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Influence of Particle Organic Carbon Sedimentation Within the Seasonal Sea-ice Regime on the Catch Distribution of Northern Shrimp (*Pandalus borealis*)

by

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Abstract

Based on sediment trap data collected at a depth of 500 m below the ocean surface, as well as the in situ sea-ice regime, we have upgraded the sedimentation model to map the amount and distribution of particulate organic carbon (POC) for the Greenland Sea from Ramseier et al., 1999. The derived model is based on ice regimes defined by: (1) ice concentration, (2) duration of ice cover and (3) distance from an ice edge, all relative to a trap location. In the case of POC the sedimentation can be determined using a mean annual ice concentration. To better understand the distribution of the POC sedimentation the model divides the seasonal ice cover into three distinct sub-regions, collectively named the Biological Marginal Ice Zone (BMIZ). The BMIZ does not include all the seasonal sea ice cover extent, as would a Marginal Ice Zone. There is a centrally located sub-region within the BMIZ, where the sedimentation is non-linear resulting in a band of localized high sedimentation. This results in an elevated export of biologically produced particles to the deeper ocean. It is this result of localized sedimentation that is likely to affect the distribution of shrimp. As an initial test we have selected the Northern Shrimp Fishery area between 49ºN and 60ºN, Labrador Sea. Two data sets provided by the Department of Fisheries and Ocean, (1) commercial catches for 1989 and 1996, and (2) research catches for October-December 1996 and 1997, were analyzed in relation to the POC distribution based on mean annual seasonal sea ice cover extent. Binning the commercial data according to POC, results in a coefficient of determination for a linear regression between catch per hour and POC of r^2 = 0.926 (1989) and 0.964 for 1996. Similarly, binning the commercial data for 1989 and 1996 according to depth, results in a coefficient of determination r^2 = 0.995 and 0.948 respectively. The research data on the other hand was binned according to (1) POC, (2) depth and (3) temperature with linear regression between total catch/shrimp and POC. The coefficients of determination r^2 for 1996 are (1) 0.304, (2) 0.763, and (3) 0.745 and for 1997 are (1) 0.535, (2) 0.897, and (3) 0.954 respectively. The overall conclusion is that POC plays an important role as a food supply, and its distribution provides locations where to search for shrimp. The extent of POC can be derived

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from ice information mapped from space using operational satellite sensors, day and night and through clouds, thus providing a useful tool.

Keywords: Particulate organic carbon, sea ice, Labrador Sea, Greenland Sea, sediment trap, shrimp catch.

1. Introduction

This paper is the first to correlate particulate organic carbon (POC) sedimentation within the mean annual seasonal sea ice extent with the catch statistics (presence) of northern shrimp. Based on sediment traps deployed over an 8 year period, an empirical model on sedimentation at a depth of 500 m was developed for the Is Odden-Nordbukta region, Greenland Sea (Ramseier et al., 1999). This model quantifies the POC sedimentation as well as provides a sedimentation pattern on a yearly basis for the Northern Hemisphere. We applied this POC model to the Labrador Sea with the use of the mean annual sea ice concentration obtained from passive microwave satellite data. Since the model makes use of the local hydrographic conditions of the Is Odden-Nordbukta region of the Greenland Sea, applying it to the Labrador Sea will cause some differences in the extent (due to currents) as well as in the amount of POC sedimentation. We feel for this first approach, due to the resolution of the satellite data (25 x 25 km), the differences are going to be minimal. The shrimp catch data for the Labrador Sea was provided in two groups, one representing research data for the years 1996 and 1997, and the other commercial data for the years 1989 and 1996. Mapping the extent of POC sedimentation, based on the local seasonal sea ice regime, can provide a useful tool for locating and managing shrimp stocks for both the research and commercial fisheries.

It is generally known that a direct correlation between the abundance of shrimp and organic content of the ocean bottom sediments exists. Shrimp feed on or near the ocean floor as well as in the pelagic zone (Shumway et al., 1985). The importance of pelagic feeding for pandalid shrimp, primarily during the night, has been recognized for many years. With time (and improved sampling from the pelagic zone), both phases are recognized as important, particularly for large, oceanic populations (Pearcy, 1970; Wienberg, 1981; Hudon et al., 1992). In a review by Butler (1971) on the biology of pink shrimp he states and we quote: “There is a direct relationship between abundance of pink shrimp and high organic content in sediment (Bigelow and Schroeder, 1939; Wigley, 1960). Haynes and Wigley (1969) reported that, in the Gulf of Maine, occurrence was almost wholly restricted to areas of moderate (0.5 to 1.5%) to high (>1.5%) amounts of organic carbon”. The benthic communities below the euphotic zone are dependent on the food supply through the water column. The magnitude of the organic carbon supply depends on temporal and spatial patterns of the export flux of pelagic primary production from the euphotic zone (Ritzrau et al., in press). The POC model (Ramseier et al., 1999) was used by Ritzrau et al. (in press) to calculate the carbon budget for the East Greenland Sea (between 67º and 79º N) resulting in a balance with the requirements of the benthic community, i.e. they established a pelagic-benthic coupling. Since the northern shrimp is partly a benthic feeder (Shumway et al., 1985), the use of organic carbon in form of POC, to establish a correlation between catch and POC, is appropriate.

2. Methods

2.1 Sedimentation Trap Deployment

Six automated Kiel Sonderforschungsbereich 313 (SFB) time series sediment traps (opening 0.5 m^{-2}, 20 collector cups; Salzgitter Electronics) were deployed at a depth of 500 m for the period 1988-1996 (Figure 1a-c). The sediment traps were located in the Is Odden-Nordbukta region, a dynamic sea ice area where the formation of the ice tongue is an important local feature. Samples were poisoned in situ with mercury chloride and treated in the laboratory as described by v. Bodungen et al. (1991). Here we concentrate on the fluxes of POC as determined by gas chromatography.

2.2 Hydrography

The sediment traps were located below predominantly seasonal ice-covered, cold fresh surface water of polar origin (<150 m deep, entering the Greenland Sea through Fram Strait). Beneath this layer water masses influenced by the warm and salty return Atlantic intermediate water are present to a depth of ≈800 m (Hopkins, 1991). The East Greenland Current (EGC) to the south along the Greenland continental shelf margin transported these water masses. At the Jan Mayen Ridge the EGC is partially deflected to the east and Polar Surface Water is transported eastward with the Jan Mayen Current (JMC) into the Greenland Sea (Hopkins, 1991; Legutke, 1991; Bourke et al., 1992).

Four of the six SFB moorings, denoted as OG moorings in this paper (Figure 1b), were located in the area affected by the JMC. Surface currents range between 3-6 cm s^{-1} and at a depth of 500 m, where our traps were located, the current was measured by a float to be 2.45 cm s^{-1}. We assumed a sinking velocity of 100 m d^{-1} as proposed by Bauerfeind et al. (1994) for the rapidly settling fraction based on a comparison of shallow and deep moored traps in the Greenland Sea and a mean current speed of 3.5 cm s^{-1}.

Applying this order of magnitude calculation to the particle collection funnel indicates that the surface area extends 15 km upstream of our trap positions. The satellite data grid size of 25 km x 25 km per cell suggests that we should consider an area that covers the trap position itself and one cell upstream from that location. Such a selection covers a minimum particle-settling rate of 60.5 m d^{-1} for a distance of 25 km. Two additional traps, OG7 and OG10, were located at 74° 59.51'N, 10° 37.05'W and 75º 03.4'N, 04º 35.7'W respectively (Figure 1b). The mean current was estimated to be ≈15 cm s^{-1} (Fahrbach, personal communication, 1994.) For these traps we choose three satellite grid cells to derive the mean sea ice concentration.

2.3 Satellite Data

The ice information was derived from the Scanning Multichannel Microwave Radiometer (SMMR) aboard the NASA NIMBUS-7 spacecraft between 1978-87 (Gloersen and Barrath, 1977) and the Special Sensor Microwave/Imager (SSM/I) which is part of the operational United States Defense Meteorological Satellite Program (Hollinger, 1990). The data for both sensors were provided by the National Snow and Ice Data Center, Boulder, Colorado (NSIDC, 1992). Brightness temperatures collected during the daily orbits were averaged onto an earth-located fixed grid of 25 km x 25 km. For the ice analysis we used the ice concentrations derived by the NASA Team algorithm from the brightness temperatures (Cavalieri et al., 1984; Gloersen and Cavalieri, 1986). Since the ice information can be collected day and night as well as through clouds the satellite sensor is a powerful tool for studying ice regimes anywhere on this planet earth.

2.4 Shrimp data

***Research survey data* -** Multispecies research trawl surveys have been conducted annually by the Department of Fisheries and Oceans (DFO)- Science in the Newfoundland - Labrador offshore area since 1995. These surveys employ a stratified-random sampling design that was developed for groundfish but use a lined, Campelen 1800 shrimp trawl as the sampling gear. Survey coverage has been extensive in areas off northeastern Newfoundland and southern Labrador (49º 15' N to about 54º 45' N) where shrimp are abundant. However, farther north, coverage is not adequate to address the highly patchy distribution of shrimp seen in these areas. No surveys have been conducted north of 61º N.

Data on surveys conducted in 1996 and 1997 (between 49º 15' N and 61º N) include trip, set, year, month, day, time, latitude, longitude, depth (m), bottom temperature (C), number and weight of shrimp. (The data used to generate this paper extends only to 60º N.) The additional data does not change significantly the results nor does it change any of the conclusions.) Fishing protocols require the trawl to be towed for 15 minutes at 3 knots at each survey station. Adjustments of catch to the standard are made in instances where protocols cannot be met.

***Commercial fishery data* -** The offshore shrimp fleet comprises about 12 vessels operating under 17 licenses. These are large stern trawlers which, in most cases, are technologically advanced and, in some instances, were built specifically to harvest shrimp. All vessels tow small-meshed otter trawls equipped with sorting grates to minimize unwanted by-catch. Some of the larger vessels are capable of towing two trawls, simultaneously.

Details of fishing activity by the offshore shrimp fleet in the Newfoundland - Labrador offshore area (49º 15' N to 61º N) were obtained from official DFO logbook records for 1989 and 1996. (The data used to generate this paper extends only to 60º N. The additional data does not change significantly the results nor does it change any of the conclusions.) The data sets included year, month, day, latitude, longitude, depth (m), catch (kg) and effort (hours fished). Most records denote individual fishing sets but, when latitude and longitude are identical, two or more sets are represented. Logbooks account for most of the total effort each year and are considered representative of the fishing activity of the fleet. Catch-per-unit-effort (CPUE - typically kg h^{-1}) can be used to interpret change in the fishable stock over time.

3. Particulate Organic Carbon Model

The model presented here was originally developed based on five sediment traps for the Is Odden-Nordbukta region of the Greenland Sea by Ramseier et al. (1999). The model as presented below was upgraded from the original one by including all six traps rather than the original five sediment traps. The model presented below is also the one we use for the Labrador Sea to map the POC sedimentation pattern and distribution.

3.1 POC amount

The model components include the mean annual sea ice regime ($IR_{\%y}$) defined as the

$$IR_{\%y} = \Sigma c/365 \qquad (1)$$

where c represents the daily ice concentration in percent summed over an entire year (Ramseier et al., 1999). The second component represents the annual POC values for the respective traps (Ramseier et al., 1999). The mean annual ice concentration is shown in Figure 2 for reference purposes indicating the great variability in ice concentrations associated with the trap positions. The POC curves represent the measured values as well as the calculated values using (2) below. Applying a linear regression to the POC and ice concentration data results in an equation for calculating the amount of POC sedimentation in g m^{-2} y^{-1}

$$POC = 0.0677 * IR_{\%y} + 1.4924 \qquad r^2 = 0.856 \qquad (2)$$

We note that (2) provides an annual, average POC sedimentation rate at the 500 m depth which can be applied to the Is Odden-Nordbukta region of the Greenland Sea. Furthermore (2) is only valid for the mean annual concentration range between 18% and 64% (Ramseier et al., 1999). The model results are included in Figure 2, and provide a direct comparison with the measured values. The use of all six traps provided a marginal improvement in the coefficient of determination (r^2) from the original value of 0.852 to 0.856.

3.2 Pattern of POC sedimentation

The sediment pattern for POC is given by the empirical equation in mg m^{-2} d^{-1} based on individual cup openings of all six sediment traps. It represents a maximum value and is best used as a relative amount if applied to areas other than the Is Odden-Nordbukta region.

$$POC = a + b\sqrt{\frac{c \times d}{pIR_{\%y}{}^3}}\, e^{-c\left(\ln \frac{IR_{\%y}}{d}\right)^2} - \frac{1}{16c} + (-ltIR_{\%y})$$

a, b, c, d and *lt* are the constants corresponding to 7.19, 1400, 1.3, 50, and –0.0645. The ice regime $IR_{\%y}$ is defined in (1).

The model can be described best by illustrating the POC sedimentation with a schematic as shown in Figure 3. The seasonal sea ice cover is usually referred to as the Marginal Ice Zone (MIZ) which extends from the ice limit all the way to the coast. Now assume that the model represents a profile or narrow area originating at a given latitude to the Labrador coast extending across the ice covered areas to the open ocean, i.e. the MIZ. Based on the results of the sediment traps, this line can be further divided to represent five distinct biological processes which are all part of the marginal ice zone (MIZ) and Biological Marginal Ice Zone (BMIZ) as discussed in Ramseier et al., 1999. The first sub-area (1) is ice-free extending from the open ocean to a point 80 km from the mean maximum ice limit, which represents the open ocean sedimentation component of total flux, for which we have chosen the value of 1 g m^{-2} y^{-1} (Noji et al., 1999). The second sub-area (2) is a primary production belt 80 km wide, parallel to the mean maximum ice limit, as observed by Smith et al. (1987) and further refined by Ramseier et al. (1999). The observed POC flux is 2.62 g m^{-2} y^{-1} (Ramseier et al., 1999). The third sub-area (3) is seasonal and starts at the boundary of the mean maximum ice limit (0%) up to the 18% ice concentration boundary with identical flux values as sub-area (2). Sub-area (4) is a biologically active zone that takes over at 18% continuing to the 64% ice concentration boundary. The amount of POC sedimentation is given by equation (2), which provides an average for the sub-area. The actual distribution is given by equation (3). Sub-areas (2) to (4) are identified as the BMIZ because they are biologically very productive. The last sub-area (5) is a quasi-permanent part of the ice cover that extents from the 64% ice concentration contour to the coast with a POC flux of 1.83 g m^{-2} y^{-1}.

In summary, the sub-area of interest for the following analysis of the shrimp catch data and the amount of POC as well as the peak of POC sedimentation evolves around sub-area (4) of the BMIZ.

4. Results

Figure 4 presents the mean ice regime for the commercial and research shrimp fishing positions for the years 1989, 1996 and 1997. The southern ice boundary is the furthest south for the year 1997 extending as far as 47ºN, followed by the year 1989 at 47º 30'N, and 1996 with a minimum extent at 50'N. The total area covered by ice, extending from the southern ice limit to 60ºN, the northern limit of the provided shrimp fishing data for this paper, was greatest for the year 1997 (362503 km^2 with a mean annual ice concentration of 16.2±10.7%), followed by 1989 (361990 km^2, with a mean annual ice concentration of 16.7±10.7%) and 1996 (332596 km^2, with a mean annual ice concentration of 15.8±13.5%). Applying equation (3) to the Labrador Sea ice regime for the years 1989, 1996 and 1997 results in a POC distribution as presented in Figure 5. In 1996 the ocean area shows a number of missing satellite data (dropouts 25 x 25 km square, black points in Figure 4). Through the smoothing process of the data, these black points can appear as POC data points, particularly in Figure 5 for 1996 as well and to a lesser extend for the other years. Since no fishing data was used for the analysis in these areas there is no effect on the results. The POC distribution is in mg m^{-2} d^{-1}. The extent and southern limits of the POC distribution mimic the ice regime. It is greatest for the year 1997, slightly less for 1989 and a minimum in 1996. The POC distribution as shown is valid for the 18% to 64% ice concentration range. The highest intensity of POC (about 32 mg m^{-2} d^{-1}) is associated with a maximum of 30% ice concentration (Ramseier et al., 1999).

4.1. Research data on shrimp caught

To analyze the research data for the years 1996 and 1997 we concentrated on three parameters: (1) temperature, (2) depth, and (3) POC. We further subdivided the data into bins of equal size. For POC the bins were of 2 mg m^{-2} d^{-1} for the range 10-32 mg m^{-2} d^{-1}. The catch data is given in the amount caught within a 15-minute trawl period. The number of shrimp caught is given, which permits us to evaluate the size effect of shrimp as associated with the three parameters mentioned above. The temperature data is subdivided into 0.4ºC bins between –0.4 to 4.4ºC, and the depth data into 100 m bins ranging between 100-1500 m depth. The results are given in Figures 6-8 for the years 1996 and 1997.

Figure 6 illustrates the behavior of the temperature bin data as related to the total weight of the shrimp catch in tons per bin as well as the total weight in weight per shrimp (g). The total POC per bin is given in mg m^{-2} d^{-1}. The bin data was then subjected to a linear regression between the shrimp parameters and the POC. The results are given as a coefficient of determination (r^2) value within the figure. In a similar way Figure 7 illustrates the depth bin data, and Figure 8 the POC bin data.

4.2. Commercial data on shrimp caught

The commercial shrimp data for the years 1989 and 1996 were evaluated by the amount of shrimp caught per hour. The parameters were (1) depth and (2) POC. The depth data was binned in 50 m intervals ranging from 150-800 m. The total POC per bin is given in mg^{-2} d^{-1}. Figure 9 illustrates the behavior of the depth bin data as related to the total weight per hour caught in tons per bin as well as the total POC per bin in g m^{-2} d^{-1}. In a similar way as the research data, the bin data was then submitted to a linear regression for obtaining coefficients of determination.

5. Discussion

5.1. General

Table 1 gives an overview of the coefficients of determination for all the years and for both the research as well as the commercial data. It is evident from the Figures 6-8 that the coefficients of determination (r^2) vary extensively between the research and commercial data sets. This is not surprising since the fishing location distributions shown in Figures 4 and 5 are quite different. The research locations show a stratified-random sampling approach, whereas the commercial data is grouped in a few patches. These patches are areas where the commercial fisheries, based on experience, know where the shrimp are located. The surprising aspect is that the coefficients of determination are very high for the POC for both commercial years. Examining Figure 4 shows that the commercial data is located within the mean annual sea-ice extent. Furthermore the POC data shown in Figure 5 indicates that most of the fishing positions are located within the elevated POC sedimentation area. This aspect is reflected to some extent in the high determination coefficients for the commercial data, as compared to the research data.

Examining the depth results for the commercial data show very high coefficients of determination similarly as the POC data. In 1989 most of the shrimp are caught at the depth of 375±25 m as observed in Figure 9. In 1996 this depth is 425±25 m a slight shift to deeper waters. The commercial POC data shows on the other hand a different pattern. In 1989 most of the shrimp were caught in the POC levels >25 mg m^{-2} d^{-1} as compared to 1996 where the POC level ranged between 12 and 25 mg m^{-2} d^{-1}, well below the level of 1989. Both depth peaks are located well within the BMIZ that is sub-area (4) in Figure 3. The significance of the POC amounts is actually not a critical parameter as long as sedimentation is present. The important result is where the POC is located at the ocean floor as a result of the biological fallout through the water column. With the current limited data set it is not possible to address the effect of the quantity of POC on the catch data. This will have to await the analysis of several years of data. In summary, with the seasonal ice cover present, currents, eddies, vertical mixing, all have an affect on the distribution and eventual sedimentation of the POC at the ocean floor (Ramseier et al. 1999), as well as the temperature and depth as seen in Figures 6, 7, 9 and summarized in Table 1.

The research data does mimic some of the commercial results. The temperature bin data provides high coefficients of determination for 1997 followed by the depth bin data and the POC bin data. In 1996 the highest coefficients of determination are with depth, and a mixture of POC and temperature depending if total catch or catch/shrimp parameters (size of shrimp) are examined. The research temperature catch data for 1996, as well as the research POC catch data for 1997 show low coefficients of determination in comparison with the other parameters for the same year. Because the research data systematically samples the total area, the lower coefficients of determination are expected.

5.2. POC variations

Depth dependence of POC - We also examined the depth dependence on POC based on the equation from Martin et al. (1987). The model presented in section 3 was established for a sedimentation depth of 500 m. We recalculated the POC sedimentation, using the exponential equation from Martin et al. (1987) for the depth at which the shrimp were caught. Figure 10 shows the results. As can be seen from the coefficients of determination (0.964 no Martin equation, 0.965 with equation) the impact is very small since the changes in depth from the 500 m reference depth are rather small.

Changes in mean yearly POC levels and extent – Based on the mean yearly sea ice concentrations we calculated the POC coefficient of determination for the years 1986 to 1989 as well as the mean of the years. We found that the differences were rather small, with r^2 values varying between ±0.05 to ±0.14 for the POC binned data. The interpretation of these results seems to indicate that ice variations from year to year have little effect on the catch of the shrimp due to the fact that shrimp live for several years, are an opportunistic omnivore, functioning both as a predator and scavenger (Shumway et al. 1985).

5.3. Implications of the POC sedimentation

The results show that the shrimp catch data depends on temperature of the water at the depth caught, temperature range being 3 to 4ºC, the depth with a range of 340-500 m, and a POC level >10 mg m^{-2} d^{-1}. Figure 5 shows the distribution of the POC sedimentation at a depth of 500 m extending from the southern ice limit (Figure 4) up to Davis Strait. Examining an updated version of the DFO catch data between 60 and 61ºN shows that all the positions for both the research and commercial fisheries are well within sub-area (4) of the BMIZ. The fishery extends also from east of Resolution Island northward along the shelf edge off southeast of Baffin Island. This area too shows a high level of POC sedimentation. In other words the trend established between the southern limit and 60ºN continues further north. One aspect that is not reflected in the model is the varying current conditions between the Labrador coast and the Greenland West coast. This would result in a slightly different distribution of the POC, e.g. further north along the Greenland coast where the West Greenland current is active. A closer examination of the research data as well as a better knowledge of the type of bottom (substrata of soft mud, sand/silt and occasional rocks) would be required.

6. Summary

Particulate organic carbon is an important food supply for shrimp, thus an important indicator where shrimp are located. The sedimentation pattern of POC can be mapped for the Northern Hemisphere based on a model developed by Ramseier et al. (1999). Input parameters to the model are the mean annual sea ice concentrations. These parameters were obtained using passive microwave satellite data from the SSM/I series in combination with the NASA Team sea ice algorithm. For the years used in this study, nearly all research and commercial fishing in the Labrador Sea occurred for depths less than 550 m, with some locations to 1450 m. These depths are within the biological marginal ice zone an active area of POC sedimentation. Thus, the model for POC sedimentation provides an additional tool for mapping potential areas for fishing. Temperatures at the depth shrimp are caught also showed a similar correlation with catches and POC, however this parameter is not easy to map on a large scale. Depth shows also a strong correlation with catch as well as POC. The POC sedimentation pattern is mapped using satellite data thus covers all areas of the BMIZ, on a daily basis regardless of night or cloud cover. The data shows clearly that in the majority of the cases the commercial fisheries know where to fish.

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Table 1. Coefficients of determination for the commercial and research data in relation to effort and number of shrimp caught.

Year	Com 1989	Com 1996	Res 1996	Res 1996	Res 1997	Res 1997
Parameter	Shrimp h^{-1}	Shrimp h^{-1}	Catch	Catch/shrimp	Catch	Catch/shrimp
Temperature	None	None	0.136	0.745	0.856	0.954
Depth	0.995	0.948	0.556	0.763	0.781	0.897
POC	0.926	0.964	0.487	0.304	0.01	0.535

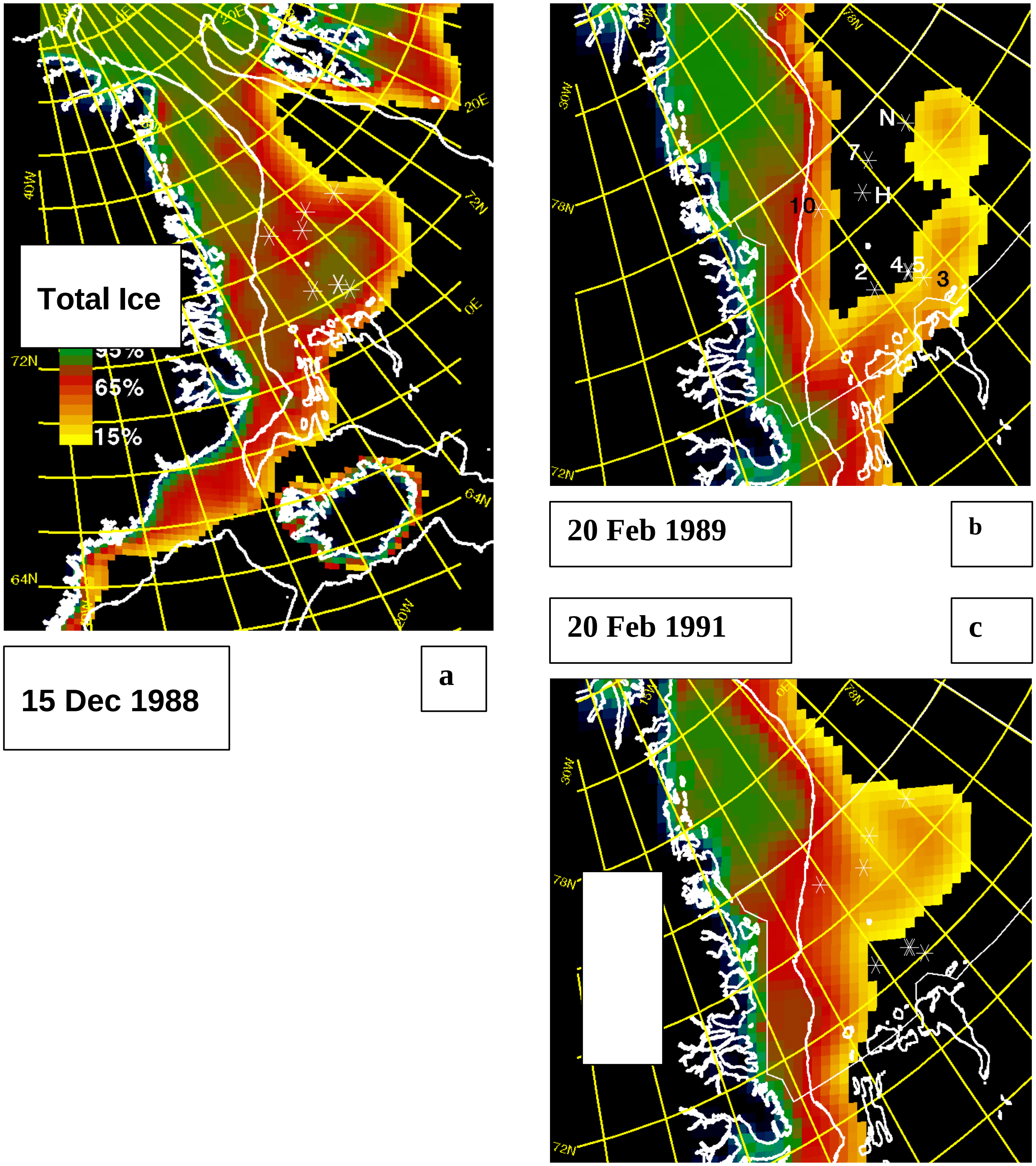

Fig. 1. Greenland Sea a) Sediment trap mooring locations between 72 - 75º N. b) OG trap positions are labeled 1-10, c) the Is Odden-Nordbukta region during an ice- poor year.

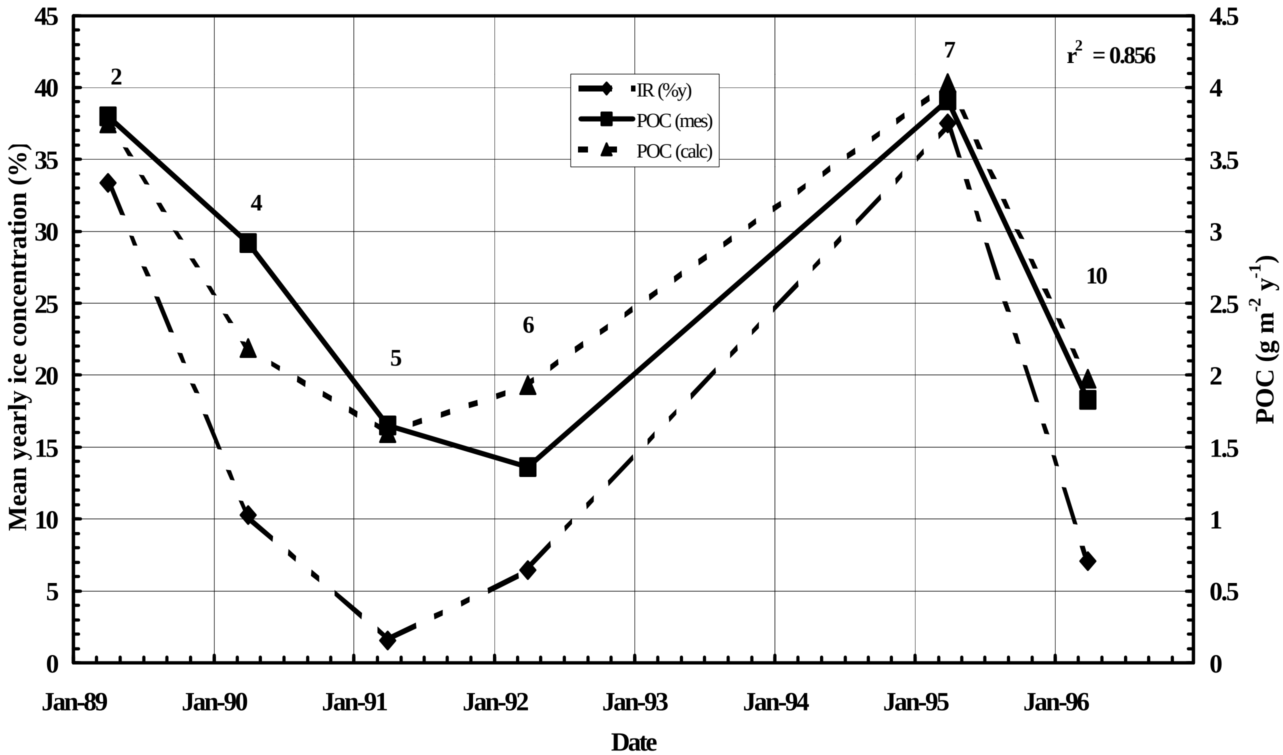

Fig. 2. Results from the Greenland Sea analysis depicting the parameters IR (%y), the mean yearly ice regime, and the yearly amount of particulate organic carbon (POC_{mes}) contained in the sediment trap for all the SFB traps identified with the corresponding number. The model results (POC_{calc}) based on equation (2) are also given. The coefficient of determination based on a linear regression between IR (%y) and (POC_{mes}) is given on the top right hand corner of the figure.

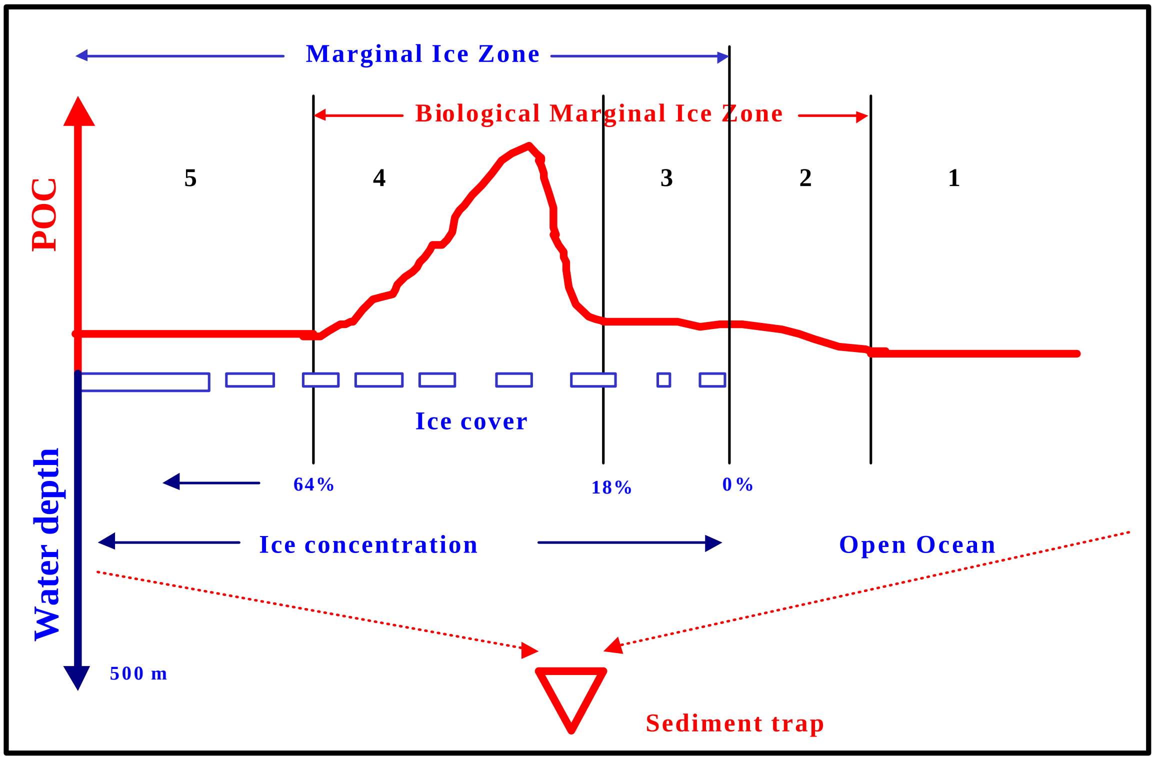

Fig. 3. Schematic model for the POC sedimentation across a vertical slice of ocean. The left-hand boundary represents the coast extending to the right to the open ocean. The numbers identify the sub-areas discussed in the text, representing different sedimentation processes.

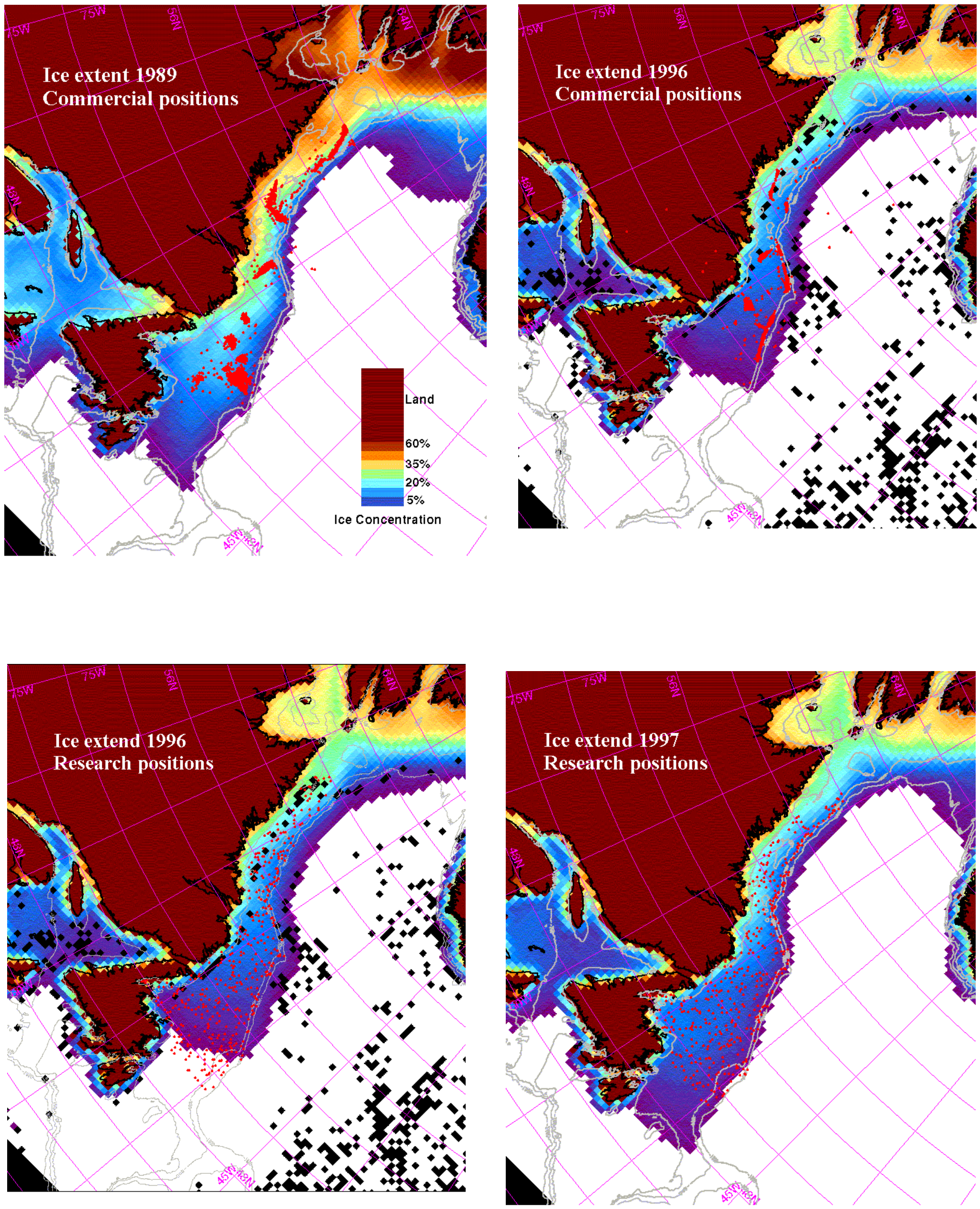

Fig. 4. Mean yearly sea ice extent along the Newfoundland and Labrador Coast for the three years examined. Included in the figure are the fishing positions for both the commercial and research fishery. The bathymetry contours are for depths of 150, 600 and 1200 m. The black points, predominantly in the open ocean are explained within the text.

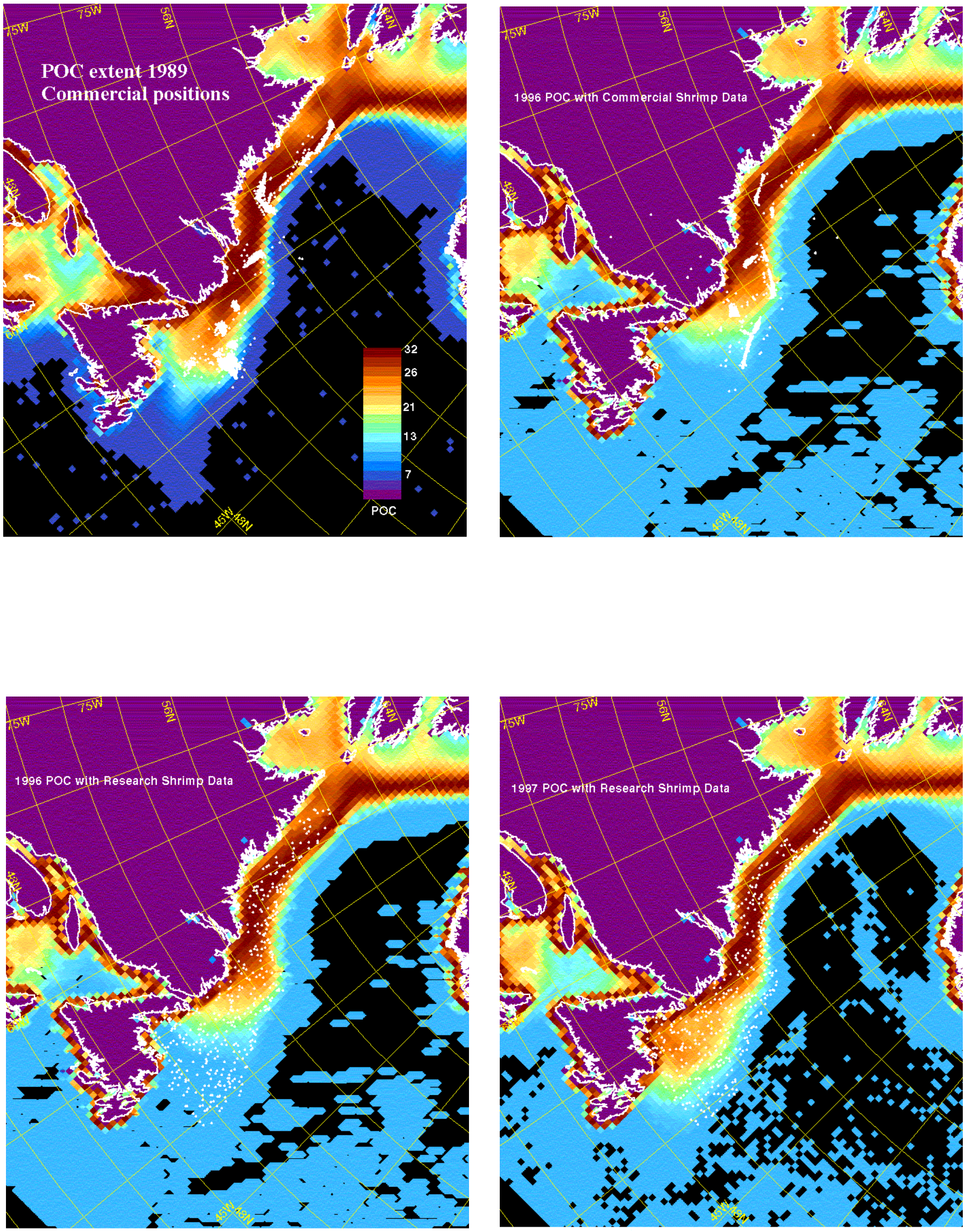

Fig. 5. Mean yearly POC extent for sub-area 4. The POC distribution is obtained by multiplying the mean ice conditions in Figure 4 with equation 3. Shown also are the commercial and research fishing positions. In the 1996 commercial figure some fishing locations are on land or far out in the open ocean. These points have been eliminated in the analysis for this paper.

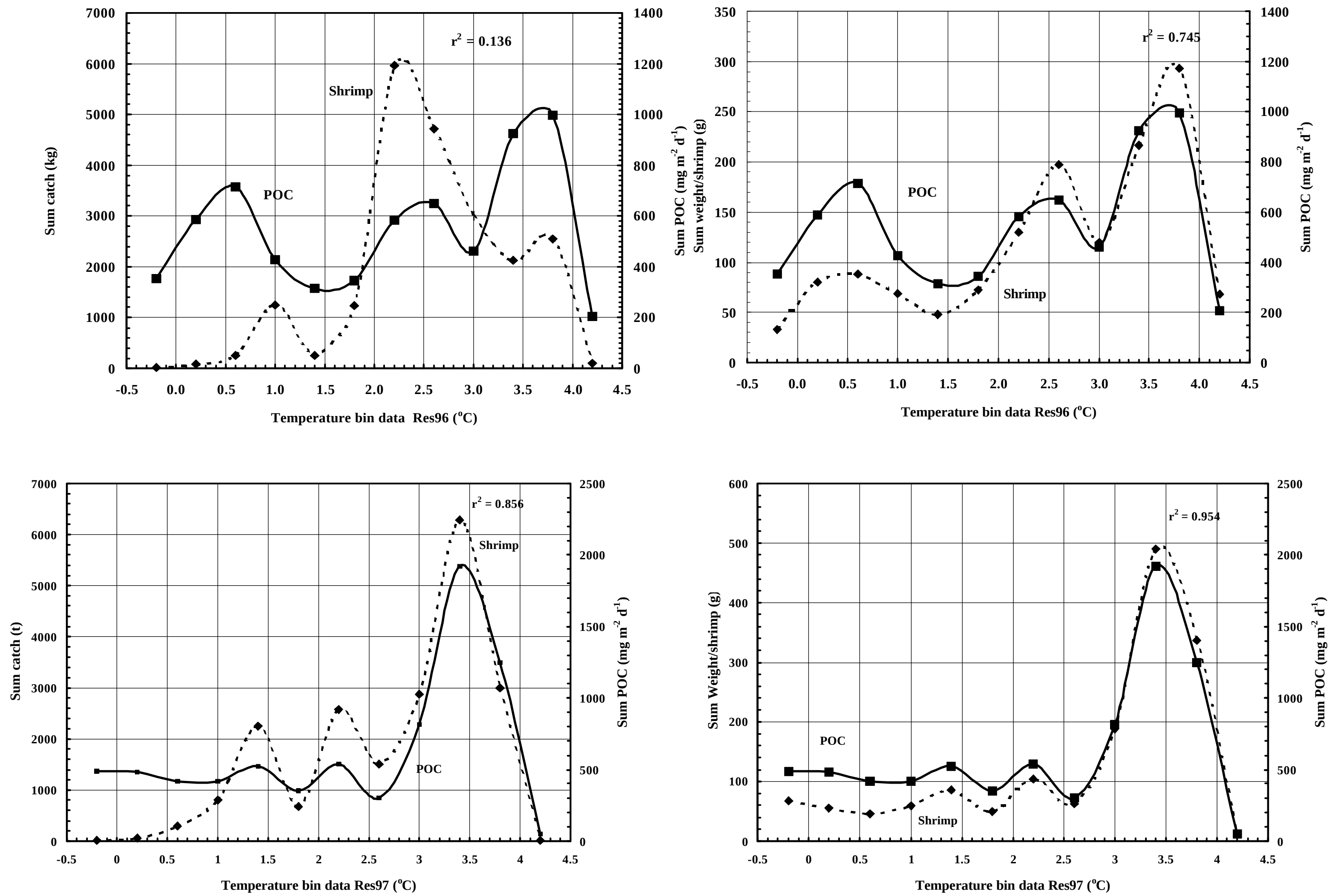

Fig. 6. The research temperature bin data is shown as a function of total shrimp catch (summed within the individual bins) as well as the summed total weight per shrimp, and the POC (summed within the individual bins).

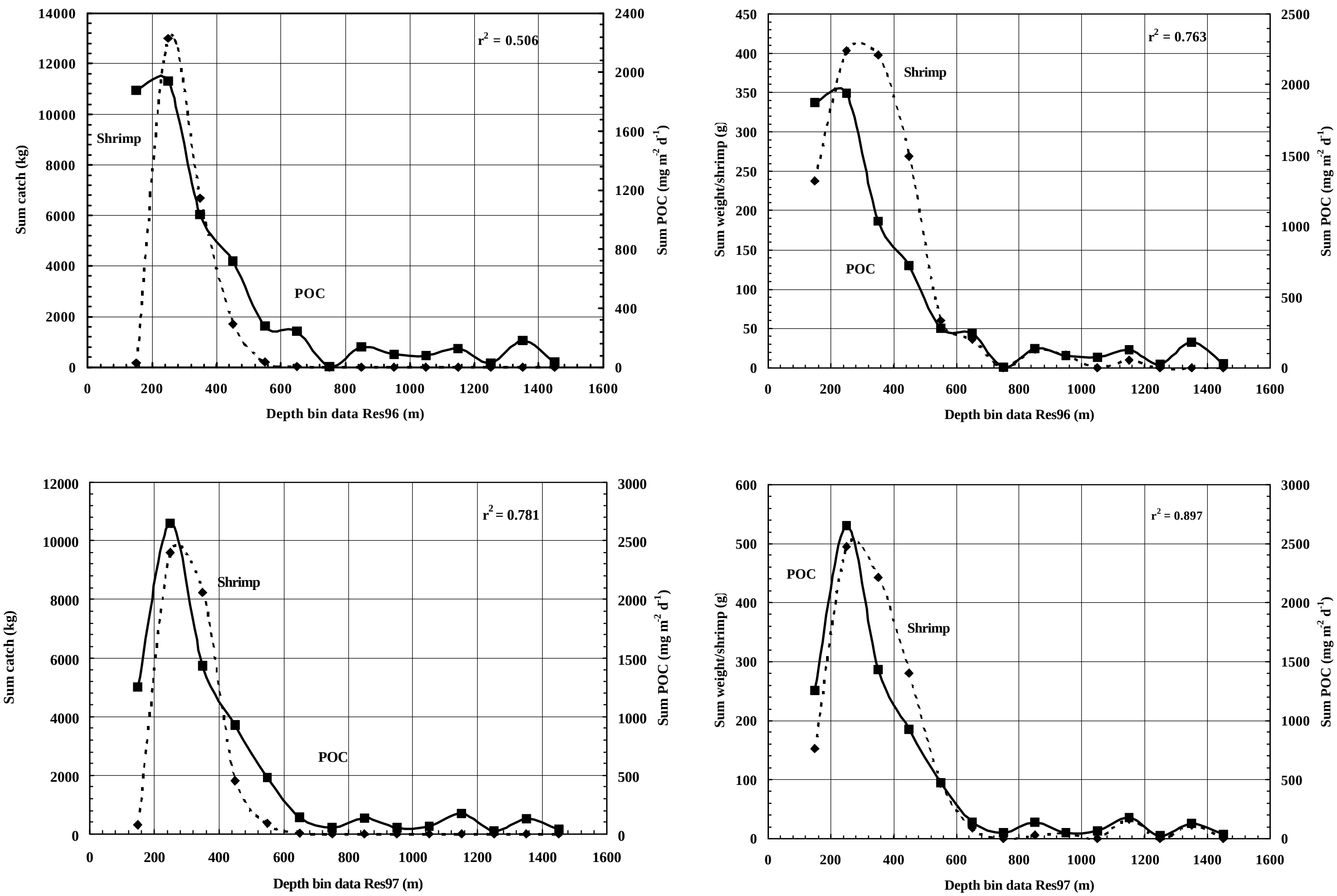

Fig. 7. The research depth bin data is shown as a function of total shrimp catch (summed within the individual bins) as well as the summed total weight per shrimp, and the POC (summed within the individual bins).

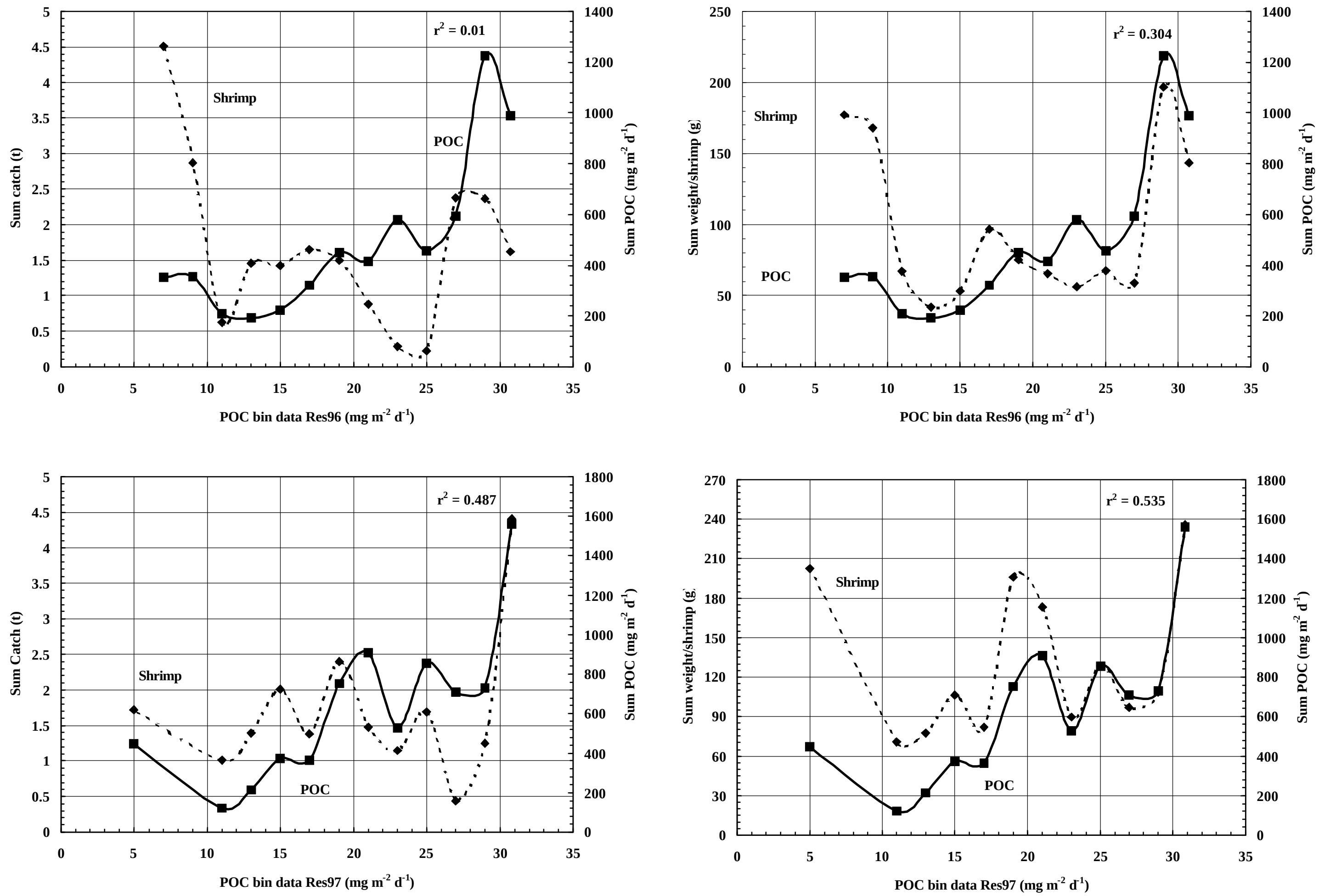

Fig. 8. The research POC bin data is shown as a function of total shrimp catch (summed within the individual bins) as well as the summed total weight per shrimp, and the POC (summed within the individual bins).

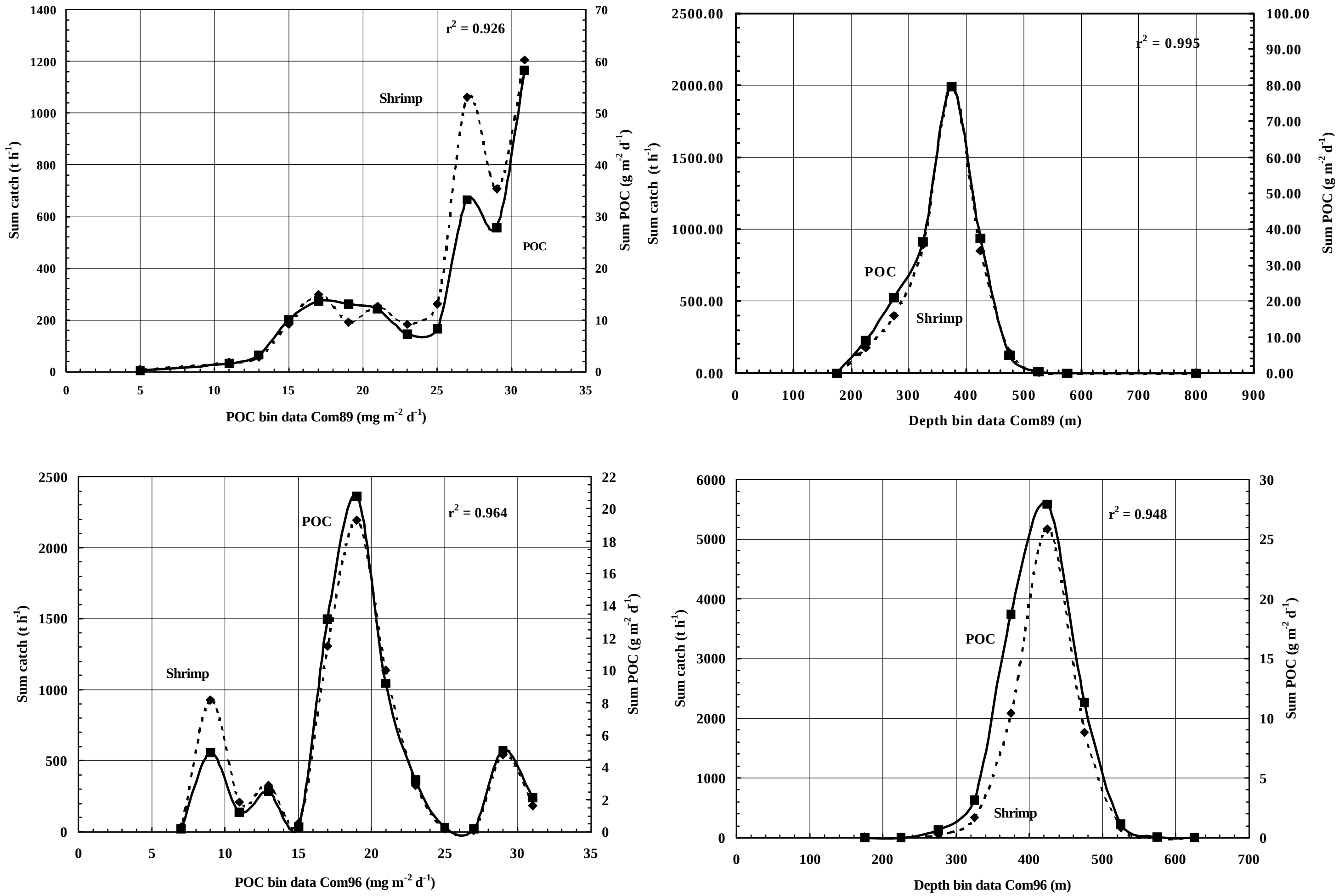

Fig. 9. The commercial POC and depth bin data is shown as a function of the effort (summed within the individual bins) and the POC (summed within the individual bins).

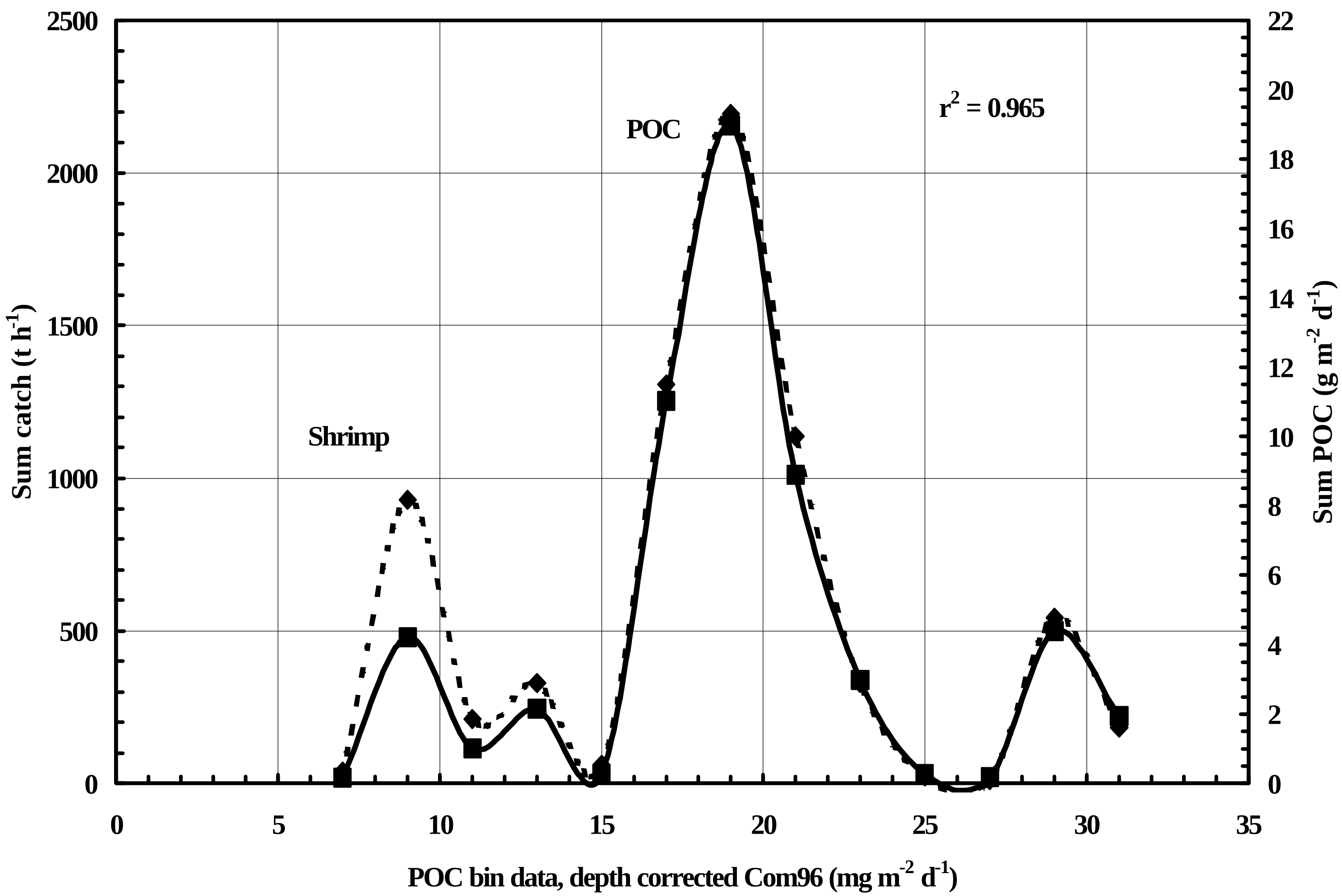

Fig. 10. The commercial POC and depth bin data, corrected for the exponential behavior of the POC with depth, is shown as a function of the effort (summed within the individual bins) and the POC (summed within the individual bins).