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The Effects of Changes in Environmental Temperature on Growth and Reproduction of the Northern Shrimp (Pandalus borealis) from Cartwright Channel (Division 2G)

by

D. G. Parsons

Department of Fisheries and Oceans, Fisheries Research Branch
P. O. Box 5667, St. John's, Newfoundland, Canada A1C 5X1

SPECIAL SESSION ON ENVIRONMENTAL CONDITIONS

INTRODUCTION

Trawl surveys for northern shrimp have been conducted annually onboard the R.V. Gadus Atlantica from 1980 to 1987, inclusive, during the July - August period. These surveys were designed, primarily, to estimate the minimum trawlable biomass of shrimp in the areas where commercial fisheries occur. Biological samples were collected, routinely, from each area fished for examination back at the laboratory, and, after each fishing set, a reading of bottom temperature at that depth was obtained. In analysing the data for age and maturity over the time series (Parsons et al., 1988a), trends were noted, especially in the data from the Cartwright Channel. Given that temperatures observed during the July - August surveys in this area have shown some obvious changes during the 1980's (Parsons et al., 1988b), it was thought that the observed trends in the biological data might be related to temperature.

The effects of changes in temperature on the biology of northern shrimp have not been well-established. Parsons and Tucker (1986) showed no clear relationship between fecundity and environmental temperature, especially at the extremes of the range of temperature tolerance. Nunes (1984) showed that, under controlled conditions, changes in temperature affected time of spawning, as well as the proportion of spawning females and the number of eggs produced. Some of these findings, however, were contradictory to those observed in the wild (viz. earlier spawning at 6° C than at 3° and earlier spawning for some multiparous females than for primiparous females). Shumway et al. (1985) reviewed in detail northern shrimp biology, including what has been documented on the effects of temperature. Much of the published literature relating temperature changes and productivity are from controlled laboratory studies, with very little supporting data from the natural environment, and most of the work on temperature and growth has dealt with larvae and juveniles. The accepted philosophy is that both growth and maturation are delayed in colder water (Allen, 1959; Rasmussen, 1969; Butler, 1971), based on observations from different populations. The effects within populations, however, have not been extensively studied.

This paper examines some of the biolgical and environmental data obtained during the eight surveys in Cartwright Channel in an attempt to demonstrate some of the ways in which shrimp in that area respond to changes in temperature.

METHODS AND MATERIALS

Samples of shrimp were collected from Cartwright Channel from sets in which shrimp were abundant and a broad size range was represented. The gear used each year from 1980 to 1987 was a Sputnik 1600 shrimp trawl with mesh size ranging from about 80 mm in the wings to 42 mm in the codend. The last 6 m of codend was lined with 13 mm mesh to reduce the loss of smaller animals. Samples were preserved in 10 % formalin for observation at the St. John's laboratory.

Bottom temperatures for the depths fished were recorded at the end of each fishing set using expendable bathythermographs (XBT). An estimate of the mean temperature in the channel for each survey was obtained by averageing the bottom temperatures from all stations in depths greater than 350 m. Most of the shrimp biomass is found within this depth range.

Oblique carapace lengths (Rasmussen, 1953) were measured to the nearest 0.1 mm using Vernier calipers and subsequently combined to 0.5 mm for analysis. Males and females were separated based on the characteristics of the endopod of the first pleopod and females were further separated into primiparous (first time spawners) and multiparous (spawned previously) groups using the sternal spine method of McCrary (1971). Ovigerous females and females with large ovaries were considered to be spawners in the current year while females with small and undeveloped ovaries at the time of sampling were considered non-spawners.

The survey in 1986 was conducted during August when most females were ovigerous. Only three animals in the biologial sample were identified as being primiparous (it is not possible to separate the females once the eggs have been deposited). Average length of primiparous females in 1986, therefore, was calculated from the sampling data from all sets made in the channel during the survey, rather than from the standard biological sample.

The relationships between the biological data and bottom temperatures were determined using the linear regression procedure of SAS (Statistical Analysis System).

A number of important assumptions were made in this study: 1) that the primiparous females (transitionals and females with sternal spines) constitute a separate year class; 2) that the undeveloped ovaries observed in the July - August surveys would have remained in that condition until at least the next spring; and 3) that the temperatures used are reasonably representative of the average annual conditions existing in the channel over the period in question.

RESULTS

A summary of the biological and environmental data is given in Table 1 and Fig. 1. The mean lengths of primiparous females showed a general decline from 1981 to 1986 followed by a substantial increase in 1987. The per cent of non - spawning females increased from about 4 % in 1981 to almost 33 % in 1985, then decreased to 5 % in 1987. The average bottom temperature in 1982 was lower than in the previous two years, some increase was observed in 1983 and 1984, followed by a pronounced decrease in 1985. There was a general decreasing trend from 1980 to 1985 and an obvious increase from 1985 to 1986/87.

No relationship between mean length of primiparous females and temperature in each year was apparent ($r^2 = 0.09$),(Table 2). However, if the length in year i is compared to the temperature in year i-1, the r^2 value increases to 0.60 and least squares regression results in a significant slope ($P < 0.05$), (Table 2, Fig. 2). The average temperature for 1979 from the same depth range was 2.68 °C ($n = 19$).

Least squares regression of per cent non-spawners against mean temperature (Table 3, Fig. 3) resulted in a significant negative slope ($P < 0.05$) and an r^2 value of 0.51. There was no improvement in the relationship by lagging the temperature data.

DISCUSSION

Results of the cursory analysis of biological data suggest that both growth and reproduction are affected by changes in temperature. The mean size of females at age 7 (Parsons et al., 1988a) is apparently influenced by the mean bottom temperature in the previous year - the warmer the water, the larger the size. Other age classes are likely affected in the same way, but in order to demonstrate this, extensive modal analyses are necessary to separate the normal components in length frequency distributions. The separation of primiparous females is more straightforward and less subjective by using only biological characteristics. Some of the observed difference in mean size might be due simply to differences in the growth rate of individual cohorts and a more meaningful study might be to compare the growth of different year classes under varying temperature regimes. However, the existing data base is insufficient for such a comprehensive study. Nevertheless, the relationship determined here is significant and gains credibility in that it can be used to predict the mean size of the same age class in 1988. The mean bottom temperature in 1987 was 2.78 °C, the highest in the series, implying a relatively large mean size in 1988. The observed mean size from the 1988 survey was 23.23 mm whereas the predicted value from the linear relationship was 23.21 mm.

The proportion of non-spawning females increased with a decrease in temperature, implying a decrease in average fecundity. Given that the total reproductive capacity will likely depend more on the abundance of females in a given year rather than slight changes in average fecundity, the significance of such a decrease in colder years is questionable. Also, the females which do not spawn can continue to grow (ovigerous females do not moult for eight months or more) and that proportion of the year class will be substantially larger the following year. Larger females carry more eggs and, in that sense, there is some compensation in total fecundity due to the additional growth.

Based on these preliminary results, it would appear that decreases in the mean temperature within the channel result in reduced productivity, a cold year reducing the number of spawners in the same year and the mean size of females in the following. The smaller females also would produce, on average, less eggs. An increase in the length of the ovigerous period also would be expected in cold years (Allen, 1959), providing more time for egg mortality through loss and disease. Yet, during the years of declining temperatures (1980 - 1985), the estimates of biomass fluctuated, with the estimate in 1984 (over 3000 t) being the highest for that period (Parsons et al., 1988b). This would not be expected over a period of low productivity. Therefore, abundance of shrimp, as observed in the area, might be more a measure of availability, with shrimp highly concentrated in some years and more dispersed outside the channel in others. It is possible that such availability changes might in some ways be related to overall environmental conditions within the channel (i.e. temperature, food supply, predators, etc.). The question of abundance under these conditions becomes more difficult to resolve.

The relationships described here are dependent on the suitability of the July - August bottom temperatures as being representative of mean annual conditions within the channel. Although it is suspected that temperatures in these depths do not fluctuate in any systematic way over the year, there is very little information to support this assumption. Therefore, before any firm conclusions can be made on the affects of temperature, more information on a year-round basis is required.

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Table 1. Average carapace length (mm) of primiparous females, per cent non-spawning females and average bottom temperature[1] (°C) in Cartwright Channel, 1980 - 1987. (n = sample size)

YEAR	LENGTH	PER CENT	TEMP.
1980	22.87 (223)	15.90 (805, 128)	2.52 (27)
1981	23.30 (131)	4.15 (386, 16)	2.68 (34)
1982	23.18 (192)	19.67 (488, 96)	1.91 (28)
1983	22.65 (156)	27.19 (445, 121)	2.24 (36)
1984	21.95 (235)	30.34 (412, 125)	2.23 (28)
1985	22.13 (23)	32.89 (304, 100)	0.89 (34)
1986	21.63[2] (62)	18.97 (464, 88)	2.77 (33)
1987	23.85 (86)	5.02 (279, 14)	2.78 (27)

[1] Mean bottom temperatures calculated from all fishing sets > 350 m.
[2] Calculated from all survey sets sampled in 1986.

Table 2. Results of least squares regression analysis - average length of primiparous females against average bottom temperature.

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          ANALYSIS OF VARIANCE - AVERAGE LENGTH / TEMPERATURE YEAR i

                          SUM OF          MEAN
   SOURCE       DF       SQUARES        SQUARE        F VALUE        PROB>F

   MODEL         1    0.34937820    0.34937820          0.578        0.4759
   ERROR         6    3.62702180    0.60450363
   C TOTAL       7    3.97640000

       ROOT MSE        0.7774983      R-SQUARE         0.0879
       DEP MEAN           22.695      ADJ R-SQ        -0.0642
       C.V.             3.425857

                              PARAMETER ESTIMATES

                      PARAMETER          STANDARD      T FOR HO:
VARIABLE   DF          ESTIMATE             ERROR    PARAMETER=0      PROB > |T|

INTERCEP    1       21.89571664        1.08670386         20.149          0.0001
X           1        0.35484278        0.46675344          0.760          0.4759

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          ANALYSIS OF VARIANCE - AVERAGE LENGTH / TEMPERATURE YEAR i-1

                          SUM OF          MEAN
   SOURCE       DF       SQUARES        SQUARE        F VALUE        PROB>F

   MODEL         1    2.39055715    2.39055715          9.045        0.0238
   ERROR         6    1.58584285    0.26430714
   C TOTAL       7    3.97640000

       ROOT MSE        0.5141081      R-SQUARE         0.6012
       DEP MEAN           22.695      ADJ R-SQ         0.5347
       C.V.             2.265292

                              PARAMETER ESTIMATES

                      PARAMETER          STANDARD      T FOR HO:
VARIABLE   DF          ESTIMATE             ERROR    PARAMETER=0      PROB > |T|

INTERCEP    1       20.57862659        0.72681087         28.314          0.0001
X           1        0.94480956        0.31415875          3.007          0.0238
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Table 3. Results of least squares regression analysis - per cent non-ovigerous females against average bottom temperature in year i.

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                            ANALYSIS OF VARIANCE

                          SUM OF          MEAN
   SOURCE       DF       SQUARES        SQUARE        F VALUE        PROB>F

   MODEL         1 418.57019770 418.57019770            6.350        0.0453
   ERROR         6 395.48918980  65.91486497
   C TOTAL       7 814.05938750

       ROOT MSE         8.118797      R-SQUARE         0.5142
       DEP MEAN         19.26625      ADJ R-SQ         0.4332
       C.V.                42.14

                            PARAMETER ESTIMATES

                      PARAMETER          STANDARD      T FOR HO:
VARIABLE   DF          ESTIMATE             ERROR    PARAMETER=0      PROB > |T|

INTERCEP    1       46.93165429       11.34758472          4.136          0.0061
X           1          -12.2821        4.87393523         -2.520          0.0453

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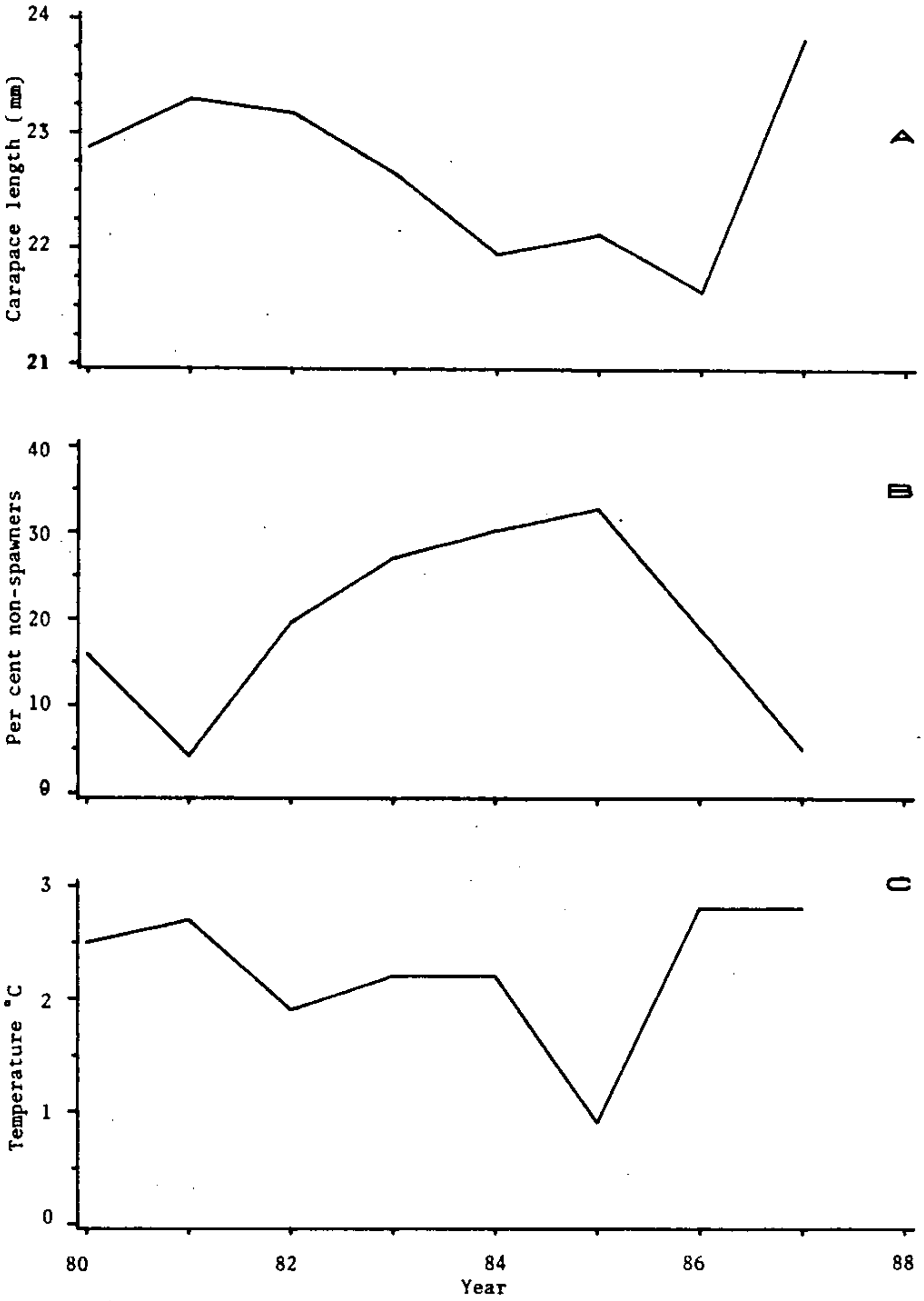

Fig. 1. Mean length of primiparous females (A), per cent non-spawners (B), and mean bottom temperatures (C) - Cartwright Channel, 1980 - 87.

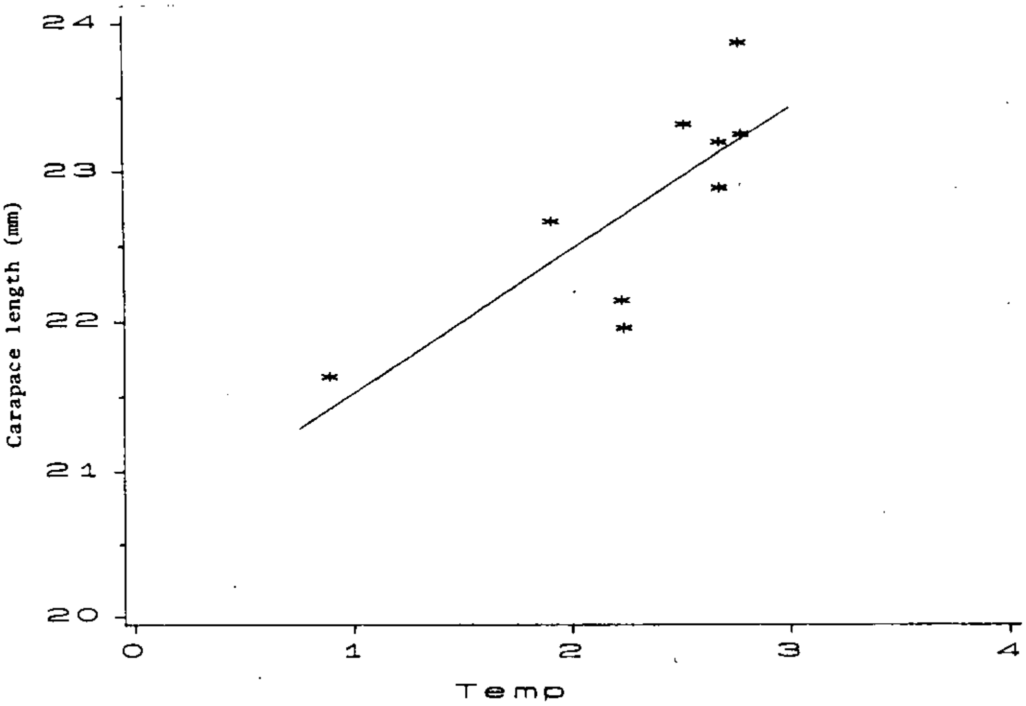

Fig. 2. Mean length of primiparous females in year i versus mean bottom temperature in year i-1, Cartwright Channel, 1979/80 - 86/87.

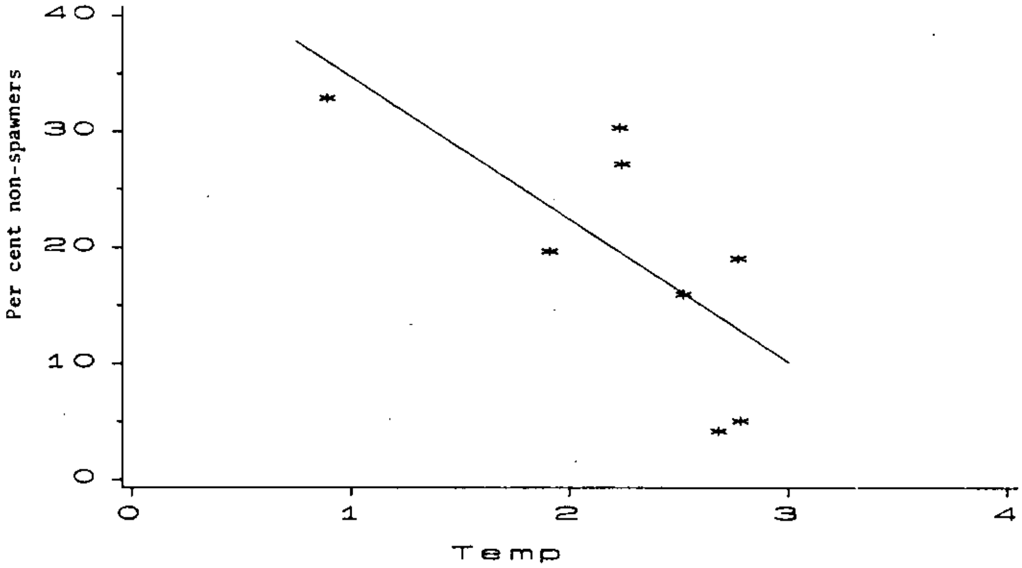

Fig. 3. Per cent non-spawning females versus mean bottom temperature, Cartwright Channel, 1980 - 87.