

Variation in fish condition between Atlantic cod (*Gadus morhua*) stocks and implications for their management

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Abstract

A comparative analysis of the fish condition (Fulton's K) of 11 cod stocks in the North Atlantic in relation to the temperature of their habitat and their reproductive potential is presented. It is shown that the cod stocks in the North Atlantic display different levels of mean condition, which are partly due to the different temperature regimes of their habitats. Cod stocks living in colder waters, e.g. Southern Gulf of St Lawrence, Greenland and Grand Bank cod stocks, were more poorly-conditioned than cod stocks living in warmer waters, e.g. North Sea and Irish Sea.

The α -coefficient obtained from a standardised Ricker's recruitment-spawning stock biomass (SSB) relationship represents the function's slope at the origin and was defined as an indicator for the recruitment potential of a given stock. The α -coefficients were found to be correlated with the mean condition factors of the stocks in 9 of the 11 cod stocks analysed. This indicates that stocks consisting of poorly-conditioned individuals appear to be very susceptible to reduced recruitment at low SSB, while the stocks which consist of well conditioned fish seem to behave more robust with a higher probability of good recruitment at low SSB. The positive effect of the cod condition on their reproductive potential generally implies that the well-conditioned stocks in the Northeast Atlantic can sustain higher exploitation rates than the poorly-conditioned stocks in the Northwest Atlantic. This implication is confirmed by a positive relationship between the estimated biological management reference points F_{med} and the mean cod condition factors of the stocks.

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Introduction

Atlantic cod (*Gadus morhua*) stocks are found around the North Atlantic margin and have been a major target for the fisheries for several centuries. All of them exhibit a common life history pattern, but with considerable regional variations in their recruitment, growth rate, age of maturity, migration patterns, food and spawning time. It is not surprising that population parameters also vary between stocks since they experience very different temperature regimes ranging from an average of 2°C to 11 °C (Brander, 1994).

Fulton's K condition factor has been demonstrated to be a measure of the energy reserves of fish (Lambert and Dutil, 1997 a, b), cod with a low condition index presumably resulting from adverse environmental, poor feeding conditions or parasitic infections (Yaragina and Marshall, 1999; Lambert and Dutil, 1997 a, b). Fish production is determined by the processes of recruitment, growth and mortality, but most of the inter-annual and long-term variability in production is ascribed to recruitment (Brander, 1994).

In the present study, we test the hypothesis that observed differences in reproductive potential (i.e. recruitment potential) between cod stocks are partly due to the variation in their condition. This possible relationship would have major consequences for the long-term management strategies of the stocks. Furthermore, we analyse the average habitat temperature effect on the condition of the cod in the various stocks. The influence of temperature on the production (growth and recruitment) of the cod stocks has been frequently analysed and become recently more apparent (e.g. Brander, 1995, 1996; Rätz et al., 1999).

Materials and methods

Calculation of mean cod condition by stock

The geographical distribution of the 11 cod stocks considered in this analysis is shown in Figure 1. Mean condition values were derived from round weight (ungutted) and total length of individual cod measured during the fall or early winter season only, when the cod reach their highest condition over the year and the stocks have been regularly sampled. Various laboratories have provided the data used to calculate an overall condition factor for each stock and the data sources and respective sample periods are given in Table 1. The selection of stocks and sample periods was based solely on availability of data.

The number of weight and length measurements exceeded 1000 individuals for all stocks with the exception of the southern Grand Bank cod stock (NAFO Div. 3NO). The observed weights and lengths were pooled over all years and used to formulate the respective weight-length regression for each stock. The Fulton's K factor of each cm-group from 30 to 90 cm for each stock was then calculated as: $K=100*(W/L^3)$ where W is the round weight (g) and L is the total length (cm). The mean condition for each stock was determined from the average K factor over the size groups 30 to 90 cm and based on pooled data in order to avoid fish size and year effects, respectively.

Calculation of the reproductive potential by stock

The assessment of the reproductive potential of a given cod stock is based on the concept of Ricker's recruitment-spawning stock equation (Ricker, 1975), which is expressed as: $R=a*SSB*exp^{(-SSB/b)}$, where R is the number of recruits and SSB is the spawning stock weight. The coefficient a is the slope of the recruitment-SSB function at its origin and thus can be used to indicate how quick a given stock achieves its maximum recruitment relative to increasing SSB, while the coefficient b represents the value of SSB that produces the maximum recruitment. We define the value of the Ricker's a-coefficient as the recruitment potential of a given stock (Fig. 2), i.e. the higher the a-value (slope), the greater the probability of high recruitment at low SSB.

Ricker's recruitment-spawning stock biomass relationships were calculated for each stock. The relevant data sources were derived from analytical assessments (VPA) and time periods are specified in Table 1. The data series of the Northeast Arctic cod and the Icelandic cod stocks have been shortened by omitting the first 6 years of the assessment period. This period is characterised by very high spawning stock biomasses with very low recruitments and thus leads to an overestimation of the slope a-coefficient of the Ricker curve. Thus, the omission of the first years of the long time series, resulted in a better model fit to the recruitment data at low spawning stock biomass. Recruitment age is 3 years for

all stocks and was used as proxy for the year class strength at age 0. In those stock assessments where the recruitment age was either 1 or 2 years, respective numbers at age 3 have been determined from the original assessments applying the natural mortality rates used. In order to eliminate the stock size effects and to make the stocks comparable, both the spawning stock biomass and the recruitment data have been standardised against the maximum values of the time series (standardisation to 1). Such standardised recruitment and spawning stock biomass plots and Ricker functions as well as the a -coefficients (slopes at the origin) are illustrated for the cod stocks in the Northwest and Northeast Atlantic in Figure 3 and listed in Table 1. The Ricker's a coefficients of George Bank cod and Faeroe Plateau cod were considered unrepresentative due to the short time series and the very high year to year variation in spawning stock biomass patterns, respectively.

F_{med} values

F_{med} is one of the precautionary reference points generally accepted as a long term measure of stock management in terms of safe exploitation rates which a stock can sustain with a low risk of a collapse (Caddy, 1998). The values of F_{med} pertaining to the stocks examined in the present study are given in Table 1, together with the source of information.

Mean habitat temperature data

Data on mean annual bottom temperature for the stock distribution areas have been adopted from Brander (1995) and are presented in Table 1. These estimates should be regarded as tentative and imprecise in a few cases (Brander, 1995), but such errors may be expected to increase the variance rather than to introduce a bias in the relationship between temperature and condition. More recent studies on Northeast Arctic cod (Ottersen et al., 1998) indicate temperatures somewhat below the value used here.

Results

Condition factor of the cod stocks and temperature effect

The overall mean condition factors of the various stocks are listed in Table 1. The heterogeneity in condition of cod stocks reveals that the Northeast Atlantic cod stocks are generally better conditioned than the stocks in the Northwest Atlantic, the only exception being the Northeast Arctic stock. The best conditioned cod displaying K-values greater than 1.0 are those inhabiting the Irish Sea, the Seas west of Scotland and around Ireland and the North Sea. In contrast, the Northwest Atlantic cod stocks, e. g. those of the Greenland, Labrador, Grand Bank and Southern Gulf of St Lawrence are generally poor conditioned with K-values smaller than 1.0 with the George Bank cod being the only exception. The cod of the Icelandic and the Faeroes stock are indicated to be similar poor conditioned like the north-western stocks. The relationship between the condition factor and average annual bottom temperature is well defined (Fig. 4) and accounts for 65 % of the observed variance. It can be concluded that cod stocks living in warmer waters on average show better condition than stocks living in cold waters.

Relation between Ricker a -coefficients and condition factors

The a -coefficients derived from the standardised recruitment-SSB relations, the defined values of recruitment potential, were found to be positively correlated with the condition factors. Figure 5 illustrates the linear model explaining 46 % of the observed variation in Ricker's a -coefficients. Thus, the well-conditioned cod stocks are indicated to have a higher chance of good recruitment at low SSBs (higher recruitment potential) than stocks which consist of poorly-conditioned fish. It remains unclear however, whether the stocks on George's Bank and on the Faeroe Plateau fit in with these observations since they were excluded from the analysis due to the short time series of data and the high year to year variation in SSB, respectively.

Condition factor and biological reference points

A significant positive relationship was found between F_{med} and fish condition (Fig. 6). This implies that the better-conditioned cod stocks can sustain higher levels of exploitation in the long-term than poorly-conditioned stocks.

Discussion

Condition indices of cod have been usually interpreted to indicate their physiological status, cod with a low condition index presumably having experienced adverse physical environment or insufficient nutrition. Measurement of simple condition indices such as the Fulton's K as used in the present study have been demonstrated to provide an adequate and simple way of estimating the energy reserves of cod (Lambert and Dutil, 1997a). Different stocks or populations display different levels of condition according to the characteristics of their habitats (Dennis and Bulger, 1995; Grecay and Targett, 1996; Perry et al., 1996). Condition indices of cod follow inter-annual variations and seasonal cycles, with lower energy reserves occurring during spawning and maximum levels from September to December (Lambert and Dutil, 1997 a,b; Yaragina and Marshall, 1999; Marshall et al., 1999; Lloret and Rätz, 1999). The data used in the present analysis have been restricted to the third and fourth quarter to avoid such seasonal effects and high variation due to spawning processes.

We have shown in this paper that different cod stocks in the North Atlantic display different levels of condition, which are partly associated with the temperature regimes of their habitats. Cod stocks living in cold waters, e.g. Southern Gulf of St Lawrence, Greenland, Labrador and Grand Banks (Northwest Atlantic), are generally poorer conditioned than cod stocks living in warm waters, e.g. North Sea and Irish Sea cod stocks (Northeast Atlantic). Spatial heterogeneity of the fish condition has been also found in other fish species, e.g. pink salmon (Perry et al., 1996), blacknose dace (Dennis and Bulger, 1995) and weak fish (Grecay and Targett, 1996). These variations were consistent with spatial differences in food availability and environmental conditions. Temperature has been related to inter-annual fluctuations in condition of cod off Greenland (Lloret and Rätz, 1999), and has been demonstrated to influence growth and recruitment of different cod stocks (Jørgensen, 1992; Brander, 1994, 1995; Shelton and Lilly, 1995; Rätz et al., 1999). Poor condition due to adverse environmental or biological effects may also lower the chances of survival and thus leading to an increase of natural mortality (Love, 1958; Wilkins, 1967; Krivobok and Tokareva, 1972).

We have found a positive relationship between and the a -coefficients derived from the standardised Ricker's recruitment-spawning stock biomass relationships of 9 analysed cod stocks and their mean fish condition. Defining the Ricker's a -coefficient as an indicator of recruitment potential of a given stock disregards the second function's parameter denoting the SSB at maximum recruitment. The effect of the second parameter on the size of the a -coefficient has been diminished by the standardisation of both SSB and recruitment estimates to their maximum values. The usefulness of the Ricker's a -coefficients to reflect and compare the recruitment potential of the cod stocks is illustrated in Figure 3. The better-conditioned cod stocks in the Northeast Atlantic seem to have a higher recruitment potential than the poor conditioned stocks in the Northwest Atlantic characterized by a very sensitive reaction in recruitment reduction with decreasing spawning stock size. However, Ricker's coefficients need to be interpreted with caution due to the uncertainties regarding the available data quality and quantity (Fréchet, 1991; Chouinard and Fréchet, 1994; Sinclair, 1999). Inadequate data led to the rejection of the coefficients from the George's Bank and the Faeroe Plateau cod in this study. However, the relationship between fish condition and recruitment success was also demonstrated through lower fecundity and reductions in egg quality of poor conditioned cod (Kjesbu et al., 1992; Lambert and Dutil, 1998). Poor recruitment of haddock and Northeast Arctic cod has been linked to poor condition of reproducers (Marshall and Frank, 1999; Marshall et al., 1999).

F_{med} is one of the precautionary reference points generally accepted as a long term measure of stock management in terms of safe exploitation rates which a stock sustains with a low risk of a collapse (Caddy, 1998). Since the calculation of F_{med} is also based on data from the relation between recruitment and SSB, the significant correlation between F_{med} and mean fish condition of the 11 analysed cod stocks is not surprising and also underlines the positive effect of the fish condition on the reproductive potential of the stocks. The relation between F_{med} and mean fish condition implies that the well conditioned cod stocks in the Northeast Atlantic sustain higher exploitation levels than the cod stocks in the Northwest Atlantic, which consist generally of poor conditioned fish. The linkage between the fish condition and fish stock management was also drawn to underline the importance to improve the knowledge about the complex of variation in individual fish weight at length data as a reaction to environmental and biological effects and implications to reproductive success.

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Table 1. Mean Fulton's condition factor (K) for 11 stocks from the North Atlantic, together with years when samples were collected, and a-coefficients of the spawning stock biomass-recruitment relationship (Ricker, 1975), F_{med} , and average bottom temperature (Brander, 1994). Sources of information are indicated by numbers. Ricker's a coefficients in brackets are considered unrepresentative and therefore excluded from the analysis.

Cod stock (NAFO/ICES Div.)	Code	Condition factor			Ricker's a coefficient SSB-R			F_{med}	Biol. Ref. point	T
		K	Years	Source	a	Years	Source			
Greenland (NAFO 1+ICES XIVb)	GR	0.882	82-98	1	0.421	55-89	12	0.09	20	3
Georges Bank (NAFO 5Z)	GB	1.027	92-99	2	(0.590)	78-98	13	0.53	21	8
S. Gulf of St Lawrence (NAFO 4TVn)	SL	0.976	71-98	3	1.630	50-93	14	0.50	22	2.5
Southern Grand Bank (NAFO 3NO)	SB	0.884	81	4	0.296	59-92	15	0.40	23	2.5
Labrador / Grand Bank (NAFO 2J+3KL)	LA	0.950	81-83, 86-88	5	0.552	62-90	16	0.38	22	2
NE Arctic (ICES I+II)	NE	0.882	89-98	6	1.014	53-94	17	0.46	17	4
NW Scotland and Ireland (ICES VIa)	SC	1.055	92-98	7	1.827	66-96	18	0.59	18	10
Irish Sea (ICES VIIa)	IR	1.128	91-98	8	1.450	68-97	18	0.89	18	10
North Sea (ICES IIIa+IV+VIId)	NS	1.008	93, 97-99	9	1.197	63-97	19	0.75	19	8.6
Iceland (ICES Va)	IC	0.923	30-98	10	1.394	61-97	20	0.52	20	5.8
Faeroe Plateau (ICES Vb)	FP	0.970	94-97	11	(2.276)	61-97	20	0.40	20	7.4

References (sources):

- 1 Weight-length data from the Institute for Sea Fisheries, Germany
- 2 Weight-length data from Northeast Fisheries Science Centre, USA
- 3 Weight-length data from the Gulf Fisheries Centre, Canada
- 4 Weight-length relationship given in Wells (1982)
- 5 Weight-length data from the G. Lilly DFO, Canada
- 6 Weight-length relationship from the Marine Research Institute, Norway
7. Weight-length data from the Marine Laboratory, Scotland
- 8 Weight-length data from the Dpt. of Agriculture for Northern Ireland
- 9 Weight-length data from the Institute for Sea Fisheries, Germany, and CEFAS, UK
- 10 Weight-length data from the Marine Research Institute, Iceland
- 11 Weight-length data from the Fiskerirannsóknarstofan, Nóatú., FO-100 Tórshavn, Faeroe Islands.
- 12 SSB and recruitment data given in Rätz *et al.* (1999)

- 13 SSB and recruitment data given in O'Brien (2000)
- 14 SSB and recruitment data given in Sinclair (1994)
- 15 SSB and recruitment data given in Stansbury *et al.* (1998)
- 16 SSB and recruitment data given in Lilly *et al.* (1998)
- 17 SSB and recruitment data given in ICES CM / Assess: 2 (1998)
- 18 SSB and recruitment data given in ICES CM / Assess: 1 (1998)
- 19 SSB and recruitment data given in ICES CM / ACFM: 8 (1999)
- 20 SSB and recruitment data given in ICES CM / ACFM: 15 (2000)
- 21 presented L. O'Brien
- 22 Maguire and Mace (1993)
- 23 Motos and Sarausa (1998)

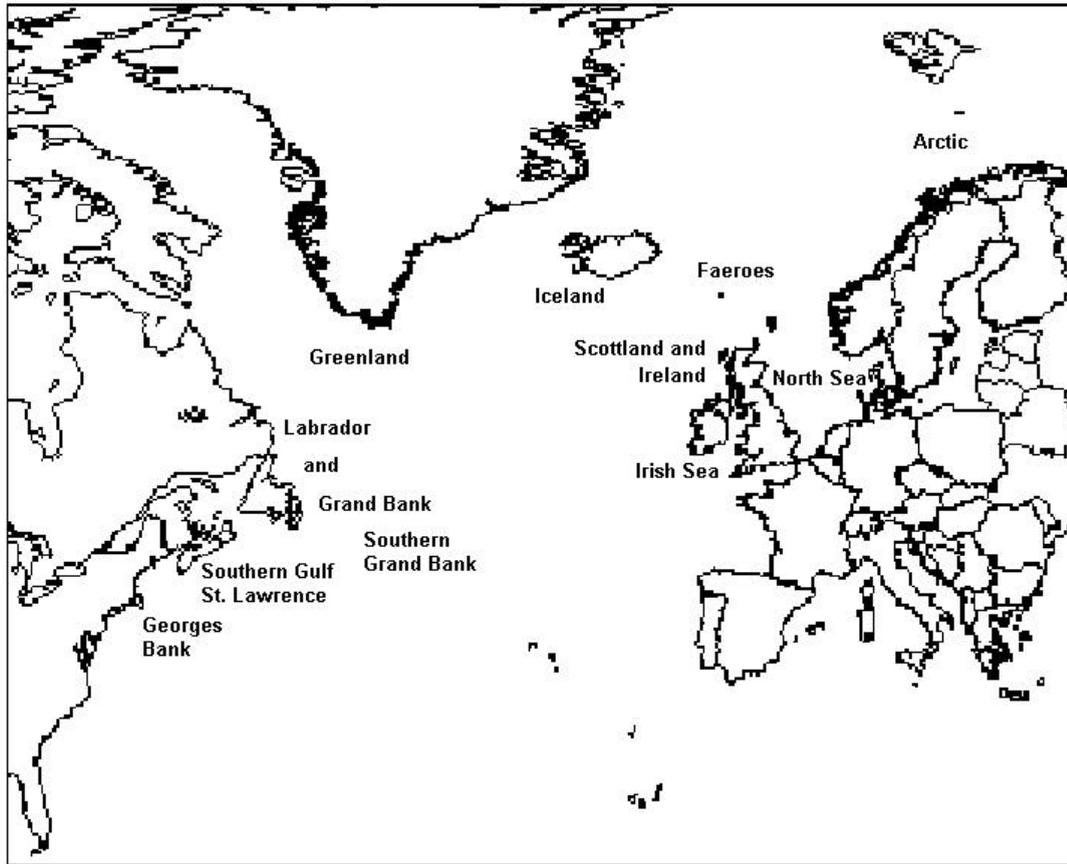


Fig. 1 Geographical distribution of selected cod stocks throughout the North Atlantic as specified in Table 1.

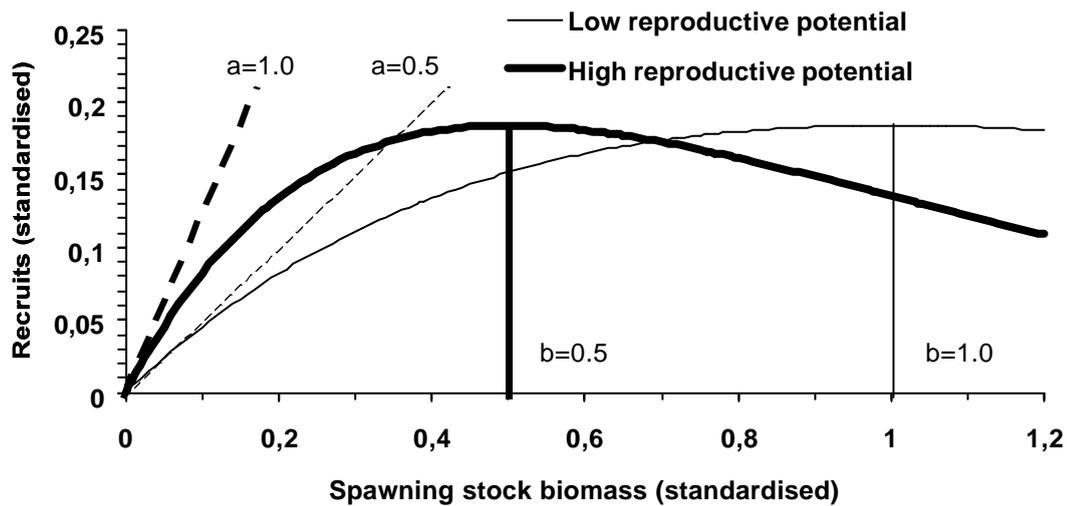


Fig. 2 Two examples of theoretical recruitment-spawning stock biomass relationships, one with a low and one with a high reproductive potential (a and b represent the coefficients of the Ricker recruitment – spawning stock biomass function).

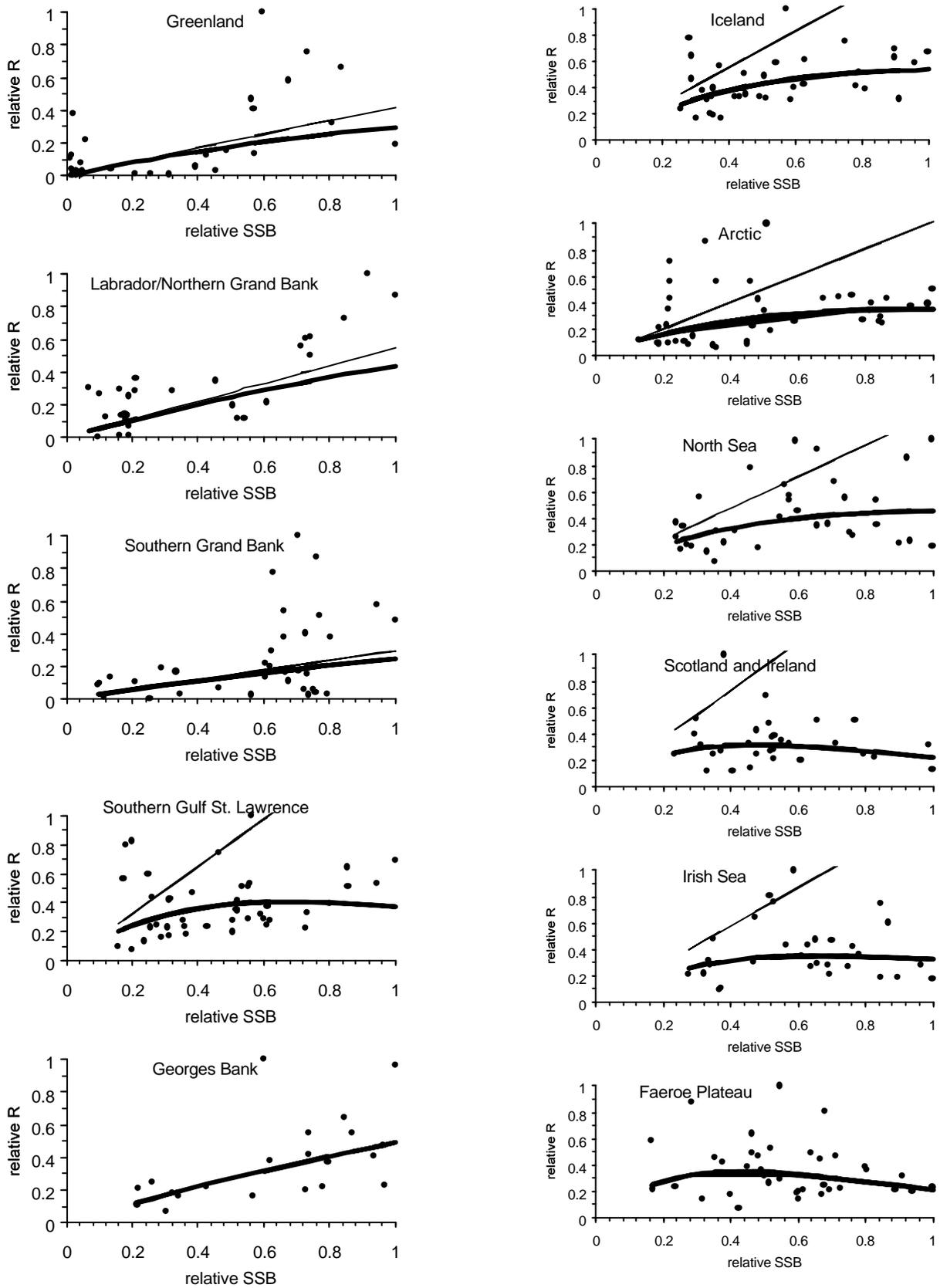


Fig. 3 Standardised Ricker functions for 5 Northwest (left panel) and 6 Northeast (right panel) Atlantic cod stocks. Parameters are given in Table 1. The linear lines represent the slope of the functions in their origins defined as reproductive potential (Ricker's a coefficient).

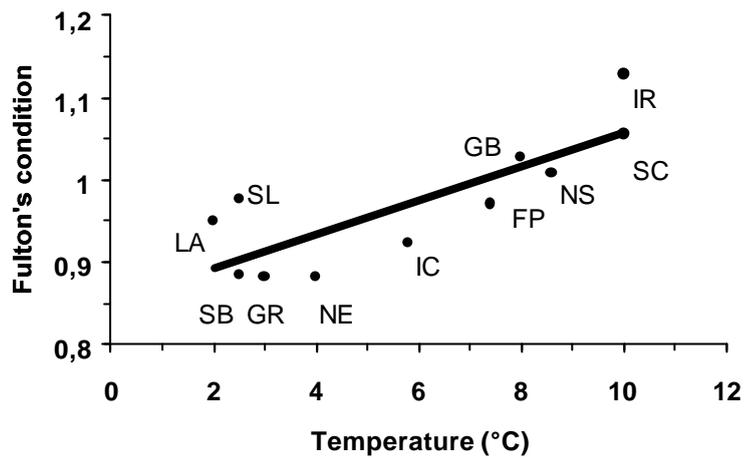


Fig. 4 Linear regression between condition factor and average bottom temperature (°C) for 11 North Atlantic cod stocks. Stock abbreviations are given in Table 1. $f(x) = 0.853 + 0.020x$, $r^2 = 0.654$, $p < 0.003$, $n = 11$.

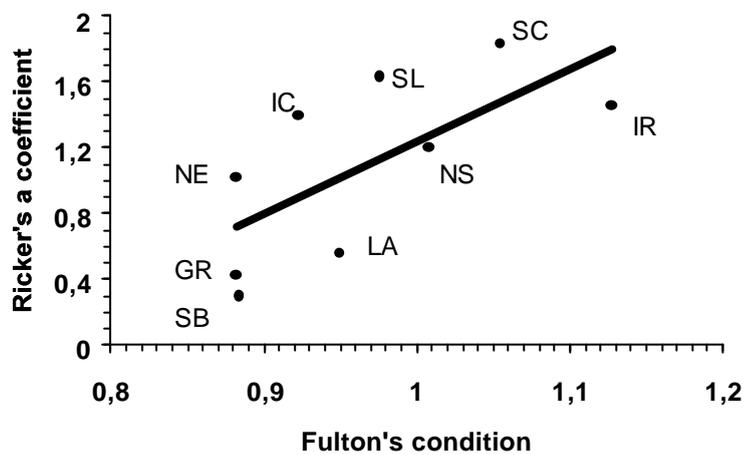


Fig. 5 Linear regression between Ricker's a coefficient (standardised) and Fulton's condition factor for 9 North Atlantic cod stocks. Stock abbreviations are given in Table 1. $f(x) = -3.121 + 4.359x$; $r^2 = 0.459$, $p < 0.045$, $n = 9$.

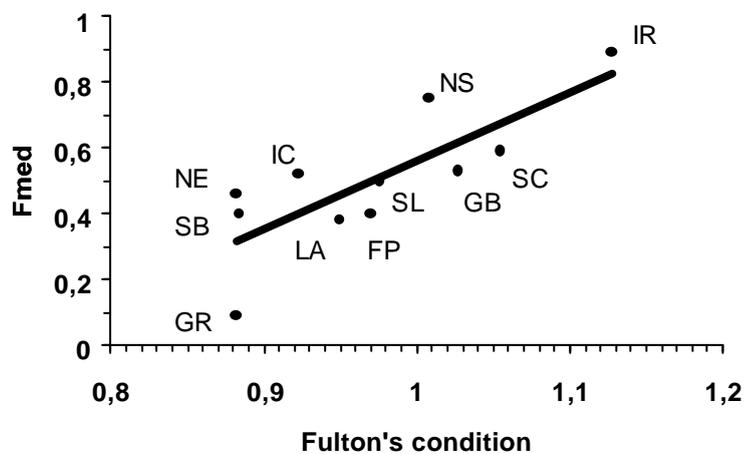


Fig. 6 Linear regression between Fmed and Fulton's condition factor for 11 North Atlantic cod stocks. Stock abbreviations are given in Table 1. $f(x) = -1.525 + 2.086x$; $r^2 = 0.634$, $p < 0.003$, $n = 11$.