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Recent trends in bottom temperatures and distribution and abundance of cod *(Gadus morhua)* in NAFO Subdivisions 3Pn and 3Ps from the winter/spring multi-species surveys

Évolution récente des températures au fond et de l'abondance et la répartition de la morue *(Gadus morhua)* dans les sous-divisions 3Pn et 3Ps de l'OPANO, d'après les relevés plurispécifiques hivernaux et printaniers

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ABSTRACT

An analysis of near-bottom temperatures in NAFO Division 3P during winter and spring surveys are presented in relation to the spatial distributions and abundance of cod (*Gadus morhua)* for the years 1983 to 2001. Interannual variations in the near-bottom thermal habitat were examined by calculating the areal extent of the bottom covered with water in 1°C temperature bins. The analysis revealed a significant shift in the thermal habitat in the region with the areal extent of subzero °C bottom water covering the banks increasing dramatically from the mid-1980s to the mid-1990s. During this time period zero catch rates dominated on St Pierre Bank and in the eastern regions of 3Ps. Beginning in 1996 the area of 0°C water on the banks decreased significantly reaching very low values in 1998 and a complete disappearance in 1999 and 2000. The areal extent of bottom water with temperatures >1°C on the banks was about 50% of the total area during 1998 the first significant amount since 1984 and it increased further to about 70% during 1999 and to 85% during 2000. During 1999 and 2000 larger catches of cod became more wide spread over St. Pierre Bank region as the cold sub-zero °C water disappeared from the area. There were many zero catches in the eastern areas during 2001 as colder water returned to the region. During all surveys most of the larger catches occurred in the warmer waters (>2-3°C) along the slopes of St. Pierre Bank and areas to the west of St. Pierre Bank. An examination of the cumulative distributions of temperature and catch indicates that cod are associated with the warmer portion of the available temperature range, with a slightly warmer preference based on weight than numbers.

RÉSUMÉ

Ce document présente une analyse qui met en relation les températures mesurées près du fond dans la division 3P de l'OPANO lors des relevés hivernaux et printaniers et les répartitions spatiales et l'abondance de la morue (*Gadus morhua*) pour la période 1983 - 2001. Nous avons étudié les variations interannuelles de l'habitat thermique près du fond en calculant la superficie du plancher océanique pour chaque intervalle de 1 oC de la température de l'eau de fond. L'analyse a montré un changement significatif de l'habitat thermique dans la région, la superficie des bancs où l'eau de fond est inférieure à 0 oC ayant fortement augmenté du milieu des années 1980 au milieu des années 1990. Au cours de cette période, la plupart des mouillages d'engins effectués dans le cadre des relevés sur le banc Saint-Pierre et les secteurs orientaux de 3Ps n'ont capturé aucune morue. À partir de 1996, la superficie des bancs où l'eau était à 0 oC a significativement baissé, atteignant des valeurs très faibles en 1998 et disparaissant complètement en 1999 et en 2000. En 1998, la superficie des bancs où la température de l'eau dépassait 1 oC représentait environ 50 % de la superficie totale, soit la première fois que cette mesure donnait une valeur appréciable depuis 1984, et elle a augmenté encore pour atteindre environ 70 % en 1999 et 85 % en 2000. En 1999 et en 2000, des prises de morue accrues s'étendaient sur la région du banc Saint-Pierre en même temps que les eaux de fond de température inférieure à 0 oC disparaissaient de la région. De nombreux mouillages d'engins n'ont capturé aucune morue dans les secteurs orientaux lors des relevés de 2001 coïncidant avec le retour d'eaux froides dans la région. Dans tous les relevés, la plupart des captures les plus abondantes ont été réalisées dans les eaux plus chaudes (>2-3 oC) le long des pentes du banc Saint-Pierre et dans les secteurs situés à l'ouest de ce banc. L'examen des distributions cumulatives de la température et des prises indique que la morue est associée à la portion la plus chaude de la gamme de températures observées, la relation étant plus forte pour le poids des prises que pour leur nombre.

Introduction

Canada has been conducting stratified random groundfish trawl surveys in NAFO Divisions 3P since 1972. Each area was stratified based on the depth contours from available standard navigation charts. Areas within the division, within a selected depth range, were divided into strata and the number of fishing stations in each stratum was allocated based on an area weighted proportional allocation (Doubleday 1981). The stratification scheme is constantly being revised as more accurate navigation charts become available and efforts are being made to extend the stratification scheme shoreward and into deeper water along the shelf edge (Bishop 1994, Murphy 1996). Historically the timing of the survey was quite variable starting as early as January 27th and as late as June 3rd in some years with both a winter and spring survey in 1993. In the winter months the survey at times had problems with sea ice coverage and as a result the western subdivision 3Pn was not always covered. The survey covered depths to 366 meters until 1979 and has since been extended to cover water depths to 548 meters, also some new strata extending into Placentia Bay are currently surveyed. Since 1994 annual surveys have been conducted in April. Since the spring of 1996 the research vessel surveys have used the Campelen 1800 shrimp trawl. During all surveys oceanographic data were collected as described below at each station and archived in oceanographic databases as well as included in the trawl set details.

Assessments of the cod stock in this region have indicated a steady decline in biomass from the peak in 1985 to a minimum in 1992 followed by an increase during 1993-1997 after the implementation of a fishing moratorium. Recruitment also experienced a general decline since the early 1980s remaining at historical low values during most of the 1990s with slight increase during 1999-2000 (Brattey et al. 2000). The purpose of this analysis is to review recent trends in the distribution and abundance of cod in this area in relation to their thermal habitat. We begin by examining the spatial distribution of cod in relation to the near-bottom temperature fields for the annual winter and spring research vessel surveys from 1983 to 2001. Interannual variations in the thermal habitat are then considered by examining the mean temperature fields for each survey and the areal extent of the bottom covered with water in various temperature bins. These are then compared to the mean catch rates for time period.

Data and Methods

The historical oceanographic data are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and from databases maintained at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. From 1971 to 1988 temperature data on fisheries assessment surveys were collected using bottles at standard depths and/or bathythermographs (mechanical or expendable MBT/XBT), which were deployed usually at the end of each fishing set. Since 1989 net-mounted conductivity-temperature-depth (Seabird model SBE-19 CTD systems) recorders have replaced XBTs. This system records temperature and salinity data during trawl deployment and recovery and for the duration of the tow. Data from the net-mounted CTDs are not field calibrated, but are checked and factory calibrated periodically maintaining an accuracy of 0.005^{o}C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1^{o}C.

Near-bottom temperature grids for NAFO Division 3P were produced from all available data for the winter and spring time periods for the years 1983 to 2001. Surveys before 1983 were usually incomplete. In most years except 1993, when both a winter and spring survey was conducted, most of the temperature data were obtained from a single survey. All bottom-of-the-cast temperature values for each time period were interpolated onto a regular grid and contoured using a geostatistical (2-diminsional Kriging) procedure. The area of each grid element within selected temperature ranges was integrated to produce a yearly estimate of the percentage of the total bottom area within each temperature bin. The selected temperature ranges were $\leq 0^{o}$C, 0-1^{o}C, 1-2^{o}C, 2-3^{o}C and $\geq 3^{o}$C. The mean near-bottom temperature time series was also constructed for each year. This

analysis was carried out for the complete 3P region and also for areas with water depths ≤100 m, which corresponds mainly to St. Pierre Bank. Potential sources of error in this analysis include temporal biasing, arising from the wide time interval (approximately 1-month) during which a typical survey is conducted. This source of error is probably small, however, given the low magnitude of the annual cycle over most of the near-bottom depths encountered. An additional source of error that can potentially affect the results, particularly along the shelf edge, occurs when the spatial scales of temperature variations are shorter than the grid size. This error will be small over the banks where the topography is relatively flat and larger along the shelf slopes.

The number of cod of all ages per set is also displayed together with the temperature contours from 1983 to 2001 for the winter and spring surveys. The survey catch data from 1983 to the spring of 1995, which were collected using an Engel 145 bottom trawl, were converted to equivalent Campelen trawl units based on the results of comparative fishing studies. The mean number of cod for all sets for each survey were also computed and compared to the average bottom temperature. Finally, the cumulative frequency distributions of catch numbers and weight for each temperature bin are compared to the available temperature distribution within the 3P region for all surveys from 1983-2001.

Results

The temperature and temperature anomaly plots displayed in Fig. 1 show two extremes in the ocean climate experience during the past decade with bottom temperatures on St. Pierre Bank reaching a minimum during the early 1990s and a maximum by 2000. During 1993 for example, bottom temperatures for the most part were below normal over the entire region of St. Pierre Bank and most of Rose Blanche and Burgeo Banks. Temperature anomalies reached at least 0.5-1.0^{o}C below normal in most areas, but also as low as 2^{o}C below normal in some regions of St. Pierre Bank. Temperature anomalies in deeper water off the banks however ranged from near normal to 1^{o}C above normal in some areas. By the end of the decade however, temperatures moderated and were above normal over most areas by 1998 and by 2000 sub-zero ^{o}C water had receded eastward off St. Pierre Bank to the approaches to Placentia Bay. As a result temperature anomalies on the entire St. Pierre Bank were over 1^{o}C above average (Fig. 1).

The winter and spring bottom temperature maps together with the number of fish caught per set for Division 3P are shown in Fig. 2 for the years 1983 to 2001. In general, bottom temperatures during the surveys from St. Pierre Bank eastward to Placentia Bay were below normal from 1985 to 1997, with the exception of 1988 and 1996. From 1998 to 2000 temperatures in these regions were above normal but by the spring of 2001 they had decreased to below normal values. During the cold years sub-zero ^{o}C water from the Newfoundland Shelf covered most of St. Pierre Bank and Placentia Bay. During warm years (2000 for example) temperatures on St. Pierre Bank ranged from 1-4^{o}C with sub-zero ^{o}C water restricted to the deeper portions of the approaches to Placentia Bay. In the deeper waters, typically below 100-m depth, temperatures varied considerably from one year to the next but generally remained above 2-3^{o}C often reaching as high as 6^{o}C in the deepest portions of the Laurentian Channel and along the slopes of the southwestern Grand Banks.

The most evident trend in the number of cod caught per set during each survey (displayed as expanding symbols on the temperature fields in Fig. 2) is the increasing number of zero catches in the colder sub-zero ^{o}C water on St. Pierre Bank and eastward mainly from 1985 to 1998. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank region as cold sub zero ^{o}C water disappeared from the area. There were many zero catches in the eastern areas during 2001 as colder water returned to the region. During all surveys most of the larger catches occurred in the warmer waters (>2-3^{o}C) along the slopes and areas to the west of St. Pierre Bank. There were exceptions however, for example, the 1987 survey showed many non-zero catches in sub-zero ^{o}C water, while the spring of 1983 showed many zero catches in the warmer waters of the Laurentian Channel (Fig 2a-2e).

The percentage area of the bottom habitat covered by water in various temperature bins are shown in Fig. 3 for all of the 3P area and for regions with water depths <100-m. In general, the percentage of the bottom habitat covered by <0°C water increased to approximately 30% from the mid-1980s until the mid-to-late 1990s. During the same time period however the percent area of the banks covered with <0°C water increased to approximately 75-100%. It is clear that there are two distinct oceanographic regimes in this region. One influenced by the cold-fresh water from the eastern Newfoundland Shelf, which includes much of St. Pierre Bank and regions to the east and the other includes the deeper regions of the Laurentian and Hermitage Channels and areas to the west of St. Pierre Bank. This region appears to be influenced mostly by warmer slope water from the south. As a result much of this region has temperatures ranging from 3-6°C.

Interannual variations in the spatially averaged bottom temperature (Fig. 4 top panel) of the surveyed area in Division 3P for water depths >100-m show values ranging between 2° to 4°C with an overall mean of approximately 3°C. During 1999 and 2000 the average temperature increased to over 3°C but decreased to near 2.5°C in 2001. On the banks, in water depths generally less than 100-m, the average temperature from 1980 to 1984 ranged between approximately 0.5° to 2°C. Temperatures in this depth range decreased significantly during 1985 to sub-zero values and remained low until 1997. More recently however temperatures recovered to about 1°C by 1998, 1.6°C during 1999 and to 1.7°C during 2000 (Fig 4 bottom panel). Variations in the mean number of cod per set for strata with water depths <100 m are correlated with the changes in the thermal habitat on St. Pierre Bank. There is no significant correlation between bottom temperatures and the mean numbers of fish caught per set for strata in water depths >100 m. The average number of fish caught per fishing set in 1°C-temperature bins is shown in Fig. 5. Except for the high catch rates in the sub-zero °C temperature bins in the mid-1980s catches for the most part are higher in the higher temperature ranges. In addition catch rates have decreased substantially since the mid-1990s with the exception of a few large catches during 2000 and 2001.

In an effort to investigate temperature preference by cod in this region, cumulative distributions of temperature and catch weighted (in terms of numbers and weight) cumulative distribution of temperature for various time periods are displayed in Fig. 6. The temperature distributions have been weighted annually by sampling intensity within each stratum and by strata area. The cumulative frequency distribution of temperature shows the temperature available to cod historically during the spring period in Divisions 3P. The cod number and weight temperature distributions show the distribution of catches in relation to the ambient temperature. The results indicate that on average (1972-2001) cod are associated with the warmer portion of the available temperature range with a slightly warmer preference based on weight than numbers. Approximately 20% of the cod by number are associated with sub-zero °C water, while approximately 50% are associated with water above 3°C and up to 25% associated with temperatures >5°C. The temperature distribution indicates that about 40% of the available habitat is covered by sub-zero °C water. During the warm periods of 1974-1984 and 1998-2000 the distribution of catches nearly coincide with the distribution of available temperature, but during the cold period of 1985-1995 the distributions indicate that the fish may avoid the colder portions of the habitat.

Discussion and Summary

The near-bottom habitat in the 3P region consists of two distinct oceanographic regimes. One influenced by cold-fresh water from the eastern Newfoundland Shelf, which includes much of St. Pierre Bank and regions to the east. In this region temperatures generally range from 0-2°C but are often sub-zero °C in many years. The other includes the deeper regions of the Laurentian and Hermitage Channels and areas to the west of St. Pierre Bank. This region appears to be influenced mostly by warmer slope water from the south. As a result this region experiences high variability with temperatures ranging from 3-6°C. A significant shift in the thermal habitat took place during the mid-1980s with a dramatically increase in the area of the bottom covered

with sub-zero ^{o}C water. However beginning in 1996 the area of 0^{o}C water on the banks decreased significantly reaching very low values in 1998 and a complete disappearance in 1999 and 2000. The areal extent of bottom water with temperatures >1^{o}C on the banks was about 50% of the total area during 1998 the first significant amount since 1984 and it increased further to about 70% during 1999 and to 85% during 2000.

It appears that the most significant oceanographic signal potentially influencing cod habitat in this region may be variations in the amount of sub-zero ^{o}C water advected into the region from the eastern Newfoundland Shelf by the Labrador Current. The extent of this water mass that eventually makes its way onto St. Pierre Bank from the inshore regions of eastern Newfoundland is governed by current speeds, vertical mixing by storms and surface heat input. Indeed the most evident trend in the numbers of cod caught per set was the increasing number of zero catches in the sub-zero ^{o}C water on St. Pierre Bank and the eastward regions mainly from 1985 to 1998. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank region as the cold sub-zero ^{o}C water disappeared from the area. There were many zero catches in the eastern areas during 2001 as colder water returned to the region. In general, during all surveys most of the larger catches occurred in the warmer waters (>2-3^{o}C) along the slopes and areas to the west of St. Pierre Bank. In addition, variations in the mean number of fish caught per set in strata with water depths <100 m are significantly correlated with bottom temperatures for that depth range. However, there is no significant correlation between bottom temperatures and the mean numbers of fish caught per set for strata in water depths >100 m (Fig.4).

The cumulative frequency distributions of available temperature and the cod number and catch weighted temperature distributions indicate that cod are associated with the warmer portion of the available temperature range with a slightly warmer preference for larger fish. It thus appears that very cold conditions on St. Pierre Bank during most of the surveys since 1985 up until at least 1997 may have contributed to the low numbers of fish found there. The increase in the number of cod per set on St. Pierre Bank and the increase in the number of non-zero catches in the eastern regions corresponding to the near-record high bottom temperatures during 1999 and 2000 also indicate a preferred towards a warmer habitat. Theses distributions may be explained by factors other than temperature however, for example, by factors that may co-vary with temperature such as prey distribution or other environmental variables. We also note that since the spring of 1998 there has been an increase in the number of cod caught per tow in survey sets on the Grand Bank (Divisions 3NO) that may be attributed to an improved thermal environment (Colbourne and Murphy, 2000). In addition the recently observed expansion in the spatial distribution and increase in abundance of yellowtail flounder (*Limanda ferruginea*) on the Grand Bank coincided with the improved thermal environment during the latter half of the 1990s (Walsh et al. 2000, Colbourne and Bowering 2001).

There may be several other possible reasons for these observations. Variations in the catch rates in the warmer water of the most western regions of subdivision 3Pn may be influenced by environmental conditions in the Gulf of St. Lawrence, either for cod or their prey, or both. Also the extreme variations in the catch rates on St. Pierre Bank in particular may be the result of a temperature dependent increase in catchability or related to other biological or environmental factors such as increase in prey species or a shift to a more suitable environment for prey species. More research however is required to investigate this. Although the numbers of fish from the 1983-1995 surveys have been converted to equivalent Campelen trawl units there may be some residual effects remaining in the series, which may have contributed to some of the increase in the catches of smaller fish during 1996-2001. In summary, it is possible that variations in water temperature in the area, particularly on St. Pierre Bank and the off Placentia Bay may influence spawning success and possibly improved survival and growth rates of cod. The results presented here indicate a temperature preference towards the warm water habitat of the 3P region.

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