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Comparison of Spawning Characteristics of Cod (*Gadus morhua*) Stocks in the North Atlantic

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Abstract

A fundamental problem in studying fish populations is to identify the processes which govern their dynamics and the appropriate scales (in time and space) at which to investigate these processes. One possible way to identify the processes is by describing the life history characteristics and comparing those characteristics for different areas in which the species occurs. Some preliminary results of a comparative study of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus* (L.)) life histories and population dynamics, undertaken by scientists within ICES, are presented to stimulate further development of the initiative.

This paper concentrates principally on the timing and location of cod spawning, and briefly summarizes the information available for most of the geographic range of the species in the North Atlantic. It looks in greater detail at the area around the British Isles and at the Scotian Shelf, in order to investigate variability in timing of spawning on a smaller scale. Some conclusions are drawn about the processes and scales which may be appropriate for further investigation.

Key words: Cod, *Gadus morhua*, distribution, life history characteristics, regional comparison, spawning

Introduction

A fundamental problem in studying fish populations is to identify the processes which govern their dynamics and determining the appropriate scales in time and space at which to investigate these processes. For example, annual recruitment to some fish stocks is influenced by temperature; such a relationship might arise in several ways, but it is difficult to distinguish which of the many possible processes in fact operate and therefore what the appropriate measure of temperature should be.

One possible way to identify efficient processes is by description of the life history characteristics of the species concerned and comparison of those characteristics for different areas in which the species occurs. This is one of the purposes of a comparative study of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus* (L.)) life histories and population dynamics, being undertaken by a group of scientists within ICES. I have been asked to prepare a paper for this symposium on behalf of that group in order to present some preliminary results and to stimulate further development of the initiative. The paper is partly based on information supplied through the ICES comparative study and some of the issues of methodology and sampling procedure which arise are discussed here.

This paper will concentrate principally on the timing and location of cod spawning, and will briefly summarize the information available for most of the geographic range of the species. It will look in greater detail at the area around the British Isles and at the Scotian Shelf in order to investigate variability in timing of spawning on a smaller scale and the factors which may be responsible for observed differences in timing between different spawning sites. Finally, some conclusions will be drawn about the processes and scales which may be appropriate for further investigation.

One of the characteristics of temperate fish species is their relatively short spawning period, whereas tropical species breed over a long period of the year (Fig. 1). In a species such as cod in the North Atlantic, eggs are generally released over a period of a few weeks in spring and one may compare the timing of spawning and its duration (the mean and standard deviation of the egg production curves) between different stocks, or within the same stock in different years. Possibly the best example of the latter type of comparison is for the Arcto-

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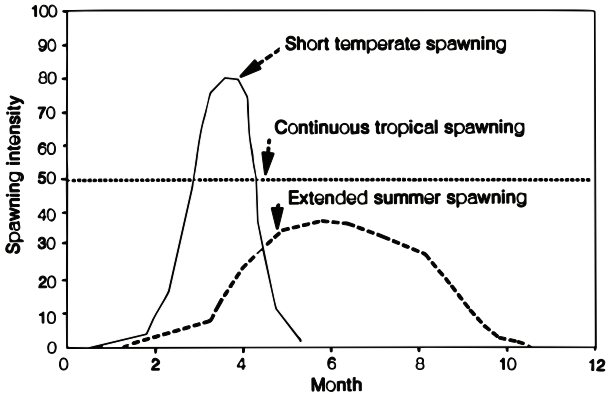

Fig. 1. Schematic graph of seasonal spawning characteristics.

Norwegian cod in the Vestfjord, where "spawning intensity" over an eight year period shows remarkable consistency from year to year (Fig. 2).

These estimates of "spawning intensity" are derived from egg surveys, which are probably the most accurate but the procedure is costly. There are alternative methods for estimating the spawning period, and one of these which has also been applied to Arcto-Norwegian cod for the period since 1929 is based on an index of the weight of roe. This method has shown that over the period 1930–60, spawning tended to occur later by about 7–15 days and the delay was ascribed to a decline in the average age of spawning fish over that period (Pedersen, 1984). For this stock there was no evidence that year-to-year variability in temperature affects the date of spawning, but this may be because the vertical temperature differences in the spawning area are greater than the year-to-year differences and the fish can select a preferred temperature by vertical movement. These Arcto-Norwegian cod spawn at a temperature of 4° to 6°C, at the thermocline between the cold coastal water and the warmer Atlantic water. The time of spawning at the main spawning site of the Arcto-Norwegian cod, at Lofoten, is about 2 weeks earlier than at the northernmost spawning field.

To what extent can the Arcto-Norwegian cod be used as a paradigm for the other cod stocks? Is it generally true that the timing of cod spawning at a particular site is calendar fixed and does not respond to proximate environmental variability (e.g. annual temperature variation)? Is it generally true that the location of spawning is fixed either geographically or in relation to a hydrographic feature or discontinuity? Which factors govern the observed differences in timing between different spawning sites? These are the sorts of questions which the comparison of spawning characteristics

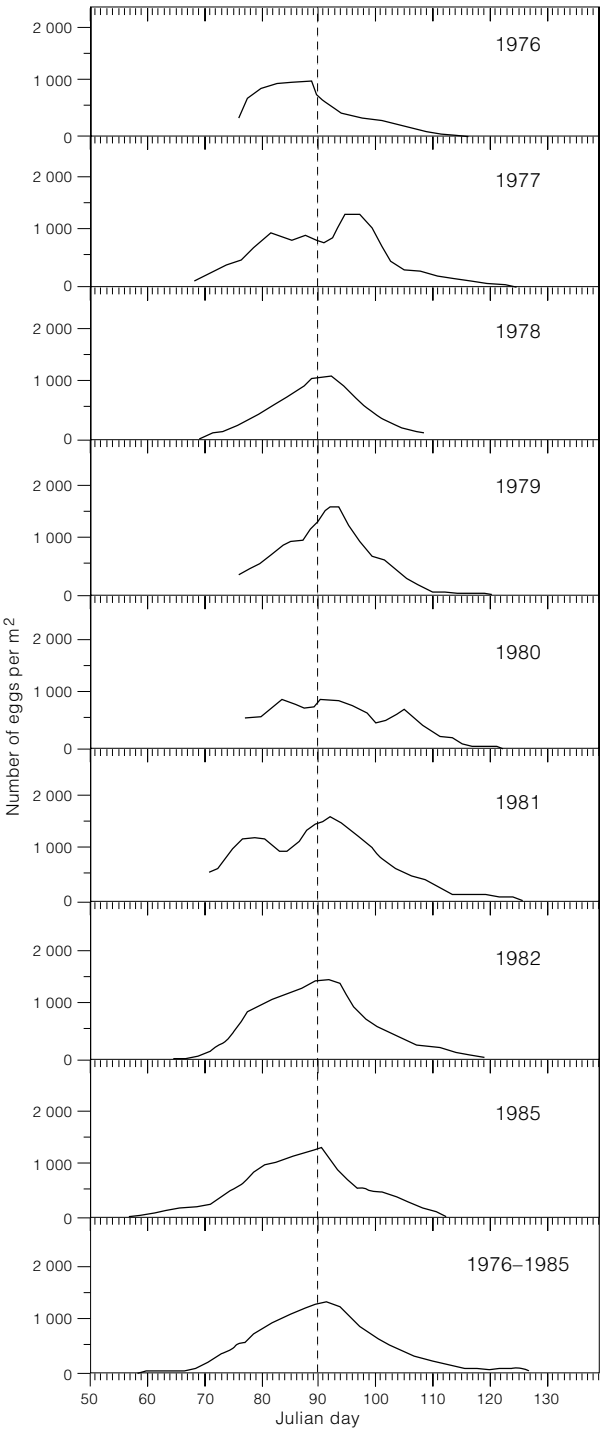

Fig. 2. Seasonal "spawning intensity" for the Arcto-Norwegian cod. Vertical bars represent mean date of 50% spawning for the period 1976–83 (from Pedersen, 1984).

between different cod stocks is designed to answer. The development of generally applicable models of the relationship between cod population

dynamics and the physical environment (e.g. in the context of the ICES Cod and Climate program) depends partly on answers to questions of this kind. However, this paper is intended to have much less scope, and will concentrate principally on the timing and location of cod spawning, and will briefly summarize the information available for most of the geographic range of the species.

Pepin and Myers (1991) recently proposed that variability of recruitment may be a function of the duration of the pelagic phase and that this could be tested among stocks of single species. This and similar hypotheses require information on the duration of the pelagic period of the life history. Since the pelagic period lasts from the time of spawning to the time of settlement, information on time of spawning will be useful in this regard and information on time of settlement will also be sought through the ICES checklist.

Materials, Methods and Results

The ICES checklist of spawning characteristics provides information on location and timing of cod spawning from many published and unpublished sources (Anon., 1990). The major spawning sites and dates of peak spawning are shown in Fig. 3 and 4. The most southerly stock in the Northeast Atlantic spawns in the English Channel (50°N) in January-February and the northernmost stock spawns around northern Norway (70°N) in April. The most southerly stock in the Northwest Atlantic spawns on Georges Bank (42°N) during the first 3 months of the year. Further information on the duration of spawning in different areas and the depth at which it occurs is given in Table 1. Spawning takes place at depths ranging from 15 m to more than 800 m, but as can be seen from the gaps in Table 1, there is no information on depth of spawning for most areas.

The quality and kind of information available on timing of spawning varies a great deal, even for supposedly well studied areas such as the North Sea. Figure 3 shows a scatter of points in the North Sea, which presumably is intended to indicate widespread spawning. Since there has been no comprehensive series of eggs surveys in the North Sea it is difficult to judge the relative contribution of particular areas to the total, but Fig. 5 summarizes available information on spawning for most of the areas around the British Isles (Graham, 1923; Heesen and Rijnsdorp, 1989).

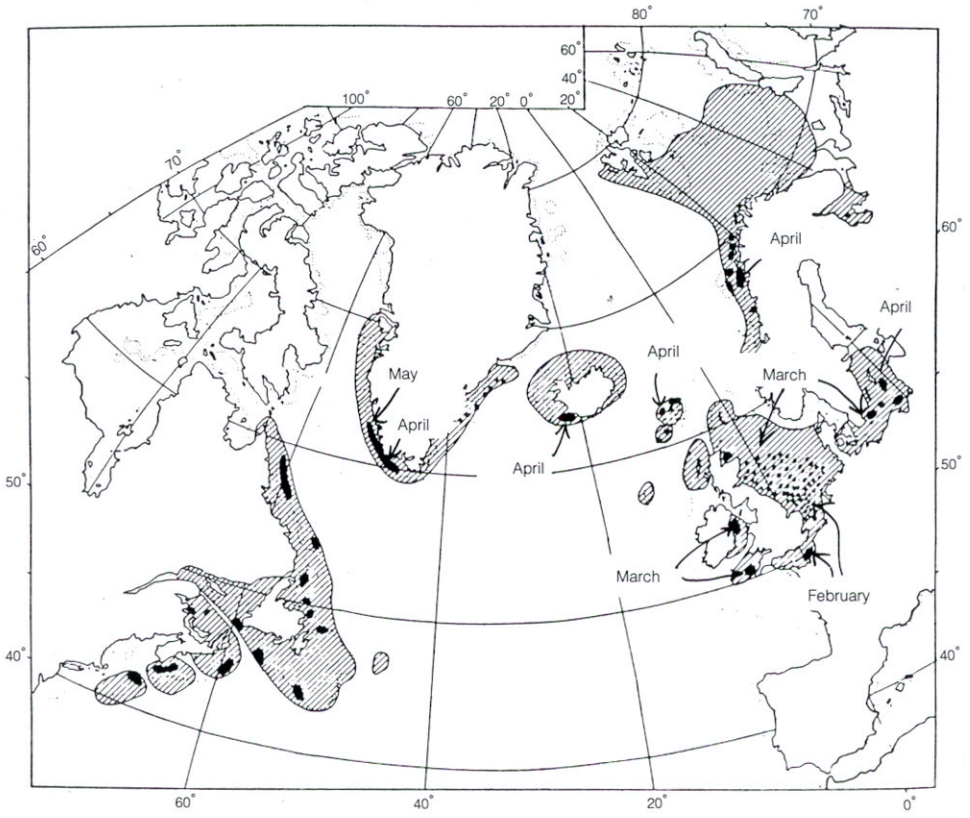

Fig. 3. Distribution of cod stocks in the North Atlantic, with their principal spawning sites and dates (month) of peak spawning (based on Anon., 1990).

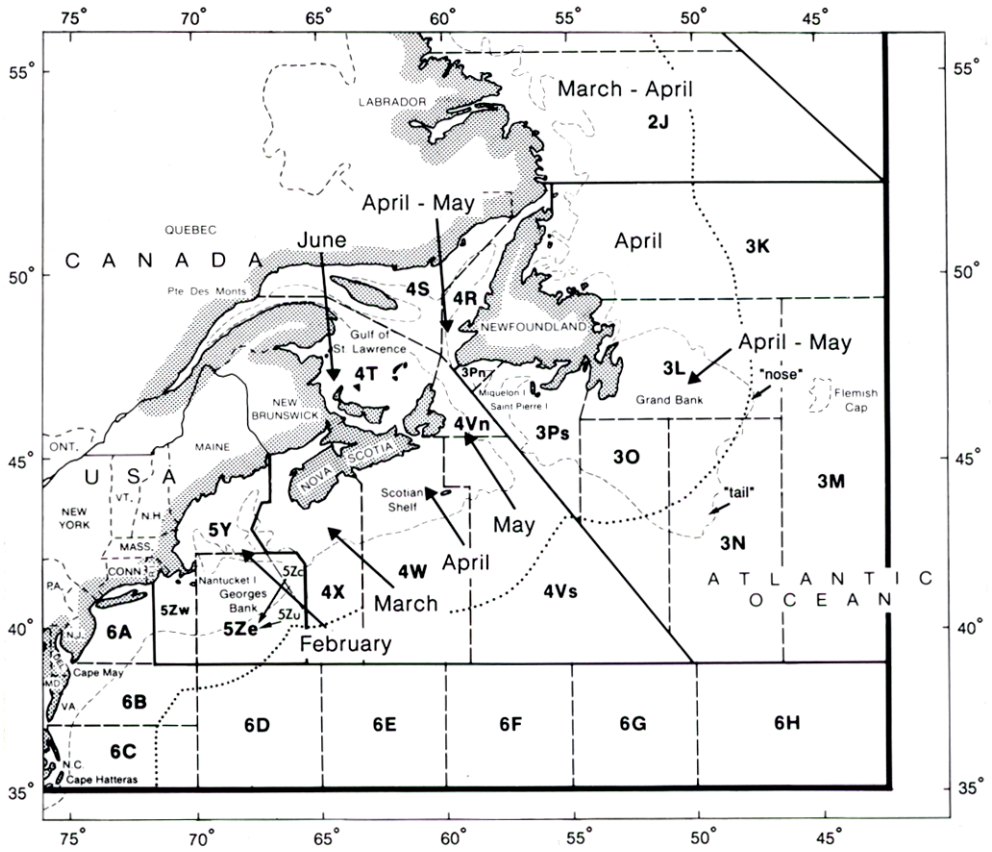

Fig. 4. Dates of peak spawning (month) for cod stocks in the Northwest Atlantic.

In the English Channel the level of spawning is low, but the fact that it is the most southerly stock in the Northeast Atlantic and one of the earliest to spawn gives it some interest. Spawning starts in January at two locations close to the coast of France. Off the northeast coast of England, spawning begins in early-February about 40 miles offshore and it remains mainly offshore. Egg surveys of the Bristol Channel in 1990 show a clearly defined spawning in space and time and surveys in 1953, 1971, 1972 and 1980 confirm that this is a regular area.

A detailed picture of the location and timing of spawning on the Scotian Shelf was obtained from ichthyoplankton surveys carried out in 1979–81 (Brander and Hurley, 1992; fig. 6). Here spawning is widespread, but occurs mainly on the various offshore banks. The timing is earliest at the southwestern end of the area and progressively later to the northeast (Fig. 7).

Discussion

Several questions which were posed above might be answered by comparisons between cod stocks. These are: is the location of spawning fixed?, does it vary from year to year in response to environmental factors?, and, can we identify the factors responsible for variations in timing between areas? The material collected so far in the checklist exercise can assist in answering these questions, but it quickly becomes apparent that the questions could be answered more fully if they were posed as part of the checklist exercise from the outset. Therefore, the next stage of this exercise should perhaps be to approach the contributors again with more specific information requirements.

There are three principal factors to consider regarding the question about causes of variation in timing between areas: latitude, temperature and production timing. Latitude *per se* (and its relation to day length) is not a dominant factor since the latitudinal ranges are very different on the two sides of the Atlantic, but within each area it may play a role. One contrary example seems to be the timing of spawning off Labrador, which is apparently earlier further north.

Spawning occurs over a fairly wide temperature range (perhaps 0° to 10°C, although it is much easier to tell the temperature at which eggs occur

TABLE 1. Timing and location of cod spawning throughout the North Atlantic, from the checklists of cod spawning characteristics.

Location	Depth (m)	Peak timing	Range
		Northwest Atlantic*	
5Z		Feb–Mar	Dec–May
4X		Apr	Feb–May
4VsW		Apr–May	Feb–Jun
			Oct–Dec
4T4Vn	35–90	late May–mid June	May–Sep
3Pn4RS			Apr–May
3Ps			May–Jun
3NO			May–Jun
2J3KL			Apr–May
		Central Atlantic	
West Greenland	600–800	Apr	Mar–Jul
East Greenland	170–400		Mar–Jul
Iceland		Apr	Mar–May
Faroe Bank		Mar–Apr	Feb–May
Faroe Plateau	80–180	Mar	Feb–May
		Northeast Atlantic	
White Sea	15-100	Apr	Mar–May
NE Arctic	100–500	Apr	Mar–Apr
Norway Coast	50		Feb–May
Skagerrak			Feb–Apr
E. Baltic	60		Mar–Aug
W. Baltic	40–50		Feb–Apr
N. North Sea		Apr	Feb–Apr
C. North Sea		end Feb	Jan–Apr
S. North Sea		mid Feb	Jan–Apr
English Channel		early Feb	Jan–Mar
Bristol Channel		late Mar	Feb–Apr
Irish Sea		Mar	Mar–Apr

* NAFO Divisions and Subdivisions.

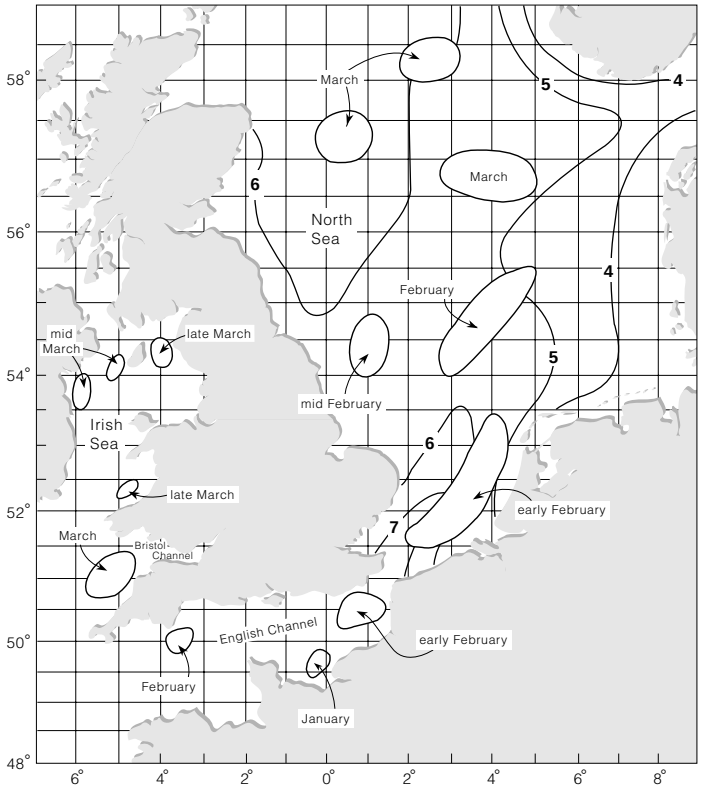

Fig. 5. Distribution and timing of cod spawning around the British Isles, with March surface isotherms (°C) for the North Sea.

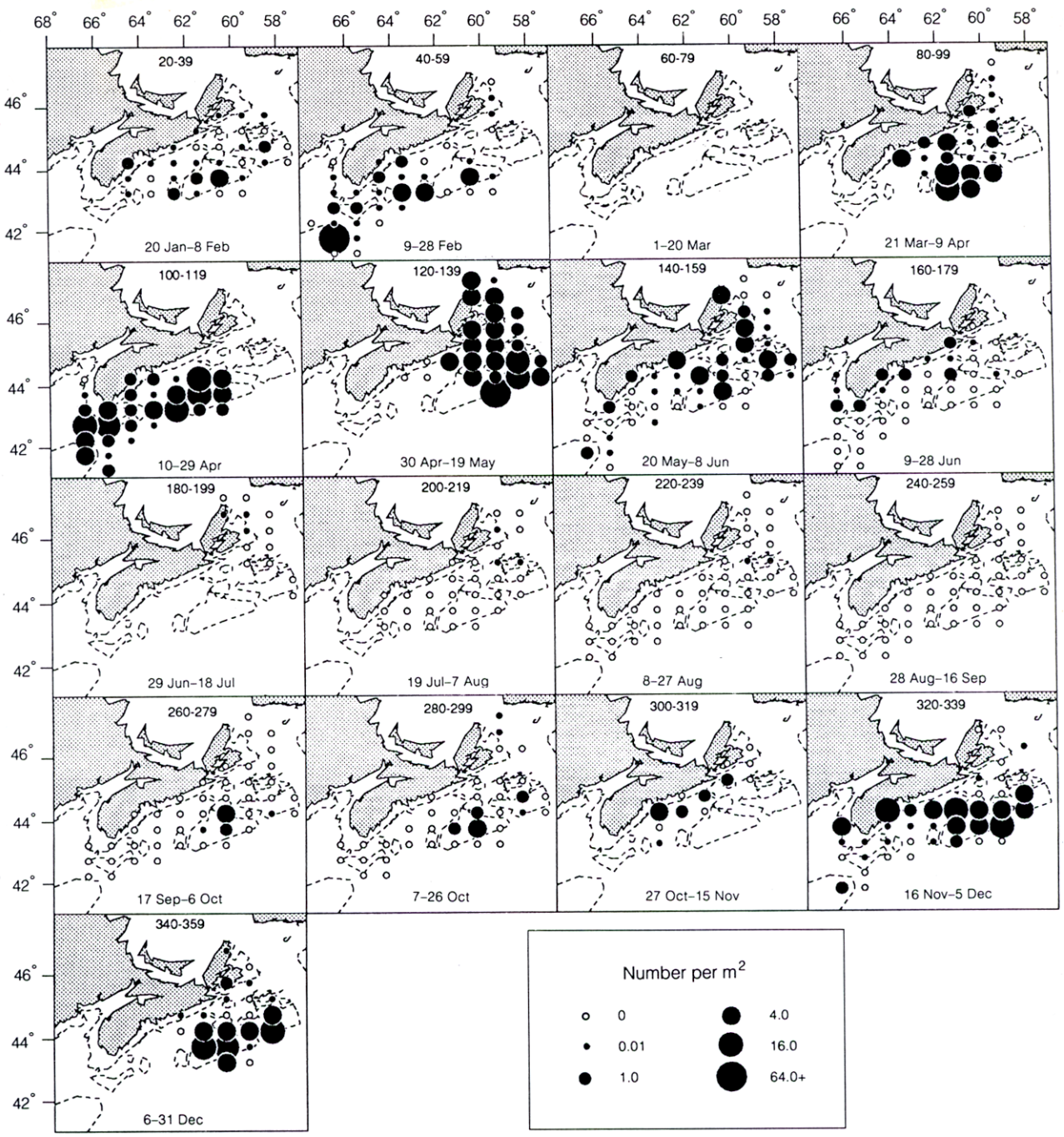

Fig. 6. Distribution of stage 1–3 cod eggs from Scotian Shelf Ichthyoplankton Surveys (SSIP) in 1979–81 (from Brander and Hurley, 1992).

than the temperature at which spawning occurs, in the areas with strong vertical or horizontal temperature gradients there may be considerable differences). Within the North Sea, cod spawn at a time when temperature is stable and the differences in timing of about 1 month between the south and the north do not correspond to a difference in temperature (Fig. 5).

It is difficult to define or measure production timing as it may affect cod spawning. In the North Sea the Continuous Plankton Recorder shows a difference in timing of peak abundance of the zooplankton *Calanus finmarchicus* of 2 weeks between the north and south, which is similar to the difference in time of cod spawning. On the Scotian Shelf the timing of peak abundance of *Calanus* sp. in

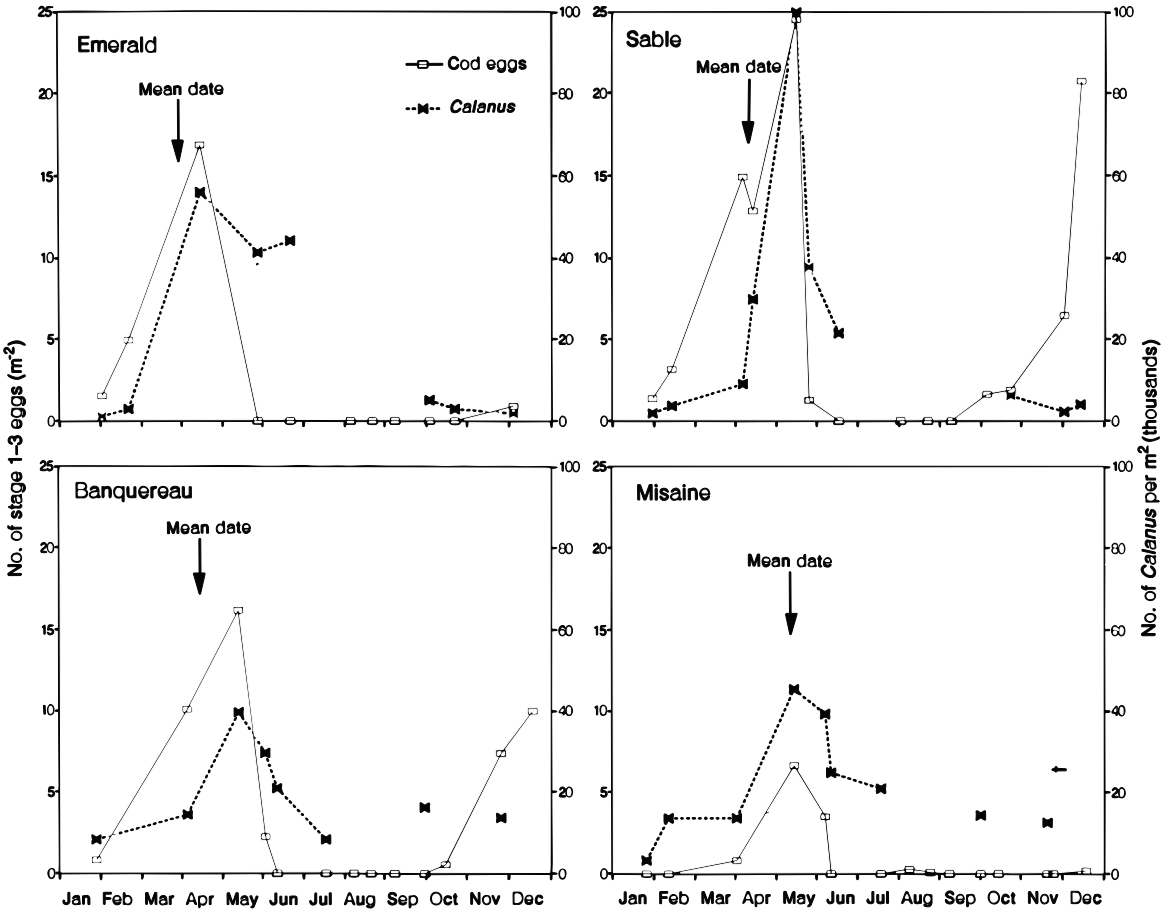

Fig. 7. Numbers of stage 1–3 cod eggs and *Calanus finmarchicus* per m^2, averaged arithmetically in 20-day periods for Emerald, Sable, Banquereau and Misaine Banks. Data for the years 1979, 1980 and 1981 have been combined. The averages of the dates of sampling within each 20-day period have been used in the plots, not the midpoint. The arrowed date is the mean date of cod spawning.

TABLE 2. Proposed table structure for data on duration of the pelagic stage for cod eggs and larvae.

Location	Duration (d)	Distance (km)	Final size (mm)
		Northwest Atlantic*	
5Z			
4X			
4VsW			
4T4Vn			
3Pn4RS			
3Ps			
3NO			
2J3KL			
		Central Atlantic	
West Greenland			
East Greenland			
Iceland			
Faroe Bank			
Faroe Plateau			

TABLE 2. (Continued)

Location	Duration (d)	Distance (km)	Final size (mm)
		Northeast Atlantic	
White Sea			
NE Arctic			
Norway Coast			
Skagerrak			
E. Baltic			
W. Baltic			
N. North Sea			
C. North Sea			
S. North Sea			
English Channel			
Bristol Channel			
Irish Sea			

* NAFO Divisions and Subdivisions.

spring is over a month later close to the Laurentian Channel than it is on Emerald Bank, and these coincide with the differences in timing of cod spawning (Fig. 7). Production timing may therefore affect the timing of cod spawning, but this can only be examined by looking at the relationship on a sufficiently fine scale.

The process of bringing together information on North Atlantic cod for comparative purposes and for modelling population dynamics is an iterative one in which preliminary evaluation and interpretation suggest new questions and ways of defining and measuring things. So far the checklist exercise has helped to retrieve some of the historic material. The plan is to edit the contributions for a publication by ICES in 1993. If the approach has any value beyond this, it is probably as providing a means of bringing together information which can be used to test existing hypotheses or models which arise from programs such as the ICES Cod and Climate. For example it would be very useful to complete Table 2 in order to follow up Pepin and Myers (1991) suggestion that variability is a function of duration of the pelagic phase.

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