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Fisheries and Population Biology of Lobsters *(Homarus americanus)* at St. Chads-Burnside, Newfoundland

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FISHERIES AND POPULATION BIOLOGY OF LOBSTERS (*HOMARUS AMERICANUS*) AT ST. CHADS-BURNSIDE, NEWFOUNDLAND

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Characteristics of the lobster fishery in the St. Chads-Burnside area of Bonavista Bay on the northeast coast of Newfoundland are described. Results from on going monitoring of the fishery for catch and effort, catch rates and composition of landings as well as temperature conditions during the fishing season for the 1970 to 1986 period are presented. Details of various aspects of lobster population biology and ecology in the area such as length-weight relationships, growth, estimates of standing stock, recruitment, exploitation rates and movements are included along with a discussion of some general management considerations for the fishery.

RÉSUMÉ

Ennis, G. P., P. W. Collins, and G. Dawe. 1989. Fisheries and population biology of lobsters (Homarus americanus) at St. Chads-Burnside, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1651: iv + 44 p.

On décrit les caractéristiques de la pêche du homard dans le secteur St. Chads-Burnside de la baie de Bonavista, sur la côte nord-est de Terre-Neuve. On présente aussi les résultats des contrôles continus concernant les prises et l'effort, les taux de prises et la composition des débarquements ainsi que les températures durant la saison de pêche, de 1970 à 1986. Le document comprend des renseignements détaillés sur divers aspects de la biologie et de l'écologie de la population de homard dans le secteur, notamment les rapports entre la longueur et le poids, la croissance, les estimations sur le stock actuel, le recrutement, les taux d'exploitation et les mouvements de population. On traite aussi de considérations générales sur la gestion de la pêche du homard.

INTRODUCTION

The lobster fishery and various aspects of lobster population biology and ecology in the St. Chads-Burnside area of Bonavista Bay on the northeast coast of Newfoundland have been studied since 1967. There have been a number of short-term projects to elucidate details of biology, ecology and behaviour, but the study has mainly involved annual monitoring of the fishery for catch and effort, catch rates and composition of landings. As well, bottom temperature during the fishing season (and year-round in recent years) has been monitored. Annually in autumn, following the molting period, shell condition sampling for estimating proportions molting and tagging of commercial lobsters for estimating standing stock, recruitment and exploitation rate during the spring fishing season have been conducted. Results of various short-term projects have been reported (Ennis 1971, 1972, 1973, 1980a, 1983a, 1984a, 1984b). In this paper we present results up to 1986 from the ongoing annual data collecting activities.

MATERIALS AND METHODS

Starting in 1968 a number of fishermen in the St. Chads-Burnside area were provided each year with logbooks and asked to record their daily catches (by number) of commercially legal lobsters and effort expended (traps hauled) throughout the fishing season. Also, lobster landings from several fishermen have been sampled for carapace length and sex periodically throughout each fishing season. Counts of traps in use were obtained from 1972 to 1981 by field staff who covered the fishing grounds in boat and counted lobster trap buoys. In this area traps are set close to shore on individual lines so that one buoy indicates the presence of one trap. These counts were done during early June when fishing effort, as indicated by the number of traps in use, is at its peak.

Thermographs have been maintained on the bottom near St. Chads at a depth of approximately 9 m during the lobster fishing season (April 20-July 15) each year from 1970 to 1979. Since April 1980, thermographs have been maintained at the site year-round.

In the fall of 1967, following the molting period, special fishing was carried out near St. Chads. Commercially legal lobsters were tagged with carapace strap tags (Wilder 1954) and released immediately after being removed from the traps. Field staff maintained frequent contact with fishermen during the following spring fishing season to ensure return of all recaptured tags. Carapace strap tagging was repeated in 1974 and has been each year since but over a much larger proportion of the lobster fishing grounds in the St. Chads-Burnside area than in 1967. Highly visible secondary marks (colored lobster claw bands positioned on the carpopodite of each claw) have been applied as well since 1976 to obtain estimates of tag loss over the 6-month period between tagging and the start of the following spring fishing season. Also starting in 1974, all lobsters caught during the autumn tagging period were examined for shell condition to determine whether each had molted during the preceding summer molting period (Ennis 1977).

Details of biological sampling and sphyrion tagging that have been carried out in the St. Chads-Burnside area are provided in Ennis (1971, 1972, 1980a). In addition to molt increment data, spyrion tagging provided data on distance moved and time at large.

RESULTS AND DISCUSSION

THE FISHERY

General Description

St. Chads and Burnside are neighboring communities located in the central portion of Bonavista Bay on the northeast coast of Newfoundland (Fig. 1). The lobster grounds in the area are a relatively narrow band of rocky bottom extending approximately 25 to 75 m offshore from mostly low to medium height (5-30 m) cliffs to depths generally less than 25 m. Many islands, inlets and smaller bays in the area provide a shoreline of approximately 45 km which has traditionally been fished by residents of these two communities. At the present time 10 licensed individuals fish for lobsters in the area and the number of conventional wooden-lathed traps each is licensed to use ranges from 50 to 300. A limit of 200 traps per fishermen was proposed for the area (Ennis 1982) but a uniform trap limit has not been implemented. Traps are set individually and usually in depths less than 20 m. Fishing is carried out from 6-9 m open boats mostly outboard but also inboard powered and practically all hauling is done manually. The annual fishing season opens April 20 and closes July 15, egg-bearing females and all lobsters smaller than 81 mm (3 3/16 in) carapace length are protected from exploitation.

Catch and Effort

Lobster fishing statistics (landings and number of traps) are available for Bonavista Bay (Statistical Area C) from 1953 and for Statistical Sections 10, 11 (which includes the St. Chads-Burnside area), 12 and 13 within Bonavista Bay since 1969 (Fig. 1). Statistical sections are the smallest units for which these data are available from the fisheries statistical reporting system.

Annual lobster landings in Bonavista Bay have fluctuated markedly (Fig. 2). From a peak of 662,419 lb (300 t) in 1958, landings declined (except for fairly high landings in 1966-67-68) to a low of 102,239 lb (46 t) in 1972 and subsequently increased steadily to 379,264 lb (172 t) in 1979. These longer term trends coincide with similar trends in landings for Newfoundland as a whole (Ennis 1982). Since 1979, landings have fluctuated between 356,957 lb (162 t) in 1981 and 219,385 lb (100 t) (preliminary data) in 1987.

A measure of nominal effort that is available (from 1956 to 1973) is the number of traps that fishermen indicated on their licence applications they intended to fish each year. For Bonavista Bay, this number increased from 23,788 in 1956 to 63,952 in 1965 then declined to 33,007 in 1972. The sharp drop which occurred in 1971 and 1972 was probably precipitated by the sharp drop in landings in 1969 and further declines to 1972. A licensing policy was implemented in 1976 which eliminated a number of licence holders from future participation in the fishery and restricted those remaining to the number of traps they had indicated on their 1975 licence applications that they intended to fish that year. As per this policy, in 1978 the licensed fishermen were registered to fish 51,891 traps. The consensus among DFO field personnel (and among fishermen) is that considerably more traps than the number allowed are being used. Obviously, there was a substantial increase in effort between 1972 and 1978 and this undoubtedly contributed to the increase in landings over this period (Fig. 2). The number of registered traps declined to 43,882 by 1982 through attrition of licensed fishermen. There have been substantive changes in requirements for licence transfer resulting in very few licences being eliminated from the fishery in recent years. Also, licences for which fewer than 100 traps are registered automatically increase to 100 traps when transferred while those for which more than 100 are registered remain at the higher number. This has resulted in an increase in the number of registered traps to 46,185 in 1987.

The pattern of accumulative catch and tag returns (derived from logbooks provided by several fishermen) over the fishing season varies somewhat from one year to another (Fig. 3). By mid-June (with 8 of the 14-week season gone by) the percentage of the total catch for the season already taken ranged from 61 in 1984 to 80 in 1983 and 1986 and the percentage of total tag recaptures ranged from 65 in 1984 and 1985 to 87 in 1983. Usually, fishing activity, as measured by the estimated number of trap hauls, increases sharply during the first two or three weeks of the season and drops sharply towards the end of the season (Fig. 3). The pattern of fishing activity over most of the season is quite variable. It is influenced by weather conditions and by the presence of ice during the early part of the season in some years. Variability in the percentage of available tags recaptured during weekly intervals over the season tends to fluctuate with changes in fishing activity (Fig. 3) but changes in bottom temperature (through its effect on lobster catchability) also contributes to this variability. Mean bottom temperataure during a particular part of the fishing season varies considerably from year to year and the pattern of change in temperature over the season is also highly variable (Fig. 3).

Catch Rates

The pattern of variation in weekly catch rates over the course of the fishing season is quite variable from year to year (Fig. 4). In some years there were pronounced peaks, usually during the 4th to 7th weeks of the season, while in others catch rates tended to be uniform throughout the season. Several factors contribute to catch rate variation over the fishing season. These include the fishing-up process, temperature changes, and variability in the number of traps on the grounds, number of traps hauled, soak time and weather conditions. Although there are frequently sharp fluctuations, temperature increases over the fishing season (Fig. 5) and tends to keep catch rates much higher than would be the case if the low early season temperatures prevailed throughout. When mean weekly catch rates for a season are adjusted to a standard temperature (see Ennis et al. 1982), the week to week fluctuations are smoothed and the decline over the season is usually more pronounced (Fig. 12, Table 5). The highest and lowest mean CPUE's for 1-week intervals are 0.58 lb (0.26 kg)/trap haul during the 6th week of fishing in 1979 and 0.04 lb (0.02 kg)/trap haul during the 1st week of fishing in 1984.

Season averages ranged from 0.17 lb (0.08 kg)/trap haul in both 1971 and 1974 to 0.37 lb (0.17 kg)/trap haul in 1976. Year to year variation in total trap hauls, exploitation rates and standing stock contribute to the variability in mean CPUE's between seasons. Despite the licensing policy implemented in 1976, the number of traps used increased by around 75% from 1976 to 1981 (Table 1). There was a reduction in the total number of trap hauls for the 1976 season from an estimated 37,500 in 1975 to 27,200 (Table 1). Since 1976, however, total annual trap hauls increased substantially and have ranged from 48,100 in 1977 to 74,400 in 1983. Exploitation rates ranged from 62 to 65% from 1975 to 1977 but have generally been much higher in subsequent years. The highest was estimated at 84% in 1985 (Table 1). Petersen tag-recapture estimates indicate substantial variation in standing stock over the 1975 to 1986 period. Standing stock increased in 1977, remained fairly high through 1984, then dropped in 1985 and 1986 (see later section).

Size and Sex Composition of Landings

In the St. Chads-Burnside area, lobsters just below the minimum legal size of 81 mm (3 3/16 in) carapace length grow an average of 12 mm on molting in the case of males and 10 mm in the case of females (Ennis 1972). This means that the majority of lobsters growing to commercial sizes in any year will be contained within the 81-92 mm and 81-90 mm size ranges for males and females, respectively. The percentage of lobsters landed that are within theses recruit size ranges has ranged from 53.4 to 75.5 for males and 53.5 to 80.2 for females (Fig. 6). These percentages fluctuate due to annual variation in exploitation rate and recruitment to the standing stock. Since 1975, however, they have generally been higher than during the late 1960s-early 1970s and this is a reflection of higher exploitation rates. The sexes are usually very close to equally represented in the landings, however, the M:F ratio has varied from 1:1.27 (in favor of females; $P < .001$) in 1971 to 1:0.76 (in favor of males; $P < .001$) in 1975 (Table 2).

Water Temperature

Temperature conditions on the St. Chads-Burnside lobster grounds vary considerably during the fishing season and between fishing seasons. At the start of the season (April 20), temperature on the bottom at a depth of 9 m ranges between -2 and 1°C (Fig. 5). Temperatures around 0°C sometimes persist well into May. By the end of May, temperature ranges from <-1 to around 4.5°C and by the end of the season (July 15) from around 1 to 12°C. Sharp fluctuations of 4 to 6°C over periods of 2 to 4 days usually occur several times during each fishing season. These occur as a result of strong onshore or offshore winds either piling up warm surface water or causing deep, cold water to upwell in the near-shore area. Accumulated degree-days (above 0°C) from April 20 to July 15 are available for 13 years from 1970. These range from 146.7 degree-days in 1985 to 469.0 in 1981. During the annual temperature regime, the mean temperature decreases to a minimum of <-1°C during March, it doesn't increase to 0°C until sometime in May and reaches a maximum of around 12°C during August. Fall cooling begins in September (Fig. 7).

BIOLOGY

Various aspects of the biology and ecology of lobsters in the St. Chads-Burnside area have been treated in detail in other papers. References are provided for all of these, however, only those aspects not previously published or those for which additional data or analyses are available will be covered in detail in this report.

Length-weight Relationships

Curvilinear carapace length-whole weight relationships derived from log-log (base 10) regression analysis are presented for St. Chads-Burnside lobsters (Fig. 8). The log-log equations are as follows:

males: $\log ww = 3.1374 \log cl - 3.3693$ ($n = 381$; $r^2 = .99$)
non-ovigerous females: $\log ww = 2.9443 \log cl - 3.0081$ ($n = 423$; $r^2 = .99$)
ovigerous females: $\log ww = 2.8102 \log cl - 2.7172$ ($n = 28$; $r^2 = .96$)

The log-log relationships for males and non-ovigerous females were compared by analysis of covariance. Mean squares were significantly different ($P < .001$). For the male relationship the slope was significantly greater than 3 ($P < .001$), indicating positive allometric growth, whereas for non-ovigerous females the slope was significantly less than 3 ($P < .001$), indicating negative allometric growth. Details of additional length-weight and various length-length relationships for Bonavista Bay lobsters are provided in Ennis (1971).

Reproductive Biology

Details of size-maturity relationships for male and female lobsters in the St. Chads-Burnside area are provided in Ennis (1980a).

Growth

Growth per molt. Premolt and postmolt carapace lengths for sphyrion tagged lobsters that were known to have molted only once between tagging and recapture were analyzed using a program (HIATT) which was developed by Somerton (1980) for fitting a pair of straight lines to crustacean growth increment data. Plots of premolt-postmolt data often demonstrate an abrupt change in scope which is associated with attainment of sexual maturity. However, for both male and female data from the St. Chads-Burnside area a single straight line (the so called Hiatt growth diagram) fitted the data better than a pair of straight lines (Fig. 9).

The single straight line equations derived from least squares regression of postmolt carapace length on premolt carapace length are:

males: $y = 1.1241 X + 2.3525$ ($n = 54$, $r = .98$)
females: $y = 1.0007 X + 9.7348$ ($n = 56$, $r = .97$)

Analysis of covariance demonstrated that these relationships had similar residual variances but different slopes ($P < .01$). The slope for males is significantly greater than 1 ($P < .01$) and meets Kurata's (1962, p. 31) requirement ($b > 1.05$) for progressive growth, i.e. molt increment increases with premolt size. The slope for females, however, is not significantly different from 1 ($P > .9$) and meets Kurata's requirement ($1.05 > b > .95$) for arithmetic growth, i.e. molt increment is constant in relation to premolt size. Molt increments calculated from the equations above for premolt carapace lengths of 70 and 100 mm are 11.04 mm and 14.8 mm, respectively for males, which represent relative molt increments of 15.8% and 14.8%, and for females is 9.8 mm at both sizes which represent relative increments of 14.0% and 9.8%.

Proportions molting. Estimates of proportions molting were derived from the fall shell condition sampling as described by Ennis (1978a). Curves of proportion molting in relation to size thus derived (Fig. 10) show substantial annual variation for males and particularly for females. Much of this variation is related to year to year variation in temperature conditions (Ennis 1983a) and, at least in the case of females, to variation in density of lobsters (Ennis 1987). A detailed consideration of possible biases associated with the method of estimating proportions molting and of other factors related to the greater variability among females is provided in Ennis et al. (1982, 1986).

The data for all years were combined and "average" proportion molting-size relationships were derived (Fig. 10). The probit equations for these relationships are:

$$\text{males: } y = 14.1448\ X - 0.0977\ (n = 5502)$$
$$\text{females: } y = 11.2748 - 0.0645X\ (n = 4344)$$

The data (Fig. 10) indicate that for both sexes all animals in the 60-70 mm carapace length range molt in a given year. There is no evidence that in this area lobsters of this size range molt more than once annually. Estimates from the probit equations indicate that proportion molting drops to 50% at 94 mm and 97 mm for males and females, respectively and to near 0% at 127 mm and 148 mm. At sizes >105 mm, 3 of 27 males and 15 of 19 females were molters. The prevalence of molters among large females is inconsistent with the data at smaller sizes and probably relates to their reaching large sizes as a result of their egg-bearing status during the preceding fishing season providing protection from exploitation (Ennis et al. 1986).

Growth curves. Growth curves were generated by combining molt increment and proportions molting data (all years combined - Fig. 11) as described by Ennis (1978a, 1980b). Ages 6 and 7 were assigned to the starting size of 61 mm CL. The basis for assigning these ages is given in Ennis (1980b). Estimates of mean size at successive ages were obtained and these were run on a version of the Allen (1966) program to generate estimates of the von Bertalanffy parameters. The resulting equations are as follows:

$$\text{males: } l_t = 114.1\ [1-e^{-0.3108(t-3.6650)}]$$

$$\text{females: } l_t = 121.6\ [1-e^{-0.2113(t-3.7875)}]$$

Growth curves derived from these equations (Fig. 11) indicate that males attain larger sizes at age up to 15 years beyond which females grow faster. The larger L_∞ for females is likely to be an artifact associated with the sampling situations imposed by the fishery as considered in the preceding section.

Estimates of Standing Stock

Standing stock was estimated using both the Petersen and Leslie methods, initially for 1971 and subsequently for each year from 1976 to 1986. Details of the analyses and a consideration of the assumptions of the models are provided by Ennis et al. (1982) in relation to similar estimates in a study of lobsters at Comfort Cove, Notre Dame Bay. The general conclusion regarding these assumptions reached in the Comfort Cove study apply as well to this study of lobsters at St. Chads-Burnside. The main difference related to the Petersen model and involved an estimated tag loss of 3.9% at St. Chads-Burnside (Table 3) compared to 1.7% at Comfort Cove. Where violations of the assumptions could be identified, corrections were made to eliminate bias in the estimate. Absolute accuracy is not a major consideration since the main purpose of this study is to measure and explain major fluctuations in abundance. Any biases that may be present should be consistent from year to year and any substantial differences in the estimates should reflect real changes in population size.

The data on which the Petersen estimates are based are provided in Table 4 and those for the Leslie estimates in Table 5 and Fig. 12. Confidence limits for the Petersen estimates (Fig. 13) ranged from ±8.2 to ±17.0% and those for the Leslie estimates (Fig. 13) ranged from -10.8 to -32.0% and from +16.8 to +413.7. Confidence limits were unacceptably wide for the 1978, 1979, 1984 and 1985 Leslie estimates. Otherwise, trends in the two estimates were similar. The Petersen estimates indicate a sharp upward trend from 1975 to 1977, relatively small-scale fluctuations up to 1984, and a sharp downward trend in 1985 and 1986.

Since 1975, exploitation rates in the St. Chads-Burnside area fishery have ranged from a low of 61.6% in 1977 (Table 1) to a high of 83.9% in 1985 and have been generally increasing over the period. Recruitment is a major factor in determining the size of the standing stock, particularly with the high exploitation rates in recent years. The upper limits of the recruit size ranges (81-92 mm for males; 81-90 mm for females) were determined from the premolt-postmolt relationships. The number of recruits (i.e. the number of lobsters that molted to commercial size (≥81 mm CL) since the preceding fishing season) was estimated as described by Ennis (1979) using data from the preceding fall shell condition sampling and from commercial catch sampling during the fishing season. The proportion of recruits in the standing stock has been increasing since 1975 and reached 70.4% in 1985 and 1986 (Table 6).

The increased recruitment in 1976 and 1977, as indicated by the standing stock estimates for the St. Chads-Burnside area lobster population, appears to have been widespread in Bonavista Bay. The landings data for Bonavista Bay (since 1953) and for Statistical Sections (since 1969) 10, 11 (which includes the St. Chads-Burnside area), 12 and 13, all of which make up Bonavista Bay, indicate increased abundance beyond 1975 (Fig. 2). The sharp drop in recruitment in 1985 was not reflected in the landings. The exploitation rate at St. Chads-Burnside increased from 69.5% in 1984 to 83.9% in 1985 and this trend apparently was widespread enough to keep landings relatively high throughout the Bay. However, landings dropped in 1986, despite as 82.3% exploitation rate, reflecting the decreased recruitment indicated by the standing stock estimates. Preliminary data indicate a further drop in landings in 1987.

Ecology

Food and feeding, short-distance seasonal movements, and various aspects of territorial behaviour of lobsters in the St. Chads area are described in Ennis (1973, 1983a, 1984a, 1984b).

Tagged lobsters at large for 11 to 13 months moved an average of 0.4 km at St. Chads (Table 7). Rank correlation coefficients (Table 8) indicated no significant relationship between time at large and distance moved. There was a high proportion of tagged lobsters that did not move or that moved only short distances. For example, 53% of the lobsters at large 11 to 13 months (335-395 days) or more were recaptured in the immediate vicinity of where they were initially caught and tagged and 88% of the remainder moved no more than 1 km (Table 9). There was little variation related to sex or size in the proportion of non-movers. Only in the case of males was there a significantly greater proportion of non-movers among the larger animals (Table 9).

There were no significant differences in the distance-traveled (m)/time-at-large (d) ratio between males and females or between the two size groups considered within each sex, either including or excluding the non-movers (Table 10). At St. Chads the coast is irregular and heavily indented (Fig. 14). The "lobster grounds" are a very narrow band of rocky bottom that slopes very steeply from the mainly 5-10 m high cliff shoreline to a depth of about 25 m at 25-75 m from shore. Headlands are generally 25-30 m and higher cliffs that rise almost vertically from the water's edge in many places. Adjacent to these headlands the bottom slopes even more steeply and is mainly rocky ledges and large boulders. These features of the coastal physiography and bottom topography appear to impede and possibly restrict the movement of lobsters in the area.

GENERAL DISCUSSION

The increased recruitment in Bonavista Bay during the mid to late 1970s was part of a widespread phenomenon. In Notre Dame and Placentia Bays there were sharp increases in recruitment during the 1970s as well (Ennis et al. 1982, 1986). The cause of the increased recruitment during the 1970s is uncertain. Environmental conditions for survival of lobster larvae to settlement stage or for survival and growth of post-larval and early juvenile stages may have been much better than average during the late 1960s - early 1970s. Another possibility is improved conditions (e.g. reduced competition) for growth and survival of early juveniles and prerecruits because of low levels of recruit abundance as indicated by commercial landings during the early 1970s.

In all three bays, the period of increased recruitment was preceded by a period of sharply declining landings and fishing effort. It is difficult to judge whether these events in the fishery might have affected the level of egg production to the point where subsequent recruitment was affected. Exploitation rates might have declined somewhat as a result of the declining effort thereby allowing greater relative levels of egg production but the declining landings over the period would indicate reduced levels of abundance of egg-bearing females that would negate the preceding effect. It seems likely that the dramatically increased recruitment observed in these areas was mostly independent of events in the fishery.

Along with the increased recruitment during the 1970s there were dramatic increases in fishing effort (Ennis 1982) that also contributed to the increased landings in Notre Dame, Bonavista, and Placentia Bays over the period. The increased exploitation rates observed at Comfort Cove, Arnold's Cove and St. Chads-Burnside over this period are no doubt indicative of a general trend in these area and in Newfoundland generally.

Assessment using data from several Newfoundland areas, including St. Chads-Burnside, clearly indicate that current exploitation rates are considerably in excess of those that would maximize yield per recruit at the current minimum legal size (Ennis 1978b, 1980c). In addition, an egg per recruit assessment (Ennis 1985) indicates that egg production could be substantially increased with an increase in size limit and/or a reduction in exploitation rate.

A large portion of the annual egg production in Newfoundland lobster populations is by undersized females carrying eggs for the first time (Ennis 1985, 1987). Attard and Hudon (1987) found that large female lobsters both extrude and hatch their eggs earlier than smaller females and also that energy content per egg increased with female size. Larvae hatched early have a survival advantage associated with higher temperature and the higher energy content of eggs from large females would likely enhance larval survival as well. If so, large females contribute relatively more to recruitment than their greater fecundity.

Whether increased egg production would result in increased recruitment to standing stocks is unknown. Ennis (1985) suggested that, because current levels of landings are well below historical levels in most fisheries, parent stock sizes are probably at the low end of the range, i.e. on the ascending limb of a stock-recruitment curve; in which case it seems reasonable to assume that, within the limits of habitat carrying capacity, an increased level of egg production within a population would result in increased recruitment.

The catch and effort data that are available for the Newfoundland lobster fishery are not amenable to analysis using surplus yield models which might give a reliable indication of MSY and associated fishing effort. The main reasons are an inconsistent and largely inadequate measure of effort and highly variable application and enforcement of the size limit and berried female regulations over the history of the fishery. There is little doubt that were a surplus yield analysis possible, it would show that current effort is substantially greater than that associated with MSY and current yields are substantially less than MSY.

Sharp declines in recruitment occurred at Arnols's Cove and Comfort Cove following peaks in 1976 and 1981, respectively (Ennis et al. 1982, 1986; and unpublished data) and more recently at St. Chads-Burnside. Lobster fisheries are very heavily dependent on recruitment sincce the preceding fishing season because of very high exploitation rates and relatively slight variation in recruitment can result in substantial fluctuation in landings. Historically, there have been substantial declines in landings in all Newfouandland lobster fishing areas (Ennis 1982), presumablty at lower levels of exploitation than currently prevail. At the current high exploitation rates, considerable instability in landings, with declines to levels of the early 1970s and possibly lower, should be anticipated.

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Table 1. Counts of lobster traps on the fishing grounds at St. Chads-Burnside (1975-81), estimated number of trap and exploitation rates for each season, 1975-86.

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Trap counts	520	531	456	657	883	824	929	-	-	-	-	-
Est. trap hauls*	37,514	27,238	48,133	50,028	54,663	63,209	71,037	59,880	74,471	64,871	70,782	68,174
Exploitation rate (%)	63.1	65.2	61.6	68.7	80.2	64.0	82.5	71.1	79.4	69.5	83.9	82.3

*Calculated from actual trap hauls of select fishermen and proportion of select fishermen's tag returns to total returns.

Table 2. Sex ratios in commercial landings at St. Chads-Burnside, 1971-86.

Year	Male	Female	M:F	P	X^2
1971	995	1267	1:1.27	<.001	32.71
1972	977	873	1:0.89	<.025	5.85
1973	1228	1390	1:1.13	<.005	10.02
1974	452	413	1:0.91	>.10	1.76
1975	1597	1216	1:0.76	<.001	15.60
1976	1514	1399	1:0.92	<.05	4.54
1977	1456	1243	1:0.85	<.001	16.81
1978	1757	1592	1:0.91	<.005	8.13
1979	2093	1859	1:0.89	<.001	13.86
1980	1301	1494	1:1.15	<.001	13.33
1981	1549	1565	1:1.01	>.75	0.08
1982	1288	1510	1:1.17	<.001	17.61
1983	2093	2004	1:0.96	>.10	1.93
1984	1616	1868	1:1.16	<.001	18.23
1985	1998	2025	1:1.01	>.50	0.18
1986	1789	1905	1:1.06	>.05	3.64

Table 3. Estimates of tag loss between tagging in the fall and the fishing season the following spring at St. Chads-Burnside, 1977-85.

Year	No. of fishermen canvassed	No. of tags returned	No. of lobsters observed with secondary marks only	% tags lost
1977	11	258	14	5.4
1978	15	325	12	3.7
1979	17	361	14	3.9
1981	16	403	14	3.5
1982	9	276	7	2.5
1984	11	146	6	4.1
1985	11	450	19	4.2
All years	-	2219	86	3.9

Table 4. Data from which Petersen estimates of population size at St. Chads-Burnside were obtained.

Year	No. of lobsters tagged preceding fall			No. of tagged lobsters in population at beginning of fishing season			No. of tagged lobsters returned during fishing season			Exploitation rate (%) M and F combined	No. of tagged lobsters returned by fishermen providing catch data		No. of lobsters caught by fishermen providing catch data	
	M	F	Total	M	F	Total	M	F	Total		M	F	M	F
1975	270	127	397	260	122	382	160	81	241	63.1	101	45	2343	1784
1976	113	75	188	109	72	181	72	46	118	65.2	54	29	3025	2796
1977	323	148	471	311	142	453	189	90	279	61.6	112	45	3808	3251
1978	299	190	489	287	183	470	204	119	323	68.7	131	79	4609	4177
1979	300	194	494	288	187	475	228	153	381	80.2	135	93	5024	4462
1980	287	210	497	276	202	478	179	127	306	64.0	87	69	2966	3405
1981	302	186	488	290	179	469	231	156	387	82.5	116	73	3919	3960
1982	260	237	497	250	228	478	177	163	340	71.1	80	88	2810	3295
1983	340	160	500	327	154	481	262	120	382	79.4	107	53	3591	3437
1984	172	135	307	165	130	295	114	91	205	69.5	42	49	2913	3367
1985	324	212	536	311	204	515	267	165	432	83.9	157	110	3912	3965
1986	296	204	500	285	196	481	237	159	396	82.3	150	100	3280	3492

Table 5. Data on which Leslie estimates of population size at St. Chads-Burnside were obtained.

	Week of fishing season	Observed CPUE	Avg. temp (°C)	CPUE adusted to 4°C	Cummulative catch
1975	1	0.064	0.2	0.221	39
	2	0.088	1.2	0.185	142
	3	0.159	1.2	0.334	382
	4	0.269	0.8	0.670	1216
	5	0.132	1.9	0.218	2075
	6	0.145	2.7	0.192	2484
	7	0.186	3.1	0.224	3036
	8	0.186	4.3	0.176	3686
	9	0.236	5.2	0.193	4417
	10	0.142	6.1	0.102	5081
	11	0.196	7.0	0.126	5665
	12	0.194	7.8	0.114	6354
	13	0.145	8.0	0.083	6757
1976	1	0.108	0.2	0.373	19
	2	0.199	0.6	0.547	149
	3	0.183	0.7	0.478	380
	4	0.355	1.2	0.746	1051
	5	0.419	3.5	0.463	2378
	6	0.341	4.0	0.341	3713
	7	0.287	4.4	0.267	4736
	8	0.263	5.7	0.200	5529
	9	0.232	7.0	0.149	6025
	10	0.340	8.4	0.187	6541
	11	0.292	8.9	0.153	7217
	12	0.253	8.8	0.133	7789
	13	0.250	10.6	0.112	8153
1977	1	-	-	-	-
	2	0.160	0.4	0.490	126
	3	0.166	0.3	0.539	553
	4	0.250	3.0	0.308	1203
	5	0.291	3.9	0.297	2233
	6	0.396	4.8	0.345	3898
	7	0.339	4.2	0.327	5766
	8	0.261	4.7	0.231	7292
	9	0.300	4.0	0.300	8701
	10	0.169	7.1	0.107	9797
	11	0.189	6.7	0.126	10582
	12	0.196	5.9	0.145	11415
	13	0.282	6.7	0.188	12167

. . . Cont'd

Table 5. (Cont'd.)

	Week of fishing season	Observed CPUE	Avg. temp (°C)	CPUE adusted to 4°C	Cummulative catch
1978	1	0.244	1.1	0.533	17
	2	0.255	1.4	0.497	225
	3	0.181	1.7	0.318	801
	4	0.204	2.2	0.308	1659
	5	0.449	2.6	0.609	3545
	6	0.313	3.9	0.319	5537
	7	0.224	3.1	0.270	6629
	8	0.252	4.0	0.252	7681
	9	0.260	3.8	0.270	8725
	10	0.268	6.1	0.193	9887
	11	0.281	6.0	0.205	11222
	12	0.201	9.8	0.097	12321
	13	0.272	9.4	0.136	13127
1979	1	-	-	-	-
	2	0.106	-0.9	0.421	15
	3	0.289	0.1	1.068	126
	4	0.231	0.8	0.576	622
	5	0.369	0.4	1.130	2258
	6	0.427	0.4	1.307	4990
	7	0.474	3.1	0.570	8276
	8	0.273	1.9	0.450	10960
	9	0.203	2.2	0.306	12392
	10	0.194	6.3	0.136	13525
	11	0.151	5.8	0.113	14411
	12	0.173	6.9	0.112	15096
	13	0.139	5.5	0.109	15660
	14	0.140	9.8	0.067	15841
1980	1	0.137	0.6	0.376	195
	2	0.162	1.1	0.354	779
	3	0.223	1.4	0.434	1383
	4	0.293	1.8	0.498	2628
	5	0.194	1.4	0.378	4148
	6	0.148	1.9	0.244	5141
	7	0.201	3.1	0.242	6302
	8	0.199	3.9	0.203	7667
	9	0.185	4.6	0.167	8984
	10	0.179	5.0	0.151	10141
	11	0.172	5.1	0.143	11037
	12	0.245	7.1	0.155	11843
	13	0.294	7.7	0.174	12387

. . . Cont'd

Table 5. (Cont'd.)

	Week of fishing season	Observed CPUE	Avg. temp (°C)	CPUE adusted to 4°C	Cummulative catch
1981	1	0.199	0.8	0.496	158
	2	0.252	1.1	0.551	1258
	3	0.293	2.2	0.442	3233
	4	0.339	3.3	0.390	5873
	5	0.270	2.4	0.386	8630
	6	0.197	5.0	0.166	10551
	7	0.151	6.0	0.110	11814
	8	0.117	6.6	0.079	12596
	9	0.142	7.5	0.086	13297
	10	0.201	6.8	0.132	14086
	11	0.216	7.9	0.125	14887
	12	0.200	11.0	0.087	15624
	13	0.186	11.4	0.078	16033
1982	1	0.160	-0.6	0.635	68
	2	0.126	-0.6	0.500	448
	3	0.170	-0.3	0.675	1342
	4	0.345	2.3	0.506	2770
	5	0.307	2.6	0.416	4332
	6	0.181	1.8	0.308	5545
	7	0.139	2.3	0.204	6482
	8	0.218	4.6	0.196	7651
	9	0.229	5.9	0.169	9094
	10	0.162	5.9	0.120	10182
	11	0.200	4.8	0.174	10963
	12	0.227	4.1	0.223	11688
	13	0.246	6.5	0.168	12180
1983	1	-	-	-	-
	2	0.118	-1.9	0.468	3
	3	0.104	-0.4	0.413	143
	4	0.246	1.6	0.447	1125
	5	0.395	1.6	0.717	3997
	6	0.211	2.5	0.294	6856
	7	0.251	2.5	0.349	8677
	8	0.203	2.9	0.256	10599
	9	0.164	5.3	0.132	12174
	10	0.177	5.7	0.134	13410
	11	0.196	6.3	0.137	14569
	12	0.184	7.9	0.107	15672
	13	0.161	6.5	0.110	16495

. . . Cont'd

Table 5. (Cont'd.)

	Week of fishing season	observed CPUE	Avg. temp (°C)	CPUE adusted to 4°C	Cummulative catch
1984	1	-	-	-	-
	2	-	-	-	-
	3	-	-	-	-
	4	0.029	-1.6	0.115	1
	5	0.076	-1.7	0.302	99
	6	0.187	0.0	0.742	1044
	7	0.257	-0.6	1.020	2913
	8	0.241	2.4	0.344	5044
	9	0.208	3.2	0.245	7064
	10	0.207	4.5	0.190	8656
	11	0.230	5.3	0.185	10253
	12	0.261	6.2	0.185	12048
	13	0.201	4.2	0.194	13501
	14	0.267	6.3	0.187	14110
1985	1	-	-	-	-
	2	0.068	-0.9	0.270	15
	3	0.069	-0.5	0.274	81
	4	0.050	-0.4	0.198	166
	5	0.128	0.4	0.392	660
	6	0.225	0.7	0.588	2042
	7	0.280	3.2	0.330	4222
	8	0.153	-0.2	0.607	6036
	9	0.143	0.4	0.438	7100
	10	0.183	2.0	0.293	8381
	11	0.189	4.0	0.189	9855
	12	0.172	5.7	0.131	11196
	13	0.166	3.5	0.183	12266
	14	0.104	4.7	0.092	12721
1986	1	0.115	-0.1	0.493	220
	2	0.180	1.3	0.364	1117
	3	0.148	1.5	0.278	2061
	4	0.212	1.4	0.413	3272
	5	0.207	3.3	0.238	5164
	6	0.168	4.3	0.159	6830
	7	0.154	3.5	0.170	7950
	8	0.079	4.5	0.072	8502
	9	0.111	4.9	0.095	8887
	10	0.125	5.7	0.095	9452
	11	0.115	7.4	0.070	10069
	12	0.123	9.5	0.061	10509
	13	0.106	10.2	0.049	10701

Table 6. Estimates of the percentage of recruits in the standing stock at St. Chads-Burnside, 1975-86.

	Standing stock estimate		Percent in recruit size range[1]		Percent molters in recruit size range[2]		Number recruits in standing stock		Percent recruits in standing stock M and F combined
1975	5998	4773	68.0	72.1	83.2	81.1	3394	2791	57.4
1976	6052	6806	69.6	75.7	92.9	96.1	3913	4951	68.9
1977	10517	10109	70.9	80.2	89.1	88.7	6644	7191	67.1
1978	10058	9609	66.0	73.4	92.7	91.1	6153	6425	64.0
1979	10678	8926	70.4	73.0	92.7	92.7	6968	6040	66.4
1980	9339	9877	70.0	72.6	93.8	94.4	6132	6769	67.1
1981	9750	9635	70.9	75.1	93.9	89.7	6491	6491	67.0
1982	8711	8481	75.5	71.9	92.1	96.4	6057	5878	69.4
1983	10909	9868	67.6	78.5	94.0	92.7	6932	7181	67.9
1984	11249	8824	70.0	72.0	92.1	94.2	7252	5985	65.9
1985	7727	7325	72.6	77.8	92.9	94.5	5212	5386	70.4
1986	6214	6813	75.5	73.9	92.3	96.1	4331	4839	70.4

[1]Based on commercial catch sampling.

[2]Based on shell condition sampling preceding fall.

Table 7. Summary of time-at-large/distance-moved data for tagged lobsters at St. Chads.

Time at large (days)	No. of lobsters	Mean CL (mm) at tagging	Distance moved (m)		% No movement	% Moving			
			Range	Mean		up to 500 m	501-1000 m	1001-1500m	>1500m
1-30	57	80.4	0-2050	145	88	4	2	2	5
31-60	14	80.9	0-670	82	86	7	7	0	0
61-150	21	76.1	0-4880	280	86	5	5	0	5
151-250	45	86.5	0-2290	402	58	9	16	13	4
251-334	55	78.6	0-3000	333	64	13	9	11	4
335-395	17	73.9	0-2777	373	53	24	18	0	6
396-500	4	65.8	0-	0	100	0	0	0	0
501-1000	37	74.5	0-5700	570	51	16	19	5	8
>1000	25	67.1	0-850	227	67	7	27	0	0

Table 8. Spearman rank correlation coefficients for various sets of time-at-large/distance-moved data for tagged lobsters at St. Chads.

	Corr. coeff.	P	N
Including non-movers			
Males	.2790	.001	134
Females	.1666	.057	131
Excluding non-movers			
Males	-.0839	.598	42
Females	-.2247	.163	40

Table 9. Comparisons of proportions of non-movers among tagged lobsters at St. Chads. These were tested using chi square from 2x2 contingency table and corrected for continuity (χ^2_c).

	No.	Proportion	No.	Proportion	χ^2_c
Males vs females	134	0.69	131	0.70	<0.001
Males:					
71-80 mm vs 81-90 mm	41	0.56	28	0.82	3.97[a]
Females:					
71-80 mm vs 81-90 mm	40	0.65	40	0.68	0.217

[a] $\chi^2_{.05} = 3.84$, 1 df.

Table 10. Comparison of distance moved (m)/time at large (d) for different groups of tagged lobsters at St. Chads. These were tested using chi square from the Kruskal-Wallis one-way analysis of variance by ranks.

	Distance/ time at large	No. of lobsters	Distance/ time at large	No. of lobsters	X^2
Including non-movers					
Males vs females	5.4	134	5.6	131	0.00
Males: 71-80 mm vs 81-90 mm	10.0	41	3.0	28	3.61
Females: 71-80 mm vs 81-90 mm	3.7	40	4.1	40	0.03
Excluding non-movers					
Males vs females	17.3	42	18.4	40	0.81
Males: 71-80 mm vs 81-90 mm	22.8	18	16.6	5	2.01
Females: 71-80 mm vs 81-90 mm	10.7	14	12.8	13	3.05

a $X^2_{.05} = 3.84$, 1 df.

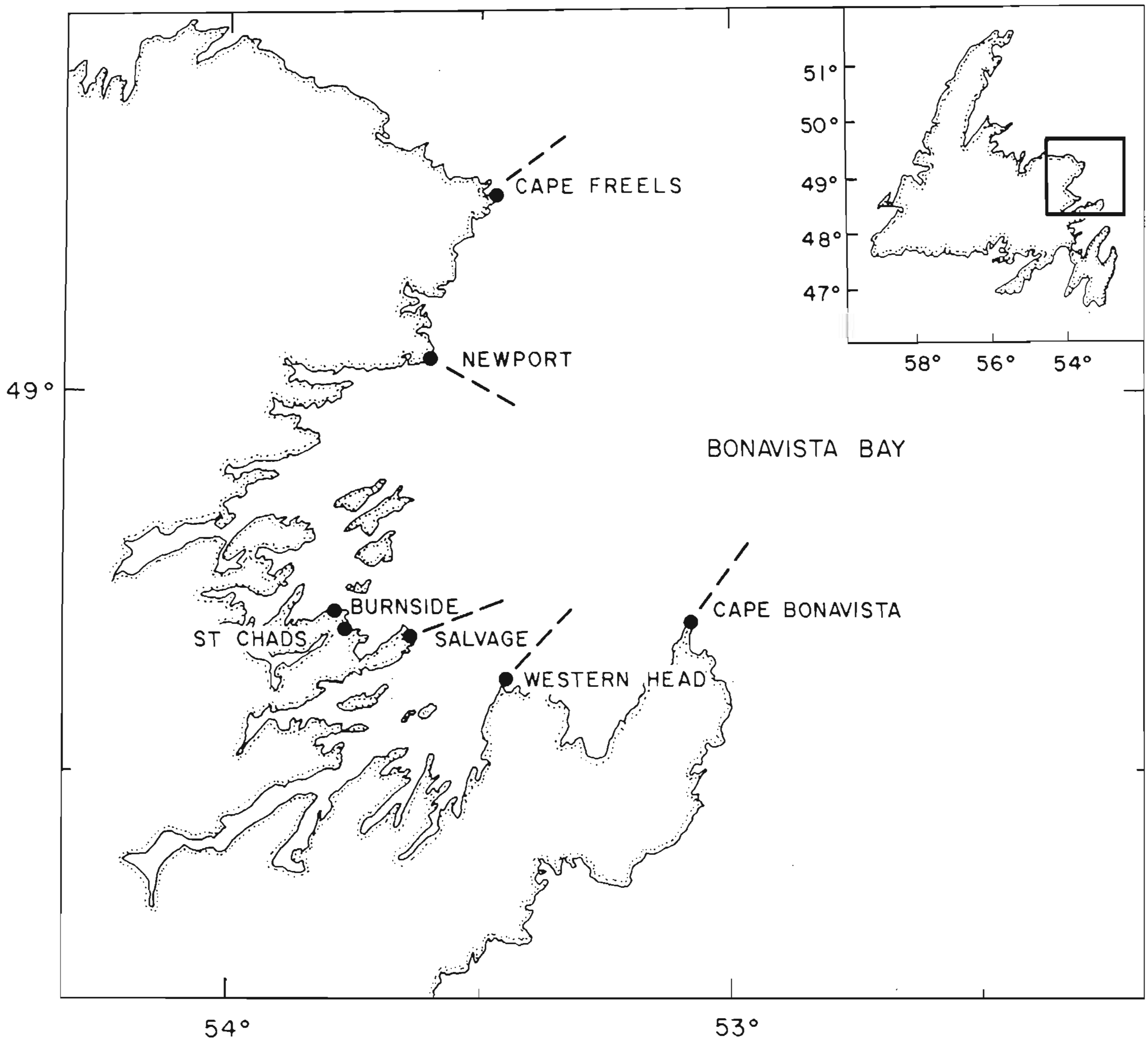


Fig. 1. Map of Bonavista Bay (Statistical Area C, Lobster Area 5), Newfoundland, with boundaries of Statistical Sections 10-13 indicated.

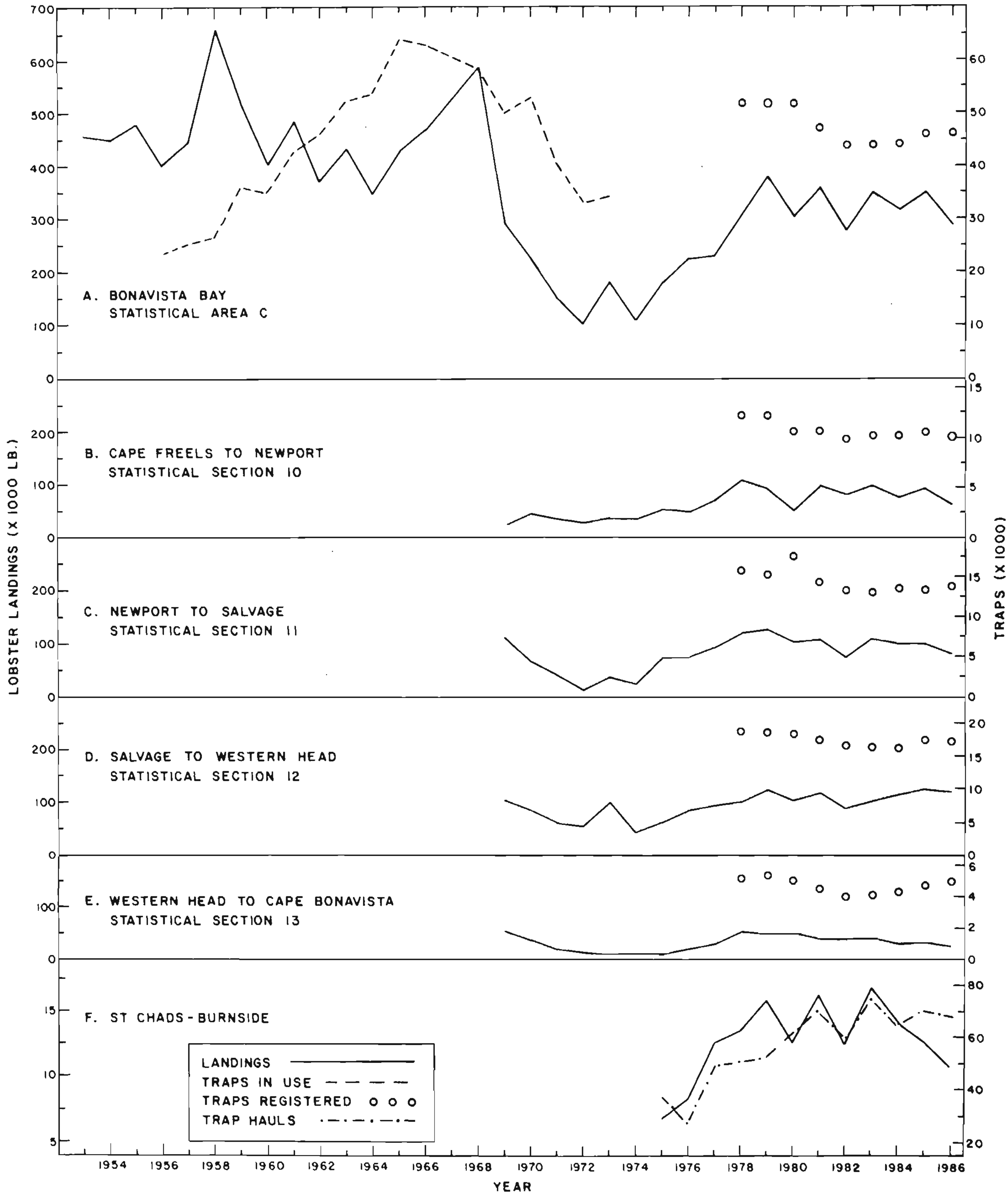


Fig. 2. History of lobster landings and effort for Bonavista Bay (Statistical Area C), for Statistical Sections 10-13 and estimated landings and trap hauls for the St. Chads-Burnside area.

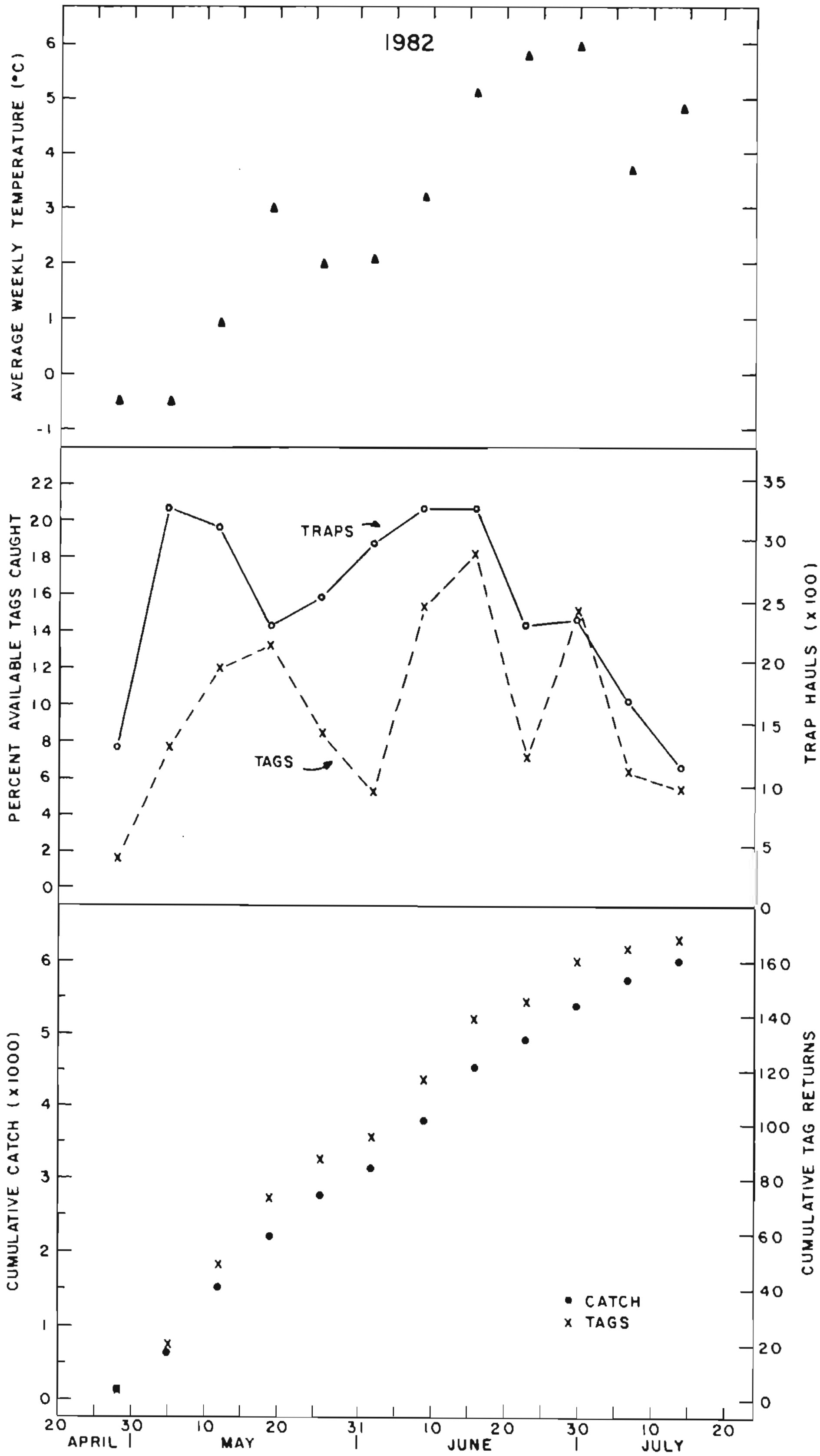
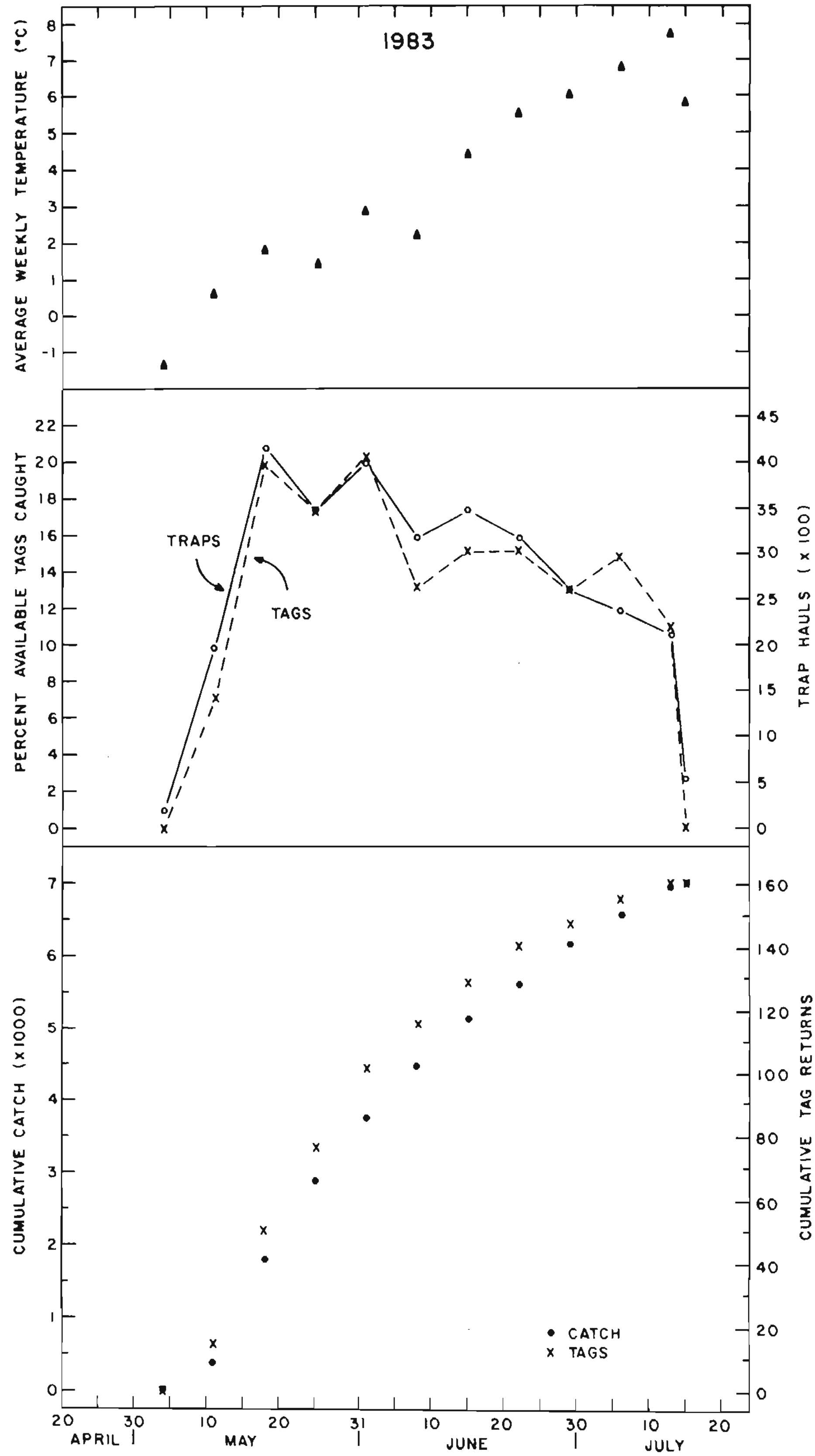


Fig. 3. Average bottom temperature, percentage of available strap tagged lobsters caught and estimated number of trap hauls at weekly intervals along with cumulative catch and tag returns during the 1982 to 1986 fishing seasons at St. Chads-Burnside.



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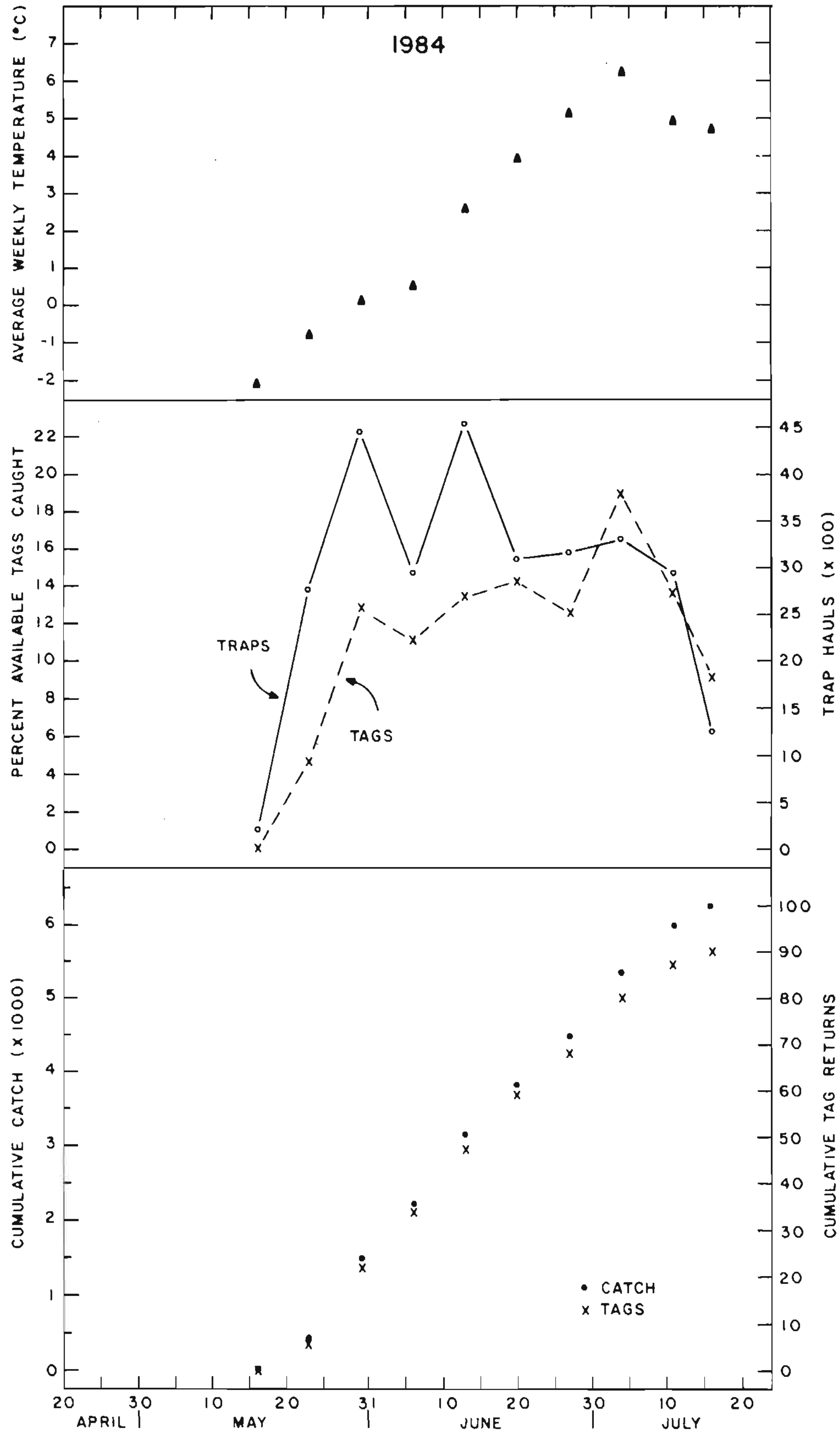
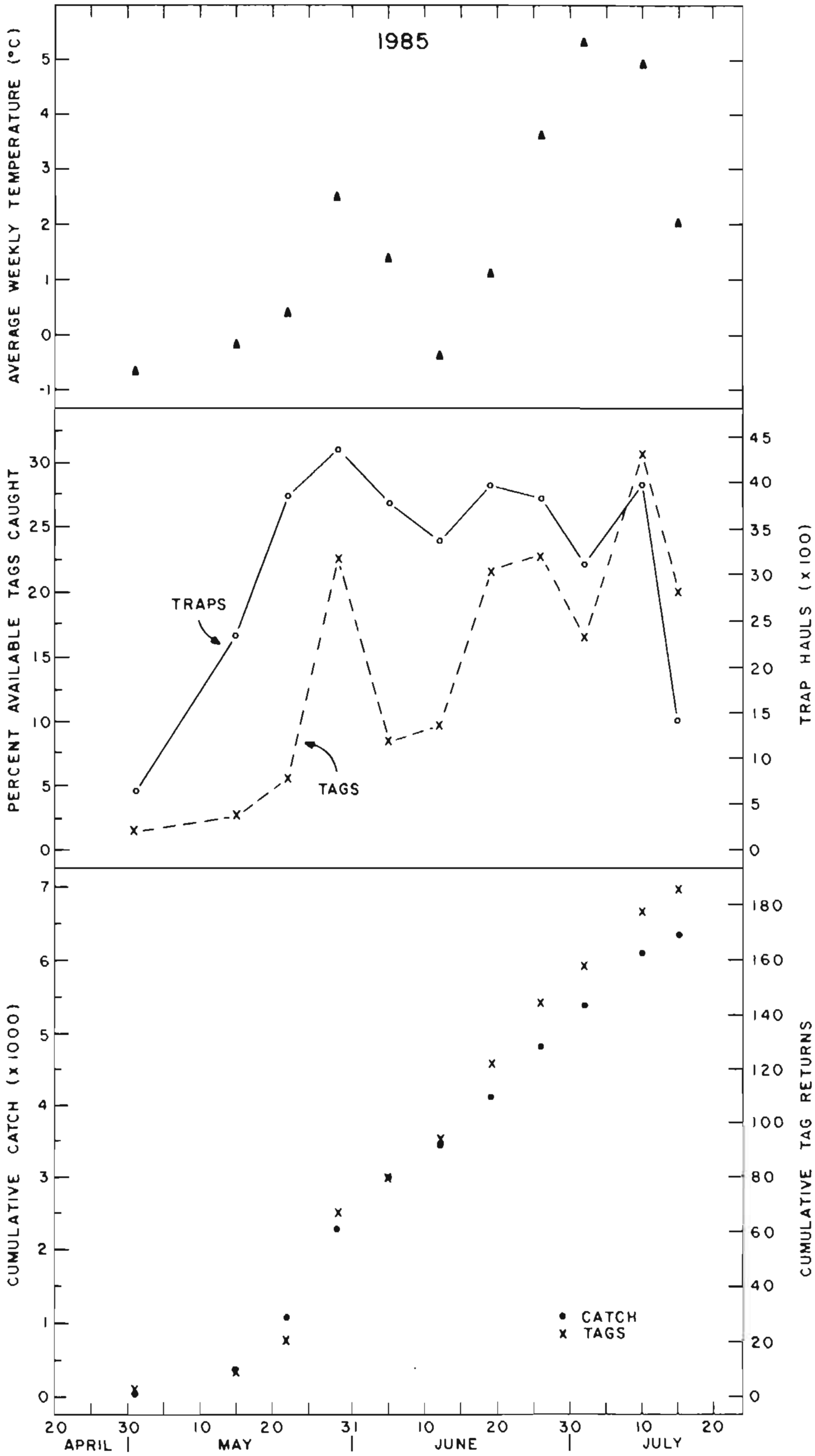


Fig. 3. Average bottom temperature, percentage of available strap tagged lobsters caught and estimated number of trap hauls at weekly intervals along with cumulative catch and tag returns during the 1982 to 1986 fishing seasons at St. Chads-Burnside.



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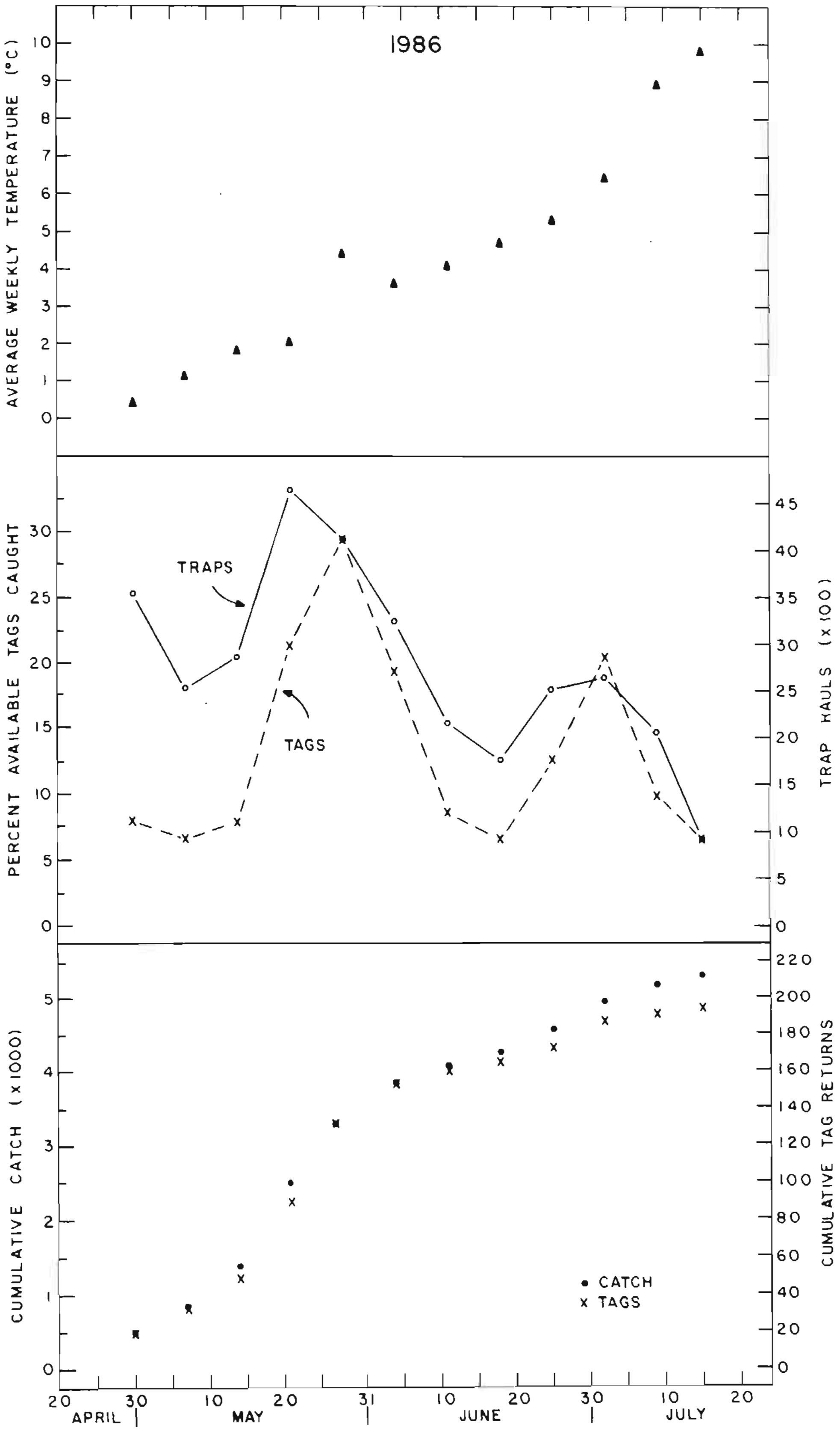

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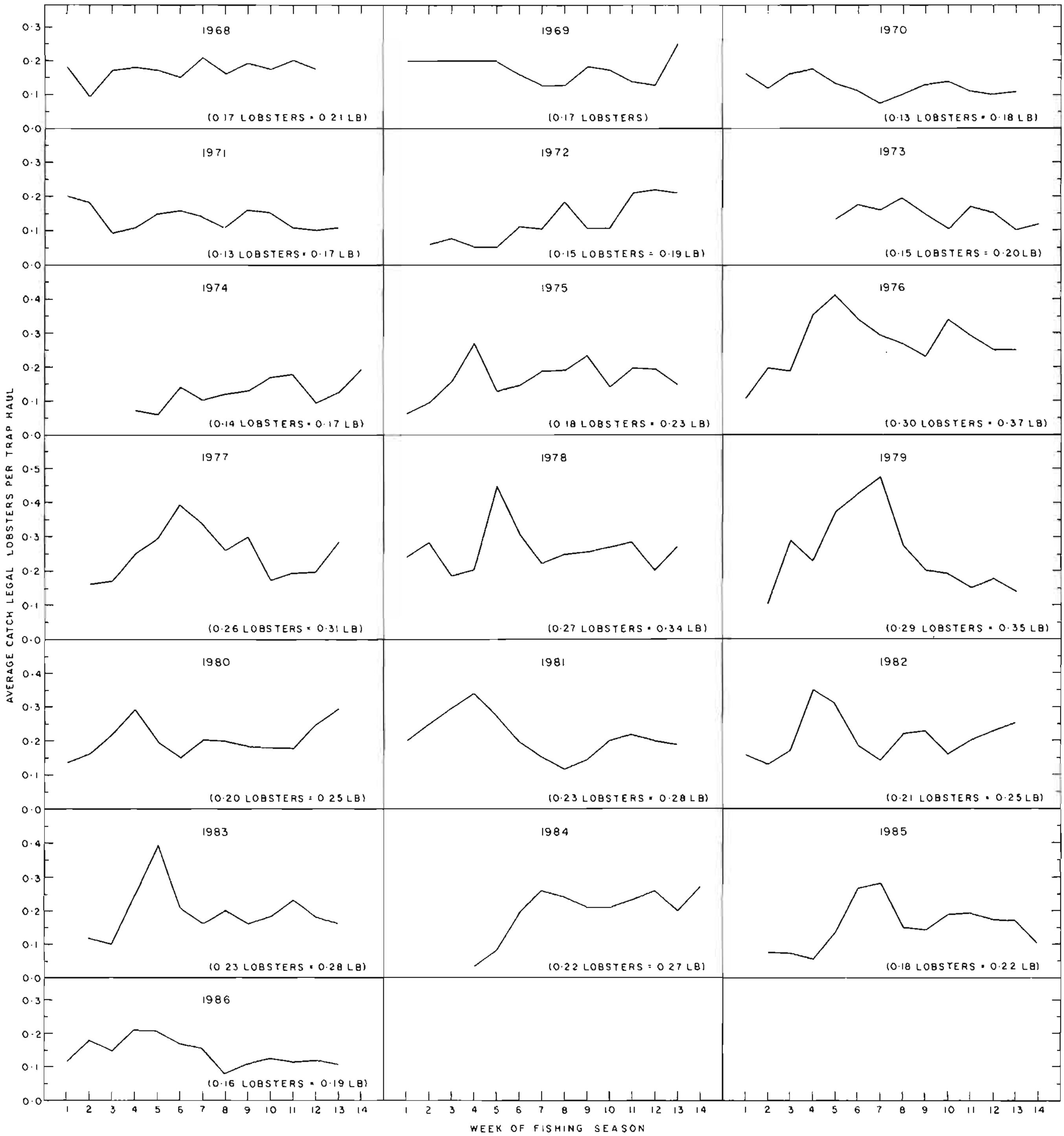

Fig. 4. Average weekly CPUE (number of commercial lobsters per trap haul) throughout the 1968-86 fishing seasons.

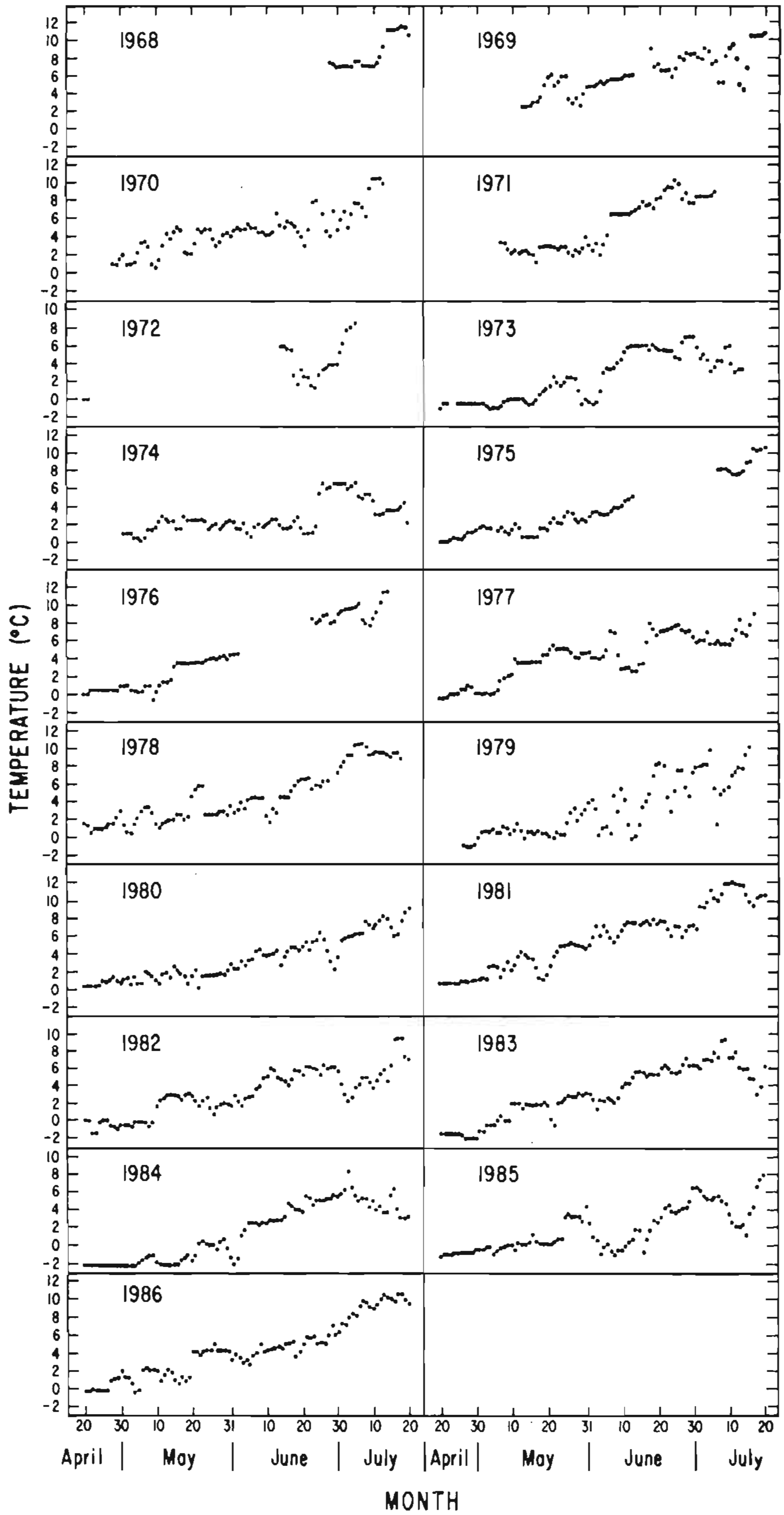

Fig. 5. Daily temperatures (°C) at a depth of 9 m on the lobster grounds at St. Chads-Burnside during April-July from 1968 to 1986.

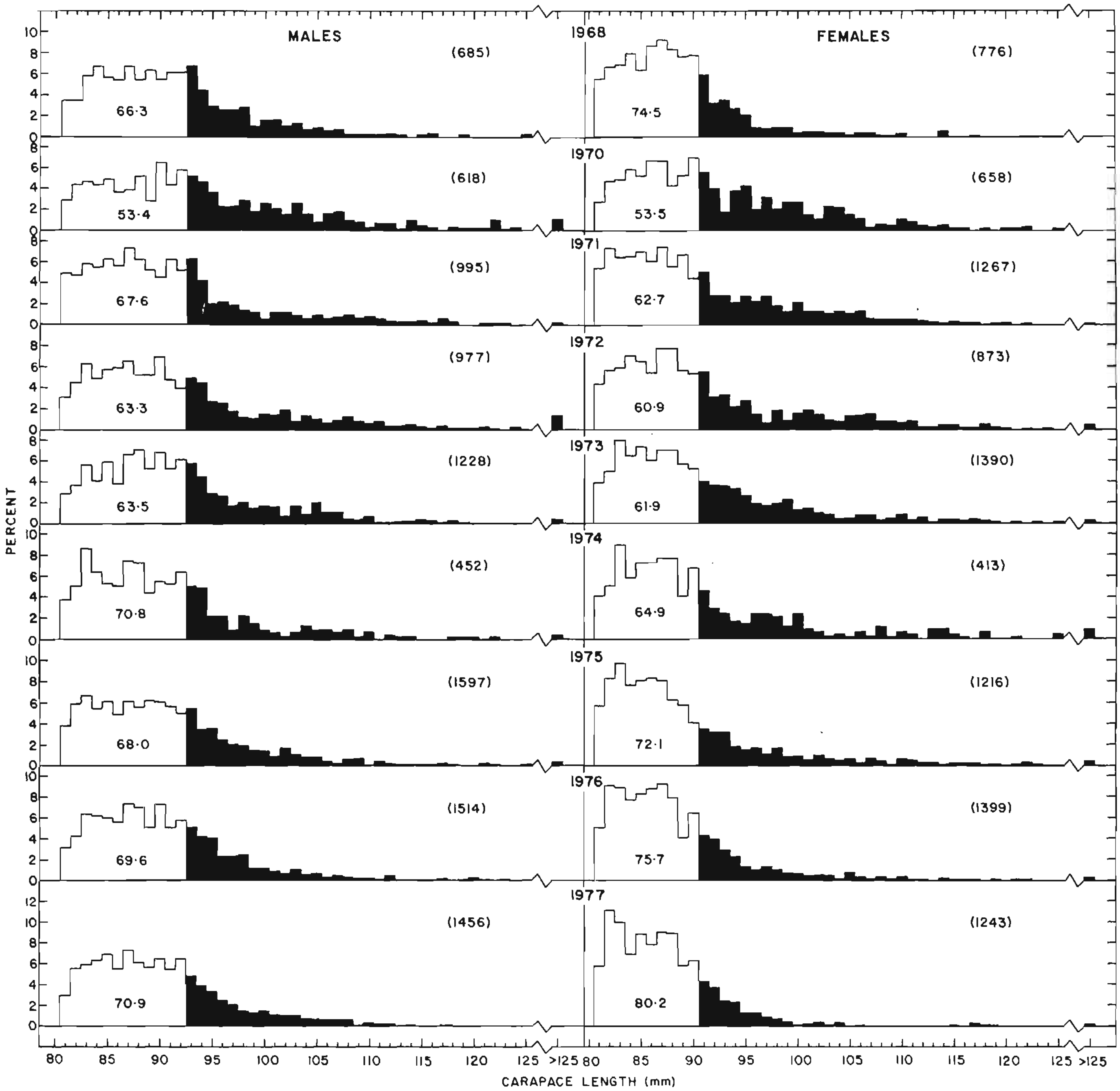

Fig. 6. Size frequency distributions of lobsters landed at St. Chads-Burnside during the 1968-86 fishing seasons. Clear areas and the numbers therein represent proportion within the recruit size ranges. Sample sizes are indicated.

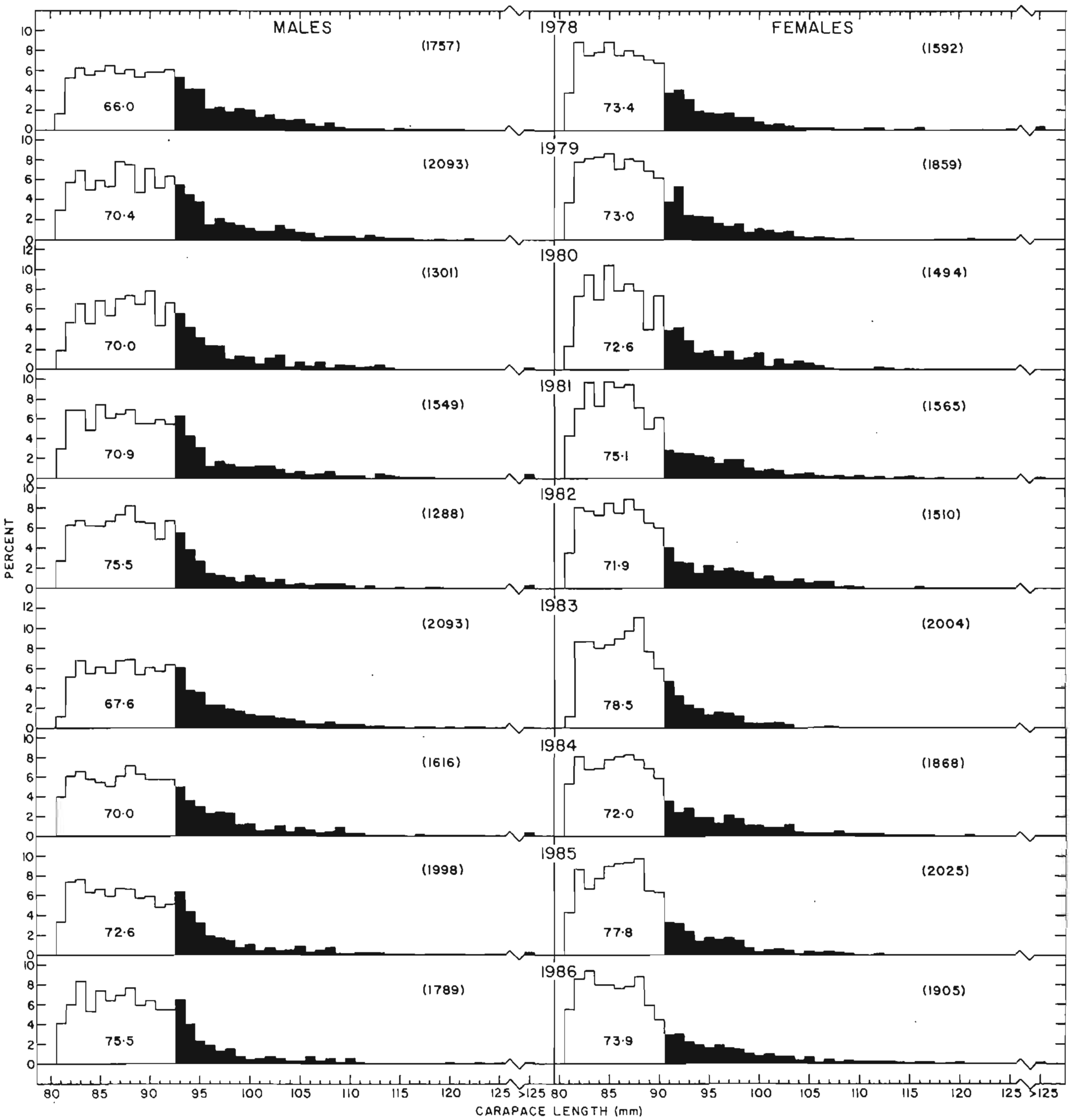

Fig. 6. Size frequency distributions of lobsters landed at St. Chads-Burnside during the 1968-86 fishing seasons. Clear areas and the numbers therein represent proportion within the recruit size ranges. Sample sizes are indicated.

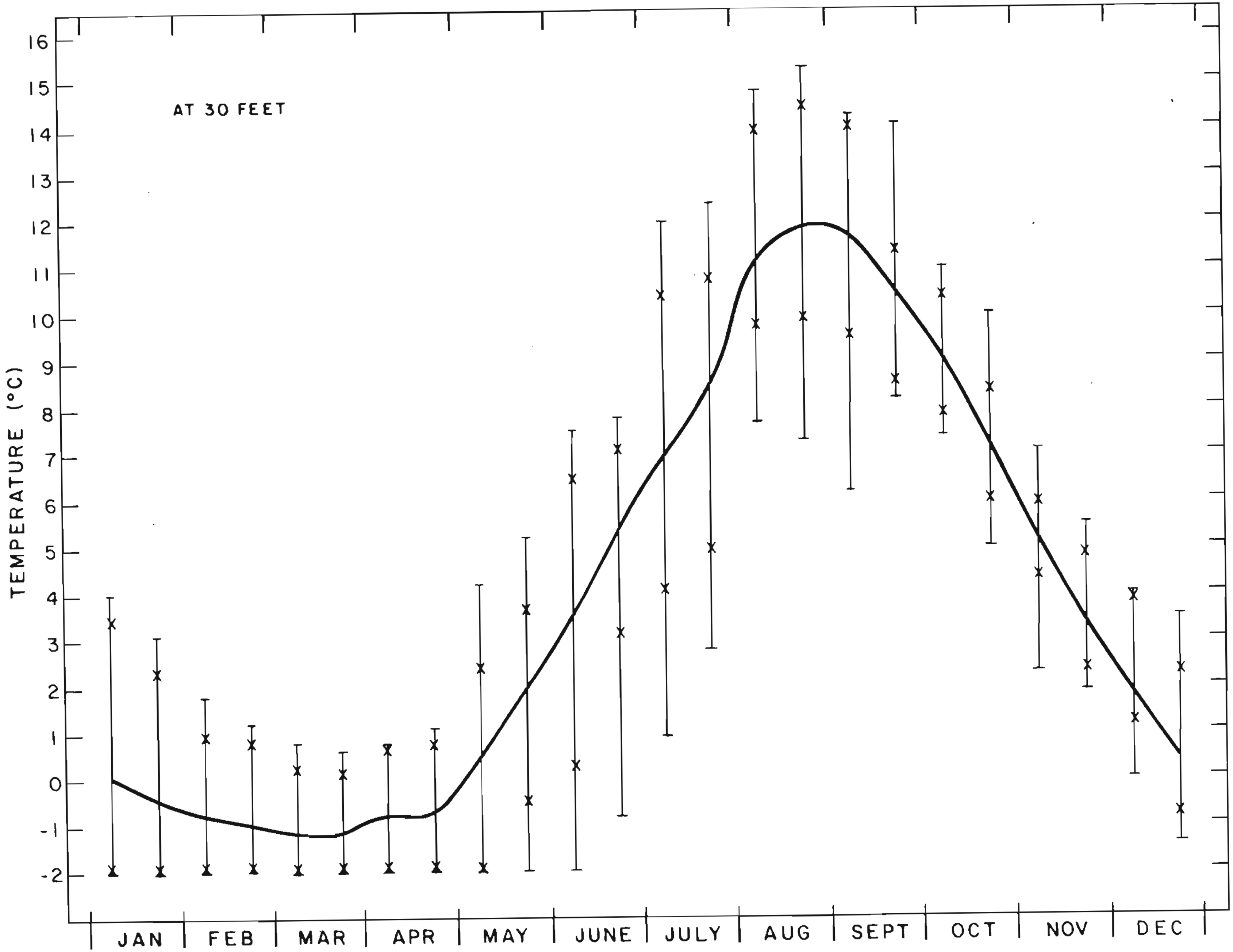

Fig. 7. Annual temperature of 9 m depth at St. Chads-Burnside. Points represent the average of the mean daily temperatures for the first and second half of each month for the years 1980-87. Vertical lines indicate the range in daily mean temperatures, x's indicate the range in 2-week mean temperatures.

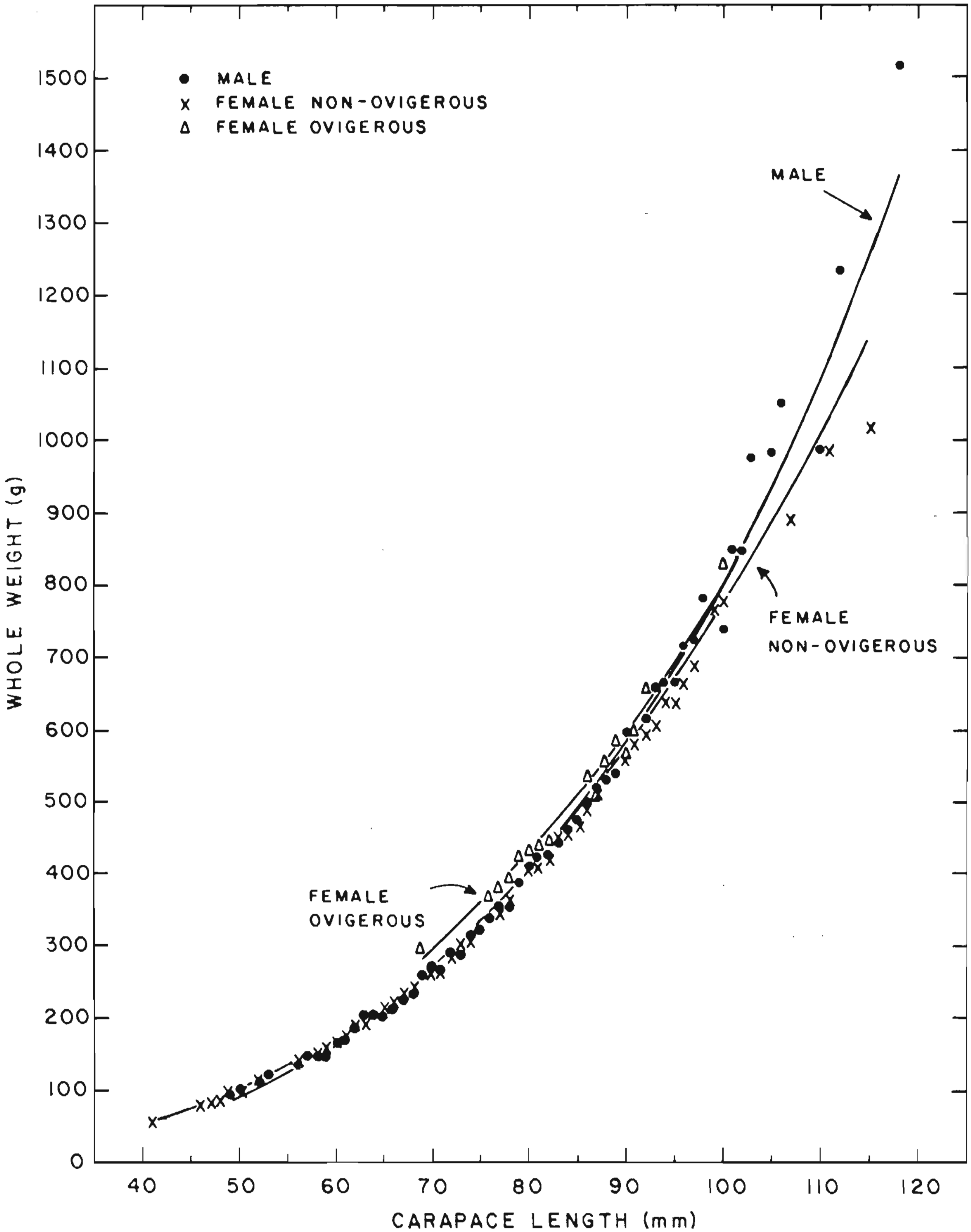

Fig. 8. Carapace length-whole weight relationships for St. Chads-Burnside lobsters.

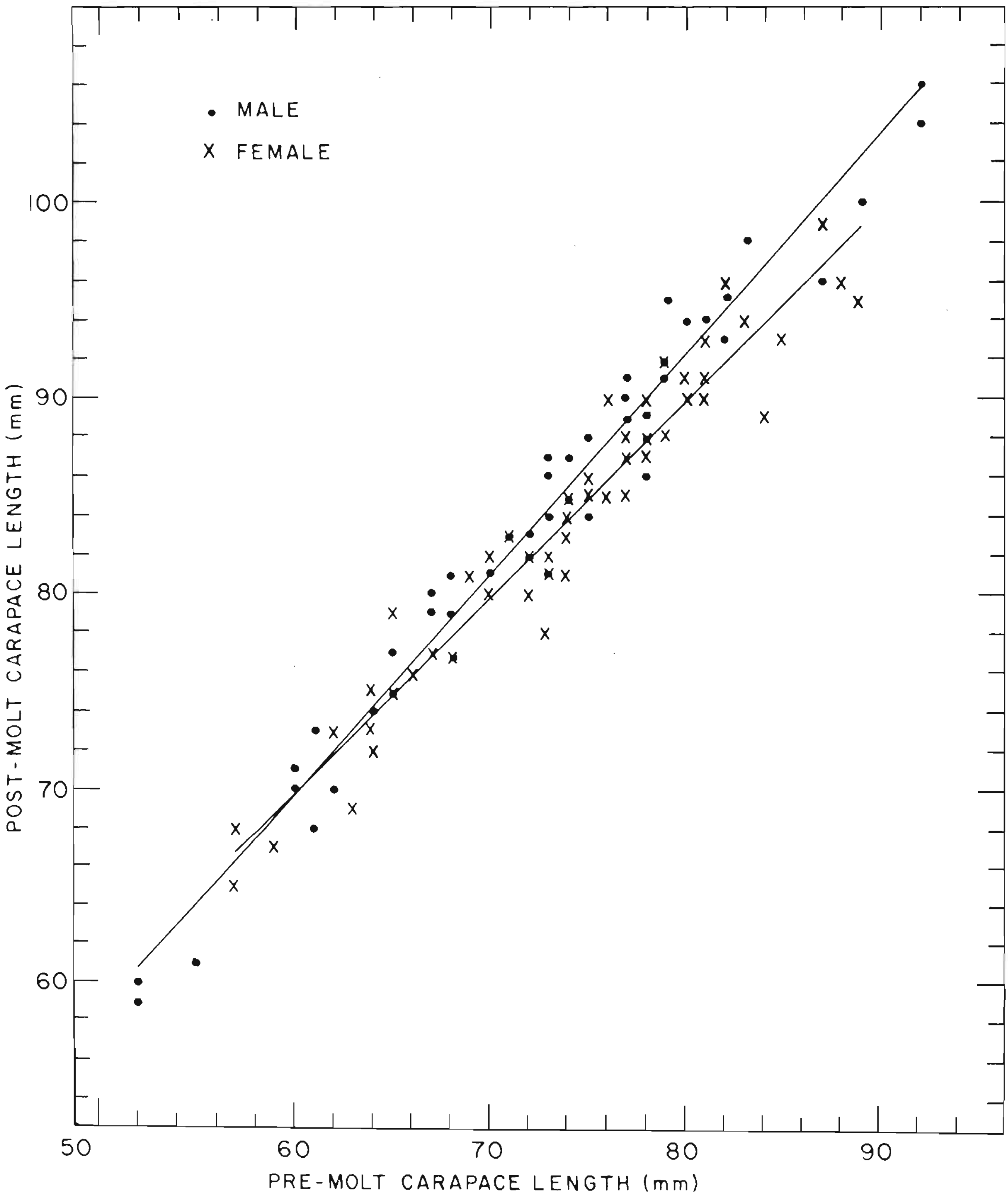

Fig. 9. Premolt-postmolt carapace length relationships for St. Chads-Burnside lobsters.

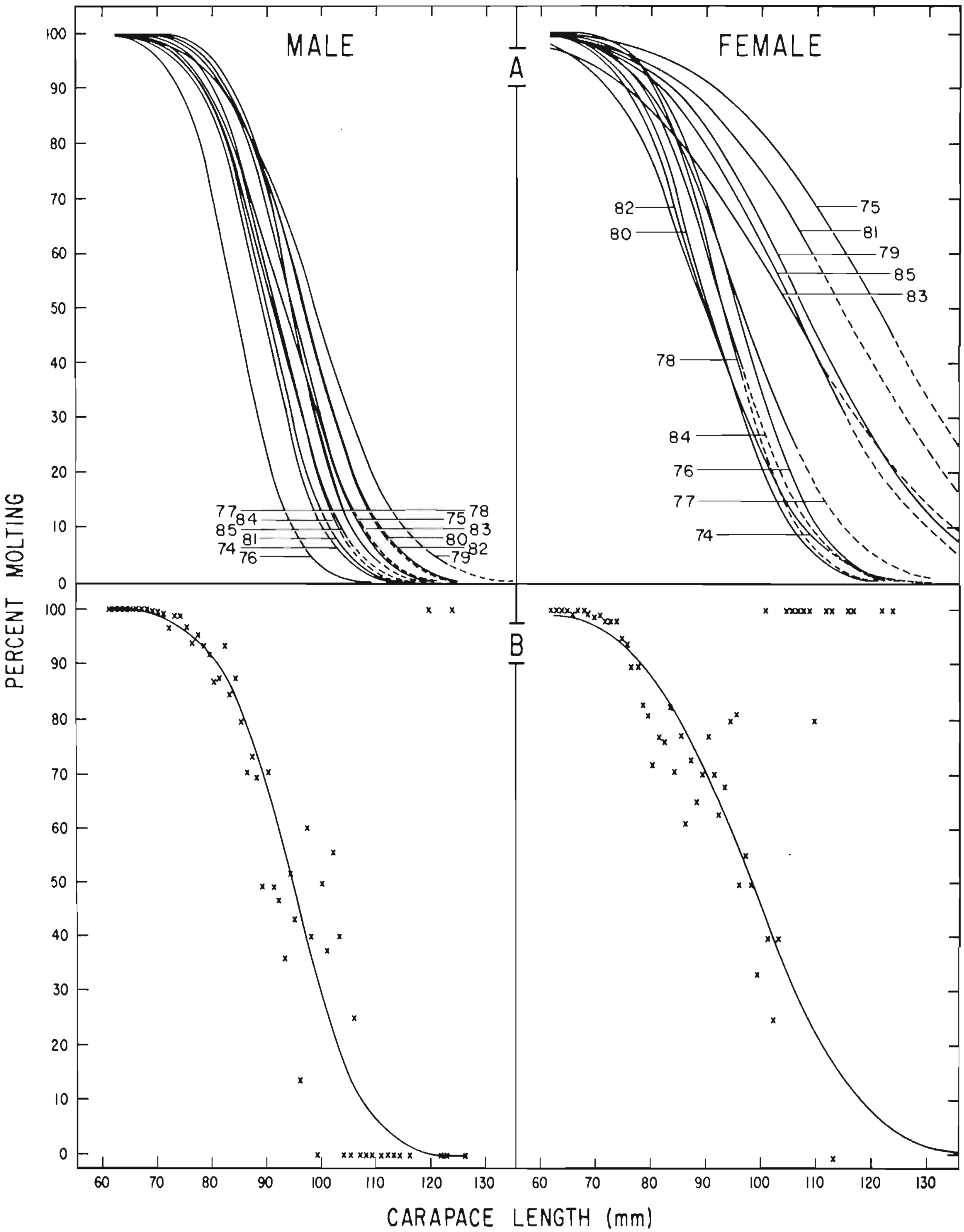

Fig. 10. Carapace length-proportion molting relationships for St. Chads-Burnside lobsters. A-relationship for each year 1974-85; B - relationship for all years combined.

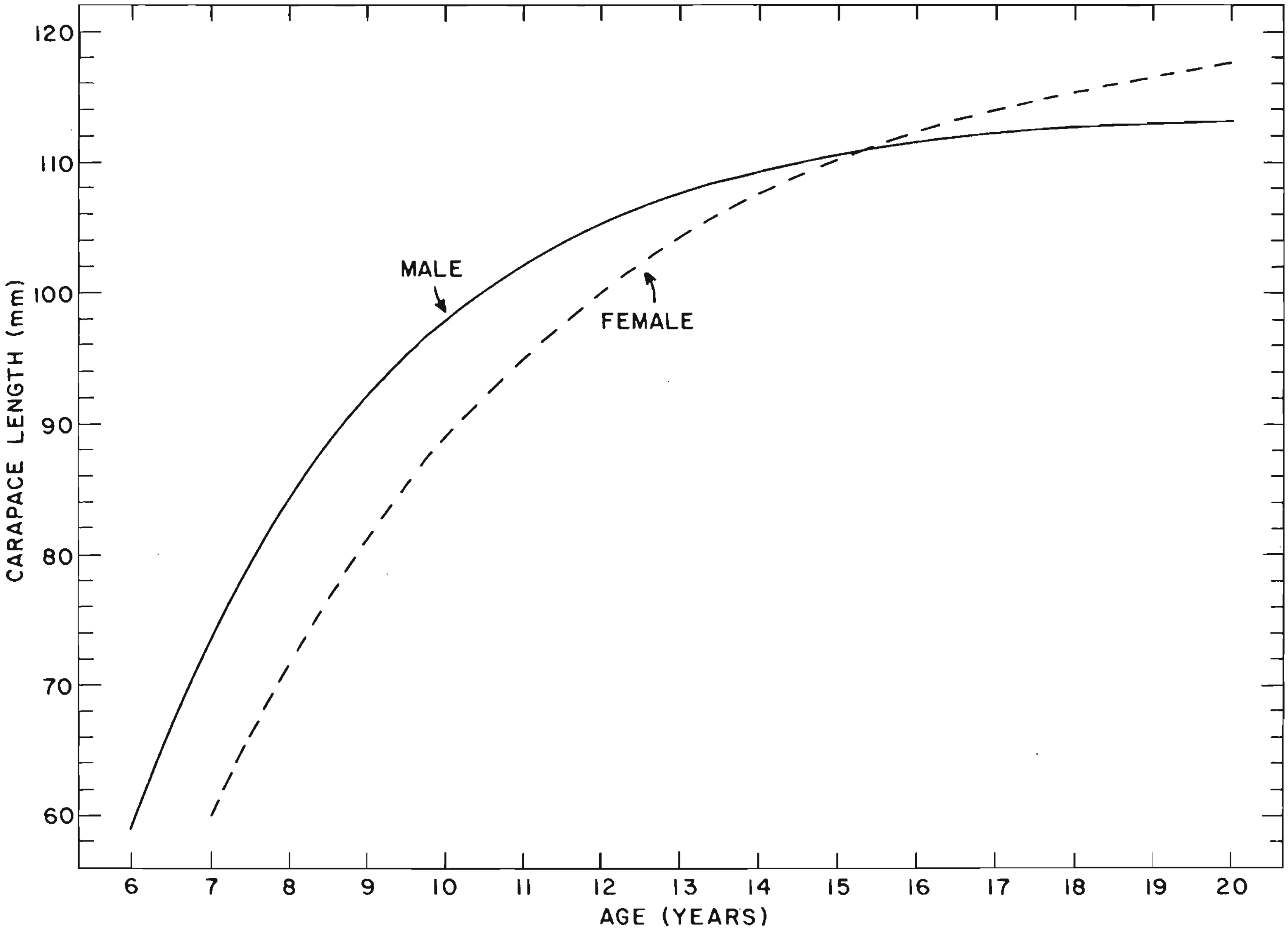

Fig. 11. Growth curves for St. Chads-Burnside lobsters.

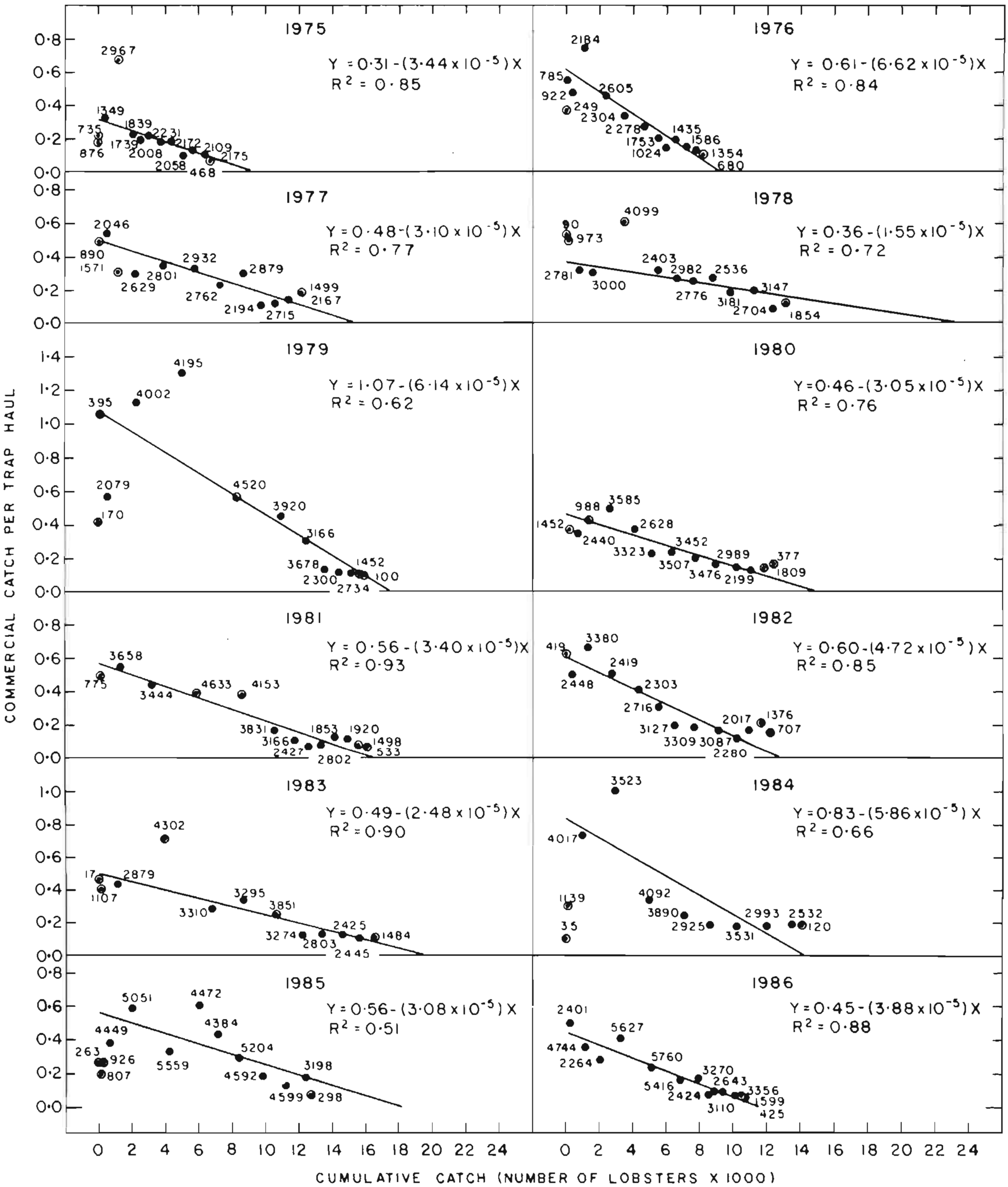

Fig. 12. Leslie analyses of St. Chads-Burnside CPUE data (adjusted to 4°) for 1975-86. Circled points were omitted from the regressions. Numbers adjacent to points are total trap hauls on which the CPUE's are based.

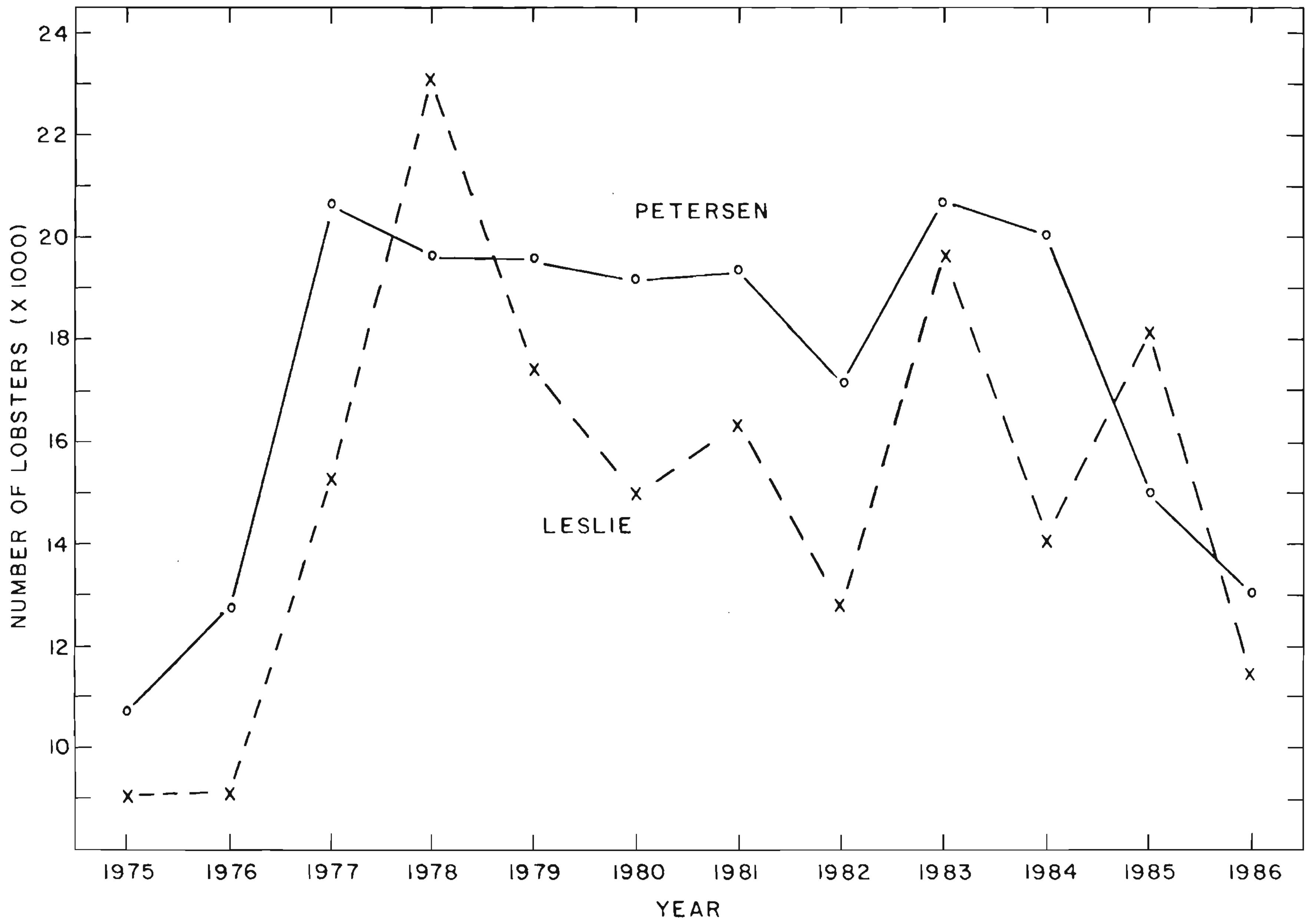

Fig. 13. Petersen and Leslie estimates of the standing stock of lobsters at St. Chads-Burnside.

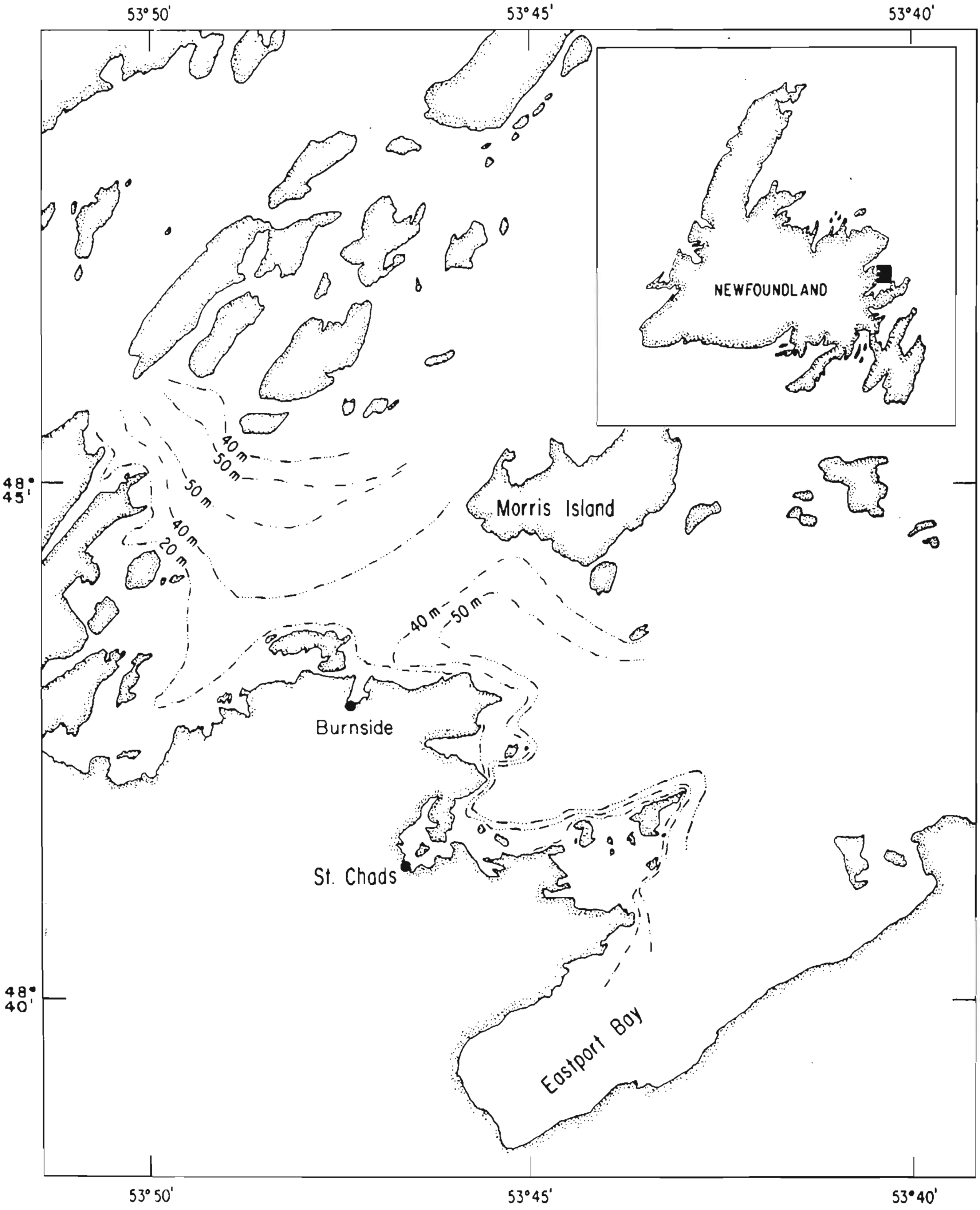

Fig. 14. Map showing configuration of the shoreline and depth contours in the St. Chads-Burnside area.