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A Comparison of Different Time Series of Atlantic Cod (*Gadus morhua*) Biomass at West Greenland and Their Potential Use for the Assessment of Northern Shrimp (*Pandalus borealis*) in NAFO Subarea 1

by

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Abstract

No unique time series of Atlantic cod biomass at West Greenland that covers the past decades exists, as analytical assessment could not be carried out since the early-1990s when the commercial offshore fishery for cod collapsed. Hvingel and Kingsley (2002) constructed a cod biomass series for the years 1955 to 2001 combining VPA estimates of stock size and survey indices, which has been incorporated in the assessment of northern shrimp in the past two years (Hvingel, 2002, 2003). This time series, however, indicates some inconsistencies of the underlying data. Alternative ones, which reduce a potential bias in the estimation of the impact of cod predation on the shrimp stock in coming years, are presented in this paper

Introduction

Atlantic cod in Greenland waters has shown large variations in abundance and distribution in the past decades. Prior to 1920 annual catches of cod were less than 500 tons (Horsted, 2000) and were restricted to inshore areas at West Greenland (Buch *et al*., 1994). Thereafter an offshore stock developed which gave rise to a large fishery frequently yielding annual catches considerably above 300 000 tons through the mid-1950s to the late-1960s with a record high level of 480000 t in 1962 (Horsted, 2000). At the same time, the spawning stock biomass was gradually reduced and the catches declined dramatically in the early-1970s. During the 1980s, annual catches were generally low and depended on single strong year-classes (1984 and 1985), which were presumed to be mainly of Icelandic origin. These year-classes gave rise to an intermediate fishery with landings of about 100 000 tons in the years 1988 to 1990 and showed a pronounced migration towards Icelandic waters when becoming mature (Storr-Paulsen *et al*., 2004). Thereafter, Atlantic cod has almost been absent from the West Greenland offshore waters (ICES, 2004).

Several attempts has been made to assess the cod stocks off Greenland, in which they have been divided either into East and West Greenland or treated as one stock unit with or without the West Greenland inshore component included. Hence, no consistent time series of biomass exist for the different stock components. Due to the severely depleted status of the offshore component, the directed cod fishery in West Greenland offshore waters was given up in 1992, and since then adequate data to update the analytical assessment have not been available (ICES, 2004).

To overcome this problem, Hvingel and Kingsley (2002) constructed a biomass series of cod at West Greenland for the years since 1955 based on VPA estimates of stock size for East and West Greenland combined and separate survey indices for East and West Greenland offshore waters available since 1982. This time series has been used to include the effect of cod predation in recent assessments of northern shrimp in NAFO Subareas 0+1 (Hvingel, 2002,

2003) adopted by the Standing Committee on Fisheries Science (STACFIS) and the Scientific Council of NAFO (Anon., 2003).

This paper compares the cod biomass series by Hvingel and Kingsley (2002) with alternative ones and identifies some inconsistencies, which may result in a substantial bias in the estimation of the impact of cod predation on the shrimp stock.

Materials and Methods

The basic data series used in this study were as follows:

- A historical VPA for West Greenland cod comprising the inshore and the offshore component is given in (Buch *et al*., 1994). Here, the period 1924 to 1989 is covered, but no attempts were made to correct for emigration.

- The offshore cod population off East and West Greenland was assessed as one stock unit and distinguished from the West Greenland inshore component for the first time in 1996 using data back to 1955 (ICES, 1996). The final year of the VPA was 1992 discarding conflicting data for the years 1993-1995, in which exceptional high fishing mortality coefficients were recorded. The effect of emigration was only covered for the 1973 and the 1984 year-class through an increase of the natural mortality for age 5 and older.

- A stratified random groundfish survey covering the shelf area outside the 3 nautical mile limit and the continental slope down to a depth of 400 m off East and West Greenland (ICES Area 14 and NAFO Div. 1B-1F) has been conducted annually by Germany since 1982. However, area coverage at East Greenland has been incomplete in three years, i.e. (1984, 1992 and 1994) and at West Greenland the northernmost area (NAFO Div. 1B and 1C) was not covered in 1995 and 2001-2003 due to technical reasons. The survey is primarily targeted at cod, and the fishing gear used is a groundfish trawl rigged with a heavy ground gear. The survey provides swept area estimates of abundance (by age) and biomass (all ages pooled) for the East and the West Greenland offshore component, which form the primary basis for the current evaluation of the status of the offshore stock (ICES, 2004).

The VPA estimates and the survey indices were combined in three different ways to construct time series of cod biomass for the entire period, i.e. 1924 to present or 1955 to present, which are listed in table 1 and described in detail below.

<u>Time series by Hvingel and Kingsley (2002)</u>

The approach by Hvingel and Kingsley (2002) involves three steps:

- For the years 1955-1992, the VPA estimates of cod biomass (age 3+), which were assumed to represent absolute biomass, for East and West Greenland offshore waters combined (ICES, 1996) were multiplied with 0.6, which was the average fraction of survey biomass allocated to West Greenland in the years 1982-1992 (Fig. 1). This includes years of incomplete survey coverage at East Greenland as well the years since 1989 in which the survey index ratio drastically declined due to the homing migration of maturing cod to East Greenland and further to Iceland. It is thus highly questionable whether the mean ratio of 0.6 is valid for the 1950s and 1960s when a spawning stocks of considerable size existed at West Greenland (Buch *et al*., 1994).
- For the years 1982-1992, the VPA estimates were partitioned into a West Greenland component using the annual East to West Greenland survey index ratios (Fig. 1). This was also done for the years 1984 and 1992 in which the area coverage of the survey was incomplete at East Greenland (ICES, 2004) and the survey index ratio might not have been representative for the relative distribution of the stock.
- For the years 1993 and forward, the survey indices for West Greenland were divided with 0.46, which is the mean survey to VPA ratio for East and West Greenland combined for the year 1990-1992. This conversion is based on a rather low survey to VPA ratio compared to the years 1986 to 1989 (Fig. 2) and includes 1992 in which the area coverage of the survey was incomplete at West Greenland.

Revised time series following the approach by Hvingel and Kingsley (2002)

Here, years of incomplete area coverage in the survey were excluded from the calculation of the fraction of cod biomass allocated to West Greenland and the mean survey index to VPA ratio:

- For the years 1955-1992, the VPA estimates of cod biomass (age 3+) for East and West Greenland offshore waters combined (ICES, 1996) were multiplied with 0.76, which was the average fraction of survey biomass at West Greenland in the years 1982-1988 excluding 1984 (Fig. 1).
- For the years 1982-1992, the VPA estimates were partitioned into a West Greenland component using the annual East to West Greenland survey index ratios, except for the years 1984 and 1992 for which the fraction of cod biomass at West Greenland was interpolated based on the year before and the year after.
- For the years 1993 and forward, the survey indices for West Greenland were divided with 1.44, which is the mean survey to VPA ratio for East and West Greenland combined for the entire overlapping period excluding the years 1984 and 1992. The annual survey to VPA ratios were highly variable (Fig. 2) and the correlation between the survey and the VPA was quite poor ($r^2 = 0.26$, n.s.).

New time series based on Buch et al. (1984)

- For the years 1924-1989, VPA estimates of cod biomass (age 3+) for West Greenland offshore and inshore waters combined were used. No attempt was made to split these estimates into an offshore and an inshore component because neither explicit biomass estimates nor comparable catch-per-unit-effort data for the two components exist.
- For the years 1990 and forward, the survey indices for West Greenland were converted to VPA estimates using the mean survey to VPA ratio for the overlapping time period, i.e. the years 1982-1989 (Fig. 3). As this ratio is very close to 1, the converted survey indices are almost identical to the original ones.

Despite a high variability of the annual survey to VPA ratios for West Greenland (Fig. 3), the survey correlates fairly well with the VPA ($r^2 = 0.91$, $p < 0.001$; Fig. 4). However, the resulting regression has not been used to convert the survey indices due to its substantial intercept, which would give biomass estimates of around 60 000 tons for all years since 1991 when the survey indices were at or below 5 000 tons.

Results and Discussion

The estimates of the absolute biomass given in Hvingel and Kingsley (2002) were substantially below the survey indices for 1986 to 1989 and above the survey indices for all other years (Fig. 5). This would correspond to a drastic change in catchability in the survey from values between 1.7 and 2.8 in the period 1986 to 1989 to about 0.5 for the years 1993 to 2003 (and all future years), and means that a survey index of 660 000 tons (as observed in 1988) was downscaled to about 310 000 tons, but the same value would result in a absolute biomass estimate of 1 450 000 tons if occurring in any coming year. This inconsistency, which might be ignored at the current low level of the cod stock, would lead to a considerable overestimation of the consumption of shrimp in the case of a future increase of the survey biomass index to the level seen in the late-1980s.

The revised biomass estimates using the approach by Hvingel and Kingsley (2002) but excluding years of incomplete survey area coverage were above the original ones in the years prior to 1982 (Fig. 5). They were almost identical to the original estimates by Hvingel and Kingsley (2002) for the years 1982 to 1992 but fell slightly below the survey biomass indices in all years thereafter. Hence, the change in the mean survey to VPA ratio from 2.1 in the years 1986 to 1989 to the value of 1.44 used for the conversion of the survey indices since 1993 was less pronounced than for the original time series used by Hvingel and Kingsley (2002).

The biomass estimates based on the VPA for West Greenland offshore and inshore waters combined coincides well with the two other time series in the years 1969 to 1975, exceeds the other two in the years 1976 to 1989 and are almost identical with the survey indices thereafter (Fig. 5). The survey to VPA ratio amounts to 2.3 in 1986 when a high amount of age 2 cod was encountered in the survey (ICES, 2004), was about 1.3 in 1987 and 1988 and between 0.3 and 0.8 in the other years of the overlapping period. It should be kept in mind that the VPA from Buch *et al*. (1994) includes both, offshore and inshore (fjord areas and coastal waters) catches, and that the inshore areas contributed to about 24 % of the total landings on average in the period 1924 to 1989 (ICES, 2004, Fig. 6). In addition to several fjord systems, the inshore catches originated from the Disko Bay (NAFO Div. 1A) and the coastal waters of the Julianehåb Bight (NAFO Div. 1F), which are included in the assessment area for northern shrimp. The German groundfish survey does neither cover the Disko Bay nor the inner part of Julianehåb Bight, and it is unlikely that the VPA estimates were substantially above the absolute offshore population biomass of cod considering that the mean survey index to VPA ratio was almost 1.

The VPA's considered in this study give estimates of stock biomass for age 3+ while the survey indices also comprises younger ages. This might explain why the survey indices were above the VPA estimates in the late-1980s when two strong year-classes were encountered in West Greenland waters. However, due to gear specifications cod is not quantitatively represented in the survey catches before age 3. Information on mean weight at age was missing for several combinations of year and age (Rätz, 2004). Moreover, using interpolated mean weights at age resulted in a biomass of age 3+ that was more than 30% above the original swept area estimate for all ages pooled in one year. Hence, it was not possible to use survey biomass indices for age 3+ for comparison with VPA estimates.

The different survey to VPA ratios applied in the conversion of the survey indices in the three time series of cod biomass has only a minor effect on the assessment of the impact of cod predation for the stock of northern shrimp if cod biomass remains at a low level, which is suggested by Storr-Paulsen and Wieland (2004) to be the case in the 2004. But an increase of the survey indices for cod to values observed in the late-1980s would lead to quite significant alterations of the estimated cod population biomass (Fig. 7) and consequently in the estimation of the amount of northern shrimp consumed by cod.

Conclusions

All of the three time series of cod biomass presented in this study would cause an underestimation of the consumption of shrimp in the late-1980s if the survey indices were closer to the absolute biomass than the VPA estimates. However, the series of biomass estimates based on Buch *et al*. (1994) appears to be preferably to the two other ones because it avoids the extension back in time using an uncertain mean biomass proportion for West Greenland and because its average deviation from the survey indices was the lowest, which should give less biased results for the coming years. However, this data series is affected by the inclusion of inshore areas, in which the major fraction of catches were taken in the mid 1920s as well as from the late-1970s to the late-1980s, and alternative approaches might be explored, e.g. based on abundance rather than on biomass.

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TABLE 1. Time series of Atlantic cod biomass ('000 tons) at West Greenland (a): East and West Greenland offshore combined, age 3+ (ICES, 1996); b): German groundfish survey, all ages (ICES, 2004); c): West Greenland offshore and inshore combined, age 3+ (Buch *et al*., 1994).

Year	1): Hvingel & Kingsley (2002) VPA a) proportion at West Greenland	Survey b) converted to VPA a)	2): VPA a) proportion at West Greenland based on survey '82-'88 ('84 excl.*)	VPA a) proportion at West Greenland based on survey ('84 and '92 interpolated *)	Survey b) converted to VPA a) based on mean survey to VPA ratio 82-'92 ('84 and '92 excl.*)	3): VPA c) West Greenland offshore and inshore combined	Survey b) converted to VPA c) based on mean survey to VPA ratio '82-'89
1924						693.2	
1925						878.1	
1926						923.6	
1927						1019.5	
1928						1045.6	
1929						1327.0	
1930						1422.5	
1931						1311.2	
1932						1127.0	
1933						963.5	
1934						933.3	
1935						914.7	
1936						963.1	
1937						1175.9	
1938						1535.5	
1939						1921.6	
1940						2296.9	
1941						2564.5	
1942						2863.4	
1943						3033.4	
1944						3248.1	
1945						3304.3	
1946						3677.0	
1947						3586.1	
1948						3740.9	
1949						4128.7	
1950						4076.5	
1951						3722.9	
1952						3285.7	
1953						2855.3	
1954						2848.3	
1955	1729.3		2204.9			2731.4	
1956	1662.5		2119.7			2298.7	
1957	1286.1		1639.8			2037.5	
1958	1333.1		1699.7			1866.2	
1959	1294.3		1650.3			1687.7	
1960	1589.2		2026.2			1823.1	
1961	1591.9		2029.7			1793.9	
1962	1459.7		1861.2			1469.2	
1963	1448.6		1846.9			1328.4	
1964	1457.0		1857.6			1327.6	
1965	1348.4		1719.2			1345.3	
1966	1386.9		1768.3			1254.9	
1967	1241.8		1583.4			1167.5	
1968	877.5		1118.8			904.9	
1969	535.9		683.3			637.4	
1970	392.7		500.6			442.2	
1971	334.9		427.0			372.8	
1972	227.5		290.1			283.0	
1973	136.8		174.5			179.5	
1974	85.8		109.4			132.1	
1975	62.9		80.2			108.5	
1976	133.0		169.6			228.8	
1977	122.4		156.1			251.7	
1978	120.3		153.4			253.5	
1979	135.3		172.4			217.3	
1980	106.9		136.3			240.4	
1981	103.6		132.1			178.3	
1982	135.1			135.1		190.9	128.2
1983	87.5			87.5		134.0	82.2
1984	52.7			57.1		79.0	25.5
1985	30.6			30.6		51.7	35.6
1986	41.4			41.4		38.4	86.5
1987	231.0			231.0		466.7	636.9
1988	307.0			307.0		481.2	606.4
1989	191.6			191.6		403.2	333.0
1990	57.5			57.5			34.3
1991	7.4			7.4			5.1
1992	8.4			9.2			0.6
1993		0.8			0.2		0.4
1994		0.3			0.1		0.1
1995		0.1			0.0		0.1
1996		0.8			0.3		0.4
1997		0.6			0.2		0.3
1998		0.3			0.1		0.1
1999		0.5			0.2		0.2
2000		1.3			0.4		0.6
2001		5.8			1.9		2.7
2002		4.6			1.5		2.1
2003		5.0			1.6		2.3

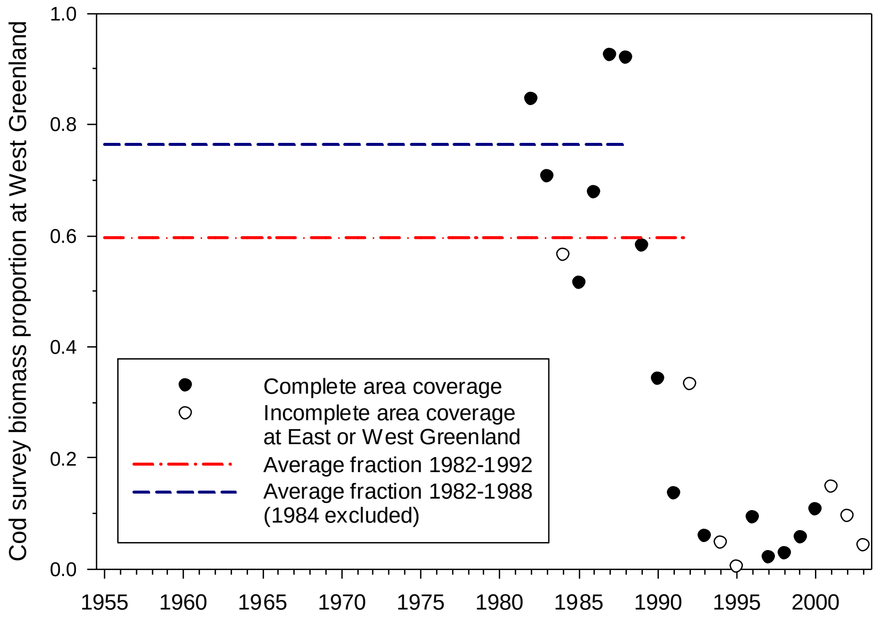

Fig. 1. Fraction of Atlantic cod survey biomass (all ages) at West Greenland.

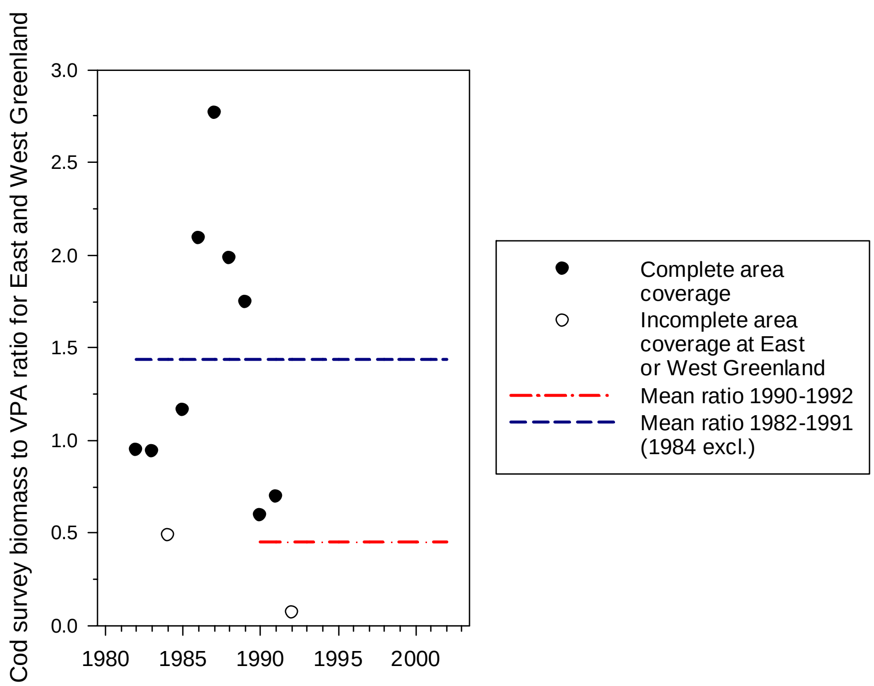

Fig. 2. Atlantic cod survey biomass (all ages) to VPA (age 3+) ratio for East and West Greenland combined.

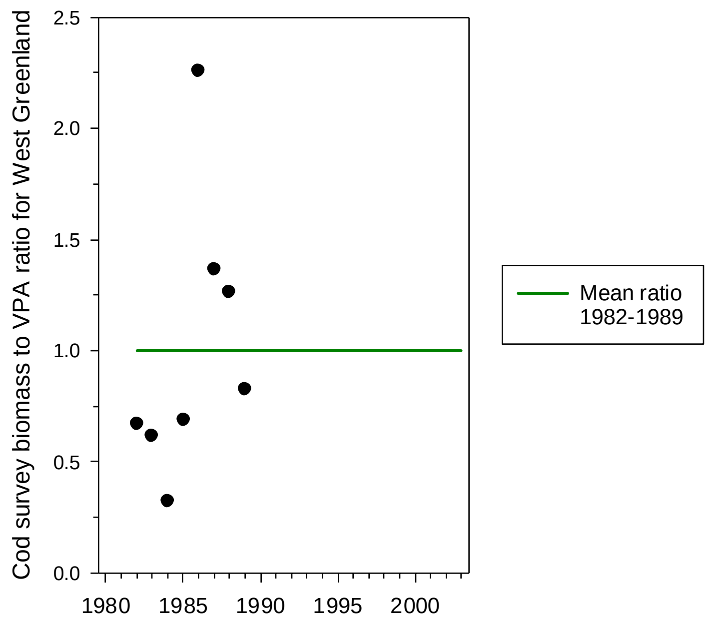

Fig. 3. Atlantic cod survey biomass (all ages) to VPA (age 3+) ratio for West Greenland.

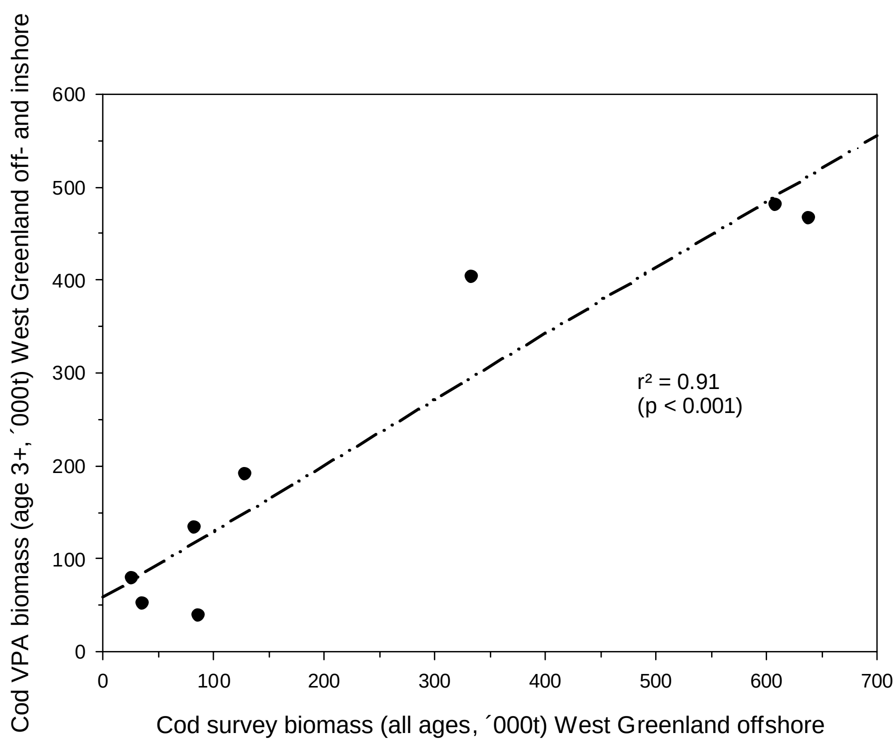

Fig.4. Comparison of Atlantic cod survey indices (all ages) and VPA biomass estimates (age 3+) for West Greenland.

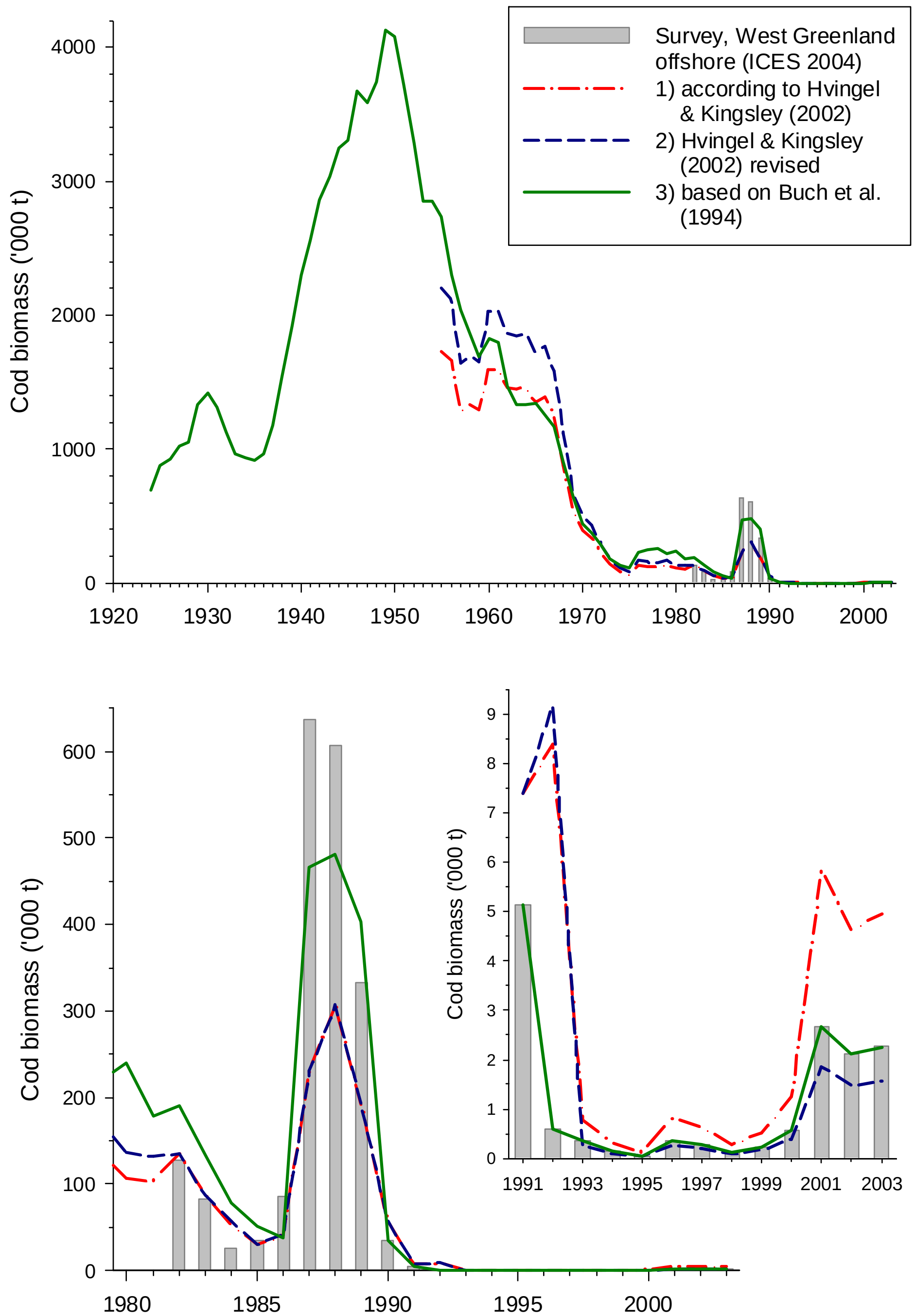

Fig. 5. Comparison of time series of Atlantic cod biomass at West Greenland, 1924-2003.

Fig. 6. Contribution of inshore areas to the total landings of Atlantic cod at West Greenland, 1924-2003 (Data from ICES (2004).

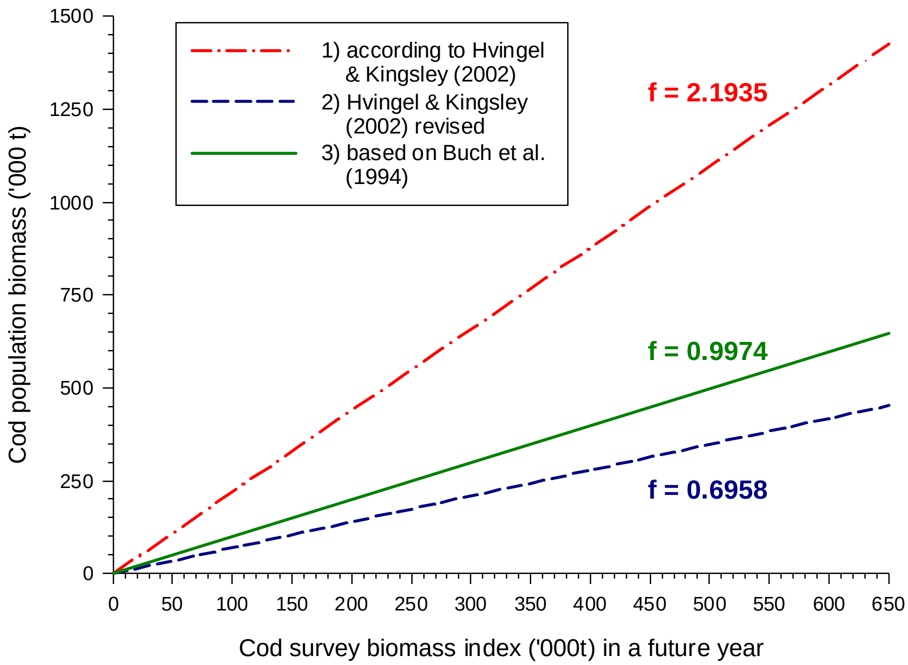

Fig. 7. Effect of survey index to VPA conversion in relation to a hypothetical increase of cod survey biomass indices in coming years (f: factor used for the conversion of survey index to cod population biomass).