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Greenhouse Induced Changes in the North Atlantic - Potential Impact on West Greenland Cod Stocks

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Abstract

Based on the assumption that cod year-class strength increases with rising temperature in a non-linear fashion, a thermal model is presented which simulates the greenhouse induced warming of the surface waters on Fylla Bank/West Greenland. Statistical coupling of average surface layer temperature data with cod year-class strength yields unrealistic year-class numbers for the model time period 1980-2050. From the model results warming would mean catastrophy for the ecosystem off West Greenland. Comparison between model year-class strength data 1982-1990 with VPA data for cod show no similarity of both data sets.

Introduction

Global change and Greenhouse warming of the troposphere have led to increasing discussions on the subject and potential influences on humankind, as well as on the biosphere as a whole. Clear indication of the Greenhouse warming signal is hard to detect, depending largely on the site of observation point. From the West Greenland area long-term observations of air temperatures are available (STEIN and BUCH, 1991) which indicate such a warming signal. In a recent paper, HANSEN and BUCH (1986) discuss methods for prediction of year-class strength of Atlantic cod off West Greenland. From the abiotic factors only water temperature yields some useful information for the prediction of year-class strength. The authors, however, conclude that greater knowledge is required about the relative proportions of recruitment from the West Greenland and the East Greenland-Iceland cod stocks before realistic predictions of year-class strength can be made.

STEIN (1990) indicates, that the climatic scenarios as shown by climatic models, as well as trends observed in the world ocean and atmosphere reveal changes in the hydrosphere and atmosphere. The model-cooling of surface water masses in the North Atlantic Ocean would imply catastrophic consequences for the fish stocks in this area, especially around Greenland. These models cover areas of bottom water production with deep convection, especially off East Greenland. Whether the model results which are based on a 3.5 * 3.5° grid (MIKOLAJEWICZ et al., 1990) yield a realistic background for consideration on the recruitment of West Greenland cod cannot be answered here, since available models do only cover parts of the complex ecosystem. They do not resolve so far biotic processes as e.g. intra- and inter-species reactions, or abiotic processes, or even biotic/abiotic reactions of the system.

However, model assumptions help to understand "if-conditions". What could happen if temperature alone will be changed with all other factors being important for the scenario, kept constant.

One of the first investigations in this way have been done by TRIPPEL et al. (1990).

They discuss potential impacts of global warming on whitefish population in the Lake Constance (Germany) under different temperature scenarios.

In a similar way the present paper makes an approach to analyse possible changes in the recruitment of West Greenland cod, with the assumption of Greenhouse induced warming of the top layers of Fylla Bank/West Greenland.

Materials and Methods

The signal of Greenhouse warming is analysed from the long-term air temperature records sampled at Nuuk/West Greenland since 1876 (Fig. 1).

For cod year-class size age 3 data and mid-June temperatures on top of Fylla Bank are taken from table 1 of HANSEN and BUCH (1986). These data represent estimates of the strength of the 1953-1979 year-classes derived from virtual population analysis (VPA), and calculated averages of temperature observations taken at 0, 10, 20, 30 and 40m depth on top of Fylla Bank.

These data were used to model a warming scenario under the assumption of a generally accepted global temperature increase of 3.0°C ±1.5°C until the year 2050.

To build up the warming scenario-model a procedure was used which takes natural variation of temperature from the original time-series into account , with an additive warming increment (TRIPPEL et al., 1990). Thus, three different model time-series of temperature have been established (1.5°C, 3.0°C, 4.5°C warming until the year 2050). Simple spread-sheet software (QUATTRO PRO), and a suitable graphics package (HARVARD GRAPHICS), were used to obtain model results (figs. 1 to 5).

It is assumed in the present analysis, that year-class strength increases with rising temperature in a non-linear fashion.

Correlation analysis of the input data yields, that variability of natural logarithmic year-class strength values is explained to almost 58% by the average surface layer temperatures (r^2 = 57.81 percent, P < 0.01).

Natural logarithmic year-class model data (1980-2050) were obtained from the temperature model scenarios by a regression

$$\text{Ln YCL} = 2.58 + 1.1464 * \text{average surface layer temperature}$$

Results

Fig. 1 displays the annual spectrum of warming/year which arises from the air temperature time-series sampled at Nuuk meteorological station. From the basic monthly time-series a linear trend was calculated. It is obvious from Fig. 1 that the winter months DEC, JAN, FEB indicate maximum warming of 0.025 °C/year to 0.03°C/year. Spring and summer months yield little warming, with the June temperature trend being even negative.

Fig. 2 shows the initial data sets in a linear (a) and a logarithmic presentation (b). Similarity between both curves (year-class strength, temperature) is obvious (Fig. 2b).

Fig. 3 shows the "thermal model". A linear increase in temperature is assumed for the years 1980 - 2050. The three curves thus indicate different increases for temperature which sum up to the 1.5°C, 3.0°C, and 4.5°C for the entire time span. Natural variation is extrapolated from the original time-series which leads to interannual warming and cooling trends.

The recruitment scenarios for the three temperature models are displayed in fig. 4. The original time-series of year-class strength ended with a value of 74 *10E+6 . The model time-series starts with 92, 94 and 97 * 10E+6 for the three temperature ranges. A first peak value is observed in 1983 with about 203, 223, 246*10E+6. With decreasing temperatures in the nineties the year-class size decreases to values around 1 million. In the first decade of the 21st century, year-class data peak at 507, 962, 1820 million (year 2005), around 2020 the year-class size diminishes to about 2 to 11 million. The scenario which follows in the thirties is characterized by events of catastrophic year-class size increase (985, 3630, 13314 * 10E+6 in the year 2032, and 763, 3181, 13190 *10E+6 in the year 2037). Mean temperatures on top of Fylla Bank have risen by this time to 3.5, 4.8, 6.0°C which is about two times as large as the thermal value for the year 1961 (3.2°C acc. to HANSEN and BUCH, 1986), a year with a year-class size of 530 million cod, labeled as of East Greenland origin. At the end of the model time-series, year-class strength data have reached 12, 66, 377 * 10E+6.

Discussion

From the air temperature time-series there is evidence that West Greenland experiences warmer winters over the entire period of observations (1876-1990). Despite the unusually cold Januaries of 1983, 1984, the overall statistical trend is positive. Annual mean conditions, although with a slightly positive overall trend (0.01 °C/year), indicate a cooling , which might have started in the 1960s. Whether this due to the increasing ice-sheet of southern Greenland cannot be answered here.

From the model results a series of "if-conditions" may be questioned:

1. If warming of the surfer layer at Fylla Bank would follow the given model, the temperature scenario near the mid of the next century would ressemble to North Sea conditions of present day.

2. If cod year-class strength data are linked to surface layer temperatures in a similar way as the model pretends, warming would mean catastrophy for the ecosystem off West Greenland. With increasing temperature, the biotic and abiotic members of the complex ecosystem would react in a way which cannot be discribed at present e.g. cod recruitment would increase to unrealistic dimensions of 20 times as large as the historic data.

3. If warming and cooling cycles will occur, primary production will implicate similar variability in biomass. More food supply on the phytoplankton and zooplankton level will cause high densities on the fish larval level. Interspecies and intraspecies competition (e.g. cannibalism) could occur, leading to smaller sizes and lower survival rates.

4. If warming is the dominant trend, as anticipated, the West Greenland waters will be governed by a two layer system: warmed surface waters on top of cold deeper water masses. The inflowing Irminger component (BUCH, 1982; BUCH,1984; STEIN and BUCH, 1985;STEIN and BUCH, 1991) would be masked by warm surface waters. This would lead to reduced vertical convection which means less nutrification of the euphotic layers. The vertical density stratification will more and more be characterized by a light warm and saline surface layer which rests on colder, less saline water. This leads to higher stability coefficients in the oceanic surface layer. According to MEYER (1968) and STEIN and BUCH (1985) high stability coefficients in the oceanic surface layer off West Greenland might have negative influences on the development of cod larvae.

Although this model approach contrasts to the results of MIKOLAJEWICZ et al. (1990)

which reveal from model computations with the Hamburg large-scale-geostrophic ocean general circulation model (OGCM) that in regions of former deep water formation (e.g. Greenland Sea) sea surface temperature will increase little, or even decrease in comparison to the zonal mean, the effective results yield in both cases a two-layered system: Light warm or cold diluted surface waters cover colder deep water layers. Taking into account a surface layer of 100m magnitude with temperature/salinity values 6.5°C/35.00 PSU, which covers deeper layers with a temperature/salinity field ranging from 5.5°C/34.80 PSU (200m depth) to 3.0°C/34.65 PSU (800m depth), the resulting density field yields stable conditions ranging from rho (s,t,p) = 1027.487 to 1027.947 (0 to 100m), and 1028.380 to 1031.323 (200 to 800m).

5. If warming of the surface waters would occur, the formation of ice would be reduced. The advection of ice would be decreasing, vertical convection during winter by surface water cooling would be reduced with the above noted effects on the foodweb.

Comparison of model year class strength data with VPA data from West Greenland (RIGET, 1990) indicates considerable differences for the years 1982 to 1990. The dominant 1984 year-class (1987 at age 3 in fig. 5) is not found in the model data. Also the rest of the VPA time series does not correlate with the model data. This confirms one of the conclusions by HANSEN and BUCH (1986) that prediction of year-class strength of Atlantic cod off West Greenland fails as long as there is no means to really discriminate between immigrants from East Greenland/Iceland and native West Greenland cod recruits.

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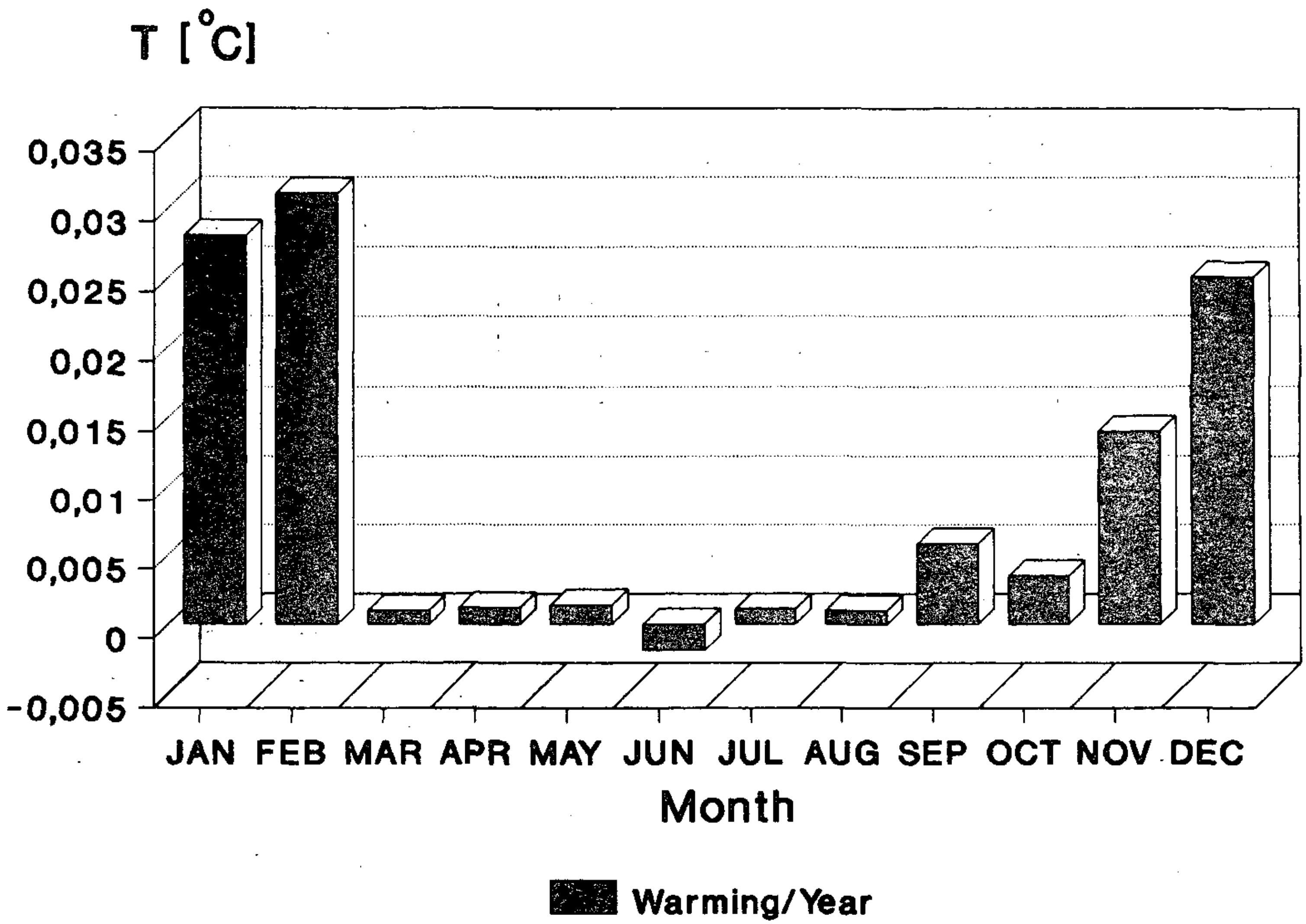
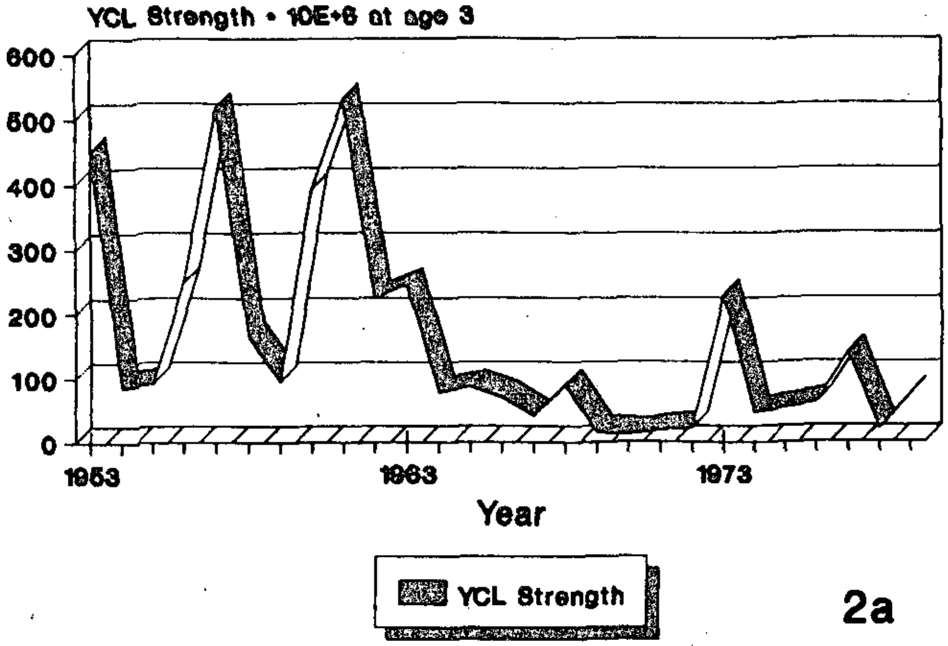


Fig. 1 Spectrum of warming/year at NUUK (1876-1990)



Data from Hansen and Buch (1986)

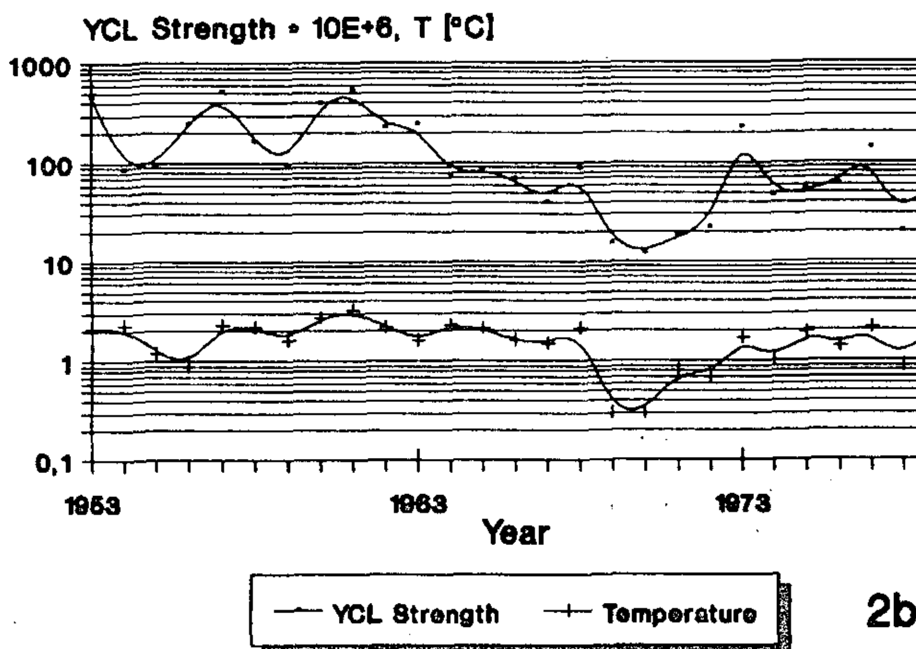


Fig. 2 Cod year-class strength and temperature
(from HANSEN and BUCH, 1986)

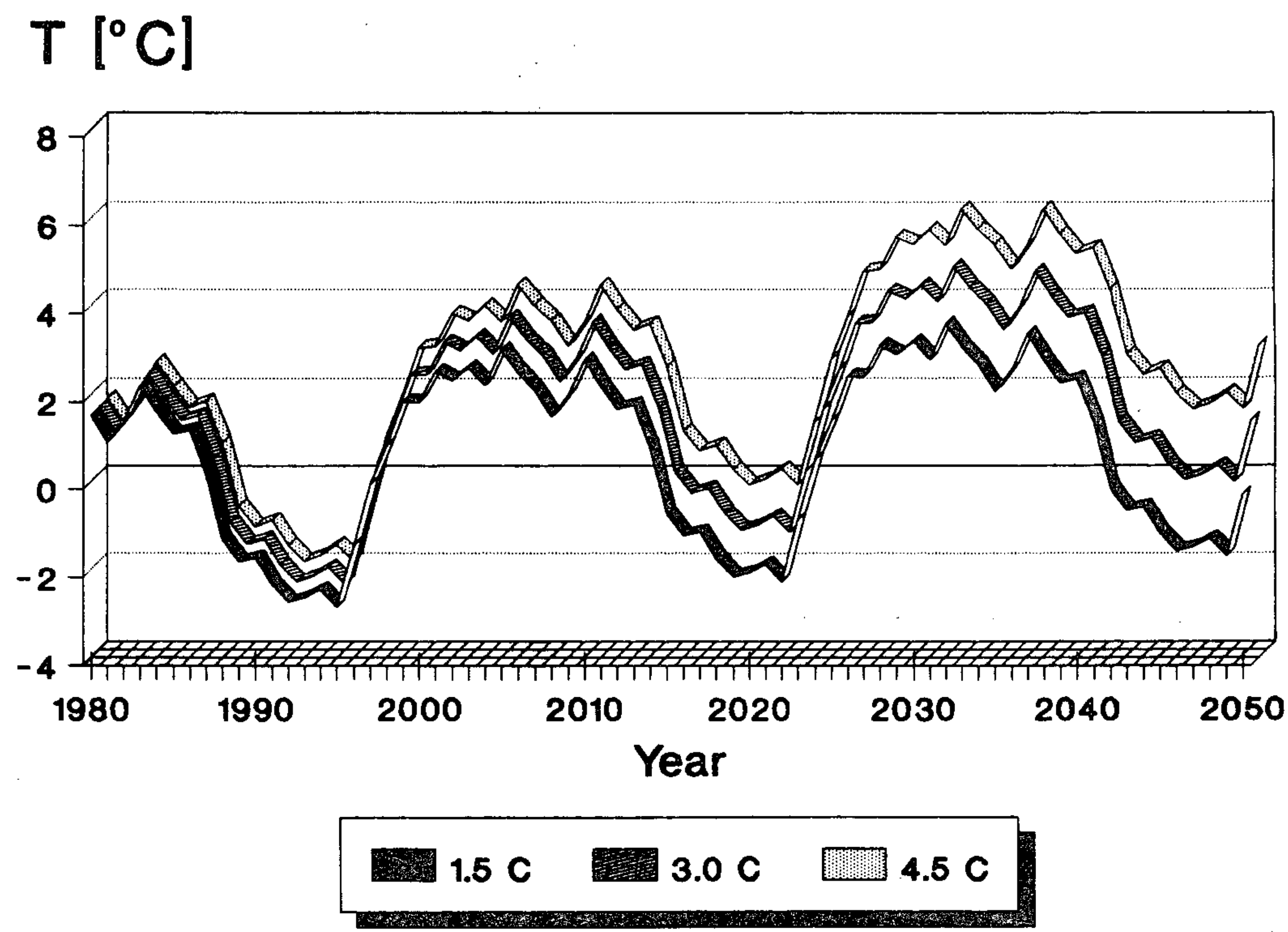


Fig. 3 Temperature Scenarios (Fylla Bank 1952-1979 June)

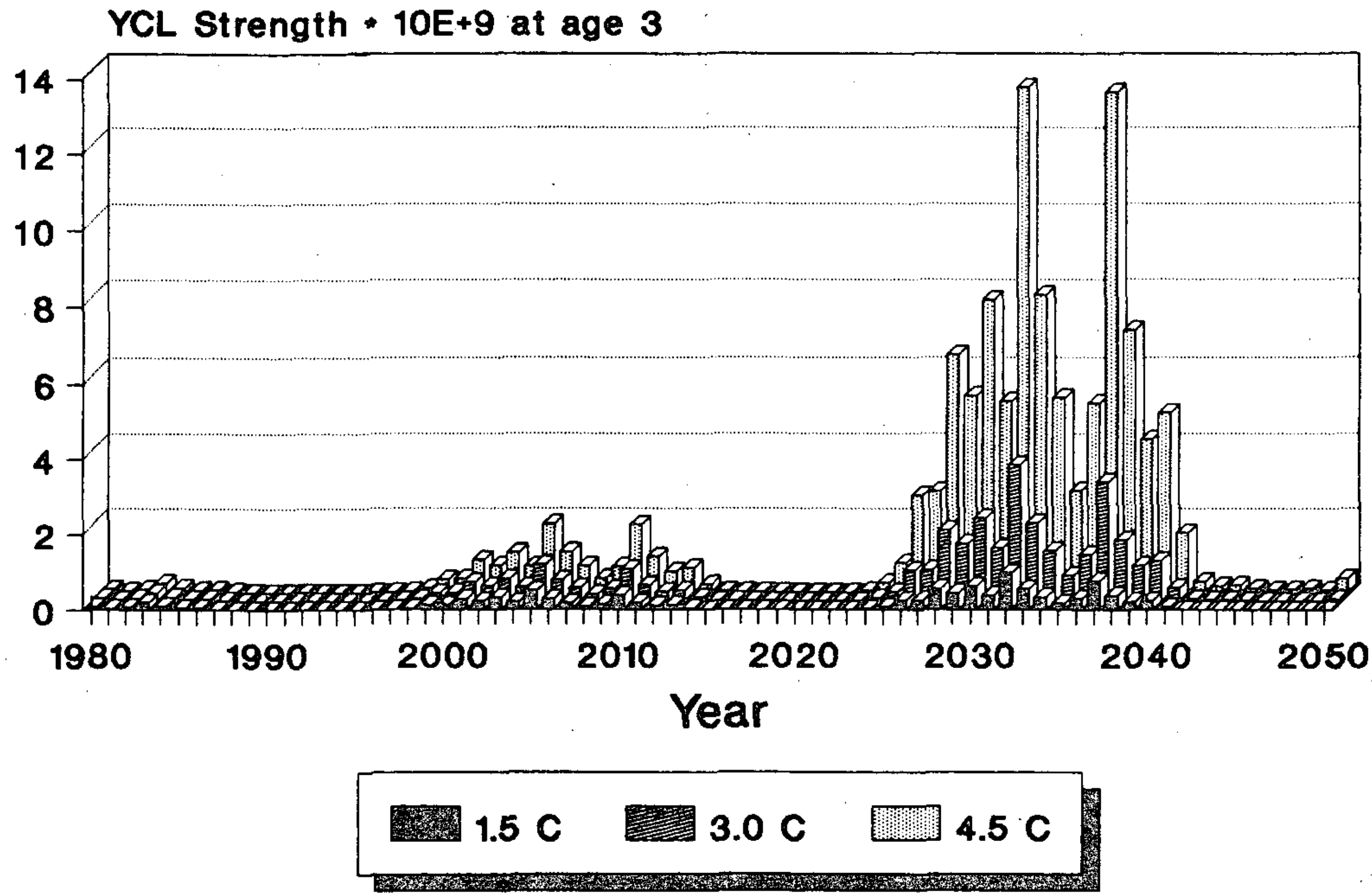


Fig. 4 Cod Year-class strength (data 1952-1979 June)

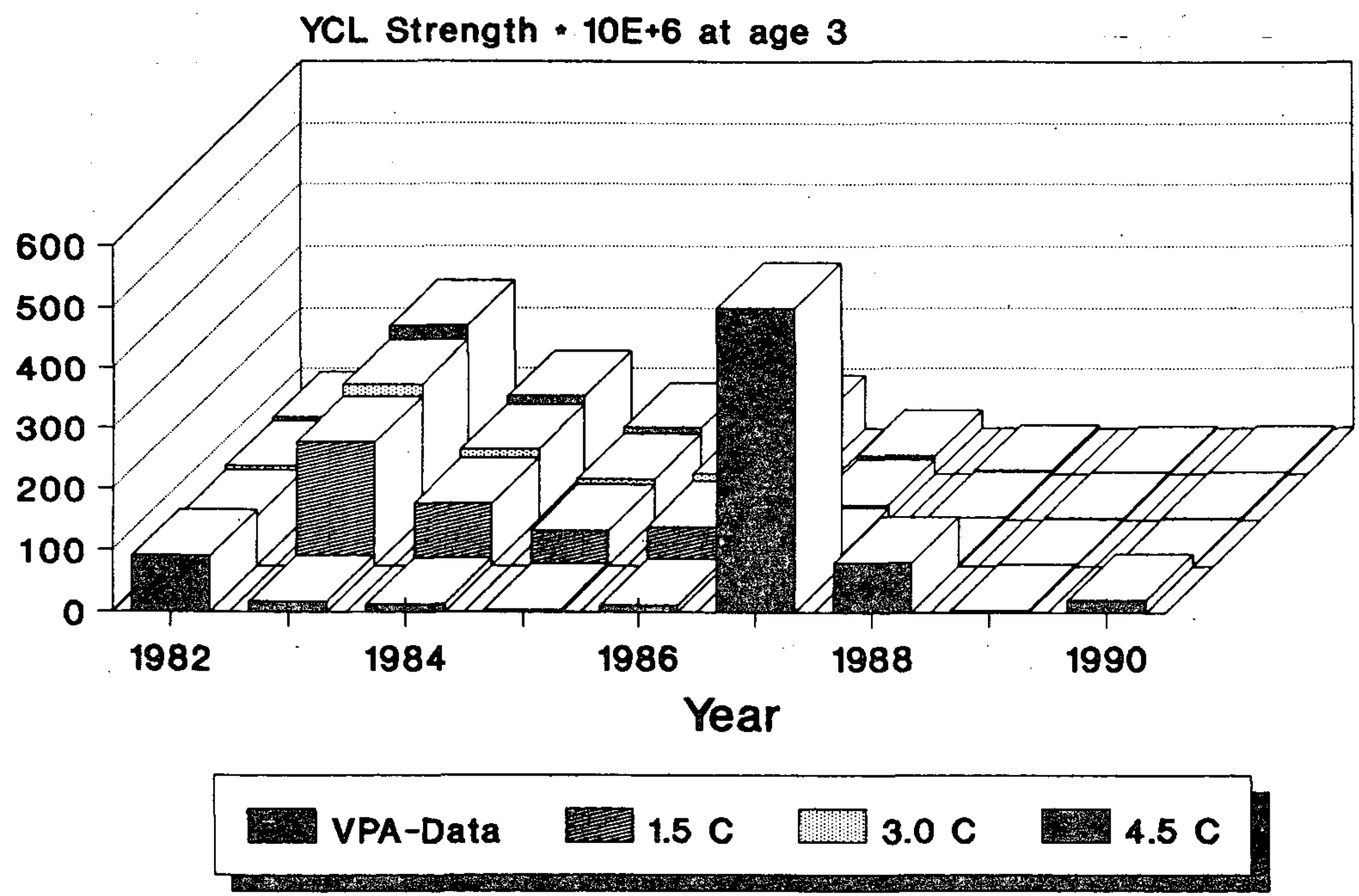


Fig. 5 Cod YCL Strength/VPA Data