

# Synchrony of recruitment across the North Atlantic: an update. (Or, “now you see it, now you don’t!”)

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About 20 years ago, Garrod and Colebrook, and Templeman, proposed that recruitment of marine fish in the North Atlantic was controlled by environmental factors that extended across the ocean basin. As evidence, they reported synchronous and lagged correlations in recruitment to stocks on opposite sides of the North Atlantic. We have updated the recruitment series and find no evidence of synchronous or lagged correlation on a basin scale in the last 20 years of data. The original evidence for basin scale correlations may have been a result of near-simultaneous decline in spawning stock biomass for many populations after 1950.

Key words: recruitment, synchrony, cod, haddock, environment.

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## Introduction

About 20 years ago, Templeman (1972) and Garrod and Colebrook (1978) proposed that recruitment of marine fish in the North Atlantic was controlled by environmental factors that extended across the ocean basin. The purpose of this paper is to test their proposals using the 20 years of data that has been subsequently collected.

The hypothesis that recruitment might be correlated across the Atlantic is not unreasonable because some of the putative forcing functions (e.g. wind stress, water temperature) are known to vary on a basin scale (e.g. Peixoto and Oort, 1992). More recent studies have also shown that recruitment is significantly correlated with Gulf Stream position in the north-west Atlantic (Myers and Drinkwater, 1989) while in the north-east Atlantic plankton is strongly related to Gulf Stream position in the north-west Atlantic (Taylor *et al.*, 1992). Continuous Plankton Recorder records also show large-scale, long-term changes in phytoplankton and zooplankton throughout the north-east Atlantic (Colebrook, 1978; Aebischer *et al.*, 1990), and similar trends are also seen in some parts of the north-west Atlantic (Myers *et al.*, 1994).

Garrod and Colebrook (1978) proposed that recruitment in marine fish populations was primarily controlled by environmental factors that operate on an oceanic scale. Their principal biological evidence for

such a relationship was a correlation matrix of 18 fish populations for the years 1950 to 1971. They found many positive correlations among regional groupings, but also correlations that extended across the Atlantic.

Shepherd *et al.* (1984) questioned Garrod and Colebrook's interpretation of their correlation matrix. They applied Barlett's sphericity test to their correlation matrix and concluded that the null hypothesis that all series are uncorrelated could not be rejected. We performed the test and obtained a p-value of 0.055; while we are unable to reject the null hypothesis at the 5% level, this is not entirely convincing. The power of this test on relatively short time series is unknown, so the question remains open.

In an insightful study, Templeman (1972) attempted to define and understand the large-scale changes in recruitment to a large number of North Atlantic haddock and cod populations. However, in contrast to more recent analyses, Templeman allowed for the possibility of *lagged* relationships between recruitment to populations on different sides of the North Atlantic. Templeman (1972) claimed to find significant lagged relationships and speculated on the role of ocean advection. Templeman's allowance for lags is an important point that appears to have been overlooked in recent studies. If significant lagged relationships can indeed be uncovered they would be useful in identifying the reasons for recruitment variability.

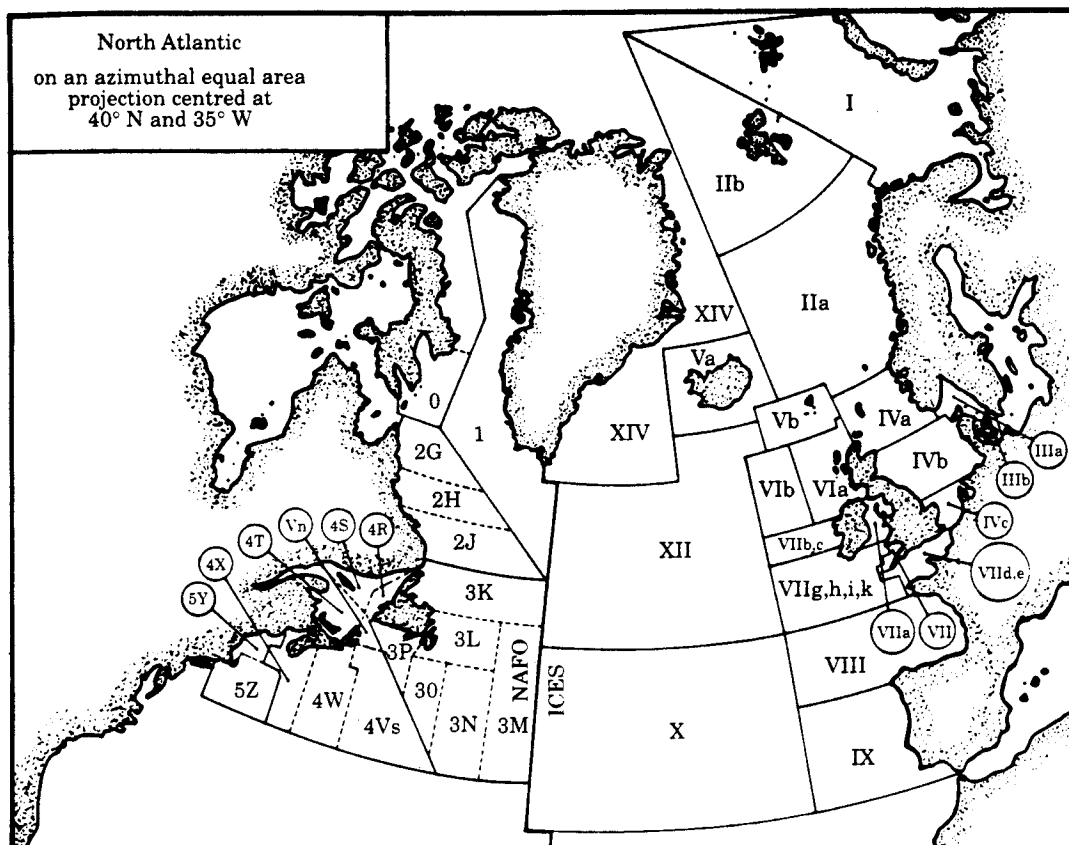


Figure 1. Map of the North Atlantic showing the management regions used to define populations for management.

The purpose of this note is to replicate the analyses of Templeman (1972) and Garrod and Colebrook (1978) as closely as possible, using data collected after they presented their ideas. We will show that the original conclusions drawn regarding the existence of pan-ocean patterns are not supported by the present study. It is not the purpose of this paper to address the question of regional coherence claimed to have been found in the north-west Atlantic (e.g. Koslow, 1984; Thompson and Page, 1989; Cohen *et al.*, 1991). That will be the subject of a future study.

## Data and methods

We have tried to assemble all time series of spawning stock biomass (SSB) and recruitment for the populations considered by Templeman (1972) and Garrod and Colebrook (1978). SSB and recruitment have been estimated by sequential population analysis (SPA) of commercial catch-at-age data jointly analysed with research survey estimates of abundance. SPA techniques include virtual population analysis (Gulland, 1965), cohort analysis (Pope, 1972), and related methods which reconstruct population size from catch-at-age data

(Megrey, 1989; Gavaris, 1988). The stock boundaries in the North Atlantic generally follow those of the North-west Atlantic Fisheries Organization (NAFO) or the International Council for the Exploration of the Sea (ICES). They are given in Figure 1. We sometimes refer to the region by an alternative name (e.g. the North Sea) if it commonly applies to the stock in practice, or if the NAFO or ICES regions do not adequately describe the presently-used stock boundaries. In the North Atlantic, data were taken from assessments from the National Marine Fisheries Service (USA) laboratory at Woods Hole, the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC), NAFO, ICES, and the Marine Research Institute, Iceland. The data are summarized by Myers *et al.* (1994).

Of the 18 stocks analysed by Garrod and Colebrook (1978) 15 of the presently considered stocks have the same boundaries. For one stock, East Greenland Cod, there is no recent age-structured assessment. Garrod and Colebrook combined Georges Bank and Browns Bank haddock in their analysis; we will test the relationships on these two stocks separately. Similarly, they combined North Sea haddock and whiting, but we will analyse them separately. We were uncertain about the exact

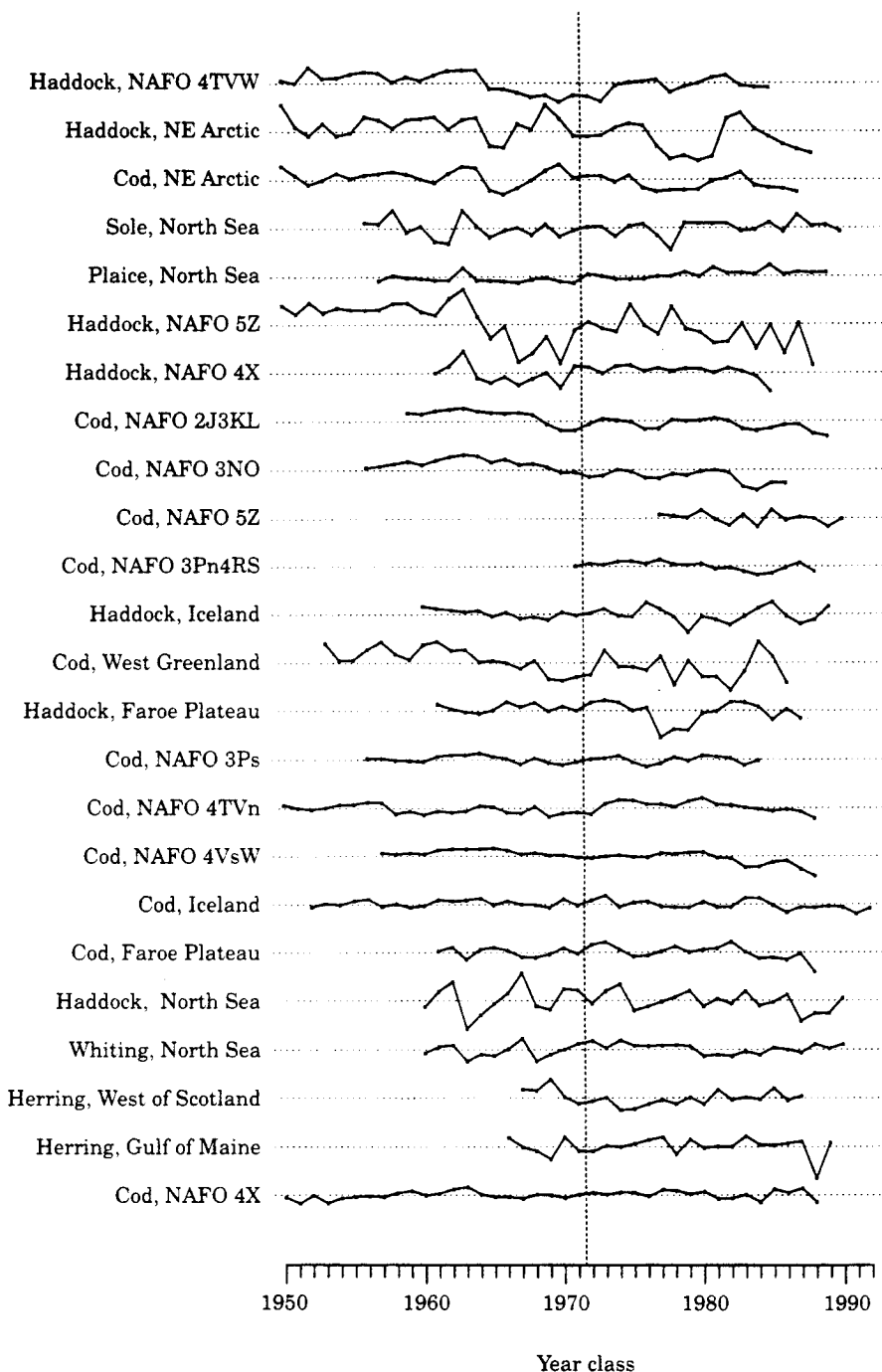


Figure 2. Recruitment time series for populations analysed. Estimates of numbers at age in a year class are log transformed (base 10) with the mean removed. The mean of each series is separated by 2 units, i.e. a factor of 100, from the one below. Thus, the distance between the horizontal dotted lines gives the vertical scale. The data to the left of the vertical dotted line are for the time period considered by Garrod and Colebrook (1978), while the data to the right are those used in the analysis in this paper.

identity of one of their stocks: "Gulf of St Lawrence" cod. The ICNAF (now NAFO) identity of this stock is listed as Div "7R+4T"; however, there is no such

stock. We assume that this is not the southern Gulf of St Lawrence cod, because it is clearly included as another stock, i.e. cod in Div. 4TVn. The northern

Table 1. Correlations (multiplied by 100) of log-transformed recruitment series (upper triangle of table) for 1972–1993 corresponding to those presented by Garrod and Colebrook (1978, table 13) for 1950–1971. In the lower triangle of the table, correlations were computed using recruitment series corrected for spawning stock biomass. Underlining represents the contouring used by Garrod and Colebrook (1978), i.e. a single underline indicates that  $r \geq 0.2$  for the corresponding correlation in Garrod and

	Haddock, NAFO 5Z	Herring, Gulf of Maine	Haddock, NAFO 4X	Cod, NAFO 4VsW	Cod, NAFO 4TVn	Cod, NAFO 3Pn4RS	Cod, NAFO 3Ps	Cod, West Greenland
Haddock, NAFO 5Z	—	<u>41</u>	14	<u>45*</u>	36	<u>51**</u>	-17	<u>-6</u>
Herring, Gulf of Maine	<u>37</u>	—	<u>2</u>	<u>44*</u>	<u>53**</u>	24	-78***	<u>35</u>
Haddock, NAFO 4X	0	<u>0</u>	—	<u>48*</u>	<u>50*</u>	<u>72***</u>	10	<u>-39</u>
Cod, NAFO 4VsW	<u>15</u>	34	<u>40</u>	—	<u>79***</u>	<u>63***</u>	<u>38</u>	-21
Cod, NAFO 4TVn	13	46*	45	<u>76***</u>	—	<u>51**</u>	<u>17</u>	-2
Cod, NAFO 3Pn4RS	<u>40</u>	<u>57**</u>	<u>81***</u>	<u>73***</u>	<u>81***</u>	—	9	-21
Cod, NAFO 3Ps	-14	-72***	22	<u>64**</u>	<u>30</u>	30	—	-26
Cod, West Greenland	<u>13</u>	<u>44</u>	<u>-43</u>	-31	-7	-25	-36	—
Cod, Iceland	38	<u>8</u>	-14	<u>-17</u>	-1	-16	<u>-50*</u>	48*
Haddock, Iceland	<u>25</u>	<u>18</u>	<u>-53*</u>	-3	<u>-15</u>	<u>-14</u>	-30	<u>52**</u>
Haddock, Faroe Plateau	<u>22</u>	<u>2</u>	<u>14</u>	-23	2	2	-11	-13
Cod, Faroe Plateau	27	<u>29</u>	38	<u>68***</u>	46*	<u>65***</u>	<u>52*</u>	-38
Cod, NE Arctic	<u>22</u>	-1	<u>14</u>	-22	13	<u>-4</u>	<u>-14</u>	-11
Haddock, NE Arctic	20	30	-25	-40	-17	<u>-24</u>	-55*	22
Sole, North Sea	<u>-3</u>	17	<u>-19</u>	-24	<u>-7</u>	<u>-9</u>	-26	12
Plaice, North Sea	<u>-20</u>	-8	<u>-73***</u>	-31	-50**	<u>-58**</u>	<u>-2</u>	8
Haddock, North Sea	-6	12	7	48*	41	11	22	0
Whiting, North Sea	38	-10	30	19	-3	24	5	10
Herring, West of Scotland	-31	12	-71***	-28	-37	-60**	-23	20

Gulf of St Lawrence stock is usually denoted as 4RS or 3Pn4RS.

Prior to the calculation of correlations we log-transformed the estimates of recruitment (R) and SSB (S). We also attempted to remove the effect of SSB on recruitment using residuals from a linear regression of  $\log(R)$  on  $\log(S)$ . Such a regression implicitly assumes that density-dependent mortality is proportional to the log density, a reasonable assumption for most ground-fish stocks (Myers and Cadigan, 1993). Time-series plots of all the log transformed data are shown in Figure 2.

A word about statistical tests. We caution the reader against taking any reported statistical relationship for recruitment at face value unless the researcher has also examined the effect of spawners, investigated independent data (e.g. research surveys) and demonstrated that the proposed relationship holds for all time periods (or explained why it does not). When we report "nominal" significance levels, they should only be used as a rough guide to the size of the correlation, because we have not accounted for the inflation of significance levels due to autocorrelation (e.g. Thompson and Page, 1989).

Colebrook (1978), while a double underline indicates that  $r \geq 0.4$ . Note that the recruitment series span different years (Fig. 2); for each correlation, data for the longest overlapping interval were used. The stocks are arranged roughly in a "clockwise" west to east pattern. The horizontal and vertical lines that intersect in the middle of the table indicate the partitioning of the stocks into the north-west Atlantic and north-east Atlantic groups used in the analysis.

Cod, Iceland	Haddock, Iceland	Haddock, Faroe Plateau	Cod, Faroe Plateau	Cod, NE Arctic	Haddock, NE Arctic	Sole, North Sea	Plaice, North Sea	Haddock, North Sea	Whiting, North Sea	Herring, west of Scotland
30	<u>9</u>	<u>-21</u>	46*	<u>15</u>	16	<u>-19</u>	<u>-24</u>	5	28	-32
<u>17</u>	<u>12</u>	<u>-17</u>	42*	-8	35	11	-6	24	-24	18
-11	<u>-53*</u>	<u>9</u>	38	<u>21</u>	2	<u>-19</u>	<u>-72***</u>	6	20	-72***
<u>-3</u>	1	-33	65***	-16	-15	-28	-34	46*	14	-40
10	<u>-11</u>	-7	46*	0	6	<u>-10</u>	-45*	41	-14	-47*
-13	<u>-14</u>	-25	41	<u>-13</u>	<u>-15</u>	<u>-13</u>	<u>-62***</u>	0	40	-59**
<u>-29</u>	-35	10	55*	<u>-2</u>	-47	-14	<u>17</u>	22	-13	-4
50*	<u>45*</u>	-10	-30	-5	13	16	5	5	13	19
—	42*	48*	<u>26</u>	<u>55**</u>	<u>47*</u>	10	-21	5	-11	<u>-6</u>
44*	—	<u>15</u>	<u>-9</u>	2	31	<u>-14</u>	-7	-8	19	3
42	<u>35</u>	—	<u>21</u>	74***	65***	23	-15	13	-14	-16
<u>17</u>	<u>-9</u>	<u>5</u>	—	40	13	-13	-10	39	-12	-5
<u>44*</u>	-5	58**	18	—	<u>67***</u>	<u>5</u>	<u>-5</u>	25	6	-9
<u>50**</u>	23	39	-4	<u>48*</u>	—	4	<u>-23</u>	16	4	-22
12	<u>-13</u>	20	-14	<u>25</u>	18	—	<u>39</u>	-50**	-39*	43*
-18	0	-36	-14	<u>2</u>	<u>7</u>	<u>39</u>	—	-10	-31	92***
-5	-13	-5	37	11	-1	-51**	-16	—	25	<u>-8</u>
-13	15	1	-5	-14	-29	-39*	-34	30	—	<u>-42</u>
<u>-8</u>	2	-39	-9	-7	3	36	89***	<u>-7</u>	<u>-47*</u>	—

## Results and discussion

### Is recruitment synchronous across the Atlantic?

The trans-Atlantic correlations proposed by Garrod and Colebrook have not held up upon re-examination (Table 1). The signs of the resulting correlations that are predicted to be positive are approximately equally positive and negative. It is also clear from Figure 3 that although the correlations reported by Garrod and Colebrook tend to be positive, the ones based on the more recent data are roughly equally spread around zero. That is, there are 56 estimates for the cross-

Atlantic correlations in Figure 3a, which were originally positive, and only 28 that were negative; an exact binomial test shows a significant difference ( $p=0.003$ ). However, in the recent correlations there are the same number of positive and negative values (42 in both cases). Thus, the hypothesis of basin-wide synchronous recruitment of the type proposed by Garrod and Colebrook is rejected by our analysis. This result is the same whether or not we remove the effect of SSB (Table 1).

We also considered the stability of Garrod and Colebrook's correlations separately on each side of the

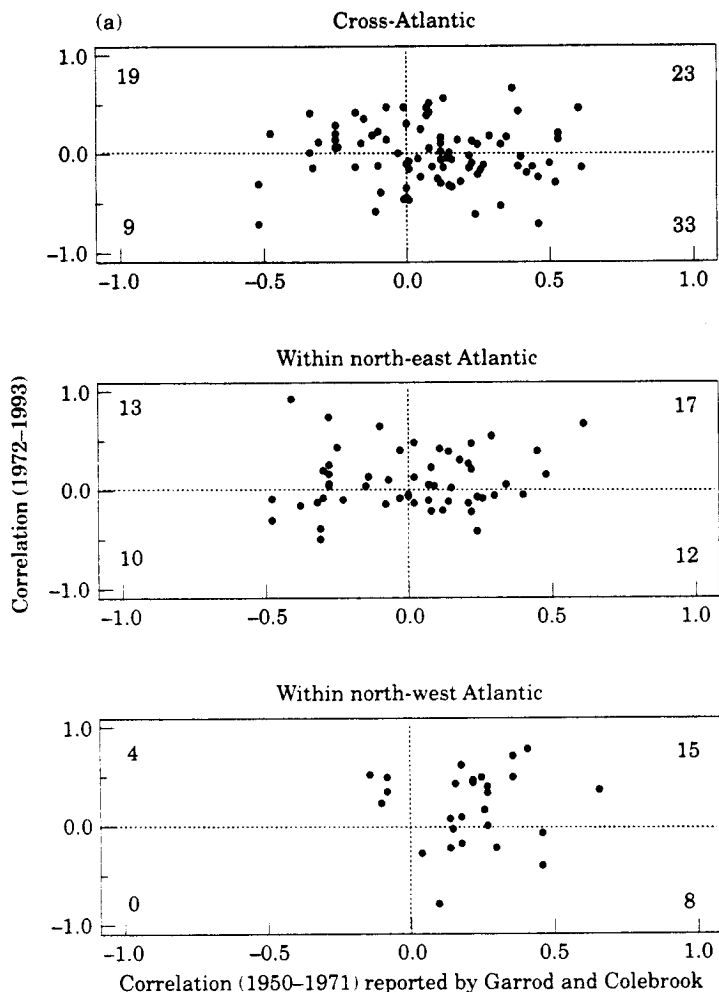


Figure 3. Comparison of correlations estimated by Garrod and Colebrook (1978) using data from 1955 to 1971 with those estimated for data 1972 to 1993. The numbers in the corners of each quadrant are the number of points within that quadrant: correlations of zero are not included in these quadrant summaries. We use: (a) log recruitment data; and (b) residuals from a spawner-recruitment model.

Atlantic (Figure 3). For the analysis within the north-east Atlantic, roughly equal numbers of estimates were originally positive (29) and negative (23), which are not significantly different. If the correlations have been stable over time, then one would expect a positive relationship between the old and new correlations. This relationship is not significant for the case where recruitment has not been corrected for SSB ( $r=0.13$ ,  $p=0.36$ ,  $n=54$ ), but is marginally significant if recruitment is corrected for SSB ( $r=0.28$ ,  $p=0.037$ ,  $n=54$ ). One of the most intriguing recruitment patterns that has remained on the same sign is the negative correlation among the flatfish and gadoid stocks in the North Sea. Garrod and Colebrook found that the two North Sea flatfish stocks they considered, sole and plaice, were negatively correlated with the two gadoid stocks they considered.

haddock and whiting. These correlations have remained of the same sign, and the ones with sole remain nominally significant. This might usefully be investigated further. Overall, however, the evidence for persistence of the correlations within the north-east Atlantic that Garrod and Colebrook found must be considered weak.

In the north-west Atlantic, the estimates in Figure 3 tended to be originally positive (exact binomial test,  $p=0.0003$ ), and the correlations have tended to remain positive ( $p=0.02$  for the recruitment corrected for SSB,  $p=0.05$  for recruitment not corrected for SSB). The conclusion that there are local correlations among stocks within the north-west Atlantic is consistent with other studies (Thompson and Page, 1989; Cohen *et al.*, 1991).

Table 2. Test of Templeman's hypothesis of a lag correlation between recruitment across the Atlantic: Templeman predicted the correlations in the table should be positive. The values listed are correlations (multiplied by 100) of log-transformed recruitment after 1970 for cod and haddock in the North Atlantic from Georges Bank to the north-east Arctic (\*significant at  $p < 0.1$ ; \*\*significant at  $p < 0.05$ ; \*\*\*significant at  $p < 0.01$ ). Stocks in the western North Atlantic are listed vertically and those in the eastern North Atlantic are listed horizontally. Note that the recruitment series span different years (Fig. 2): for each correlation, data for the longest overlapping interval were used.

Corrected for spawning stock biomass?	Lag	Stock	Stock				
			Cod, West Greenland	Cod, Iceland	Cod, north-east Arctic	Haddock, Iceland	Haddock, north-east Arctic
No	0 years	Cod 4VsW	-21	-04	-14	01	-14
		Cod 3NO	-46*	-30	10	-42	-30
		Cod 5Z	02	05	-27	06	-34
	1 year	Haddock 4TVW	-26	-45*	-24	-23	08
		COD 4VsW	-52**	05	13	-40*	-16
		Cod 3NO	-48*	11	53**	-36	22
		Haddock 4TVW	-21	00	-16	00	09
		Cod 5Z	-23	-28	-27	-27	-50
		Cod 4X	-14	-19	-29	-42*	-53**
	2 year	Haddock 5Z	31	14	-26	-07	-14
		Haddock 4X	22	57**	15	07	06
		Cod 4X	07	-07	-34	-19	-28
		Haddock 4X	36	10	-02	24	11
		Haddock 5Z	13	-03	-49**	13	-24
		Cod 4X	07	-07	-34	-19	-28
Yes	0 years	Cod 4VsW	-32	-18	-22	-03	-40
		Cod 3NO	-37	-36	-14	-32	-67***
		Cod 5Z	-03	00	-14	01	-26
	1 year	Haddock 4TVW	01	-18	14	-01	24
		COD 4VsW	-64***	-06	19	-44*	-41*
		Cod 3NO	-43*	-09	09	-34	-41
		Haddock 4TVW	12	18	-09	19	21
		Cod 5Z	-20	-30	-15	-27	-56*
		Cod 4X	-20	-20	-17	-49**	-62***
	2 year	Haddock 5Z	45*	14	-16	13	-15
		Haddock 4X	24	57**	18	09	-06
		Cod 4X	00	-04	-20	-26	-25
		Haddock 4X	42	10	-01	25	-04
		Haddock 5Z	27	-12	-38	25	-31

### Does recruitment in Europe lag that from North America?

In an analysis of cod and haddock recruitment across the North Atlantic for the 1941 to 1970 year classes, Templeman (1972) provided evidence that "successful year classes in Iceland, Greenland, and Norwegian and Spitsbergen-Barents Sea areas normally occur in the same year as or 1 year after good year classes in the Sable Island to southern Grand Bank area or of cod on Georges Bank, or 1-2 years after good year classes of haddock on Georges Bank, or haddock and of cod on Browns Bank". There are no data after 1970 on two of the populations he considered, haddock on St Pierre and southern Grand Banks, because the fishery there is commercially extinct. We used data from cohorts after 1970 to test Templeman's hypothesis so that our results would be independent. The recruitment data estimated from years after 1970 do not support Templeman's

hypothesis. The correlations he predicted to be positive were more or less equally divided between positive and negative correlations. This was true of the results with or without the effect of SSB removed (Table 2).

We could find no evidence for lagged relationship between recruitment on different sides on the Atlantic. We therefore disagree with the findings of Templeman (1972). Our findings probably differ from Templeman (1972) for a variety of reasons. Templeman's (1972) analysis can be described as hypothesis generation. He took a large amount of disparate data, both quantitative and qualitative, and attempted to detect patterns. Such a process is essential, but often produces relationships that are spurious. There is also a difference in methods. Templeman did not have access to quantitative information for many of his populations. He could not calculate cross-correlations, but had to rely on visual examination of data that were in many cases questionable.

## Conclusion

We conclude there is no evidence over the last 20 years for the type of cross North Atlantic relationships among recruitment as proposed by Templeman (1972) and Garrod and Colebrook (1978).

An important question remains, why were correlations in recruitment across the Atlantic apparent in the original analysis? First, the original cross-Atlantic correlations by Garrod and Colebrook appear to be valid, i.e. as discussed above a simple sign test indicates that the proportion of positive cross Atlantic correlations is highly statistically significant. A simple, testable explanation of these correlations is that they were caused by the huge declines in spawning stock biomass that occurred throughout the Atlantic (Cushing, 1988; Garrod, 1988). An examination of our data for cross-Atlantic relationships for the period used by Garrod and Colebrook (1950–1971) shows 40 positive and 37 negative correlations. Nevertheless, all of the six correlations which are significant at the 0.05 level are positive. However, upon adjusting for SSB, just one cross-Atlantic correlation remains significant (North Sea plaice and Haddock 4X). We interpret these results in the following way. During the 1950s and 1960s there was a massive depletion of spawning stock across the North Atlantic, which resulted in a decline in recruitment. Although some fisheries biologists doubt that there is a consistent relationship between spawners and subsequent recruitment, Myers and Barrowman (1994) have recently examined almost 200 populations and concluded that there is almost always a positive relationship *provided* there is a wide range in spawner abundance. Thus, the simplest explanation of the original correlations is that they were the result of the decline in spawning stock biomass that occurred for many populations in the North Atlantic from 1950 to 1971.

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