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Variations in the Labrador Current Transport and Zooplankton Abundance on the NL Shelf

by

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Abstract

Variation in the volume transport of the Labrador Current at the shelf break has important implications for recruitment of calanoid copepods on the continental shelf in the NW Atlantic. During the past several decades the ocean climate on the NL shelf have been characterised by several extremes, from the warm 1960s, cold early 1970s, mid-1980s and early 1990s and the recent warm trend from mid-1990s to early 2000s. As a result of the variations in stratification and the baroclinic currents the volume transport of the Labrador Current at the shelf break also show large interannual variations with an increasing trend in recent years along the Hamilton Bank and Flemish Cap sections. Variations in ocean circulation are hypothesized to influence the distribution and recruitment of zooplankton populations. In this study we focus on the response of the calanoid copepod, *Calanus finmarchicus* to variations in the volume transport of the LC. Prior to reaching maturity, this species undergoes a transition to deep waters (500 – 2000 m) and a dormancy period during autumn and winter. In order to re-populate the shelf, advective transport of individuals across the shelf-break front from nearby deep slope waters must occur. Our results indicate that volume transport variability of the Labrador Current is significantly correlated with the relative abundance of *Calanus finmarchicus*, and may impact recruitment of calanoid copepods in shelf ecosystems in the NW Atlantic.

Introduction

The Labrador Current, which transports sub-polar water to lower latitudes is a strong western boundary current following the shelf break with relatively low current variability compared to the mean flow, and a considerably weaker branch over the banks and inshore regions, where the variability often exceeds the mean flow. Mean flows in the offshore regions typically range from 30-50 cm/s, while over the banks and inshore currents are generally much less, averaging between 5-15 cm/s (Lazier and Wright 1993; Colbourne et al. 1997). The sub-surface water mass over the shelf are typical sub-polar waters with a temperature range of –1 to 2°C and salinities of 31 to 33.5. The offshore branch is warmer and saltier with a temperature range of 3 - 4°C and salinities in the range of 34 to 35. The shelf water is separated from the warmer higher density water of the continental slope region by a frontal region characterized by strong horizontal density gradients that give rise to a strong baroclinic component amounting to 30-40% of the total transport of the Labrador Current at the shelf break During the past several decades oceanic conditions in the northwest Atlantic have been characterized by several extremes, from the warm 1960s and late 1990s to cold conditions of the early 1970s, mid-1980s and early 1990s (Colbourne et al. 1994; Drinkwater 1996; Drinkwater et al. 1999). During these periods of extremes, the shelf stratification has also undergone significant changes implying potential variations in the strength of the Labrador Current (Han and Li 2004).

The continuous plankton recorder (CPR) survey[1] provides an assessment of long-term changes in abundance and geographic distribution of planktonic organisms ranging from phytoplankton cells to larger macrozooplankton (Warner and Hays 1994, Richardson et *al*. 2006). CPR collections in the northwest Atlantic began in the early 1960's and continued with some interruptions during the latter period through till 1986. Collections were renewed in 1991 and continue to present. The recorder is towed by ships of opportunity along a number of standard routes throughout the North Atlantic. The CPR device collects plankton at a nominal depth of 7m through an aperature and organisms are retained on a moving band of silk material and preserved. Sections of silk representing 18.5 km tow distance and ca. $3m^3$ of water filtered are analyzed microscopically using standard methods since the inception of the program thereby allowing valid comparisons between years. Every second section is analyzed providing a horizontal scale of ca. 37 km.

The variation in the volume transport of the LC at the shelf break has important implications for recruitment of calanoid copepods on the Newfoundland and Labrador Shelf. In this study we focus on the response of the calanoid copepod, *Calanus finmarchicus* to variations in the volume transport of the LC. This copepod species dominates the spring/summer biomass in areas across the North Atlantic and typically reproduces with the spring phytoplankton bloom. The young stages develop in the surface layers during spring/summer while older stages typically begin to migrate to deeper waters in the autumn to enter a period of dormancy. Thus, older stages of *C. finmarchicus* are largely excluded from the shelf during winter and must re-populate the shelf through advective transport of individuals across the shelf-break front from nearby deep slope waters. Recent studies in the NW Atlantic indicate that the offshore location and density gradient across this frontal zone may be influenced by the volume transport of the LC and may impact cross-shelf exchange across this boundary zone (Pickart et al. 1999, Head et al. 1999).

Data and Methods

In 1976 the International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a suite of standard oceanographic stations along sections in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (Anon. 1978). Three of these sections are occupied annually during a mid-summer oceanographic survey conducted by the Canadian Department of Fisheries and Oceans. They include the Seal Island section on the Southern Labrador Shelf and Hamilton Bank; the Bonavista section off the eastern Newfoundland Shelf; and the Flemish Cap section which crosses the Grand Bank at 47°N and continues eastward across the Flemish Cap (Fig. 1). Temperature and salinity data from these surveys were used to compute density using the UNESCO equation of state for seawater which was then used to compute geostrophic currents from the horizontal gradient of the steric height using the standard geostrophic balance relationship according to Gill (1982).

The CPR data analyzed in this report extend from 1961 to 2005 with an intervening gap from ca. 1978 to 1990. The sampling distribution for *C. finmarchicus* was uneven for both spatial and temporal scales due to the nature of opportunistic sampling with ships of opportunity, variation in shipping routes, and funding (Fig. 2). We did not differentiate the data based on bathymetry (e.g. shelf versus slope) and included all available data for the adult stages (CV-CVI) of *C. finmarchicus* bounded by the NAFO Subareas 2-6. We developed seasonally-adjusted annual mean estimates of the relative abundance of *C. finmarchicus* given the semi-quantitative nature of the CPR sampling (Richardson et al. 2006) based on general linear models (GLMs) of the form:

$$Ln(Density) = \alpha + \beta_{YEAR} + \delta_{MONTH} + \varepsilon$$

where *Density* is in units of # per m^{-2}, α is the intercept, β and δ are categorical effects for year and month effects, and ε is the error. Density is log-transformed to deal with the skewed distribution of the observations.

Results

[1] See SAFHOS web site at (http://192.171.163.165/) for a description of the CPR Program collected for The Sir Alister Hardy Foundation for Ocean Science of Plymouth, England.

Geostrophic Currents

The geostrophic currents relative to 300-m depth along the Seal Island section show distinct inshore and offshore branches of the Labrador Current (Fig. 3a). The inshore branch is located within about 100 km from the shore and the offshore branch, which is typically less than 100 km wide, is centered at about 225 km offshore over the 500-m isobath. In the offshore branch, current speeds range from 0.05 m/s at 200-m depth to greater than 0.2 m/s in the upper water column. In the inshore branch, current speeds are generally less than 0.2 m/s. Currents over Hamilton Bank show evidence of eddy circulation with northward flow on the inner bank.

The flow patterns perpendicular to the Flemish Cap section show the well-known features of the circulation. The strong baroclinic component of the offshore branch as a bathymetrically trapped jet near the edge of the Grand Bank, the general anticyclonic circulation around the Cap and the northward flowing water of the North Atlantic Current east of the Cap are evident (Fig. 3b). The inshore branch of the Labrador Current is weak with speeds typically less than 0.05 m/s and is restricted to the Avalon Channel region within 50 km of the coast. Currents over most of the Grand Bank are near 0 m/s. Peak current speeds in the surface layer of the offshore jet on the slope of the Grand Bank are over 0.3 m/s. In this region the current is about 100-km wide and extends to below 100-m depth. Typical geostrophic speeds range from 0.05-0.10 m/s in the gyre over the Cap and near 0.20 m/s to the east of the Cap in the North Atlantic Current.

Variations in Geostrophic Transport

The volume transport was calculated by integrating the speed both vertically through the water column and horizontally in the offshore direction across the offshore branch of the Labrador Current. A reference level of 135-m was chosen for both sections since this was the deepest level common to both sections that did not intersect the bottom, thus eliminating potential problems associated with a bottom reference level. Also, the main interest was to examine variations in stratification and volume transport during recent ocean climate changes on the continental shelf. Changes in shelf stratification are mainly confined to the upper layers where meteorological forcing and sea ice dynamics influences water properties. The magnitude of the resulting horizontal density gradient will then determine the strength of the geostrophic component of the Labrador Current.

The time series of volume transport of the offshore branch of the Labrador Current for the two sections show large interannual variations with an average transport of between 0.4-0.5 Sv. to the south relative to 135-m (Fig. 4). In general, the trends highlighted by the 5-year running means indicate higher than average transport during the late 1950s and into the 1960s, lower than average values during the cold period of the early 1970s and to a lesser extent during the cold period of the mid-1980s. During the late 1980s the transport increased to above average values, which for the most part, although not without exceptions, continued into the mid-to-late 1990s. Some of the annual variations are probably due to eddies or possibly high frequency internal wave propagation, which contaminates the density profiles and thus introduces noise and sometimes reversals in the horizontal pressure gradient force. The results show some similarity with those obtained by Myers et al. (1989) during the same time period (1950-1986). That is, they show a significant, albeit weak, negative correlation between the upper layer geostrophic transport and the NAO index, especially along the Flemish Cap section, indicating reduced transport during cold periods.

Variations in Calanus finmarchicus populations in relation to Gestrophic Transport

The relative abundance of the dominant calanoid copepod *Calanus finmarchicus* has declined from the 1960-70's to the recent decade across the northwest Atlantic inferred from the CPR survey (Fig. 5). The abundance of *C. finmarchicus* declined substantially by approximately 20 % during the intervening gap in the time series (1978 to 1990). An analysis of the relationship between the volume transport of the offshore branch of the Labrador Current along the Seal Island and Flemish Cap sections and relative abundance of *Calanus finmarchicus* in the NW Atlantic indicated significant negative correlations (Fig. 6). The relative abundance of *C. finmarchicus* is strongly negatively correlated ($r = -0.59$) with the volume transport of the LC across the Flemish Cap section, followed by the Seal Island section ($r = -0.44$). Although we lack information regarding the relative abundance of *C. finmarchicus* during a substantial extent of the time series from 1978 through 1990, variability in transport may be an important mechanism to account for the interannual variation in the standing stocks of calanoid copepods.

Discussion and Summary

Variations in the baroclinic component of the volume transport of the Labrador Current on the Newfoundland Shelf during recent climate changes in the Northwest Atlantic were examined in relation to the abundance of an ecologically-important calanoid copepod. During the past several decades climatic conditions in the Northwest Atlantic have been characterized by several extremes, from the warm 1960s and late 1990s to early 2000s to cold conditions of the early 1970s, mid-1980s and early 1990s. The magnitude of climate variations in the north Atlantic is often measured by the strength of the winter atmospheric pressure fields or NAO index. The ocean generally responded to these climate variations through changes in the shelf stratification due mainly to temperature and salinity changes resulting from variations in ice formation and subsequent melting and through variations in wind forcing. These variations may cause changes in the transport of major current systems. For example, strong winter northwesterly winds generally associated with high NAO index in the northwest Atlantic would be expected to erode shelf-slope density fronts and hence reduce the strength of the density driven currents at the shelf break. The results presented here generally show large interannual variations, but the trend indicates higher-than-average transport during the warm 1960s (low NAO index) and lower than average values during the cold early 1970s and the mid-1980s (high NAO index). During the late 1980s the transport increased to above average values that continued into the early 2000s.

Zooplankton populations may be sensitive to variations in ocean currents since their horizontal position is largely determined by advection. The calanoid copepods are particularly susceptible to changes in ocean circulation because of the requirement for deep water to enter into the diapause phase during the autumn and winter period. Our results indicate that volume transport variability of the Labrador Current is significantly correlated with the relative abundance of *Calanus finmarchicus*, and may impact recruitment of calanoid copepods in shelf ecosystems in the NW Atlantic. Given the correlative nature of the relationship between volume transport of the Labrador Current and the relative abundance of this marine copepod, additional work is needed to explore the processes of changes in ocean circulation and other potential indirect effects on the recruitment of calanoid copepods to the shelf ecosystem. The CPR time series represents an important opportunity for investigating the ecology of phytoplankton and zooplankton populations over ecologically-relevant spatial and temporal scales in relation to the environment.

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Fig. 1. Map of the study area showing the positions of the Seal Island, Bonavista and Flemish Cap (47 °N) transects and the general circulation in the Northwest Atlantic.

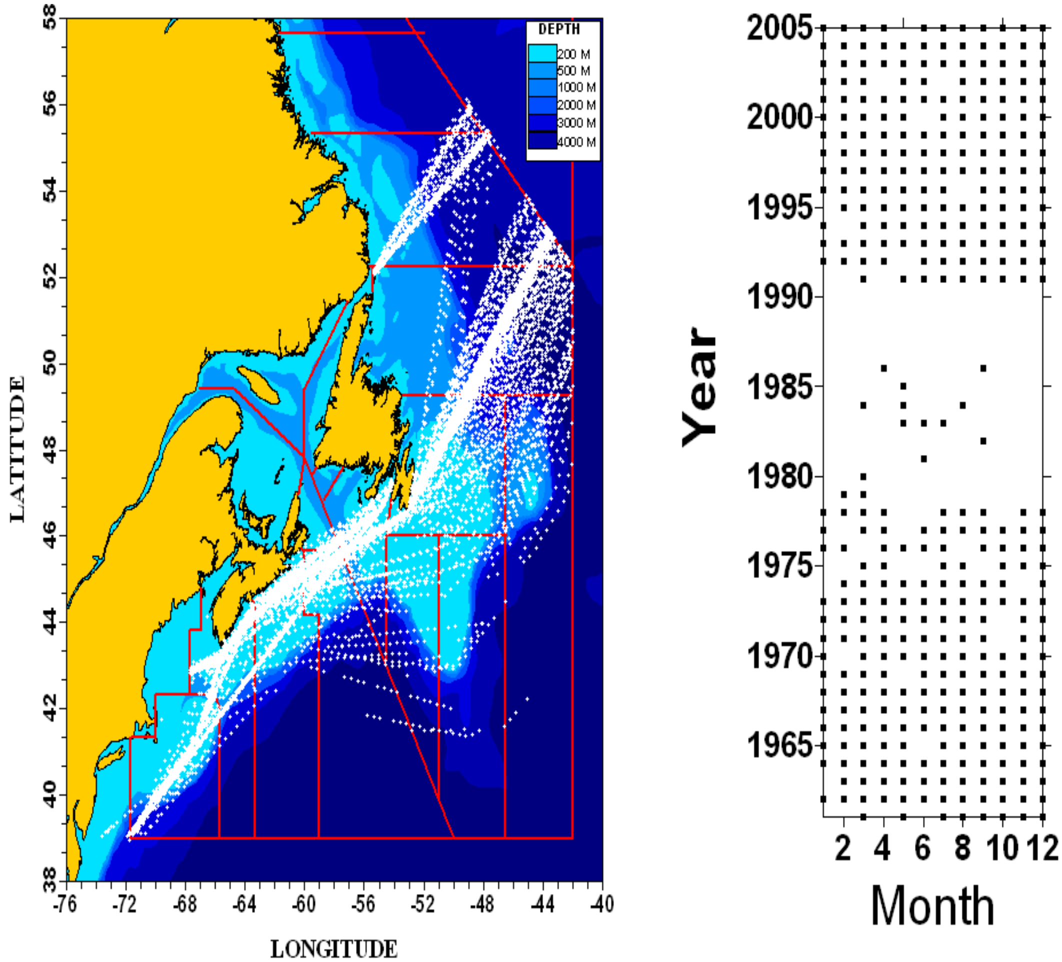

Fig. 2. Location of Continuous Plankton Recorder (CPR) stations with counts of adult (CV-CVI) Calanus finmarchicus within NAFO Subareas 2-6 covering the continental shelf and slope waters of the NW Atlantic from southern Labrador to the Gulf of Maine. during 1961-2005. Note the gap in sampling from the late 1970's through till the early 1990's and the main commercial shipping lanes across NAFO Divisions 3L and 3Ps.

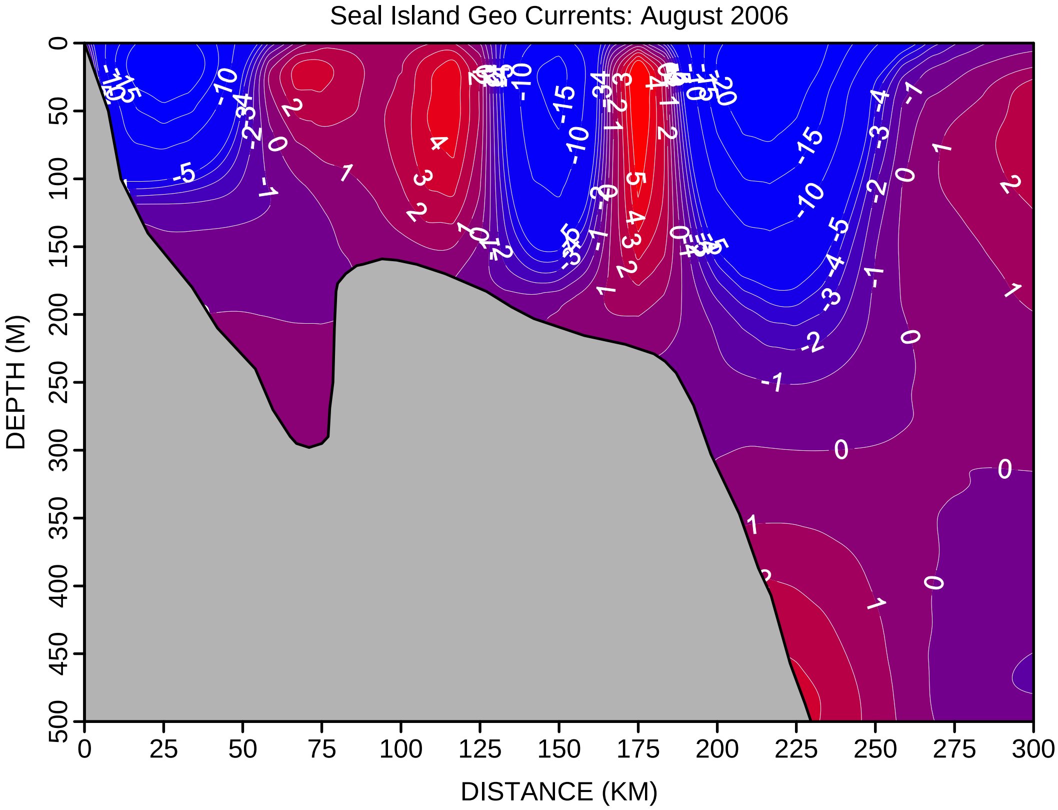

Fig. 3a.Vertical cross-section of summer geostrophic currents (cm/s) along the Seal Island section. Negative (blue) values are southward.

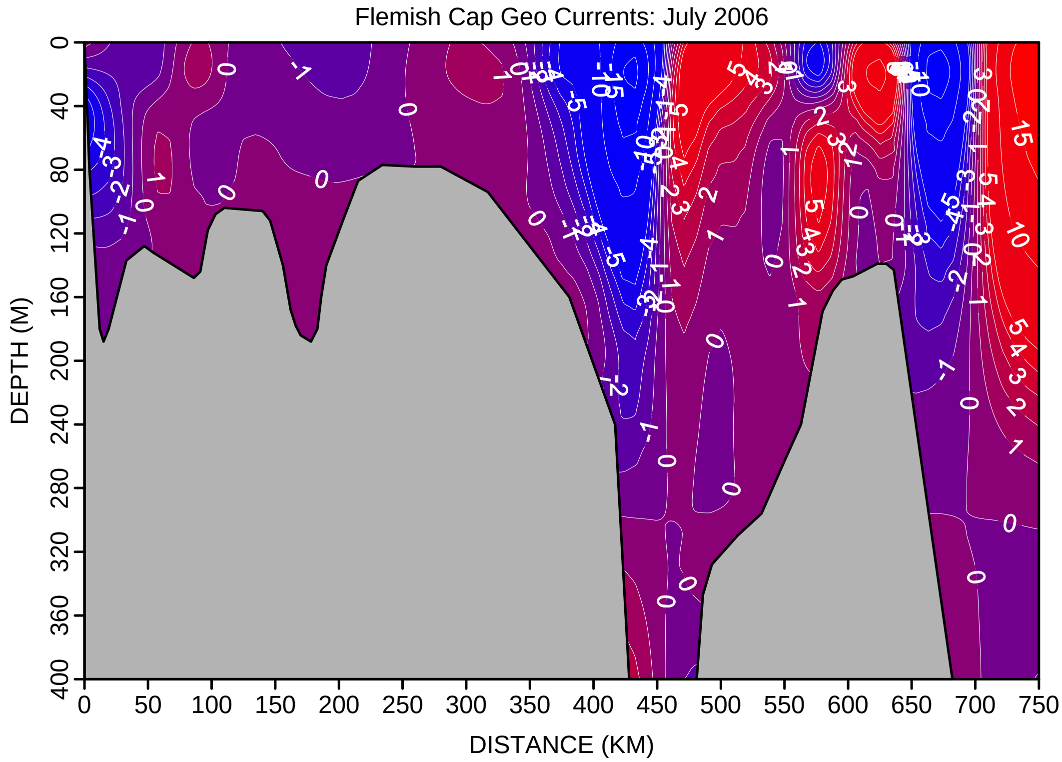

Fig. 3b. Vertical cross-section of summer geostrophic currents (cm/s) along the Flemish Cap section. Negative (blue) values are southward.

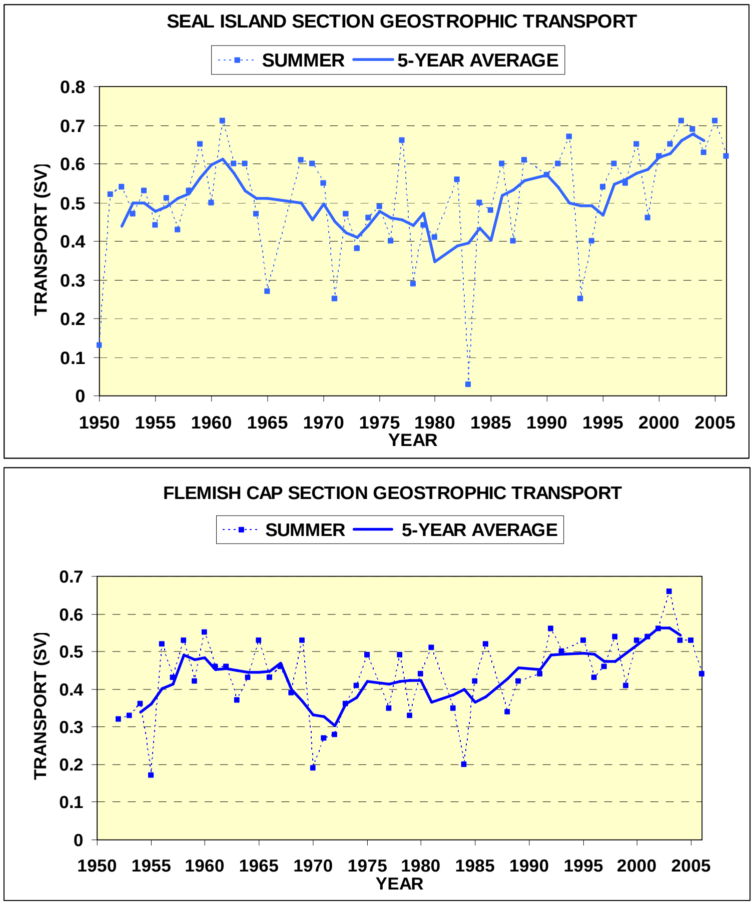

Fig. 4 Time series of geostrophic transport (Sv=10^6 m^3/s) relative to 135-m depth of the offshore branch of the Labrador Current through the Seal Island and the Flemish Cap sections. The heavy line represents the 5-year running average.

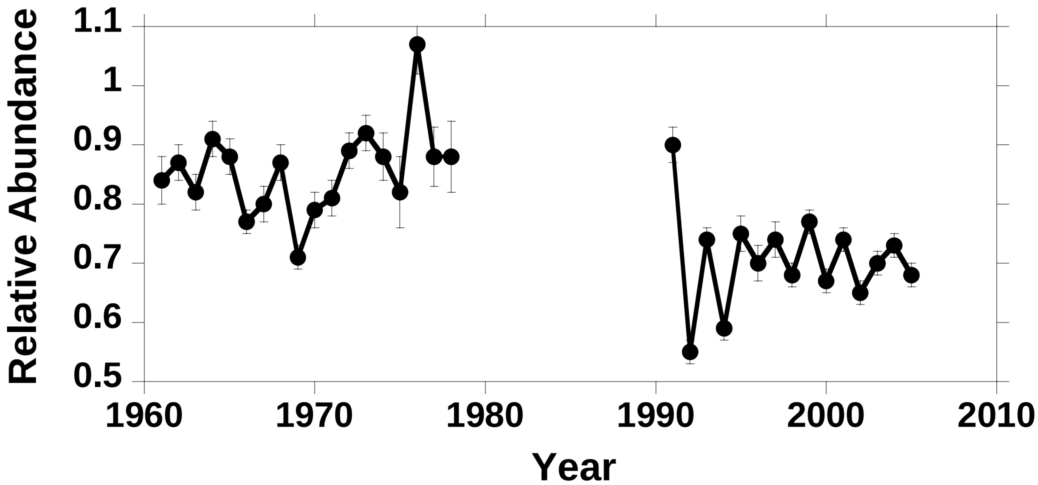

Fig. 5. Time series of seasonally-adjusted annual means (± SE) of relative abundance of *Calanus finmarchicus* in the northwest Atlantic during 1961-2005.

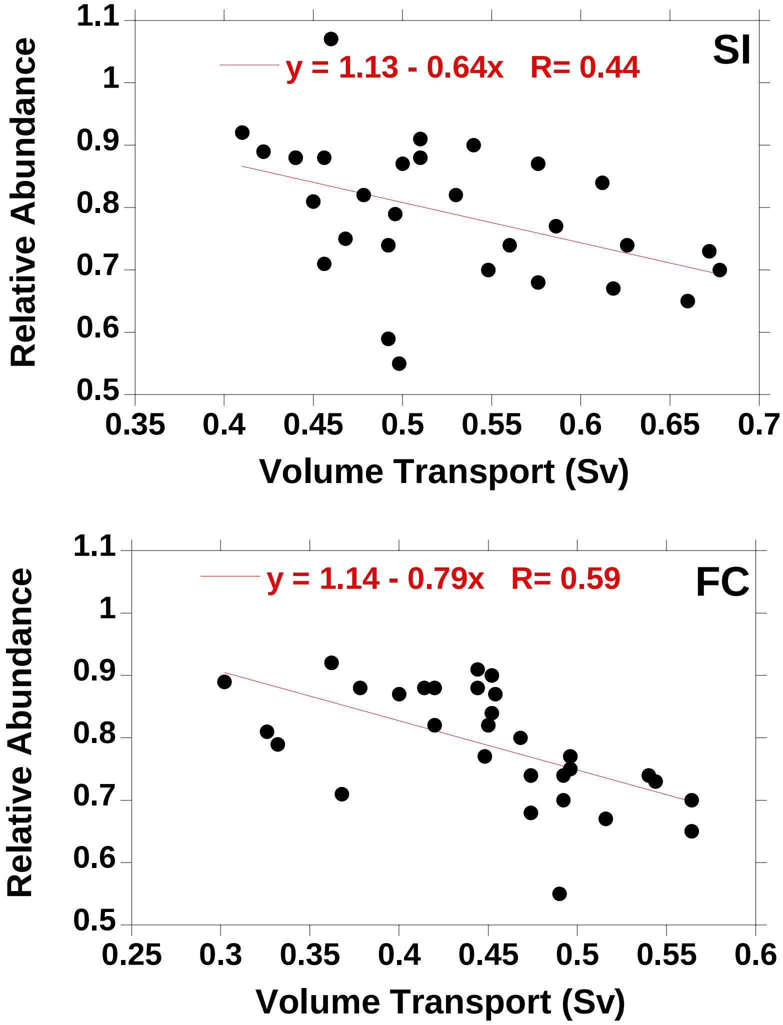

Fig. 6 The relationship between the volume transport of the offshore branch of the Labrador Current using the 5-year running averages and seasonally-adjusted annual mean relative abundance of *Calanus finmarchicus* in the NW Atlantic across the Seal Island (SI) and the Flemish Cap (FC) sections during 1961-2004.