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Recruitment of West Greenland Cod – Modelling Different Cause-Effect Regimes

by

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Abstract

Based on historical time series of cod recruitment and spawning stock biomass from Iceland and West Greenland, on sea surface temperatures and air temperatures around Greenland, and on zonal wind components between Iceland and Greenland multiple linear regression models are presented which explain the interannual variation in cod recruitment off West Greenland.

It is shown that during the decades between 1950 and 1990 there are different cause-effect regimes which seem to significantly influence the variability of cod recruitment: (a) During the 1950s and 1960s a regime under favourite sea surface temperatures with a self sustaining cod stock off West Greenland and high spawning stock biomass producing a series of good to strong year-classes, (b) during the 1970s and 1980s a regime of declining spawning stock and recruitment mostly depending on advection from Iceland, and (c) during the 1990s when the advective potential from the Icelandic cod stock was available, however, the cod recruitment in West Greenland waters was near extinction.

During the present regime (c) the initial model forecasts an increase of cod recruitment for the late-1990s. This scenario is evidentially non-realistic. Whether this is due to a “non-advective” situation in the waters between Iceland and East Greenland, or due to the impact of shrimp fishery on the juvenile cod off East and West Greenland remains speculative.

Keywords: Climate, recruitment, air temperatures, wind, advection, Icelandic cod stocks, Greenlandic cod stocks

Introduction

The decay of the West Greenland cod stock has been widely discussed in literature (e.g. Buch and Hansen, 1988; Hansen and Buch, 1986; Hermann and Horsted, 1976; Hovgard and Buch, 1990; Stein and Messtorff, 1990; Horstedt, 2000). Cod recruitment followed the same trend to near extinction during the 1990s (Rätz *et al*., 1999). Processes affecting cod recruitment are manifold: Among various physical processes like egg and larval transport from spawning grounds to their nurseries, stability of water masses, temperature of the sea and air, turbulence and wind seem to be most important (Stein and Lloret, 1995; Sundby and Fossum, 1990).

At West Greenland cod occurs at one of its northernmost limits (Hansen and Hermann, 1965). In historical times this stock was sustained not only by its own reproduction in the waters off West Greenland, but also by eggs and larvae advected from cod spawning sites at Iceland (Icelandic cod stock). Whereas Rätz *et al*. (1999) used sea

temperature and spawning stock biomass (SSB) to explain 51% of the interannual variation in cod recruitment off West Greenland, we use models which link different biological and environmental parameters to explain different "Cause-Effect Regimes" which might explain the variation in cod recruitment over four decades, from the 1950s to the 1980s.

For the advective parameters recruitment time series of Icelandic cod as well as SSB of Icelandic cod and zonal wind conditions between Iceland and Greenland are taken. Further environmental parameters, which are taken into account, are sea surface temperatures and air temperatures around Greenland.

Material and Methods

Data on Greenland cod recruitment (R) and spawning stock biomass (SSB) were taken from Anon. (MS 1996), for Icelandic cod recruitment and spawning stock biomass from Anon. (MS 2000), Table 1. These data were used to calculate a survival index [ln(R/SSB)] for the Greenland cod stock (Borovkov and Serebryakov, 1991; Borovkov and Serebryakov, 1993; Stein and Borovkov, 2000). Areas of maximum correlation index (c.f. Fig. 1, 2) were defined to download the respective time series data on air temperatures, sea surface temperatures (SSTs) and zonal wind components through the internet from the Climate Prediction Centre of NOAA.
http://wesley.wwb.noaa.gov/ncep_data/index_sgi62.html.

Three models were computed using the STATGRAPHICS software: An initial model (model 1, Fig. 3), and two models (2, 3, Fig. 4, 5) which consider different regimes. The model parameters are given in Table 2

Results

Maximum correlation for survival index [ln(R/SSB)] of the Greenland cod stock and surface air temperature is given in the Denmark Strait for an area of about 66°N-69°N, 30°W-18°W for the period FEB-JUL 1966-1989 (Fig. 1). Zonal wind components (JUL-NOV 1958-1959) yield high significant correlation for an area off East Greenland which we encompass by 64°N-67°N, 40°W-32°W (Fig. 2).

The initial model for West Greenland cod recruitment (Fig. 3) explains 76% of the variability by using Icelandic cod recruitment lnR_{icc}, surface temperature T_{MJJ}, and zonal wind component $ZW_{MAMJJASON}$. Cod recruitment injections from Iceland/East Greenland are matched for the 1973 and 1984 year-classes.

In a next step we divided the forecast models into two periods: (a) 1952-1972 and (b) 1972-1989. For period (a) best fit (r^2 = 076) was achieved with the model parameters lnR_{icc} and SST_{YEAR}, for period (b) lnR_{icc}, $lnSSB_{icc}$, T_{MJJ}, T_{FMAMJJ} and SST_{YEAR} explain 77% of recruitment variability of Greenlandic cod.

Figures 4 and 5 show that the modelled (bold red) curves match the observed patterns of cod recruitment at West Greenland (bold black) fairly good. The dotted parts of the model curves (red dotted with black data points) indicate disagreement with the periods after, or before and after the modelled periods (a) and (b).

Figure 6 outlines the periods when biological and environmental model parameters correlate significantly with West Greenland cod recruitment. Although SST_{YEAR} and T_{FMAMJJ} are both above the 0.95 level of significance, the computations for model period (a) are based upon lnR_{icc} and SST_{YEAR} alone. Zonal winds, despite being significant for the West Greenland cod recruitment (Fig. 6, blue "+" and red circle) are not taken into model computation as relevant parameters.

Discussion

The history of West Greenland cod recruitment is a deplorable story: During the 1950s and 1960s the West Greenland cod stocks produced a high spawning stock biomass based on several good recruitment events (1953, 1957, 1960, 1961 to indicate the strong year-classes). During the 1970s and 1980s West Greenland cod recruitment was only marginal, and the spawning stock biomass was based on two major injections from the Iceland/East Greenland cod stocks. For the 1990s and the present time the used models for recruitment of West Greenland cod indicate an increase which is unfortunately not realistic (Fig. 3-5). This observed collapse of the West Greenland cod stocks was mainly due to the progressive extinction of the spawners by fishing activities (Rätz *et al*., 1999).

Splitting the model into three periods was primarily done to check the goodness of the initial model for the period 1952-1989. This led to the assumption that three different regimes might explain the observed decline in West Greenland cod recruitment fairly good:

(a) a regime (1952-1972) with favourite SSTs, a self-sustaining cod stock off West Greenland with high SSB, producing a series of good to strong year-classes (Stein and Lloret, 1995),

(b) a regime (1972-1989) with declining SSB, and recruitment depending on the advection from the Iceland/East Greenland cod stock, and

(c) a regime (1989-present) with an exhausted or non-existing spawning stock and recruitment failure.

During the present regime the initial model forecasts an increase of cod recruitment based upon the 1997 and 1998 year-classes of Icelandic cod stocks. It should be noted here that the "advective" model [regime (b), Fig. 5] does not show this increase. As indicated by the annual German bottom trawl surveys to East and West Greenland there is no recruitment to the West Greenland cod stock at present (Rätz, pers. comm.). Whether this is due to a "non-advective" situation in the waters between Iceland and East Greenland, or due to the impact of shrimp fishery on the juvenile cod off East and West Greenland remains speculative.

References

ANON. MS 1996. Report of the North-Western Working Group. *ICES C.M. Doc.*, No. Assess: 15, 377 p.

MS 2000. Report of the North-Western Working Group. *ICES C.M.* ACFM: 15, 328 p.

BOROVKOV, V. A., and V. P. SEREBRYAKOV. 1991. Fluctuations of Cod Year-class Strength in the North Atlantic in Relation to the Spawning Stock Biomass and Survival Conditions. *NAFO SCR Doc.* 91/116, 1-15.

BOROVKOV, V. A., and V. P. SEREBRYAKOV. 1993. Fluctuations of Cod (*Gadus morhua*) Year-class Strength in the North Atlantic in Relation to the Spawning Stock Biomass and Survival Conditions. *NAFO Sci. Coun. Studies*, **18**: 25 (Abstract only).

BUCH, E., and H.H. HANSEN. 1988. Climate and cod fishery at West Greenland. In: Long-term Changes in Marine Fish Populations, T. Wyatt and M.G. Larraneta (eds.). *Proc. Vigo Symposium*, November 1986, pp. 345-364.

HANSEN, P.M., and F. HERMANN. 1965. Effect of long-term temperature trends on occurrence of cod at West Greenland. ICNAF Environmental Symposium, *ICNAF Spec. Publ.*, **6**: 817-819.

HANSEN, H., and E. BUCH. 1986. Prediction of year-class strength of Atlantic cod (*Gadus morhua*) off West Greenland. *NAFO Sci. Coun. Studies* **10**: 7-11.

HERMANN, F., and Sv.A. HORSTED. 1976. Fluctuations in the cod stock and the ocean climate at West Greenland. Book of Abstract of papers presented at Joint Oceanographic Assembly, Edinburgh UK, 13-24 September 1976; *FAO*, Rome (Italy); S.7, 52.

HORSTED, S.A. 2000. A Review of the Cod Fisheries at Greenland, 1910-1995. *J. Northw. Atl. Fish. Sci.*, **28**: 1-109.

HOVGARD, H. and E. BUCH. 1990. Fluctuation in the cod biomass of the West Greenland sea ecosystem in relation to climate. In: Large Marine Ecosystems. Patterns, processes and yields. K. Sherman, L.M. Alexander and B.D. Gold (eds). *AAAS Selected Symposium. Am. Ass. Adv. Sci.* Washington, DC.

RÄTZ, H.-J., M. STEIN, and J. LLORET. 1999. Variation in Growth and Recruitment of Atlantic Cod (Gadus morhua) off Greenland During the Second Half of the Twentieth Century. *J. Northw. Atl. Fish. Sci.*, **25**: 161-170.

SUNDBY, S., and P. FOSSUM. 1990. Feeding conditions of Arcto-Norwegian cod larvae compared with the Rothschild-Osborn theory on small-scale turbulence and plankton contact rates. *J. Plankton Res.* **12**:1153-1162.

STEIN, M., and V. A. BOROVKOV. 2000. Fifth Report of Joint Russian/German Project "Assessment of Short-time Climatic Variations in the Labrador Sea". *NAFO SCR Doc*. 00/2: 1-6.

STEIN, M., and J. LLORET. 1995. Stability of water masses – impact on cod recruitment off West Greenland. *Fish. Oceanogr*. **4**:3, 230-237.

STEIN, M., and J. MESSTORFF. 1990. Relationship of fluctuations in cod recruitment off West Greenland to long-term variations of the physical environment. *NAFO Sci. Coun. Studies* **14**: 39-44.

TABLE 1. Spawning stock biomass (SSB), recruitment (R) for two cod stocks in the Greenland-Iceland region. Data are from VPA (SSB in kmt, recruitment in millions ind.)

Year,	Greenland cod (offshore component)			Icelandic cod		
Year-class	SSB	R	lnR	SSB	R	lnR
1950						
1951						
1952		153,802	18,851		146,0	18,799
1953		511,983	20,054		202,0	19,124
1954		104,904	18,469		176,0	18,986
1955	1817,484	134,529	18,717	1261,0	260,0	19,376
1956	1519,495	463,649	19,955	1199,0	307,0	19,542
1957	1331,280	531,662	20,092	1145,0	153,0	18,846
1958	1469,227	226,870	19,240	1034,0	191,0	19,068
1959	1042,375	93,567	18,354	928,0	143,0	18,778
1960	1228,850	409,559	19,831	825,0	163,0	18,909
1961	1083,431	703,359	20,371	760,0	292,0	19,492
1962	1035,904	286,689	19,474	729,0	255,0	19,357
1963	1020,359	329,962	19,614	683,0	273,0	19,425
1964	887,216	105,573	18,475	569,0	328,0	19,609
1965	716,209	37,493	17,440	454,0	174,0	18,975
1966	715,515	39,073	17,481	412,0	255,0	19,357
1967	828,645	22,749	16,940	476,0	186,0	19,041
1968	775,887	87,980	18,293	594,0	178,0	18,997
1969	572,007	4,193	15,249	693,0	136,0	18,728
1970	466,971	9,181	16,033	684,0	303,0	19,529
1971	378,343	6,196	15,639	615,0	170,0	18,951
1972	248,141	24,604	17,018	477,0	265,0	19,395
1973	109,533	154,622	18,856	436,0	432,0	19,884
1974	88,940	16,618	16,626	329,0	143,0	18,778
1975	54,787	20,081	16,815	339,0	222,0	19,218
1976	30,131	26,788	17,103	283,0	246,0	19,321
1977	20,604	71,104	18,080	319,0	144,0	18,785
1978	37,794	14,247	16,472	375,0	143,0	18,778
1979	78,818	56,541	17,850	447,0	134,0	18,713

TABLE 1. continued.

Year, Year-class	Greenland cod (offshore component) SSB	R	lnR	Icelandic cod SSB	R	lnR
1980	94,123	7,705	15,857	602,0	226,0	19,236
1981	71,075	13,774	16,438	389,0	139,0	18,750
1982	57,228	1,990	14,504	266,0	144,0	18,785
1983	46,589	10,878	16,202	213,0	336,0	19,633
1984	35,644	265,710	19,398	219,0	278,0	19,443
1985	29,874	85,126	18,260	268,0	168,0	18,939
1986	32,906	1,408	14,158	268,0	83,0	18,234
1987	36,166	1,621	14,299	253,0	132,0	18,698
1988	56,409	0,635	13,361	193,0	101,0	18,431
1989	83,625	0,248	12,421	268,0	174,0	18,975
1990	41,003			343,0	151,0	18,833
1991	30,227			230,0	73,0	18,106
1992	20,732			243,0	162,0	18,903
1993				219,0	202,0	19,124
1994				260,0	88,0	18,293
1995				339,0	170,0	18,951
1996				287,0	72,0	18,092
1997				384,0	212,0	19,172
1998				387,0	195,0	19,089
1999				441,0	204,0	19,134
2000						

TABLE 2. Model results.

Model	degr.of freedom	variables in model	r^2 (adj.)
1	31	lnR_{icc}, T_{MJJ}, $ZW_{MAMJJASON}$	0.76
2	14	lnR_{icc}, SST_{YEAR}	0.76
3	12	lnR_{icc}, $lnSSB_{icc}$, T_{MJJ}, T_{FMAMJJ}, SST_{YEAR}	0.77

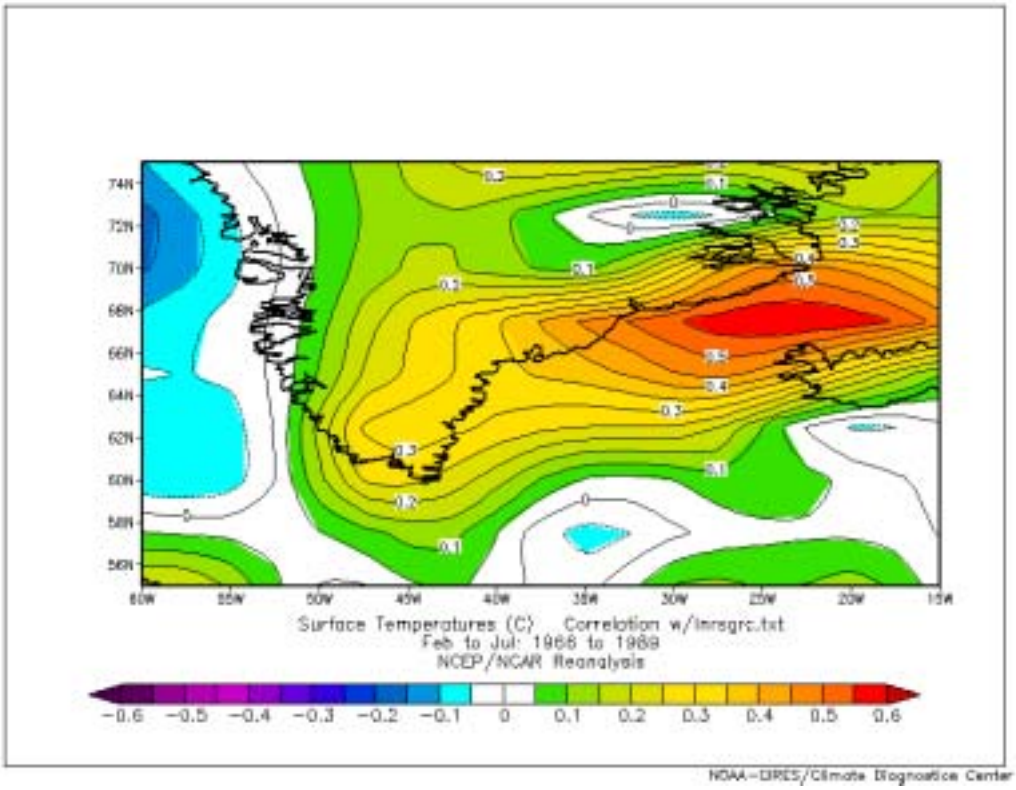

Fig. 1 Correlation between air temperature on surface (Feb-Jul 1966-1989) and survival index [ln(R/SSB)] of Greenland cod.

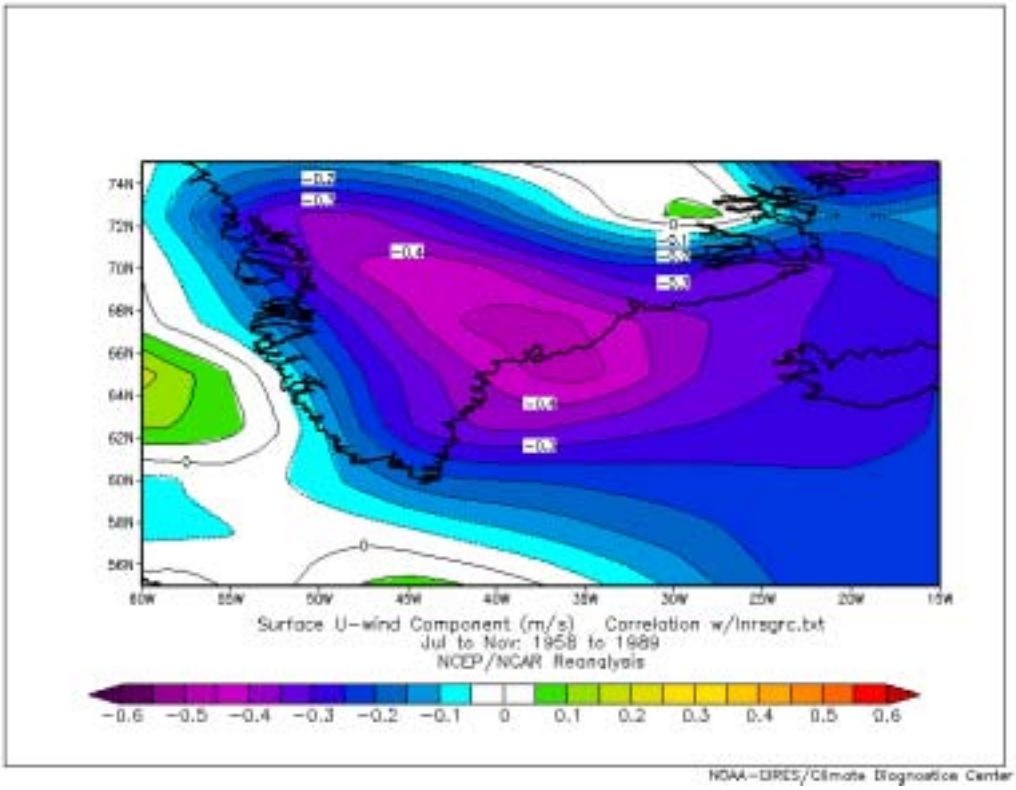

Fig. 2. Correlation between zonal wind (Jul-Nov 1958-1989) and survival index [ln(R/SSB)] of Greenland cod.

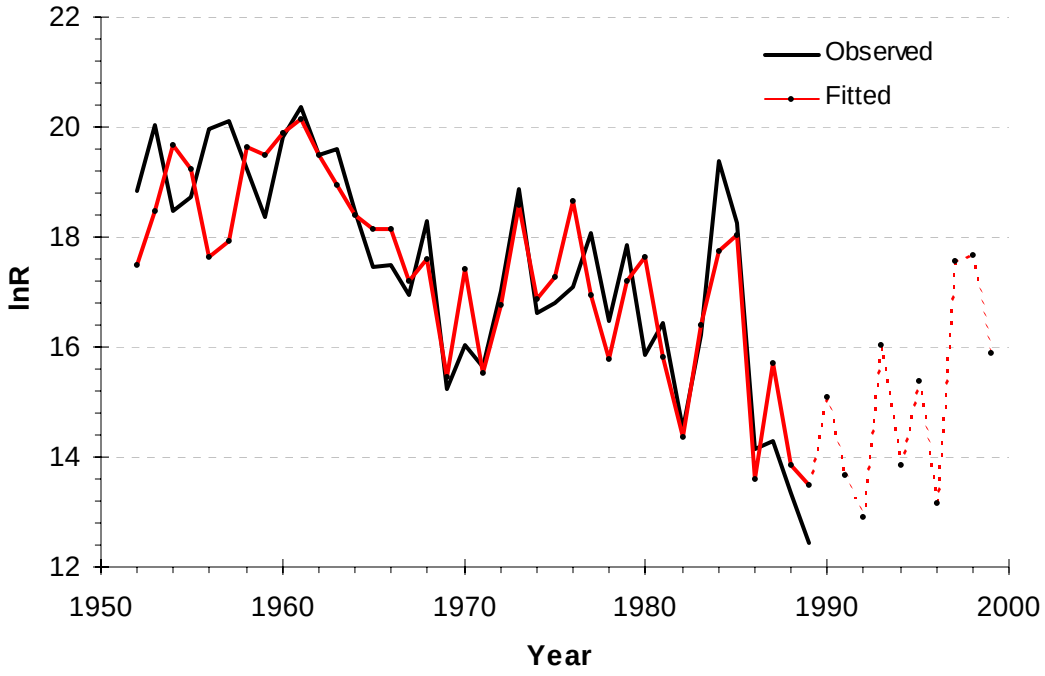

Fig. 3. West Greenland Cod recruitment **initial** model (R_{icc}, T_{MJJ}, U_{MAND}) for the period 1952-1989.

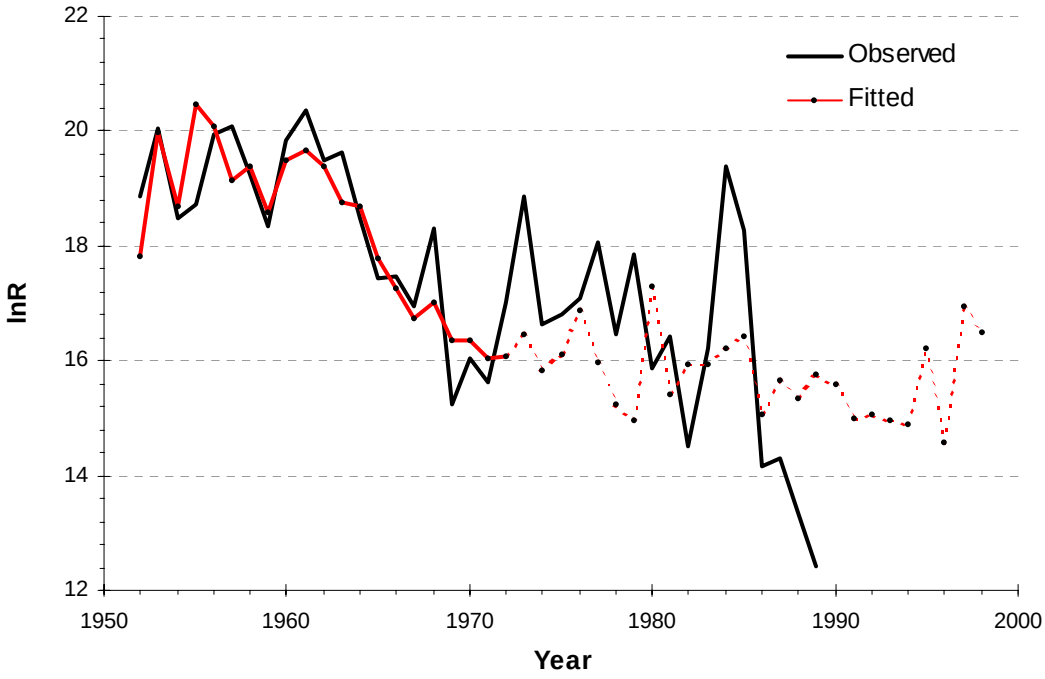

Fig. 4. West Greenland Cod recruitment model (R_{icc}, SST_{year}) for the period 1952-1972.

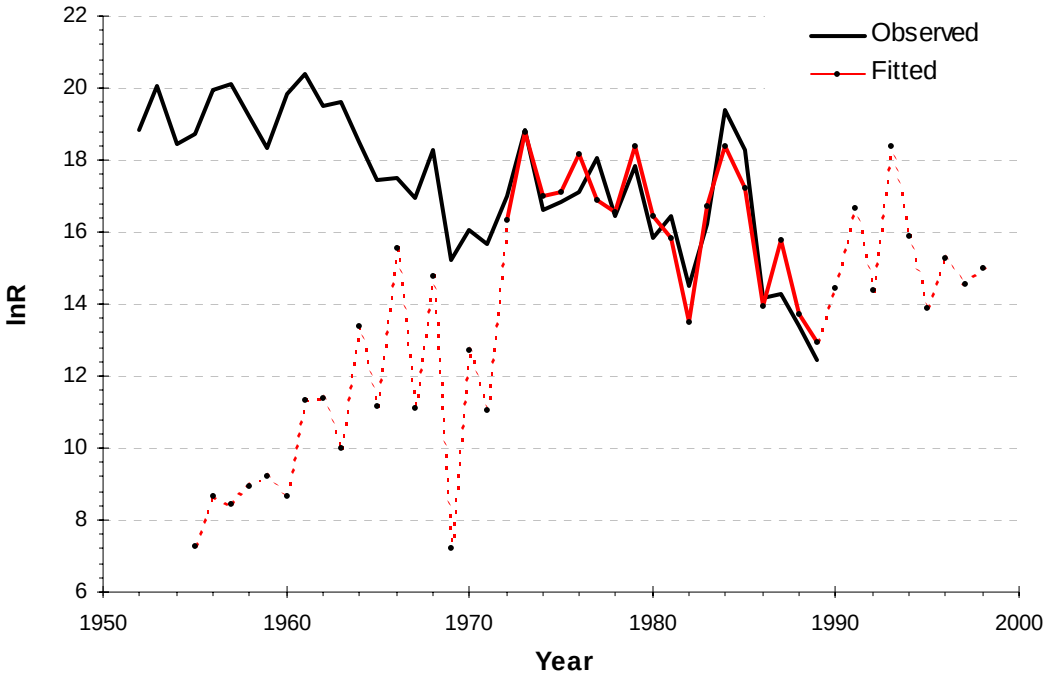

Fig. 5. West Greenland Cod recruitment model (R_{icc}, SST_{year}, SSB_{icc}, T_{MJJ}, T_{FMAMJJ}) for the period 1972-1989.

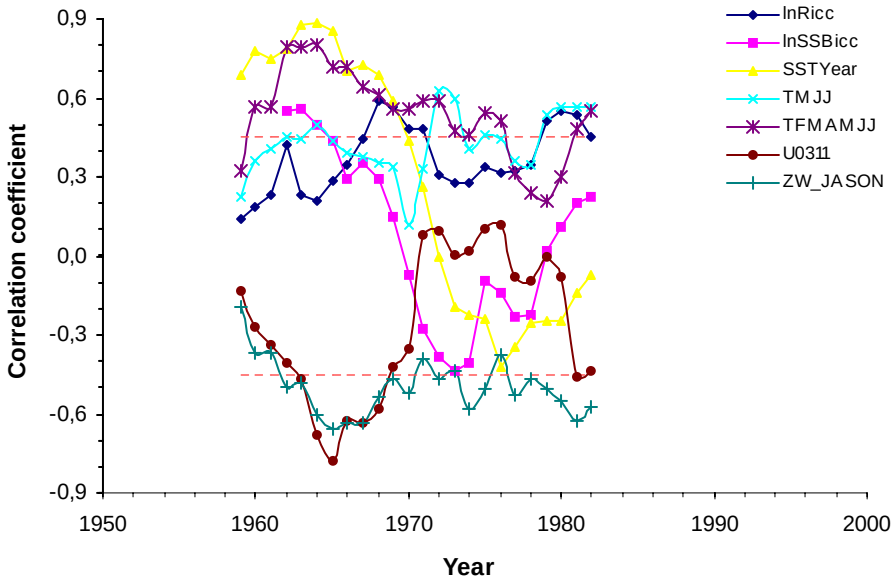

Fig. 6. Correlation coefficients of West Greenland cod recruitment with biological and environmental parameters (dashed line gives significance levels at .95).