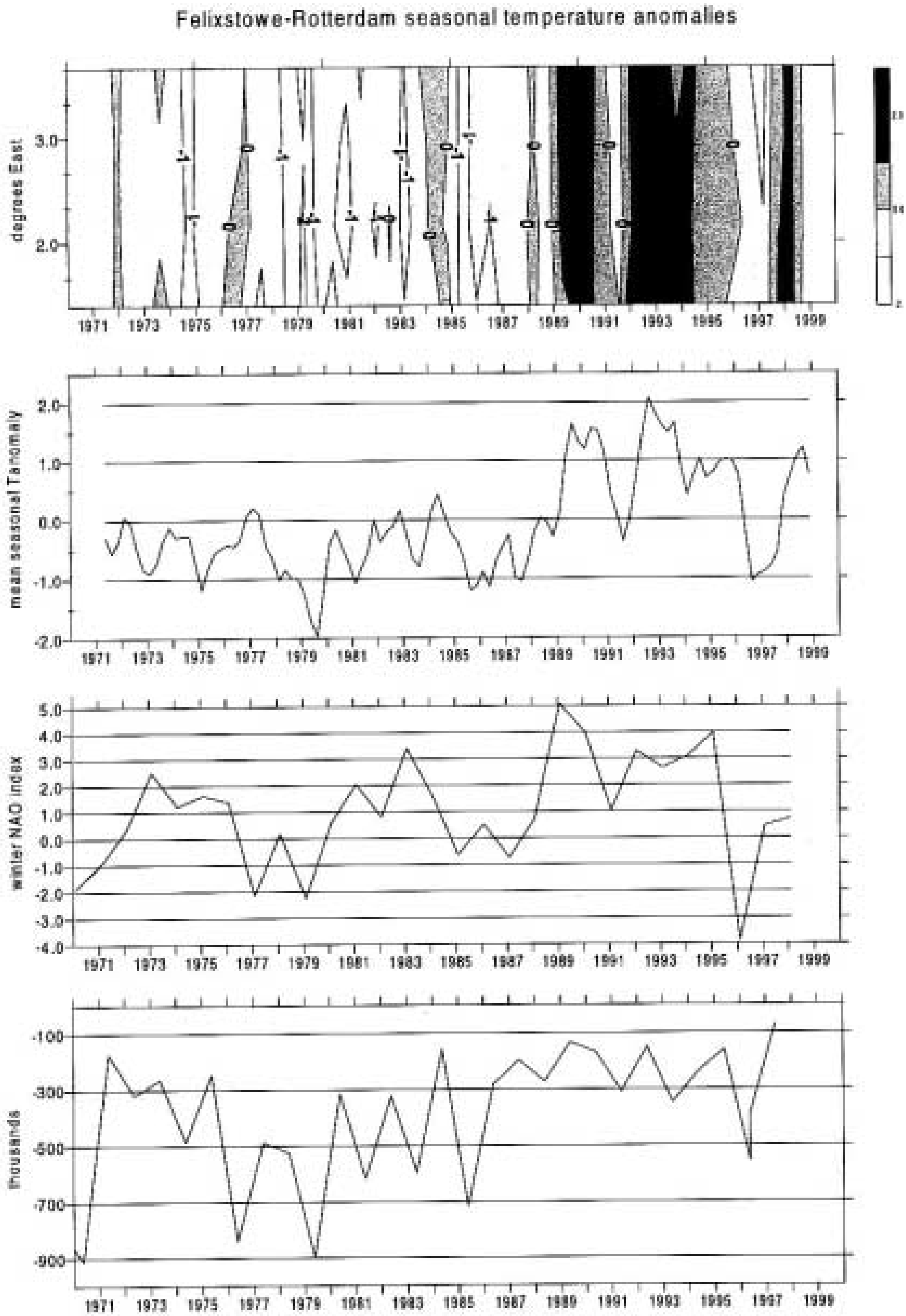

Figure 6.7. Sea surface temperature recorded from ferry passages between Felixstowe and Rotterdam in the southern North Sea, compared to the North Atlantic Oscillation index.

7 Hypotheses for the causes of the gadoid outburst

Hypothesis		Potential test	Possible lines of investigation
1	Fishing has driven down the stock biomass to a level where it cannot produce high recruitment.	Is there a discernible stock-recruit relationship?	Investigate patterns of fishing mortality in relation to recruitment.
2	Fishing since 1960s has skewed the age structure of the stock towards recruit spawners which produce eggs with poor survival potential.	How was the age structure pre-1960s, and did we see very large year classes then?	Investigate age structure data, fecundity and egg viability.
3	Changes in fishing intensity have impaired the reproductive success of fish since the 1960s.	Is there any evidence that vessel noise or disturbance affects the mating success of fish?	How has fishing intensity and methods changed over the century? Was anything different during the 1960s?
4	Changes in juvenile and adult growth, maturation and condition resulted in higher egg production per unit biomass.	Is there any evidence for changes in growth or maturation?	Investigate hydrographic and food signals which may be correlated with time series of size at age.
5	The plankton environment during the 1960s was very conducive to growth and survival of young larvae (more food, better food, fewer predators).	Is there any correlation between larval abundances and recruitment, or between larval abundance and egg production ?	If there is a correlation between larvae and recruitment then investigate: distribution of larvae, abundance and composition of plankton, temperature, stratification intensity and timing, primary production, advection variability, fisheries for planktivores, match-mismatch between spawning and plankton production.
6	The environment during the 1960s was very conducive to survival of pelagic 0-group and settlement success.	Is there any correlation between abundances of pelagic 0-group and recruitment?	If pelagic 0-group correlates with R then investigate: changes in distribution of 0-group, changes in size and growth, diet, temperature, dispersal.
7	The demersal environment during the 1960s was very conducive to growth and survival of settled juveniles (more food, better food, more favourable advection during larval phase, fewer competitors or predators).	Is there any correlation between demersal 0-group abundance and recruits at age 1 ?	If demersal 0-group abundance correlates with R then: investigate distribution of pelagic and demersal 0-group, benthos biomass and composition, abundance of small pelagic fish prey, advection variability, community abundance and distribution of competitor and predator fish species, industrial fishing activity.

8 Examination of hypotheses

8.1 Fishery-driven hypotheses

Hypothesis 1: *Fishing has driven down the stock biomass to a level where it cannot produce high recruitment.*

There are two arguments, which can be used to refute this hypothesis. Firstly, it is not true to say that a low stock biomass *of itself* imposes an upper limit on potential recruitment, at least in the cases of haddock and whiting (see Figure 8.1) for which the highest recorded year classes have been produced by stocks at relatively low levels. The example of saithe is ambivalent because there are doubts about the identity and composition of the North Sea stock and whether it is in fact distinct from the Northern Shelf stock which historically has been assessed separately (ICES 1999). Of the stocks considered here, cod is the only case for which it might be claimed with some justification that the likelihood of high recruitment is substantially reduced at the low spawning-stock levels produced by high post-1960s rates of fishing mortality. This lends impetus to the second refutation of the hypothesis, namely that fishing has undoubtedly contributed to low year class sizes *since* the so-called gadoid outburst, but cannot be implicated in the appearance of the outburst in the first place. It would be difficult to use the steady post-war increase in fishing effort and power in the North Sea to explain the abrupt rise in biomass experienced by gadoid stocks in the 1960s and 1970s.

Hypothesis 2: *Fishing since the 1960s has skewed the age structure of the stock towards younger spawners, which produce eggs with poor survival potential*.

There are a number of reasons why the age structure of the spawning stock can be expected to influence recruitment. Population fecundity, the total egg production for a population, can vary for a given stock biomass because of age-related differences in the number of eggs that a female of a given somatic weight produces. For example, 2-group haddock have around half the relative fecundity of older females (Hislop, 1988). In addition to effects on fecundity, there is now accumulating evidence that maternal age, size and condition may influence offspring viability through effects on egg size and subsequent larval viability (Chambers, 1997; Tripple *et al.*, 1997; Tripple, 1998; Marteinsdottir and Steinarsson, 1998). Consequently, older age classes make a disproportionate contribution to the number of successful recruits.

The spawning seasons of cod and haddock typically extend over several weeks to months. A protracted spawning period is likely to reduce the potential for mis-match between larval occurrence and favourable environmental conditions (Mertz and Myers, 1994). Protracted spawning in cod and haddock stocks is achieved in part by individual females spawning repeatedly (Kjesbu, 1989). In addition, recent evidence on Icelandic cod and North Sea haddock has indicated that the population spawning period is also related to age and size specific differences in the onset and duration of spawning (FAIR report CT95.0084). These studies showed that older females initiated spawning earlier and spawned over a longer time period than younger females (Figure 8.2). Declines in the numbers of old fish therefore have the potential to reduce the numbers and quality of eggs produced and the time over which eggs are spawned.

In order to consider how changes in age structure have affected survivorship in North Sea haddock an index was produced based on the proportions of age-classes which gives a positive weighting to old females (>= 4 years old) and negative weighting to young females (<2 years old). Changes in survivorship (see Section 12.1.4) were then compared with this index (Figure 8.3). Overall it does appear that most years of poor survival have coincided with a low proportion of older age-classes. However, both high and low survival has occurred in years when older fish have been present in high numbers. It is also important to note that there is not a clear downward trend in the age range between the 1960s and 1990s. Consequently, as with spawning biomass, the age structure of the stock appears to only give an indication of poor survival and does little to explain high survival. In the case of the two high survivorship years 1962 and 1967, the age composition of the spawning stock contained sufficient older age-classes to generate a relatively protracted spawning period in these years.

Hypothesis 3: *Changes in fishing intensity have impaired the reproductive success of fish since the 1960s.*

The effects of fishing on SSB and age composition are dealt with under other headings, so the remaining effects of fishing may be due to such aspects as disruption of spawning via noise pollution or more direct physical disturbance. There is no evidence that these have any effect on spawning fish, although they are intuitively appealing. For haddock the reconstruction back to 1920 indicates that fishing intensity was at least as high during the pre-war period as it has been since, while for cod the fishing intensity has increased fairly steadily since 1960.

Hypothesis 4: *Changes in juvenile and adult growth, maturation and condition resulted in higher egg production per unit biomass.*

Weight-at-age from commercial catches has been used to look at changes in growth rate in two ways:

- Weight-at-age depends on the growth rate up to that age. The trends in weight-at-age (for the four principal gadoid species) are shown in Figure 8.4. Although there are considerable changes in weight-at-age which, for cod at least, can be related to temperature (Brander, 2000) it is unlikely that these resulted in sufficiently large changes in maturity and fecundity per unit of biomass to account for the observed trends in recruitment. Where an environmental factor, such as temperature, affects growth rate, this should be taken into account in stock assessments.
- The growth rate for older fish, which are adequately sampled in commercial catches, can be analysed to look for changes related to the period of the gadoid outburst. This has been done for the four main gadoids for the North Sea, West of Scotland and other areas (Figure 8.5, from Brander, 2000). Growth rate changes for older ages are quite small and do not relate very obviously to the environmental changes, which took place during the period of the gadoid outburst. They are therefore unlikely to have had much effect. Nevertheless the trends which occurred in the North Sea are very similar to those in the West of Scotland area, which increases one's confidence that they are real changes and suggests that there are probably processes common to both areas.

There is good evidence that maturation and reproductive investment in gadoids is related to growth and condition prior to the spawning season. Consequently, maturity will be affected by the summation of food success and temperature, and potentially the density of conspecifics. Recent analyses of IBTS data for the North Sea suggest that age at maturity has varied, although for cod and haddock the revised estimates are respectively about 10 and 18% larger than those based on a constant maturity ogive. This means that the observed cod and haddock recruitment has been produced by larger SSBs than was previously thought. However, revised estimates of spawning stock biomass based on the new maturity data alter the scale of the SSB values without making any substantial change to the trajectory over time. For example, Figure 8.6 compares survivorship trends for haddock based on assessment maturity ogives and revised maturity ogives. In conclusion then, variations in maturity cannot explain much in the way of recruitment variation.

8.2 Environmental processes acting on young larvae

Hypothesis 5: *The plankton environment during the 1960s was very conducive to growth and survival of young larvae (more food, better food, fewer predators).*

The hypothesis under discussion stated that the "gadoid outburst" was the result of high survival (and growth) during the early larval stages. This high growth and survival was the likely consequence of favourable environmental conditions in the planktonic community, such as greater food availability, presence of more suitable/better quality food items, lower predation pressure, etc.

To be able to test this hypothesis directly, it is necessary to examine the degree of correlation between recruitment indices and larval abundance, and between larval abundance and egg production. Such tests are critically dependent on the availability of appropriate larval abundance indices.

The only larval data set available to the workshop was compiled from FRS Marine Laboratory Aberdeen historic records (see Section 12.1 of this Report). The initial intention was to investigate 6 years of contrasting (exceptionally good/bad) recruitment and/or survivorship for North Sea cod and haddock (1962, 1964, 1967, 1969, 1976 and 1979, see table below).

Year	**cod**	**haddock**
1962	poor	good
1964	average	poor
1967	poor	good
1969	good	poor
1976	good	poor
1979	good	good

Closer scrutiny of the larval fish time series soon demonstrated that, particularly for cod, the amount of data available was totally insufficient to test the hypothesis. Cod were found in only one of the first 4 target years (1967; no larval data from the 1970s were available), and in only 1 sample. Even when all the years were used, any relationship between the larval abundance indices (presence/absence in samples and average larval concentration in the samples) and spawning biomass, egg production and recruitment plotted for haddock (see Figure 8.7) was very unclear. The lack of meaningful relationships was likely to be compounded by interannual differences in the spatial and temporal coverage of the larval surveys (see Section 12.1).

Consequently, it was decided to use the larval data exclusively in support of any conclusions derived from the examination of alternative hypothesis, since they were clearly insufficient to test the hypothesis of environmentally driven processes acting on young larvae. The group considered that there was enough evidence in the scientific literature from other ecosystems to suggest that environmental processes acting on young larvae have the potential to play a significant part on gadoid recruitment, and that many of the mechanisms influencing such a relationship are well publicised (timing and abundance of primary and secondary production, stability of the water column, turbulence, advective processes, etc.).

It was clear that, to be able to test the hypothesis properly, it was critical to assemble/collect adequate data. Two potentially very important sets of larval fish data were identified in the discussion. FRS Marine Laboratory Aberdeen carried out comprehensive larval surveys of the northern North Sea in 1992 (see Figure 11.1 in Section 11.1) and 1996 (Figure 8.8), intensively sampling fish larvae and their bio-physical environment. Both years represented markedly contrasting conditions in terms of the NAO index, and we are confident that these data, when fully available after the pending taxonomic analysis of the samples, will enable us to test whether the inverse correlation between NAO index and recruitment, observed during the gadoid outburst, is confirmed. The characteristics of these data sets and the availability of a large volume of additional environmental data should enable us to identify which mechanisms may generate this relationship, if such relationship is substantiated.

8.3 Processes acting on late pelagic stages and juveniles

Hypothesis 6: *The environment during the 1960s was very conducive to survival of pelagic 0-group and settlement success.*

Hypothesis 7: *The demersal environment during the 1960s was very conducive to growth and survival of settled juveniles (more food, better food, more favourable advection during larval phase, fewer competitors or predators).*

The database of stock abundance and characteristics assembled as described in Section 6 was analysed to identify temporal patterns in stage specific survivorship. The aim was to determine whether there were any particular stages in the early life for which the interannual variability and trends reflected the variability in the overall survivorship to recruitment. The analysis was performed for cod and haddock only as there was some doubt as to the reliability of both VPA and survey data for some other gadoid species in the context described here.

A number of stage specific survivorship indices were derived for each year class for which the requisite data were available:

Index	Stage interval	Survivorship index
1	Overall survivorship from eggs to recruits	ln(VPA recruits) – ln(VPA spawning biomass)
2	Survivorship of early larvae (0–3 months age)	ln(IOGS) – ln(VPA spawning biomass)
3	Survivorship during late pelagic and settlement stage (3 months – 5 months age)	ln(EGFS) – ln(IOGS)
4	Survivorship from late pelagic stage (3 months old) to juveniles age 11 months (haddock) or 23 months (cod)	ln(IYFS) – ln(IOGS)
5	Survivorship from early demersal juveniles (5 months age) to juveniles 11 months old (haddock) or 23 months (cod)	ln(EGFS) – ln(IYFS)

The nature of the data used for the analyses were such that no one data series was capable of delivering unequivocal evidence as to which stage interval was most important in determining the level of recruitment. However, taken together, the results do give some indications. Furthermore, the data assembled here, poor though they are represent the only information on which such an analysis can be performed for the North Sea. In general, the outcome was relatively clear for haddock, but less clear for cod.

8.3.1 Results for haddock

The time series of overall survivorship (index 1) derived from the VPA data on haddock showed a series of high and low survivorship periods between 1970 and the present day. The segments of data on survivorship during the early larval phase (index 2) and the demersal juvenile phase (index 5) showed no relationship to the overall survivorship. However, the short series of data supporting the indices of survivorship which included the late pelagic and settlement phases (indices 3 and 4) both showed a reasonably strong relationship to the overall signal (Figure 8.9). The implication of these results is that survivorship during the late pelagic and settlement period (age 3–5 months) reflected that in the overall process, and was therefore the most critical period in the life cycle during which recruitment was set. This is not to say that early larval or settled juvenile survival is unimportant, simply that the year-to-year variability is of less significance in controlling fluctuations in recruitment.

If the above conclusion is valid, then one would expect the time series of pelagic larval stage abundances to correlate with the population egg production (indexed by the spawning biomass), and the time series of demersal juvenile abundance to correlate with the recruitment. In the main, this hypothesis is supported by the data. Spawning biomass showed a loose relationship to both the International 0-Group Survey data series for the years when this was available, and to the incidence of haddock larvae in plankton samples in the east Shetland area during the period 1956–1970 although, especially in the latter case the available data are very sparse (Figure 8.10). Similarly, both the EGFS and IYFS series on demersal juvenile haddock showed strong relationships to the VPA recruitment data, which has been well established by others. In themselves these relationships could not support the hypothesis, but taken together they provide reasonably convincing evidence that the important processes in the early life of haddock occur between 3 and 5 months age.

8.3.2 Results for cod

The equivalent analysis for cod yielded somewhat less convincing results (Figure 8.11). The overall survivorship series for cod was non-stationary and showed an increasing trend with time, unlike the situation for haddock. As for haddock, neither the early survivorship (index 2) nor the late survivorship (index 5) results correlated with the overall survivorship. However, the early survivorship showed an underlying increasing trend. The settlement survival indices (3 and 4) had trends, which matched those in the overall index, but the relationship was less clear than for haddock. Also, it was not at all clear that there was any semblance of a relationship between spawning biomass and either of the early larval abundance series, and whilst the EGFS and IYFS series showed interannual variability which reflected that in the VPA recruitment, the underlying trends were clearly different.

8.3.3 What could influence the survival of haddock and cod during the late pelagic and settlement phase?

A number of factors can be hypothesised to influence survival during the late pelagic and settlement phase (age 3–5 months, June - August):

Possible processes	**Related issues to follow up**
Time at which individuals attain the size of settlement in relation to optimality of conditions for settlement.	Feeding and growth during the pelagic phase (size at date of pelagic 0-group) may give a signal of recruitment success – cf Barents Sea cod (Sundby *et al.*, 1989).
Dispersal of pelagic stages in relation to geographical variations in the suitability of the seabed for settlement.	Late pelagic 0-group haddock in the North Sea show little interannual variability in spatial distribution compared to cod.
Competitive exclusion processes acting between year class conspecifics and with older year class conspecifics.	Density dependent feedback between year classes of haddock has been suggested by Cook and Armstrong (1986). A strong year class inhibits the success of a following one, potentially overriding the effects of a favourable physical environment.
Competitive exclusion by other species.	Unknown relationships with other species.
Benthic productivity.	Possible link to pelagic productivity during the proceeding spring and summer stratification.
Bottom temperature.	Unknown effect, but extreme temperatures might be supposed to inhibit settlement.

8.4 Interactions with pelagic fish stocks

The hypothesis under consideration here refers to the degree to which survival of gadoid young was related to stock sizes of conspecific pelagic species, particularly herring and (to a lesser extent) mackerel. The impetus for this proposition is given by the observed decline in total herring biomass which was in progress throughout the 1960s and early 1970s, and which reached a nadir in 1977 (Figure 8.12) after which fishing for herring was suspended for several years. At first sight this diminution would appear to coincide well with the period of the gadoid outburst, and it is indeed likely that the two biotic features are related in some way. However, a *causal* link between herring biomass and the gadoid outburst does not seem to be justifiable: the highest observed survivorship ratios for haddock, whiting and saithe occurred when the herring biomass was still very high. The case for the hypothesis as applied to cod is simply not compelling, as survivorship ratios for that stock have tended to increase over the entire period since 1966.

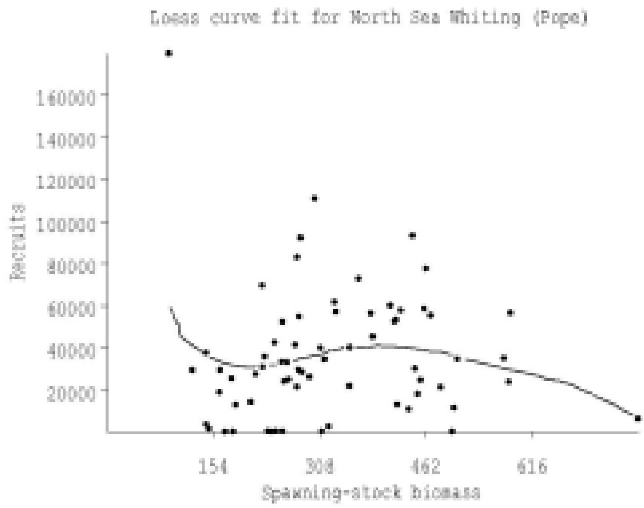

Figure 8.1.a

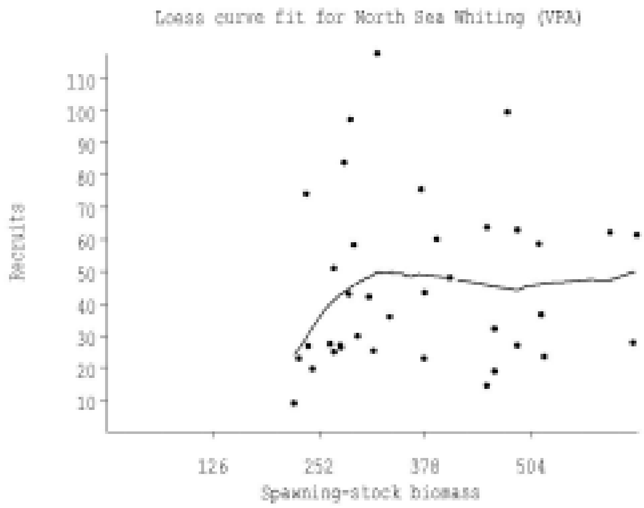

Figure 8.1.b

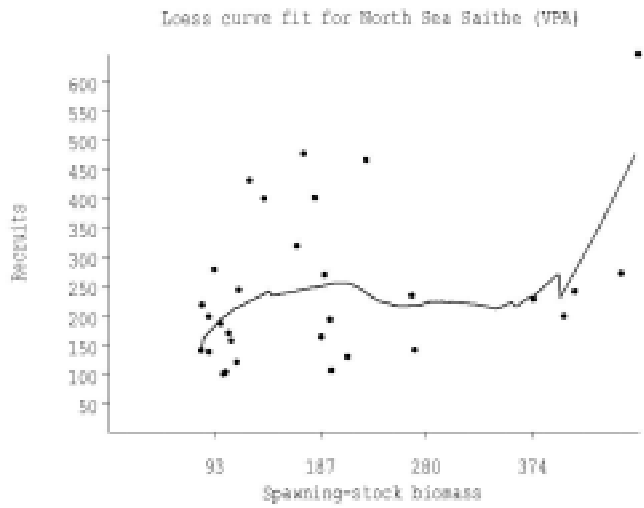

Figure 8.1.c

Figure 8.1. a-g) Plots of recruitment against parental spawning-stock biomass for four North Sea gadoid stocks. Plots indexed as "Pope" refer to the Pope and Macer (1996) time series data; those indexed as "VPA" refer to the results from the 1998 ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES CM 1999b). The dotted line shows a LOESS smoother fitted to the scatterplot in each case.

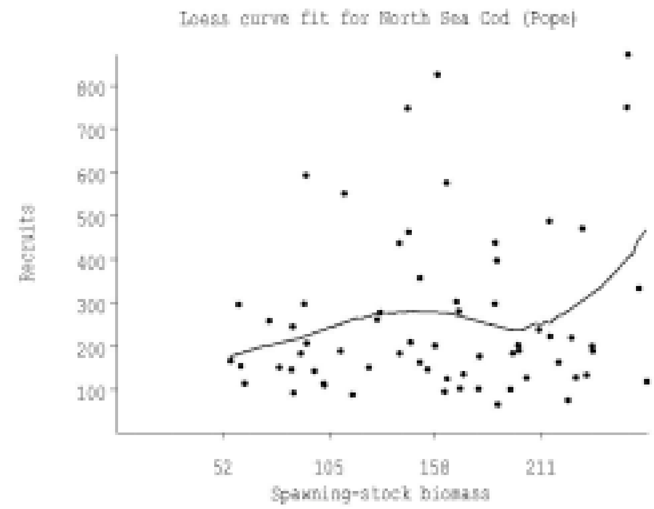

Figure 8.1.d

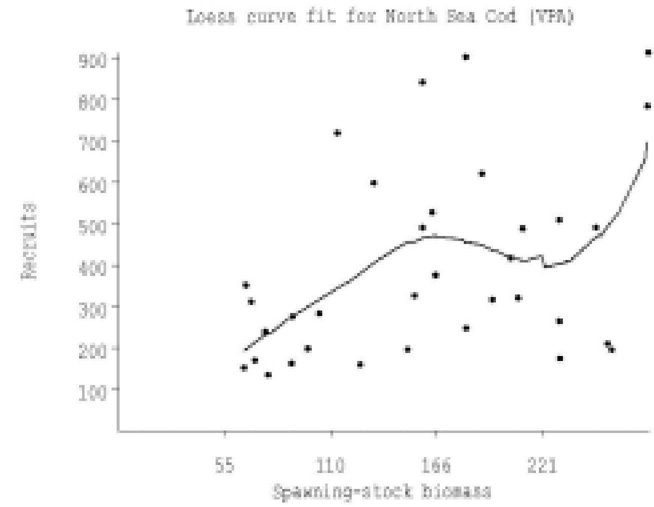

Figure 8.1.e

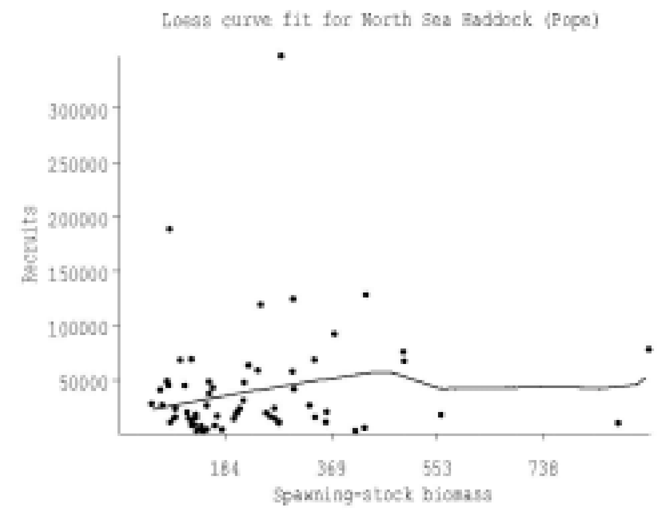

Figure 8.1.f

Figure 8.1. a-g) Plots of recruitment against parental spawning-stock biomass for four North Sea gadoid stocks. Plots indexed as "Pope" refer to the Pope and Macer (1996) time series data; those indexed as "VPA" refer to the results from the 1998 ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES CM 1999b). The dotted line shows a LOESS smoother fitted to the scatterplot in each case.

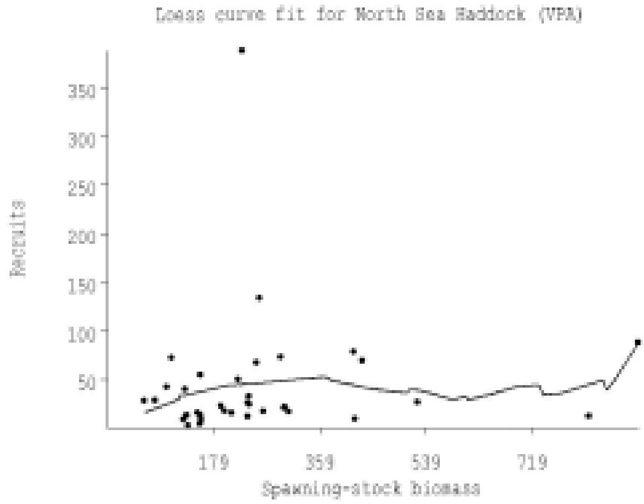

Figure 8.1.g

Figure 8.1. a-g) Plots of recruitment against parental spawning-stock biomass for four North Sea gadoid stocks. Plots indexed as "Pope" refer to the Pope and Macer (1996) time series data; those indexed as "VPA" refer to the results from the 1998 ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES CM 1999b). The dotted line shows a LOESS smoother fitted to the scatterplot in each case.

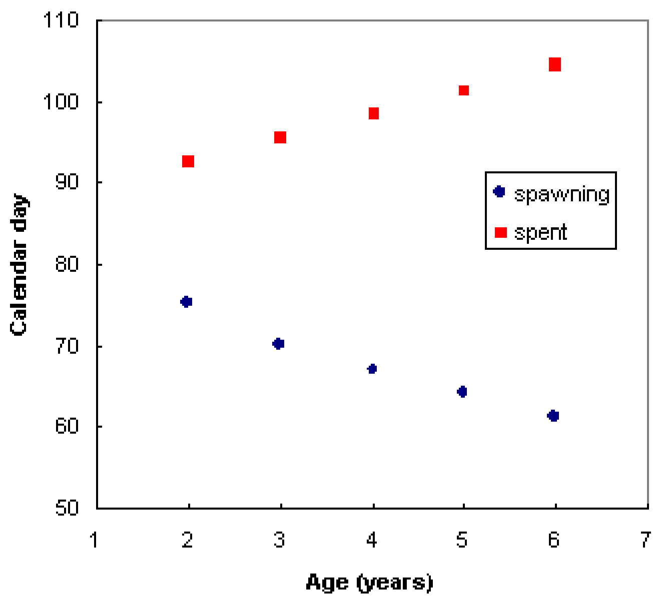

Figure 8.2. Age comparison of the calendar date at which 50% of female haddock in the northern North Sea were either spawning or spent during the 1996 spawning season, based on probit regression.

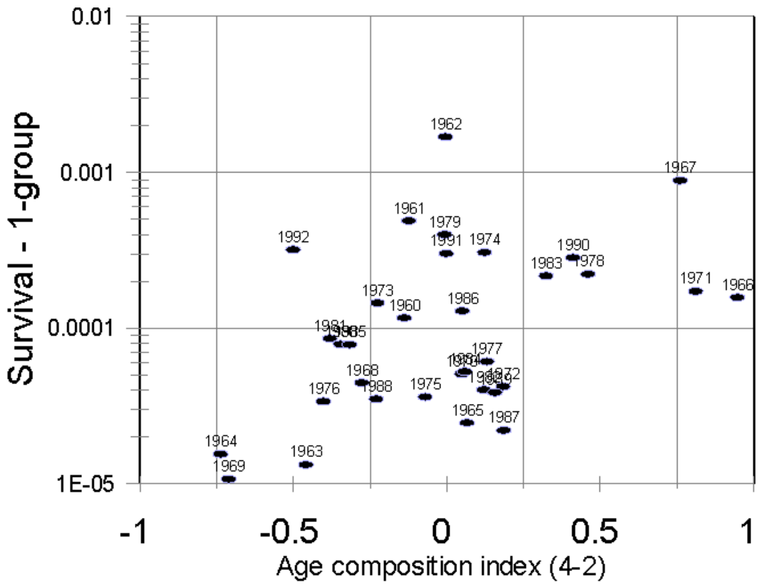

Figure 8.3. Relationship between haddock survival during development from egg to 1-group, and a stock age composition index. The age index was derived from the proportion of spawners age ≥4 relative to proportion age 2.

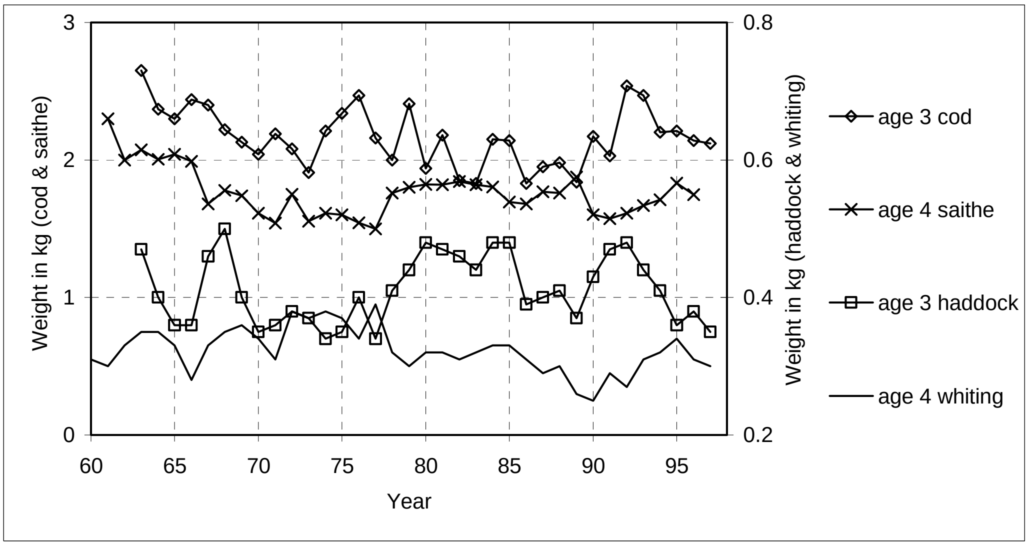

Figure 8.4. Time series of weight-at-age for the four main gadoid species in the North Sea.

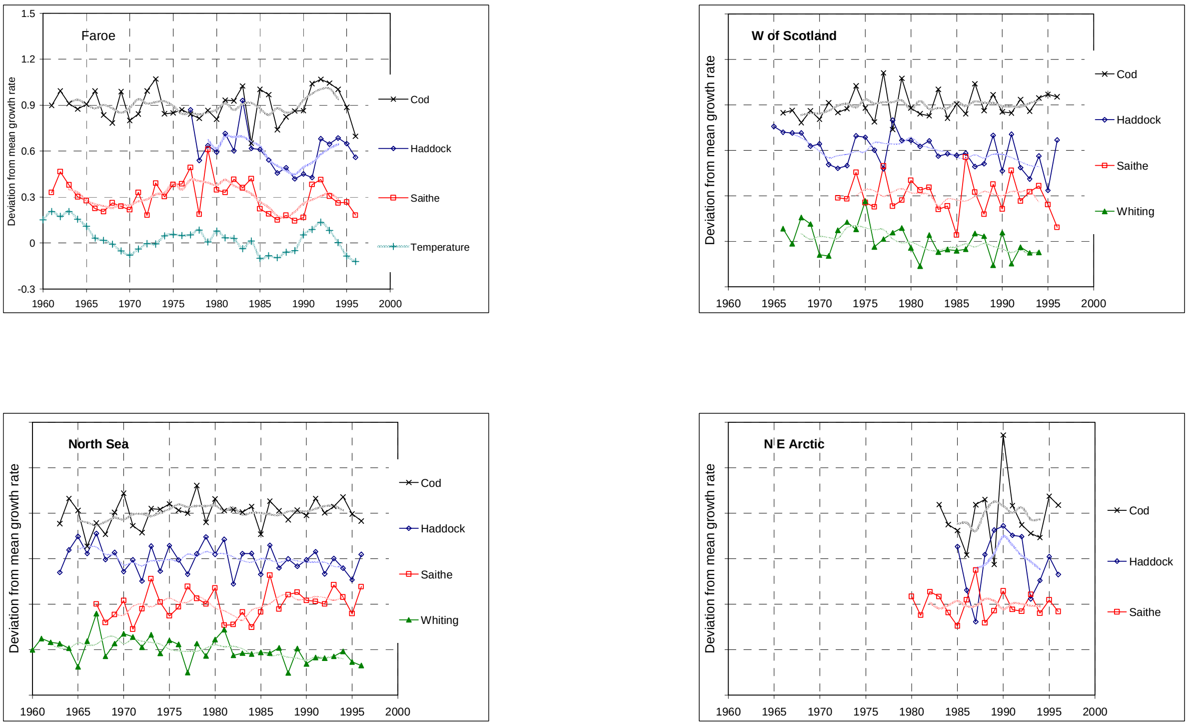

Figure 8.5. Time series of deviations from the mean growth rate for the four main exploited gadoid species in the North Sea, West of Scotland, Faroe and NE Arctic.

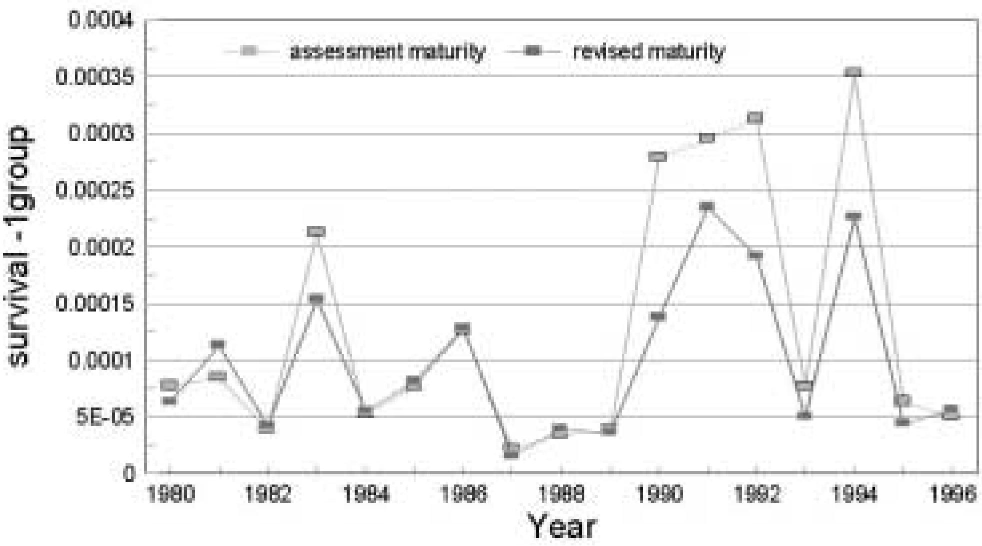

Figure 8.6. Interannual variation in haddock survival between egg and 1-group based on assessment maturity ogives, and revised ogives.

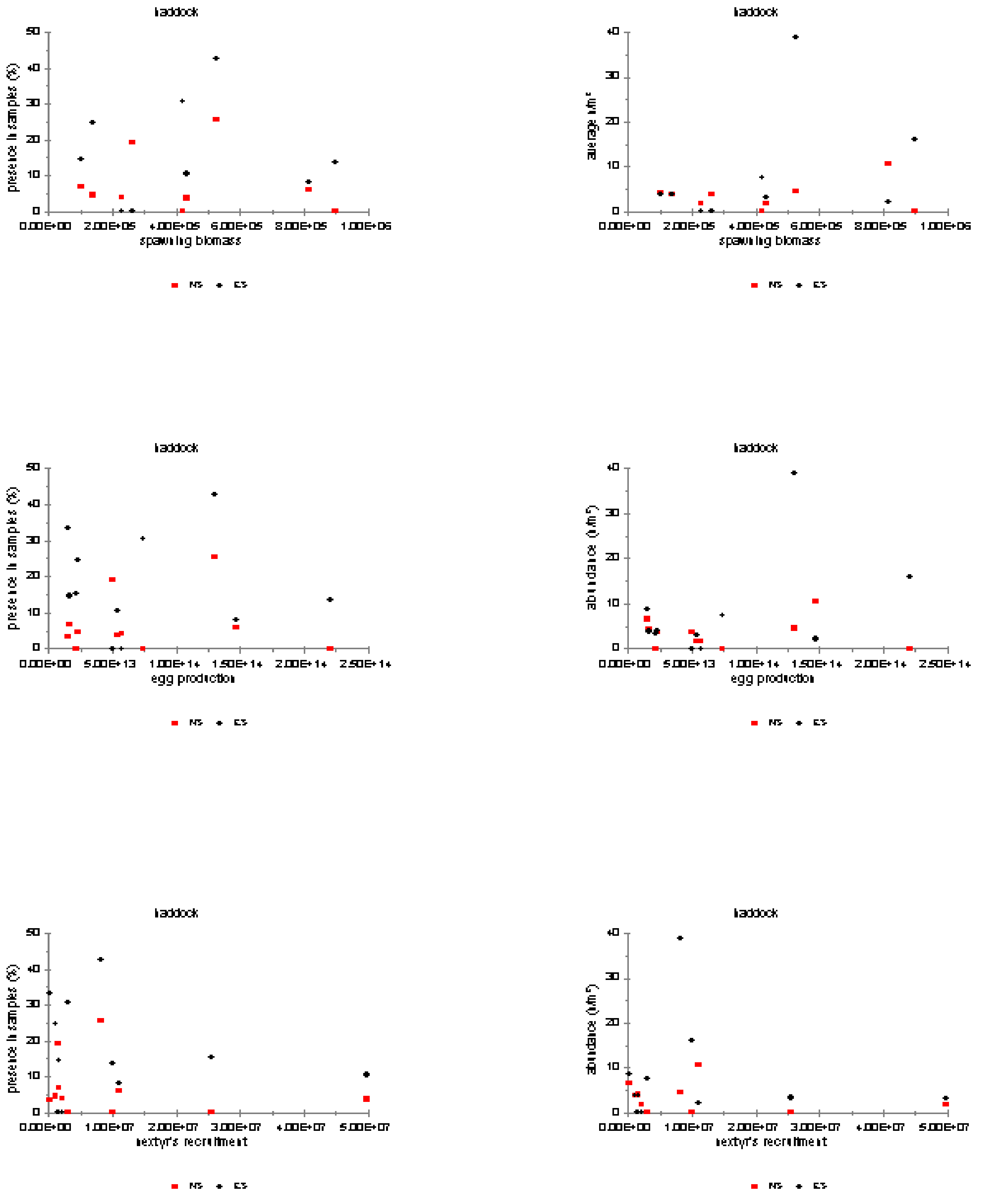

Figure 8.7. Spawning biomass, egg production, and recruitment, plotted against indices of the abundance of haddock larvae recovered from archive data on ichthyoplankton in the North Sea.

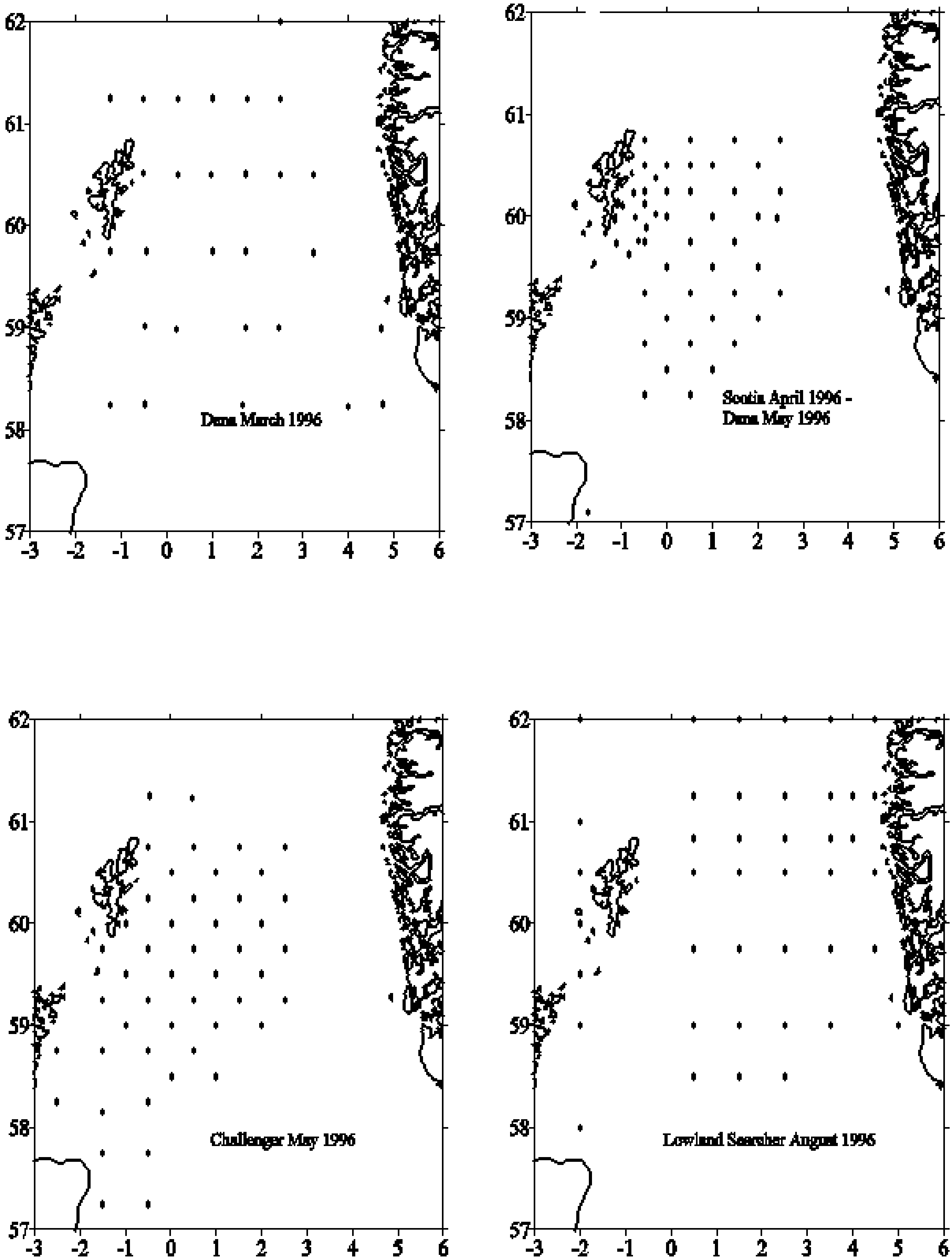

Figure 8.8. Survey coverage of the northern North Sea by the Marine Laboratory Aberdeen and the Danish Institute for Fisheries Research during 1996. Hydrographic, plankton and ichthyoplankton sampling was carried out at each location.

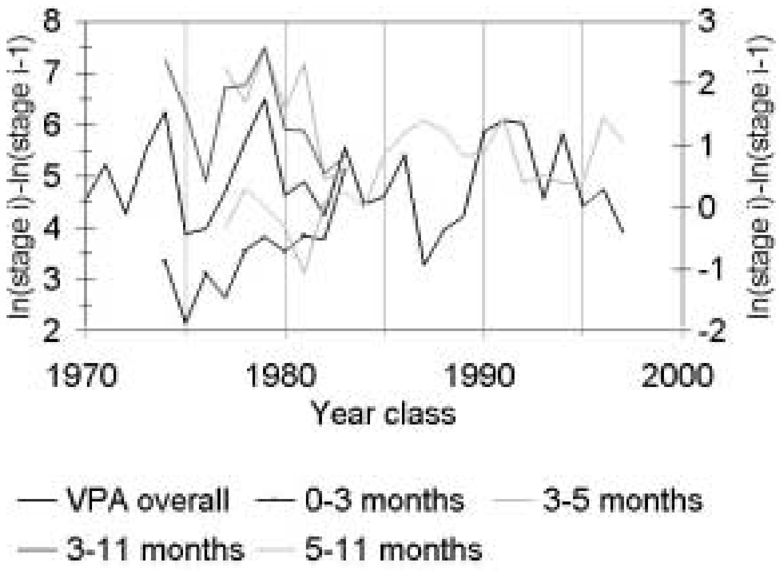

Figure 8.9. Stage specific survivorship indices for haddock early life stages in the North Sea, derived from fishery independent surveys and assessment data.

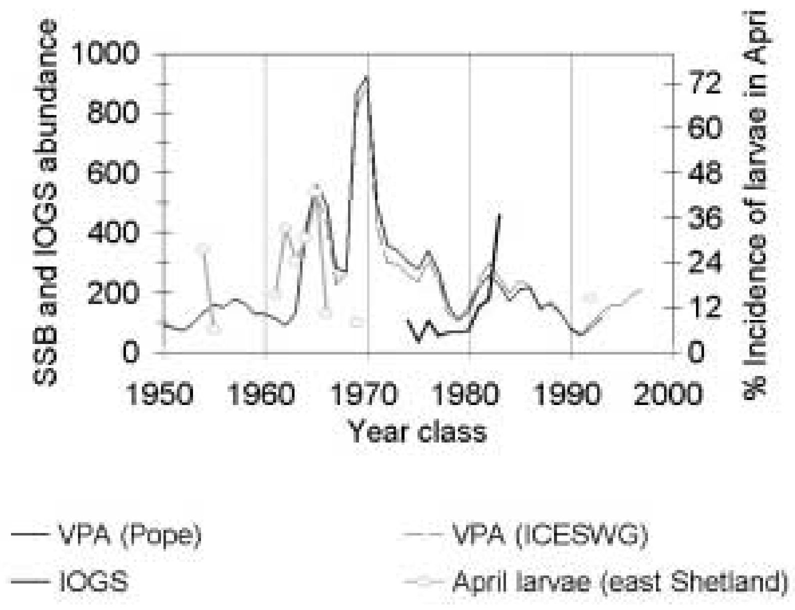

Figure 8.10. Relationships between early and late larval haddock abundance in the North Sea, and spawning stock biomass from assessment data.

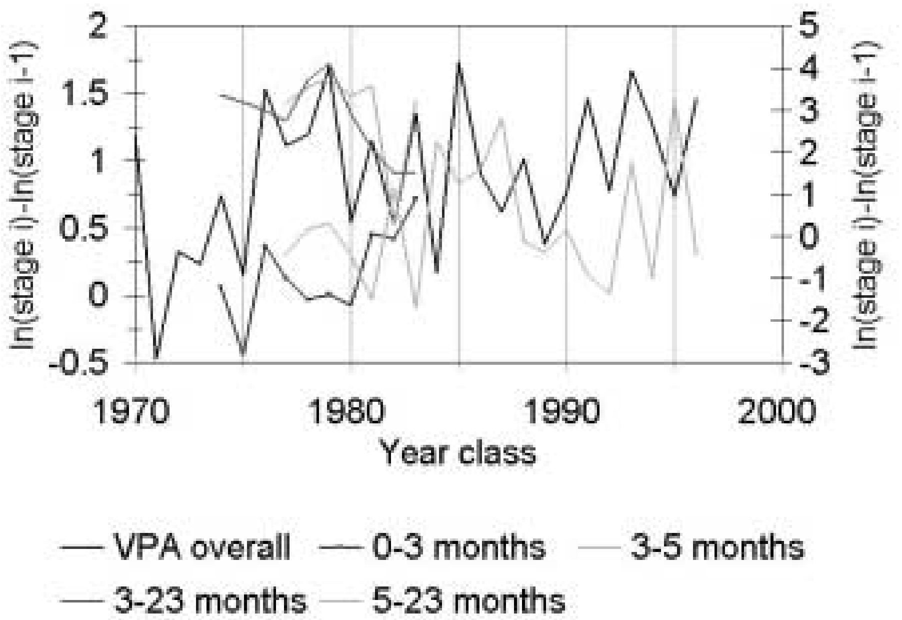

Figure 8.11. Stage specific survivorship indices for cod early life stages in the North Sea, derived from fishery independent surveys and assessment data.

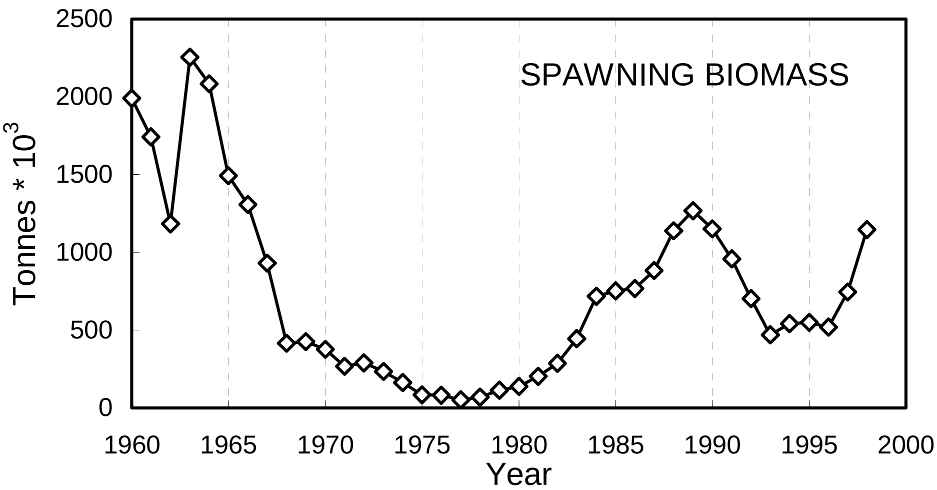

Figure 8.12. Time series of herring spawning biomass for the North Sea.

9 Overall conclusions

1. The gadoid outburst

1.1 There is no doubt that something happened to the gadoid fish stocks in the North Sea during the 1960s, but it is difficult to generalise as to the nature of the event.

1.2 The catch of the four major gadoids (cod, haddock, whiting and saithe) was greater during the 1960s than previously or since, but the increase was not due to simultaneous good recruitment across all species. There was no synchronous increase in recruitment across all species. However, for most gadoid species, both extreme high and extreme low values of recruitment were recorded in this decade.

1.3 The workshop was unable to identify any process linking individual species recruitments to environmental factors during the 1960s, but there does appear to be some global correlation between what happened to the fish stocks, the North Atlantic Oscillation, and sea temperatures.

1.4 The workshop could find no evidence to support the case for any interaction between the fate of pelagic fish stocks during the 1950s to 1970s and the behaviour of gadoid stocks. The catches, recruitment and biomass of herring follow an inverse trend to the gadoids, but predation by herring on early life stages of gadoids does not appear to be responsible since there is no relationship between herring biomass and the survival rates of young gadoids.

1.5 The increase in fishing pressure during the 1960s is unlikely to have stimulated the increase in biomass of the gadoid stocks, but was certainly responsible for the decline in biomass in the 1970s and 1980s.

2. The environment in the 1960s and since

2.1 The 1960s decade can be clearly distinguished as being different from subsequent decades in terms of a variety of physical oceanographic characteristics which all appear to be linked to the North Atlantic Oscillation.

2.1 Aspects which were clearly different included Atlantic inflow to the North Sea, sea temperatures, freshwater runoff and wind speed and direction.

2.2 There is some evidence that changes in physical conditions were responsible for changes in the timing of the spring phytoplankton bloom in the North Sea, and it would be surprising if this did not have a significant effect on the ecosystem at large.

2.3 There have been changes in the composition and abundance of zooplankton in the North Sea since the 1960s, some of which correlate with NAO signals. However, understanding of the processes responsible still eludes us in the vast majority of cases.

3. Understanding of the ecosystem

3.1 There is no comprehensive understanding of how the North Sea ecosystem functions, and it is clear that at the holistic level it cannot be explained in terms of a few parameters.

3.2 Similarly there is no clear understanding of the relative importance of processes affecting the survivorship of fish early life stages leading up to recruitment, although data analysed during the workshop gave strong indications that the late pelagic and settlement phase may be the most influential for North Sea haddock.

3.3 Even the most basic information on the ecology of North Sea gadoids is sadly lacking at present. For example, there is no North Sea wide, detailed information on the locations of spawning for cod or haddock, and no systematic surveys of the distribution and abundance of eggs and larvae.

3.4 Nevertheless, the existence of holistic correlations between, for example, recruitment variability in cod and NAO signals, indicate that there is a tangible relationship between climate and fisheries in the North Sea, even if the causal processes presently elude us.

10 Recommendations

1. Another attempt should be made to revive the failed North Sea Ichthyoplankton Surveys (NSIS) proposal to the EU FAIR programme, to conduct a comprehensive North Sea and west of Scotland wide survey of fish spawning activity and egg and larval distributions. These data will be vital for developing an understanding of how climate fluctuations affect fish stocks.

2. Our knowledge of how the NAO affects the physical environment of the North Sea clearly indicates that the Bergen - Faroe Continuous Plankton Recorder route across the northern North Sea should be reinstated. This route was terminated in 1984, but has since been shown to be one of the most valuable with respect to monitoring the consequences of changes in Atlantic inflow.

3. More research is required into the late pelagic and settlement life phase of gadoids in the North Sea, since data on haddock show that this may be one of the most influential periods setting year class strength.

4. Explicit modelling of the physical and planktonic environment in the NE Atlantic and North Sea should focus on the years 1992 and 1996 as these represent two extremes of the NAO index. 1996 may be an analogue for the 1960s with respect to atmospheric conditions. Fortuitously, there were some reasonably comprehensive surveys of hydrography, plankton and ichthyoplankton in the North Sea in these years.

5. A Theme Session on the gadoid outburst in the NW Atlantic (BF3) and the North Sea (BF4) should be held at the ICES Annual Science Conference in 2001, to compare the characteristics of the environment which occurred during the outburst period in the two regions.

11 Individual contributions

11.1 Archaeology of historical data on larval fish abundances (A. Gallego)

A total of 13 years of larval fish data were extracted from paper records of taxonomic sample analysis carried out at the FRS Marine Laboratory Aberdeen, spanning the periods of 1954–1956 and 1961–1970. In addition, more recent (1992) survey data were also used. Only North Sea stations, defined as situated east of a line running through the Orkney and Shetland areas, were considered. Sampling stations were divided latitudinally into 2 groups, labelled East of Shetland (>59° N) and North Sea (≤59° N). The following table gives the number of stations in each area, and the sampling period of the cruises, for each year.

	Number of samples				
Year	**East of Shetland**	**North Sea**	**Total**	**Sampling period(s)**	
54	113	87	200	14–29 April	20–24 April
55	80	21	101	30 March–7 April	1–2 April
56	2	81	83	21 March–4 May	
61	39	29	68	1–20 April	
62	24	29	53	4–19 March	29 April–15 May
63	69	44	113	20 March–5 April	23 March–11 May
64	62	17	79	23 April–17 May	
65	28	141	169	15–30 March	7–22 May
66	19	27	46	5–20 April	
67	1	25	26	31 March–13 May	
68	6	21	27	25 April–4 May	
69	25	33	58	10–26 March	26 April–12 May
70	22	13	35	6 April–5 May	
92	117	74	191	28 March–13 April	

Only a selected number of individual species were studied, comprising the major gadoid species present in the area (cod, haddock, Norway pout, saithe, and whiting) and sandeel (a very abundant component of the ichthyoplankton community). In addition, data were also presented for the totality of fish larvae sampled and all gadoid larvae (also including other gadoid species not considered individually). Care should be taken when using these data, given the variable temporal (see table above) and spatial (see Figure 11.1) coverage of these cruises. The raw data were summarised by percentage presence of given species (or groups of species) of the total number of samples taken in a given year (i.e. an index of presence/absence), percentage presence of given gadoid species of the total number of samples taken in a given year where gadoids were found (i.e. an index of the relative gadoid composition in the samples), and the arithmetic mean and maximum concentration (numbers m^{-2}) of a given species (or groups of species) for each year.

11.2 Data/model results from Institute of Marine Research, Bergen (G. Ottersen)

North Sea volume fluxes from the NORWECOM/POM model

Inflow to the North Sea and netflow through sections across the English Channel, from Utsira on the west coast of Norway to the Orkneys and Orkney-Shetland were presented. The results are available as monthly, quarterly and yearly values for 1955–1998.

The NORWECOM (Skogen *et al.*, 1995; Skogen *et al.*, 1997) is a coupled physical, chemical, and biological model system. The circulation model is based on the wind and density driven primitive equation Princeton Ocean Model (Blumberg and Mellor, 1987). For the present run a 20*20 km horizontal grid covering the whole shelf area from

Portugal to Norway, including the North Sea, has been used. In the vertical, the model uses 12 sigma layers. The forcing variables are six-hourly hindcast atmospheric pressure fields provided by the Norwegian Meteorological Institute, six-hourly wind stress (from the pressure fields), four tidal constituents and freshwater runoff.

Abundance of 0-group cod along the Norwegian Skagerrak coast and Oslofjord

The abundance of 0-group of a number of fish species along the southeastern coast of Norway has been monitored according to the same protocol every September-October since 1919, except for 1940–1944, (Dannevig, 1954; Johannessen and Sollie, 1994). Beach seines have been used to estimate the near-shore abundance at between 35 and 40 stations throughout this period. The data revealed a temporal dynamics in the cod time series that seems to indicate a gadoid outburst also in this area. Similar data and results were presented for the Oslofjord region.

Torungen-Hirtshals hydrographic section

The fixed hydrographic section across the Skagerrak between Torungen (Arendal), Norway and Hirtshals, Denmark has been monitored at near monthly intervals since 1952, more regularly since the 1960s (Danielssen *et al.*, 1996).

Length of Barents Sea 0-group cod

Each year since 1965 international 0-group surveys have been carried out in the Barents Sea and adjacent waters. In these late August to early September cruises data on number, length and geographical distribution of cod have been collected. Arithmetic means of length over all stations were shown. These values are published year by year in the survey reports, e.g. (ICES CM 1992/G:82).

Kola section temperatures

PINRO, Murmansk has measured the temperature along the Kola section in the south central Barents Sea since 1900. Values are averaged along the transect line and from 0–200m giving one value representative for the whole section. Monthly values since 1921 and quarterly values since 1900 have been published by (Bochkov, 1982) and (Tereshchenko, 1996). The temperature in the Kola section has been shown to reflect the regional scale variability in the Barents Sea well.

11.3 Variations in an index of stratification (B. Scott)

The stratification index is the difference between the bottom and surface (surface = 5 metre depth) density values. Density is a function of both temperature and salinity. Values between 0.3–0.4 are the dividing line between completely mixed and very slightly stratified water with the beginnings of a thermo-halocline. The data are derived from ICES hydrographic data (courtesy of Harry Dooley). The data set which was used to calculate the stratification index contains the monthly means for temperature and salinity, surface and bottom in each rectangle (1° * 1°) from 51° – 62° N and 4.5°W – 8.5°E, from 1960 to 1997.

To analyse longer-term trends the data was de-seasonalized by taking a 12-month running mean (see Figure 11.2). The North Sea was broken into 3 regions: 1) Western North Sea (Orkney, Shetland and east Scottish Coast) which is a mixed region due to strong tidal currents, 2) Northern/Central North Sea, which is a region that is predictably stratified and 3) Southern North Sea, a mixed region of the North Sea due to its shallowness (< 70 metres in depth). To investigate seasonal differences, monthly means were calculated for each rectangle, with interpolation for missing data (see Figure 11.3).

Why is a Stratification Index important?

- Stratification can be thought of as “ocean memory” as it contains in one index the recent and past effects of temperature, salinity, wind and solar radiation.
- The onset / breakdown of stratification possibly indicates the timing of the spring and fall bloom (in the North Sea).
- High levels of stratification may indicate:

→ lack of wind, increased solar heating, salinity differences.

→ less egg and larval dispersal, with more consistent (predictable) current structures and therefore increased patchiness of prey.
→ higher levels of primary production.

- Low levels indicate of stratification may indicate:

→ more wind, less heating, salinity differences.
→ possibly higher levels of egg and larval dispersal with current structures being more erratic and less patchiness of prey.
→ lower primary production.

11.4 Population fecundity and a survival index for haddock (P. Wright)

Total production of eggs (EP) of the North Sea stock was estimated as:

$$EP = \sum(Na * Pa * PFa * WFa * Ra)$$

Where Na = Number of fish-at-age; Pa = percent mature; PFa = proportion of females; WFa = mean weights of mature females; Ra = relative fecundity (number of oocytes/kg).

The number of fish-at-age, mean weights-at-age and percentage maturity were obtained from stock assessment tables (ICES, 1998). In addition, egg production was also calculated using revised maturity-at-age data extracted from the first quarter IBTS survey for the period 1980–1996. In general the revised maturity data resulted in an increased spawning stock biomass in the years of low numbers of fish >1 year old.

Survival was estimated from: (ln VPA age 1 – ln population fecundity)/ δt ,where δt = 9 months between March and January.

Survival to age 1 indicates that only 1962 and 1967 were exceptional years for haddock survival.

Length composition data for pelagic 0-group haddock

Research has indicated that there can be a positive selection for large haddock between the period from June to August when juveniles move from the pelagic to the demersal phase.

In order to consider length compositions of pelagic 0-group haddock, data were extracted from the International 0-group Gadoid Surveys 1974–1983 and 1985. Owing to differences in survey timing and duration and the fast growth of juveniles the data extraction was limited to a 10-day period for these surveys [13–23 June]. Further, because of some changes in survey coverage, only the main haddock concentrations found in 6 ICES rectangles were examined (49F1, 48F0, 48F1, 47E9, 47F0, 47F1). The data were available on numbers per 5 mm length-classes. Length compositions from stations were combined to give a population length composition using weighting based on CPUE.

Preliminary analysis indicated that there were significant differences in 0-group length compositions between years and that median length in June was not correlated with survival index. No information was available on age so differences may reflect growth or age.

11.5 Inverse dynamics of herring and sprat and links to the gadoid outburst (J. Alheit)

During the gadoid outburst, there were dramatic changes in the dynamics of pelagic North Sea stocks, namely herring, sprat and mackerel. The herring stocks had collapsed in the late 1960s and recovered again in the early 1980s (Figure 11.4). At approximately the same time, in the early 1970s, the North Sea sprat stock expanded and decreased again in the early 1980s. Corten studied these changes in the pelagic fish community in a series of papers (Corten, 1986, 1990; Corten and Van de Kamp, 1992) and concluded that changes in the shelf edge current, a branch of which flows into the North Sea (Tampen Bank Current) might have been responsible for the observed variability of pelagic stocks. The ICES Sprat Biology Workshop (ICES, 1990) investigated the expansion and contraction of the sprat stocks and came to the conclusion that they were caused by long-term environmental changes without specifying them.

Inverse dynamics of European herring and sardine populations have been known for a long time and shown to be driven by the NAO (Alheit and Hagen, 1997). It is assumed here that the antagonistic dynamics of North Sea herring and sprat are, at least partly, caused by the environmental forcing factors which are acting on both species at the same time. This view is supported by what is known on the collapse and recovery of the Celtic Sea herring stock which paralleled those of the North Sea herring (K. Brander, Figure 11.4).

The German Bight is an important nursery area for North Sea sprat (Valenzuela *et al.*, 1991). Potential retention mechanisms for sprat spawn have been described (Alheit and Bakun, 1991; Valenzuela *et al.*, 1991; Dippner, 1993). Preliminary studies indicate that wind direction and wind speed may be responsible for retaining sprat larvae in the German Bight (Alheit and Bakin, 1991). In a wider context, those environmental factors which caused the decline of North Sea sprat and the recovery of North Sea herring in the early 1980s might also have influenced the gadoid fish community in the North Sea.

11.6 Predicting cod recruitment from sea surface temperature data (J. Dippner)

A multivariate statistical model is applied to investigate the interannual variability in cod recruitment in relation to climate variability. The statistical downscaling method has been developed by von Storch (von Storch, 1995). The idea is to correlate the potential climate predictor variables with local observations and to look for high correlations. Information from fields of climate predictors and regional predictands can be related to each other in the following way: Firstly, Empirical Orthogonal Functions (EOFs, also known as “Principal Components”) of the predictors and predictands are calculated. Thus, the major part of the variance from a multidimensional vector (e.g. a sea surface temperature (SST) field with many stations) is concentrated in few new dimensions, the leading eigenmodes. The advantage is to keep the dimensionality of the model low. Secondly, a Canonical Correlation Analysis (CCA) is performed between the leading eigenmodes of the climate predictor and the regional time series. A possible time lag between the signals in climate and the local variables is taken into account. In a further step the combinations with the highest skill are selected and tested for their statistical significance. For the model validation cross-validation technique and Monte-Carlo simulations are used. Details are given e.g. in Dippner, 1997a.

This technique has recently applied to various aspects of interannual variability in the North Sea. Using the North Atlantic Oscillation (NAO) index as predictor field and the weekly SST charts compiled on a 20 N.m. grid as predictand field, Dippner (1997a) has shown that in the southern North Sea the interannual variability in SST anomalies is driven by direct air-sea interaction. Using selected areas of the SST anomalies as predictor fields and VPA data of cod, haddock, saithe, and whiting as predictands a larger part of the interannual variability of cod, saithe and whiting can be addressed to the climate variability of the SST anomalies (Dippner, 1997b). The CCA correlations and the correlation of cross validation are significantly high and the model skill is excellent. No meaningful correlation has been found for haddock. These results are in good agreement with the analyses of Svendsen *et al.* (1995).

For the Backward-Facing Workshop 4, a similar computation has been carried out with respect to the gadoid outburst. Since the SST charts of the North Sea start in 1968 – after the gadoid outburst – the weekly SST charts on a 20 N.m. resolution have been replaced as predictor field by the monthly mean COADS SST data set on a 2° * 2° grid resolution from 18°W to 9°E and from 44°N to 62°N.

This data set covers the period from 1900 to 1992. The predictor field is averaged over the winter months (December to February). The yearly values of cod recruitment for the North Sea, based on ICES data, are used as predictands for this computation instead of VPA data. Three dominant SST EOFs are used and one cod EOF for the analysis. Figure 11.5 shows the result of the cross-validation. The thin line shows the cod recruitment predicted from the COADS SST data, the full line the filtered prediction with a cut-off period of four years and the dashed line the observations. It is important to note that the corresponding EOF patterns have different signs. An anomaly in winter temperature of –1°C corresponds to an anomaly in cod recruitment of 24 billion animals. The CCA correlation is 0.72; the correlation of the cross-validation is 0.67. Both are significant with respect to the 99% confidence level. The model skill is 0.45. A clear shift from the 60s cold period to the 90s warm period can be seen, and a parallel trend is evident in the cod recruitment. This result indicates that the gadoid outburst is probably connected with climate variability.

A weak indication exists that the shift from the cold to the warm period can be connected with a long periodic oscillation in the climate system in the order of 65–70 years. This signal has been recently identified in the SST anomalies on the northern hemisphere (Schlesinger and Ramankutty, 1994) and in Greenland ice cores (Appenzeller *et al.*, 1998).

11.7 Wind climate of the North Sea 1958–1997 (Corinna Schrum)

From a wind statistic for the North Sea, presented by Siegismund and Schrum (1999), based on the atmospheric re-analysis provided by the NCEP/NCAR (available from 1958–1997; Kalnay *et al.*, 1996), it became clear that the wind climate over the North Sea has changed substantially during the last 4 decades. The main changes were found in the annual mean wind speed, the winter wind speeds and in the seasonality of the wind fields and can be summarized as follows:

* The annual mean wind speed for the North Sea shows a rising trend of about 10 % for the last 40 years, which is mainly caused by an intensification of the winter NAO (Figure 11.6). As expected a rising wind speed is seen for the season from October to January with an increasing preference of southwesterly directions.
* The angular distribution for the winter season (ONDJ), which is typically asymmetric, favouring west-southwesterly winds, was in recent years even more pronounced and is since the late eighties extended to February and March. These two months have undergone a fundamental change in their wind characteristics.
* The last decade (from 1988 to 1997) was identified to be an outstanding period compared to the other three decades: The duration of typical winter wind conditions, with high wind speeds and the preference of southwesterly winds, has extended from the usual October to January towards February and March.

This increase in westerly wind forcing results in remarkable changes in the circulation of the North Sea, i.e. the typical cyclonic circulation is enhanced and thus, the exchange between the Northern Atlantic is intensified (Schrum, 1999). Increased inflow into the North Sea for the last decade, i.e. 1988–1997 was also modelled by the NORWECOM (e.g. Iversen *et al.,* 1998).

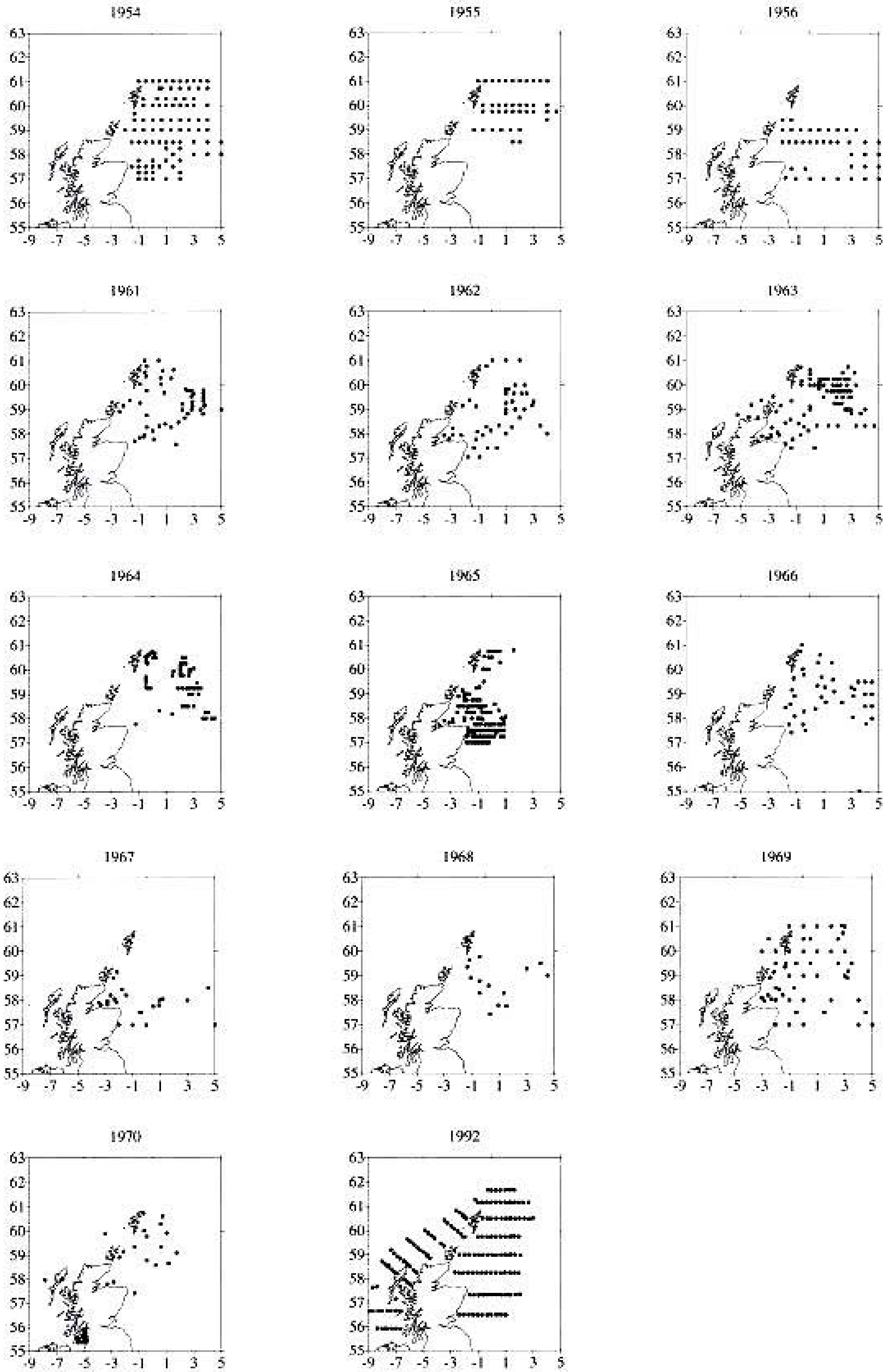

Figure 11.1. Larval fish sampling locations, 1954–1992, from archive records held at the Marine Laboratory Aberdeen.

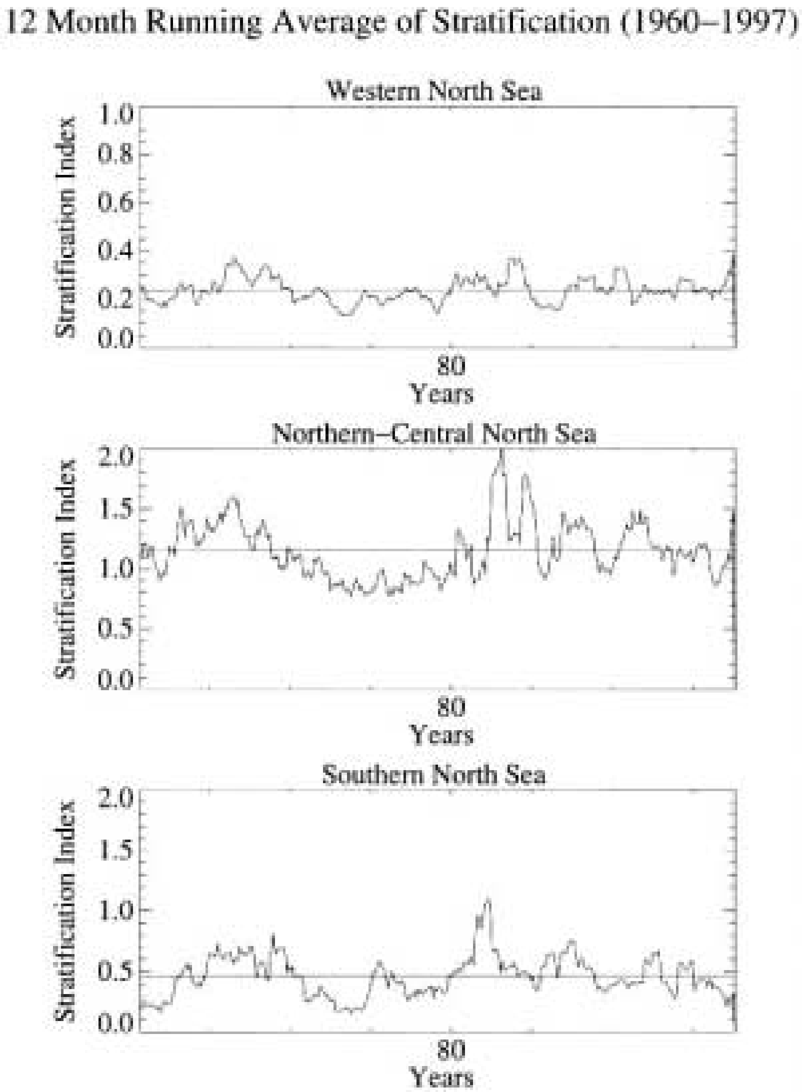

Figure 11.2. Twelve-month running mean of stratification index data for three sub-areas of the North Sea, compiled from archive data supplied by ICES.

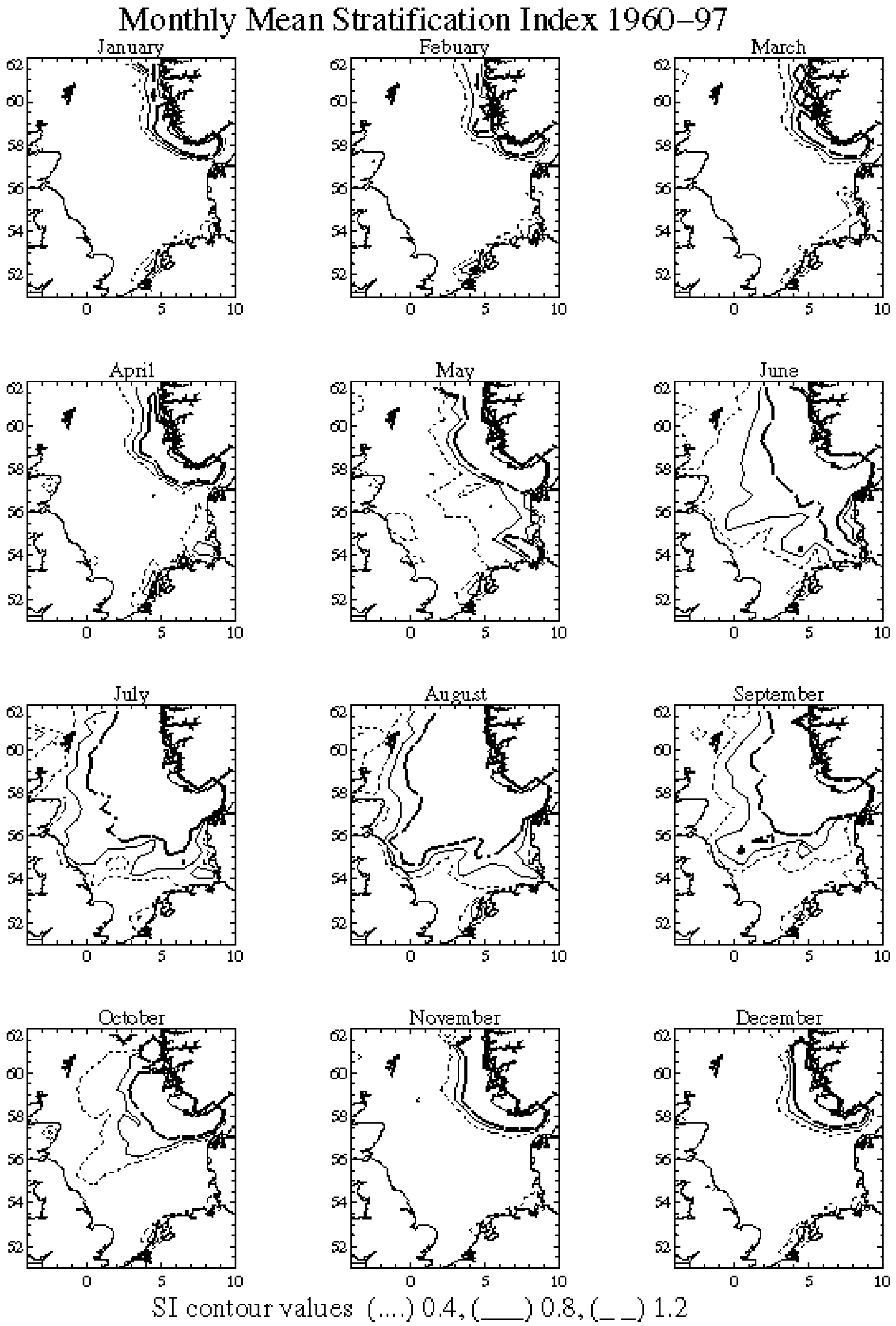

Figure 11.3. Monthly average spatial distributions of a stratification index in the North Sea, compiled from archive hydrographic data supplied by ICES from 1960 onwards.

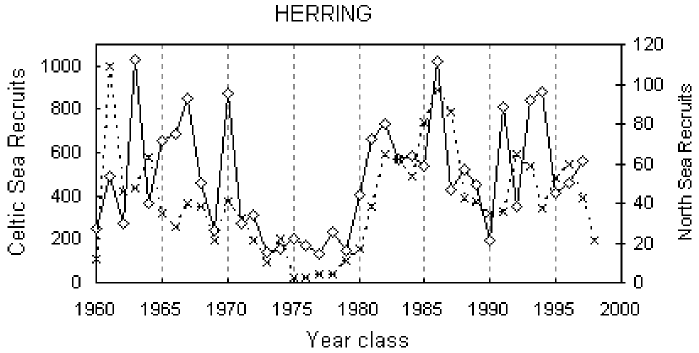

Figure 11.4. North Sea (dashed line) and Celtic Sea herring year classes follow similar trends, with a low period from 1971–1979, followed by a sharp increase to 1986.

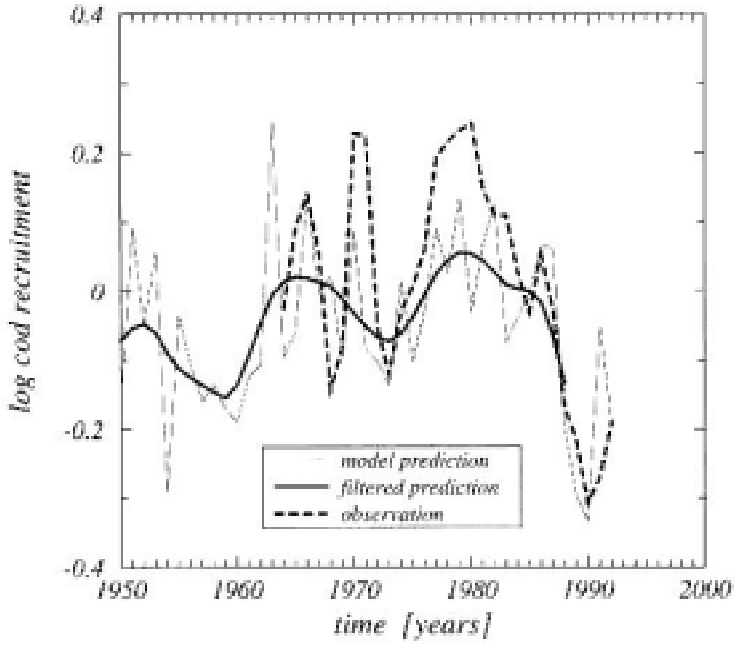

Figure 11.5. Predictions of North Sea cod recruitment from COADS sea surface temperature data.

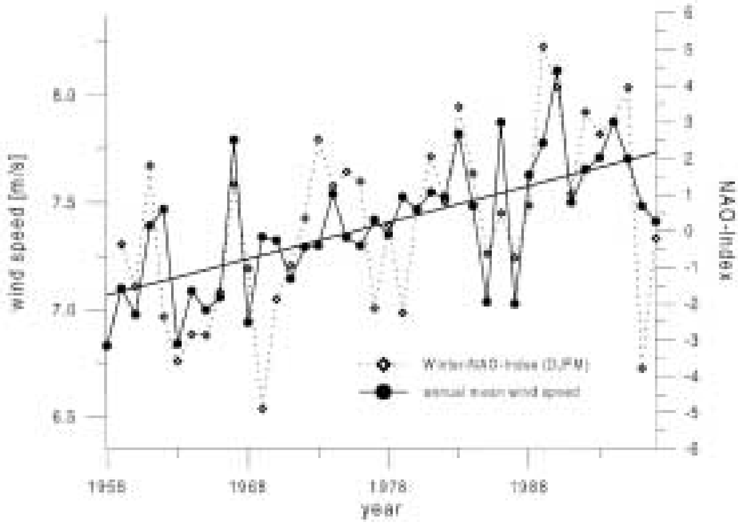

Figure 11.6. Time series of the annual mean wind speed over the North Sea for the period 1958–1997, derived from the NCEP-reanalysis (solid line) and the NAO index for the winter season (DJFM, dashed).

12 References

Alexandersson, H., Smith, T., Iden, K., and Tuomenvirta, H. 1998. Long-term variations of the storm climate over NW Europe. The Global Ocean Atmosphere System, 6: 97–120.

Alheit, J., and Bakun, A. 1991. Reproductive success of sprat (*Sprattus sprattus*) in the German Bight during 1987. ICES CM 1991/L:44.

Alheit, J., and Hagen, E. 1997. Long-term climate forcing of European herring and sardine populations. Fisheries Oceanography, 6: 130–139.

Appenzeller, C., Stocker, T. F., and Anklin, M. 1998. North Atlantic Oscillation Dynamics Recorded in Greenland Ice Cores, Science, 282: 446–449.

Bacon, S., and Carter, D. J. T. 1993. A connection between mean wave height and atmospheric pressure gradient in the North Atlantic. International Journal of Climatology, 13 (4): 423–436.

Becker, G. A., and Pauly, M. 1996. Sea surface temperature changes in the North Sea and their causes. ICES Journal of Marine Science, 53: 887–898.

Blumberg, A. F., and Mellor, G. L. 1987. A description of a three-dimensional coastal ocean circulation model. *In:* Three-dimensional coastal ocean models. Ed. by N. Heaps, American Geophysical Union, Washington D.C.: pp. 1–16.

Bochkov, Y. A. 1982. Water temperature in the 0–200m layer in the Kola-Meridian in the Barents Sea, 1900–1981. Sb. Nauchn. Trud. PINRO, 46: 113–122.

Brander, K. M. 1994. The location and timing of cod spawning around the British Isles. ICES Journal of Marine Science, 51: 71–89.

Brander, K. M. 2000. Detecting the effects of environmental change on growth and recruitment in cod (*Gadus morhua*) using a comparative approach. Oceanologica Acta, 4 (23): 485–496.

Bromley, P. J., Watson, T., and Hislop, J. R. G. 1997. Diel feeding patterns and the development of food webs in pelagic 0-group cod (*Gadus morhua* L.), haddock (*Melanogrammus aeglefinus* L.), whiting (*Merlangus merlangus* L.), saithe (*Pollachius virens* L.) and Norway pout (*Trisopterus esmarkii* Nilsson) in the northern North Sea. ICES Journal of Marine Science, 54: 846–853.

Cayan, D. R., and Reverdin, G. 1994. Monthly Precipitation and Evaporation Variability Estimated over the North Atlantic and North Pacific. Pp. 28–32 In: Atlantic Climate Change Program: Proceedings of PI's meeting, Princeton, May 9–11, 1994.

Cayan, D. R. 1992c. Latent and Sensible Heat Flux Anomalies over the Northern Oceans: Driving the Sea Surface Temperature. Journal of Physical Oceanography, 22: 859–881.

Cayan, D. R. 1992a. Latent and Sensible Heat Flux Anomalies over the Northern Oceans: The Connection to Monthly Atmospheric Circulation. Journal of Climate, 5: 354–369.

Cayan, D. R. 1992b. Variability of Latent and Sensible Heat Fluxes Estimated using Bulk Formulae. Atmosphere–Ocean, 30: 1–42.

Chambers, R. C. 1997. Environmental influences on egg and propagule sizes in marine fishes. In: Early Life History and Recruitment in Fish Populations, edited by R. C. Chambers and E. A. Tripple, 63–102. Fish and Fisheries Series 21. London: Chapman & Hall.

Cook, R. M., and Armstrong, D. W. 1986. Stock related effects on the recruitment of North Sea haddock and whiting. Journal du Conseil International pour l'Exploration de la Mer, 42: 272–280.

Corten, A. 1986. On the causes of the recruitment failure of herring in the central and northern North Sea in the years 1972–1978. Journal du Conseil International pour l' Exploration de la Mer, 42: 281–294.

Corten, A. 1990. Long-term trends in pelagic fish stocks of the North Sea and adjacent waters and their possible connections to hydrographic changes. Netherlands Journal of Sea Research, 25: 227–235.

Corten A., and Van de Kamp, G. 1992. Natural changes in pelagic fish stocks of the North Sea in the 1980s. ICES Marine Science Symposia, 195: 402–417.

Cotton, P. D., Challenor, P. G., and Carter, D. J. T. Analysis of inter–annual variability of altimeter measured global wave climate. 3rd ERS Symposium, Florence Italy, March 1997.

Curry R, and McCartney, M. 1999. Ocean gyre circulation changes associated with the North Atlantic Oscillation. Journal of Physical Oceanography, (in press).

Daan (ed.) 1989. Data Base Report of the Stomach Sampling Project 1981. ICES Cooperative Research Report 164.

Danielssen, D. S., Svendsen, E., and Ostrowski, M. 1996. Long-term hydrographic variation in the Skagerrak based on the section Torungen-Hirtshals. ICES Journal of Marine Science, 53: 917–925.

Dannevig, A. 1954. The littoral cod on the Norwegian Skagerrak coast. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 136: 7–14.

Dickson, R., Lazier, J., Meinke, J., Rhines, P., and Swift, J. 1996. Long–term coordinated changes in the convective activity of the North Atlantic. Progress in Oceanography, 38: 241–295.

Dickson, R. R. 1997. From the Labrador Sea to global change. Nature 386: 649–650.

Dippner, J. 1993. Larval survival due to eddy activity and related phenomena in the German Bight. Journal of Marine Systems, 4: 303–313.

Dippner, J. W. 1997a. SST anomalies in the North Sea in relation to the North Atlantic Oscillation and the influence on the theoretical spawning time of fish. Deutsche Hydrographische Zeitschrift, 49: 267–275.

Dippner, J. W. 1997b. Recruitment Success of Different Fish Stocks in the North Sea in Relation to Climate Variability. Deutsche Hydrographische Zeitschrift, 49: 277–293.

Fromentin, J.-M., and Planque, B. 1996. *Calanus* and environment in the eastern North Atlantic. II. Influence of the North Atlantic Oscillation on *C. finmarchicus* and *C. helgolandicus.* Marine Ecology Progress Series 134: 111–118.

Gran and Braarud, 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry and turbidity). Journal of the Biological Board of Canada, 1: 279–467.

Hislop, J. 1997. Data Base Report of the Stomach Sampling Project 1991. ICES Cooperative Research Report 219.

Hislop, J. R. G. 1988. The influence of maternal length and age on the size and weight of the eggs and the relative fecundity of the haddock, *Melanogrammus aeglifinus*, in British waters. Journal of Fish Biology, 32: 923–930.

Hislop, J. R. G. 1984. A comparison of the reproductive tactics and strategies of cod, haddock, whiting and Norway pout in the North Sea. In: Fish Reproduction, Strategies and Tactics, pp 311–329. Edited by G. W. Potts and R. J. Wootton. Academic Press, 410pp.

Hurrell, J. W., and van Loon, H. 1997. Decadal variations in climate associated with the North Atlantic Oscillation. Climatic Change, 36: 301–326.

Hurrell, J. W. 1996. Influence of variations in extra tropical wintertime teleconnections on Northern Hemisphere temperature. Geophysical Research Letters, 23: 665–668.

Hurrell, J. W. 1995a. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science, 269: 676–679.

Hurrell, J. W. 1995b. An evaluation of the transient eddy forced vorticity balance during northern winter. Journal of Atmospheric Science, 52: 2286–2301.

ICES. 1984. Report of the Working Group on the International 0-group Gadoid Surveys in the North Sea. ICES CM 1984/G:69.

ICES. 1990. Report of the sprat biology workshop. ICES Cooperative Research Report 169, 91 pp.

ICES. 1992. Preliminary report of the international 0-group fish survey in the Barents Sea and adjacent waters in August-September 1992. ICES CM 1992/G:82.

ICES. 1999a. Report of the 1998 Working Group on the Assessment of Northern Shelf Demersal Stocks. ICES CM 1999/ACFM:1.

ICES. 1999b. Report of the 1998 Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. ICES CM 1999/ACFM:8.

Iversen, A. S., Skogen, M. D., and Svendsen, E. 1998. Influx of Atlantic water and feeding migration of horse mackerel. ICES CM 1998/R:18.

Johannessen, T., and Sollie, A. 1994. Overvåkning av grunntvannsfauna på Skagerrakkysten. Fisken Havet 91. Institute of Marine Research. Bergen. In Norwegian.

Jones, P. D. 1987. The early twentieth century Arctic high – fact or fiction? Climate Dynamics, 1: 63–75.

Jones, P. D., Jonsson, T., and Wheeler, D. 1997. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and SW Iceland. International Journal of Climatology, 17: 1433–1450.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., and Joseph, D. 1996. The NCEP/NCAR 40-Year Reanalysis Project. Bulletin of the American Meteorological Society.

Kjesbu, O. S. 1989. The spawning activity of cod, *Gadus morhua* L. Journal of Fish Biology, 34: 195–206.

Knijn, R. J., Boon, T. W., Heessen, H. J. L., and Hislop, J. R. G. 1993. Atlas of North Sea Fishes. Based on bottom-trawl survey data for the years 1985–1987. ICES Cooperative Research Report 194.

Kushnir, Y., Cardone, V. J. Greenwood, J. G., and Cane, M. 1997. On the recent increase in North Atlantic wave heights. Journal of Climate, 10: 2107–2113.

Marsh, R. 2000. Modeling changes in North Atlantic circulation under the NAO minimum wind forcing of 1877–81. Atmosphere-Ocean, 38: 367–393.

Marteinsdottir, G., and Steinarsson, A. 1998. Maternal influence on the size and viability of Iceland cod *(Gadus morhua L.)* eggs and larvae. Journal of Fish Biology, 52: 1241–1258.

McCartney, M. S., Curry, R. G., and Bezdek, H. F. 1997. Interdecadal variability of subpolar warm-to-cold transformation of subtropical waters and the North Atlantic Oscillation. Science (in prep).

McCartney M. S., Curry, R. G., and Bezdek, H. F. 1996. North Atlantic's transformation pipeline chills and redistributes subtropical water. Oceanus, 39: 19–23.

Mertz, G., and Myers, R. A. 1994. Match/mismatch predictions of spawning duration versus recruitment variability. Fisheries Oceanography, 3:4, 236–245.

Myers, R. A., Helbig, J., and Holland, D. 1989. Seasonal and interannual variability of the Labrador Current and West Greenland Current. ICES CM 1989/C:16, l8pp (mimeo).

Planque, B., and Fox, C. J. 1998. Interannual variability in temperature and the recruitment of Irish Sea cod. Marine Ecology Progress Series, 172: 101–105.

Planque B., and Fredou,T. 1999. Temperature and the recruitment of Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences, 56: 2069–2077.

Pope, J. G., and Macer, C. T. 1996. An evaluation of the stock structure of North Sea cod, haddock and whiting since 1920, together with a consideration of the impact of fisheries and predation effects on their biomass and recruitment. ICES Journal of Marine Science, 53: 1157–1169.

Robb, A. P., and Hislop, J. R. G. 1980. The food of five gadoid species during the pelagic 0-group phase in the northern North Sea. Journal of Fish Biology, 16: 199–217.

Rogers, J. C. 1994. Atlantic storm track variability and the North Atlantic Oscillation. Pp. 20–24. In: Atlantic Climate Change Program: Proceedings of the PI's meeting, Princeton, May 9–11, 1994.

Rogers, J. C. 1990. Patterns of low-frequency monthly sea level pressure variability (1899–1986) and associated wave cyclone frequencies. Journal of Climate, 3: 1364–1379.

Rogers, J. C. 1997. North Atlantic storm track variability and its association to the North Atlantic Oscillation and climate variability of Northern Europe. Journal of Climate, 10: 1635–1647.

Schlesinger, M. E., and Ramankutty, N. 1994. An oscillation in the global climate system over a period of 65–70 years, Nature, 367: 723–726.

Schrum, C., 1999. Regionalization of climate change for the North Sea and the Baltic Sea. Submitted to Climate Research.

Siegismund, F., and Schrum, C. 1999. Decadal changes in the wind forcing over the North Sea, submitted to Climate Research.

Skogen, M., Eriksrød, G., and Svendsen, E. 1997. Quantification of transports to Skagerrak. In: Sensitivity to change: Black Sea, Baltic Sea and North Sea. Ed. by E. Ozsoy and A. Mikaelyan, Kluwer Academic Publishers: pp. 327–339.

Skogen, M. D., Svendsen, E., Berntsen, J., Aksnes, D., and Ulvestad, K. 1995. Modelling the primary production in the North Sea using a coupled 3-D physical, chemical, and biological ocean model. Estuarine, Coastal and Shelf Science, 41: 545–565.

Stockton, C. W., and Glueck, M. F. 1999. Long-term variability of the North Atlantic Oscillation (NAO). Preprints of the 10th Symposium on Global Change Studies (American Meterological Society, Boston 1999), pp. 290–293.

Sundby, S., Bj⌀rke, H., Soldal, A. V., and Olsen, S. 1989. Mortality rates during the early life stages and year class strength of northeast Arctic cod (*Gadus morhua* L.*).* Rapports et Procès-Verbaux des Réunions du Conseil International pour l' Exploration de la Mer, 191: 351–358.

Svendsen, E., Aglen, A., Iversen, S. A., Skagen, D. W., and Smestad, O. 1995. Influence of climate on recruitment and migration of fish stocks in the North Sea. In: BEAMISH, R.J. (ed.): Climate change and northern fish population, Canadian Special Publication of Fisheries and Aquatic Sciences, 121: 641–653.

Sverdrup H. U. 1953. On conditions for venal blooming of phytoplankton. Journal du Conseil International pour l'Exploration de la Mer, 18: 287–295.

Tereshchenko, V. V. 1996. Seasonal and year-to-year variations of temperature and salinity along the Kola meridian transect. ICES CM 1996/C:11.

Tripple, E. A., Kjesbu, O. S., and Solemdal, P. 1997. Effects of adult age and size structure on reproductive output in marine fishes. In Early Life History and Recruitment in Fish Populations, edited by R. C. Chambers and E. A. Tripple, 63–102. Fish and Fisheries Series 21. London: Chapman and Hall.

Tripple, E. A. 1998. Egg size and viability and seasonal offspring production of young Atlantic cod. Transactions of the American Fisheries Society, 127: 339–359.

Valenzuela, G., Alheit, J., Coombs, S. H., and Knust, R. 1991. Spawning patterns of sprat and survival changes of sprat larvae in relation to frontal systems in the German Bight. ICES CM 1991/L:45.

Von Storch, H. 1995. Spatial patterns: EOF and CCAs. In: Analysis of climate variability. Von Storch, H. and Navarra, A. (Eds.), Springer Verlag, Berlin, 227–253.

WASA Group 1997. "Changing waves and storms in the Northeast Atlantic?" GKSS Forschungszentrum Geesthacht GmbH, Rept 97/E/46, Geesthacht Germany 23 pp.

APPENDIX I – TERMS OF REFERENCE

Council Resolution 2.22 (C.Res.1998/2.22) set out the Terms of Reference for the Workshop:

A Workshop on Gadoid Stocks in the North Sea during the 1960s and 1970s, the Fourth ICES/GLOBEC Backward-Facing Workshop [WK6070] under the Co-Chairship of Dr M. Heath (UK), Dr J. Alheit (Germany) and Dr M. St John (Denmark) will be held in Aberdeen, UK from 11–13 March 1999 to:

a) Identify and contrast the components of the physical environment (atmospheric and oceanic) which may have contributed to observed high gadoid recruitment in the North Sea and adjacent areas during the 1960s and 1970s;

b) Determine the processes which may have governed high gadoid recruitment, in particular;

   i) variations in transport,
   ii) match mismatch in the occurrence of larvae and their prey,
   iii) growth and condition of larvae, juveniles and adults,
   iv) predation on early life history stages,
   v) variations in optimal environments,
   vi) contributions from several stock components;

c) Synthesise information on factors influencing gadoid recruitment in the Northwest Atlantic based on information presented at BF-3.

The Workshop will report to WGCCC, to the Oceanography, Resources Management, and Living Resources Committees at the 1999 Annual Science Conference, and to ACFM at its May 1999 meeting.

Justification:

This is the fourth in a series of workshops that have used a combination of retrospective analysis and new process studies and modelling in order to interpret the causes of past population events. Such events include the tilefish kill during 1881/82 and the changes brought about by a cold period in the Barents Sea and NW Atlantic Shelf. The workshop philosophy, of reanalysing and reconstructing the physical conditions related to a specific fisheries population event or period, has proved to be successful, and plans to apply it to the "gadoid outburst" in the North Sea have been underway for some time. In addition to looking at the North Sea, the workshop will also follow up on some of the results from the NW Atlantic, which emerged during the 1998 Backward-Facing meeting and will look at comparisons between stocks and how to synthesise the new knowledge of physical and biological coupling.

Other possible sources of information (e.g., analysis of the long-term sedimentary record) about factors influencing gadoid dynamics should be considered prior to the workshop and included at the discretion of the chairs.

APPENDIX II – PARTICIPANTS

Name	Institution	e-mail
Alheit, J.	IO Warnemunde, DE	juergen.alheit@io-warnemuende.de
Beare, D.	Univ St. Andrews, UK	douglas@dcs.st-and.ac.uk
Brander, K.	ICES	keith@ices.dk
Dickson, B.	CEFAS, UK	r.r.dickson@cefas.co.uk
Dippner, J.	IO Warnemunde, DE	joachim.dippner@io-warnemuende.de
Gallego, A.	ML Aberdeen/Univ Aberdeen, UK	gallegoa@marlab.ac.uk
Heath, M.	ML Aberdeen, UK	heathmr@marlab.ac.uk
Hislop, J.	ML Aberdeen, UK	hislopjrg@marlab.ac.uk
Kunzlik, P.	ML Aberdeen, UK	kunzlikp@marlab.ac.uk
MacKenzie, E.	Univ Strathclyde, UK	ed@stams.strathclyde.ac.uk
Moll, A.	IfM Hamburg, DE	moll@ifm.uni-hamburg.de
Needle, C.	ML Aberdeen, UK	needlec@marlab.ac.uk
Ottersen, G.	IMR/U.Oslo, N	geir.ottersen@bio.uio.no
Schrumm, C.	IfM Hamburg, DE	schrum@dkrz.de
Scott, B.	ML Aberdeen/Univ Aberdeen, UK	scottb@marlab.ac.uk
St John, M.	DIFMR DK	msj@dfu.min.dk
Steele, J.	Woods Hole OI, USA	steele@whoi.edu
Turrell, W.	ML Aberdeen, UK	turrellb@marlab.ac.uk
Werner, F.	Univ.N Carolina, USA	cisco@marine.unc.edu
Wright, P.	ML Aberdeen, UK	wrightp@marlab.ac.uk

The following contributed to the bulletin board discussions, but were unable to attend the workshop:

Name	Institution	e-mail
Daan, N.	RIVO, NL	niels@rivo.dlo.nl
Floderus, S.	Copenhagen, DK	sf@post.cybercity.dk
Lange, U.	Meeresforschung Hamburg, DE	ulange@meeresforschung.de
Pope, J.	NRC (Europe) Ltd, UK	popejg@aol.com
Reid, C.	SAHFOS, UK	pcre@wpo.nerc.ac.uk
Warner, A.	SAHFOS, UK	anwa@wpo.nerc.ac.uk

APPENDIX III – AGENDA FOR THE WORKSHOP

1. Welcome and introduction
2. Agreeing the agenda and structure for the workshop and the report
3. Background to the BF series (Dickson)
4. Update on BF3 (Werner)
5. What was the gadoid outburst and why are we still interested in it?
6. Objectives of the workshop
7. Overview of life history and biology of North Sea gadoids (Hislop)
8. Overview of NE Atlantic environmental changes and how they affect the North Sea (Dickson)
9. Presentations on candidate theories (by participants)
10. Overview of data sets available to the workshop (Brander, with <=5min presentations by contributors of data)
11. Sub groups build up the case for and against candidate theories, based on available evidence
12. Plenary presentations of case for and against candidate theories
13. Overview, synthesis and drafting of report
14. Review of report material