Fisheries and Population Biology of Lobsters *(Homarus americanus)* at Comfort Cove, Newfoundland

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ABSTRACT

Ennis, G. P., P. W. Collins, and G. Dawe. 1982. Fisheries and population biology of lobsters (*Homarus americanus*) at Comfort Cove, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1116: iv + 45 p.

Characteristics of the lobster fishery at Comfort Cove, Notre Dame Bay, on the northeast coast of Newfoundland are described. Results from ongoing 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 1971 to 1980 period are presented. Details of various aspects of lobster population biology and dynamics in the area such as length-weight relationships, growth, estimates of standing stock, recruitment and mortality rates are included along with a discussion of a number of management considerations for the fishery.

Key words: lobster fishery, catch and effort, catch rates, catch composition, temperature conditions, length-weight, growth, standing stock, recruitment, mortality rates.

RÉSUMÉ

Ennis, G. P., P. W. Collins, and G. Dawe. 1982. Fisheries and population biology of lobsters (*Homarus americanus*) at Comfort Cove, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1116: iv + 45 p.

Ce rapport présente les caractéristiques de la pêche du homard à Comfort Cove, dans la baie Notre-Dame, due la côte nord-est de Terre-Neuve. Il donne les résultats d'un contrôle permanent de la pêche, dont les prises et l'effort de pêche, les taux de prise, la constitution des débarquements, ainsi que les conditions de température pendant les saisons de pêche de 1971 à 1980. Sont aussi inclus les détails de certains aspects de la dynamique et de la biologie des populations de cette région, dont la relation poids-longueur, la croissance, des estimations des stocks actuels, les taux de recrutement et de mortalité, ansi que l'examen de certaines questions visant la gestion de la pêche.

INTRODUCTION

A study of the lobster fishery and various aspects of lobster population biology has been conducted at Comfort Cove, Notre Dame Bay since 1971. This paper presents general descriptions of the fishery and the biology of lobsters in the area. The time series of data that has accumulated has been analyzed to determine the extent of annual variations in population size and the factors involved as a basis for understanding the underlying causes of annual fluctuations in lobster landings.

MATERIALS AND METHODS

Samples of lobsters for biological examination were obtained at Comfort Cove in spring and fall 1967 and in spring 1971. These samples represented total catch from conventional wooden traps with the 1 3/4 in. (44.5 mm) lower lath spacing required for commercial lobster fishing in Newfoundland. Observations included various length and weight measurements, sexing, ovary color, ova and egg diameters etc. (see Squires 1970 for full details).

During June-July 1971, 521 lobsters ranging in size from 36 to 92 mm carapace length were tagged with sphyrion tags (Scarratt and Elson 1965) as soon as they were removed from the traps and released immediately afterwards in the area of capture. Most of the recaptures were made by fishermen during the following spring fishing season but some recaptures were made as late as the 1981 season. Recaptured lobsters were held by fishermen with tags attached until they could be measured and examined by research field staff.

Starting in 1971 thermographs were maintained on the bottom near Comfort Cove at a depth of approximately 9 m during the fishing season (April 20-July 15). Also starting in 1971, three or four fishermen maintained separate records of their daily catches of commercially legal lobsters and effort expended (traps hauled) throughout the fishing season. Catches of commercial lobsters were sampled for carapace length and sex throughout the fishing season as well. These data have been obtained annually. Counts of traps in use in the Comfort Cove area during early June have been obtained since 1971 by field staff who cover the fishing grounds in boat and count 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. During early June, fishing effort, as indicated by the number of traps in use, is at its peak. In some years, however, substantial trap losses due to storms occur earlier in the season and when this happened trap counts were not done.

In the fall of 1971, following the molting period, special fishing was carried out. 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. Tagging was repeated in 1974 and has been each year since.

In 1976, 1977, 1978 and 1979 highly visible secondary marks (colored lobster claw bands positioned on the carpopodite of each claw) were used to obtain estimates of tag loss over the six-month period between tagging and the start of the following spring fishing season. Starting in 1974 all lobsters caught during the tagging period were examined for shell condition to determine whether or not each had molted during the preceding summer molting period (Ennis 1977).

RESULTS AND DISCUSSION

THE FISHERY

General description

Comfort Cove is located in Notre Dame Bay on the northeast coast of Newfoundland (Fig. 1). At the present time about 35 individuals in the area are licenced to fish for lobsters on the Comfort Cove grounds which are made up of a relatively narrow band of rocky bottom extending 15 to 50 m offshore from low to medium height cliffs along approximately 17.5 km of shoreline. The number of conventional wooden-lathed lobster traps individual fishermen are licenced to fish ranges from less than 100 to over 400. A limit of 200 traps per fisherman has been proposed for the area. Traps are set individually and usually in depths less than 20 m. Fishing is carried out from small (6 m) open boats powered by outboard motors. The annual fishing season extends from April 20 to July 15 but sometimes the start of fishing is delayed by several weeks due to the late break-up of bay ice or the presence of Arctic ice. Egg-bearing females and all lobsters smaller than 81 mm (3 3/16") carapace length are protected from exploitation.

Catch and effort

Lobster fishery statistics (landings and number of traps) are available for Notre Dame Bay (Statistical Area B - Cape St. John to Cape Freels) from 1953. These data are available for smaller areas since 1969. Statistical Section 7 (New Bay Head to Farewell Head) includes the Comfort Cove area. This is the smallest unit for which these data are available from the fisheries statistical reporting system. From the research data collected at Comfort Cove, annual landings and effective effort (total trap hauls for season) were estimated for 1972 and from 1975 onwards.

In Notre Dame Bay annual landings have fluctuated markedly (Fig. 2A). The most striking feature of the historical data is the dramatic decline from peak landings of 1.39 million lbs (633 MT) in 1964 to .33 million lbs (149 MT) in 1974 and the even more dramatic recovery to 1.38 million lbs (624 MT) by 1978. The measure of nominal effort that is available (up to 1973) is the number of traps that fishermen indicated on their licence applications they intended to fish that year. A licencing 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. The consensus among DFO field personnell (and among fishermen) is that considerably more traps than the number allowed are being used. A measure of effort for recent years that would be comparable to the 1973 and earlier data would probably be in excess of the number that licence holders are allowed to use. In general, long term trends in landings and effort are similar. A notable exception is the period from 1964 to 1967 when landings dropped dramatically despite the continued increase in effort. The dramatic recovery from the very low landings in 1974 appears to be related to an increase in effort. The decline in landings since 1978 is cause for concern because there is no indication of any decline in effort.

Over the period 1969-1980 annual landings and effort (number of traps) in Statistical Section 7 have represented from 28 to 53% and from 28 to 42% respectively of the totals for Notre Dame Bay (Statistical Area B). The pattern of variation in landings and effort since 1969 have been the same for Section 7 and Area B (Fig. 2B).

The estimated annual landings at Comfort Cove from 1972-1980 represent from 3 to 7% of the total for Statistical Section 7. These landings and the estimated effort (trap hauls) at Comfort Cove reflect the same dramatic increases over the period 1972-1978 as occurred in Notre Dame Bay as a whole (Fig. 2C).

At Comfort Cove the increase in effort during the 1970's is reflected by actual counts of traps on the fishing grounds during the peak of the fishing season as well as by the estimates of trap hauls (Table 1). As a result of the increase in effort, exploitation rate increased from around 78% in 1972 to a high of 93% in 1976 but tapered off somewhat in recent years to around 90% (Table 1).

Catch rates

The pattern of variation in catch per unit effort over the course of the fishing season is highly variable from year to year (Fig. 3). Catch rates are usually highest during the first two to three weeks of the fishing season and decline rapidly as the season progresses. Although the season opens each year on April 20, the start of fishing is sometimes delayed by as much as five weeks because of ice conditions. In some such years (e.g. 1973 and 1974) catch rates remain relatively high for the remainder of the season, however, this did not occur in 1972 when, despite the 5-week delay in the start of fishing, catch rates dropped off very rapidly. Occasionally a sharp increase in catch rate occurs during the last week of fishing. This is the result of large numbers of traps having been removed from the fishing grounds.

The highest and lowest mean CPUE's for one week intervals are .88 lb (.40 kg)/trap haul during the third week of fishing in 1978 and .08 lb (.04 kg)/ trap haul during the first week of fishing in 1977. Season averages range from .32 lb (.15 kg)/trap haul in 1971 to .62 lb (.28 kg)/trap haul in 1974. Over the period 1971-1980 the mean season catch rates have been fairly stable with just minor fluctuations from year to year. With the increase in fishing effort over this period, the absence of a downward trend in catch rates suggests an increase in population size.

Size and sex composition of landings

In Comfort Cove, lobsters just below the minimum legal size of 81 mm (3 3/16 inches) carapace length grow an average of 12 mm on molting in the case of males and 10 mm in the case of females (see section on growth per molt). 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 these size ranges has ranged from 89.7 to 95.3% for males and from 88.5 to 93.4% for females (Fig. 4). Over the period 1971 to 1980 these percentages have been very stable with just minor year to year fluctuations. The fact that exploitation rates have increased substantially over this period without any trend towards increased proportions in the recruit size ranges, also suggests that population size has increased. The sexes are usually very close to equally represented in the landings, however, the M:F ratio has varied from 1:1.14 (in favor of females; $P < .005$) in 1980 to 1:0.75 (in favor of males; $P < .005$) in 1975 (Table 2).

Water temperatures

Daily temperatures representing an approximate mean (usually the mid-point between the high and low values for each day) were read by eye from the thermograph charts. At the start of the fishing season (April 20) temperatures on the lobster grounds are usually in the 0 to -1°C range (Fig. 5). Temperatures less than 1°C usually persist well into May, however, it is over this low temperature period that the highest catch rates for the season are obtained (Fig. 3). Sometime during May temperatures start to increase. Towards the end of the fishing season (July 15), temperatures range from only 4-6°C in some years (eg. 1980) to 12-14°C in others (eg. 1977). The 18°C temperatures recorded around July 20 in 1975 are exceptional. Despite increasing temperatures over the remainder of the fishing season, catch rates usually decline sharply as the standing stock becomes depleted. By delaying the start of the fishing season by 3 to 4 weeks, the cost of fishing for the season could be reduced substantially without any reduction in the level of removal from the standing stock. The socio-economic consequences of such action, however, would need to be considered beforehand. Factors such as the amount of time available for accumulating unemployment insurance benefits, the ability of local collecting systems to handle the glut situation that would develop, the extent to which the local glut would exacerbate the spring to early summer glut situation which develops in the marketplace each year, etc. could negate the positive effects of a shorter fishing season with a later opening date.

BIOLOGY

Length-weight relationships

Curvilinear carapace length-total weight relationships derived from log-log (base 10) regression analysis are presented for Comfort Cove lobsters (Fig. 6). The log-log equations are as follows:

$$\text{Males: } \log ww = 3.2479 \log cl - 3.5727 \quad (n = 181;\ r = .98)$$

$$\text{Non-ovigerous females: } \log ww = 2.8319 \log cl - 2.7791 \quad (n = 207;\ r = .98)$$

$$\text{Ovigerous females: } \log ww = 2.7559 \log cl - 2.6153 \quad (n = 43;\ r = .98)$$

These log-log relationships were compared by analysis of covariance. Only non-ovigerous and ovigerous females had similar residual variances ($P > .05$); the slopes of these relationships were also similar ($P > .5$) but the means were different ($P < .001$). For the male relationship the slope was significantly greater than 3 ($P < .001$), indicating positive allometric growth whereas for non-ovigerous ($P < .001$) as well as ovigerous ($P < .01$) females slopes were significantly less than 3, indicating negative allometric growth.

Reproductive biology

Size-maturity relationships and related observations for Comfort Cove lobsters have been treated in some detail elsewhere (Ennis 1980a) and are not included in this paper.

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 slope which is associated with attainment of sexual maturity. However, for both male and female data from Comfort Cove a single straight line (the so called Hiatt growth diagram) fitted the data better than a pair of straight lines (Fig. 7). For the male data $F = 1.07$ with 2 and 71 degrees of freedom ($F_{.05(1), 2, 70} = 3.13$); for the female data $F = 1.66$ with 2 and 89 degrees of freedom ($F_{.05(1), 2, 88} = 3.10$). A total of 166 sets of premolt and postmolt carapace lengths is included in these data however, only one set is available for premolt carapace lengths greater than 80 mm and only 7 are available for premolt carapace lengths less than 69 mm. The clustering of data over the 69 to 80 mm premolt carapace length range is considered to be the reason why the analysis did not detect a change in slope in the premolt-postmolt carapace length relationships for this area.

The single straight line equations derived from least squares regression of postmolt carapace length on premolt carapace length are $y = 1.0764x + 5.2009$ ($n = 74$, $r = .95$) for males and $y = 1.0369x + 6.9818$ ($n = 92$, $r = .95$) for females (Fig. 7). The slopes of these lines are similar ($P = .51$) but means are different ($P < .001$). Neither slope is significantly different from 1 ($P > .05$ for males; $P > .2$ for females). The slope for males, however, meets Kurata's (1962, p. 31) requirement ($b \geq 1.05$) for progressive growth, i.e. molt increment increases with premolt size, whereas the slope for females meets his requirement ($1.05 > b \geq .95$) 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 10.6 mm and 12.8 mm respectively for males, which represent relative molt increments of 15.1% and 12.8%, and for females are 9.6 mm and 10.7 mm which represent relative increments of 13.7% and 10.7%.

Proportions molting. Estimates of proportions molting were derived from the fall shell condition sampling as described by Ennis (1978). Curves of proportion molting in relation to size thus derived (Fig. 8A) show substantial annual variation for both males and females. The data for all years were combined and "average" proportion molting-size relationships were derived (Fig. 8B). The probit equations are y = 15.615-0.123x for males and y = 14.604-0.115x for females. These relationships indicate that for both sexes all animals 60-65 mm carapace length molt in a given year. There is no evidence that in this area animals of this size range molt more than once in a year. Proportion molting annually drops to 50% at 86 mm and 83 mm for males and females respectively and to 0% at around 110 mm for both males and females.

It seems likely that the decline in proportion molting to 0% at 110 mm carapace length is a sampling artifact. For the data represented in Fig. 8 the sample size (males and females combined) for animals larger than 100 mm is 6 (from a total sample of 6259) of which one had molted during the preceding molting period. This one specimen was a female at 115 mm. The size frequencies from commercial landings (Fig. 4) also show that in this area lobsters larger than 100 mm carapace length are very scarce, the reason being the very high exploitation rates which prevent all but a very few specimens from attaining sizes in excess of 100 mm.

The proportion molting at a given size is determined by the number of old-shelled (i.e. non-molted) animals caught at that size and the number of new-shelled (i.e. molted) animals caught at the corresponding postmolt size. Any difference in catchability between the old-shelled animals at the smaller premolt size and the new-shelled animals at the larger postmolt size will introduce a bias. On the basis of comparisons between diver and trap-caught samples obtained over the same period following the molting season at Arnolds Cove, Placentia Bay, Ennis (1978) concluded that old and new-shelled lobsters were close to equally trappable. Lobster traps, however, are size selective. This selectivity is determined by the entrance ring size and the spacing between laths. These control the sizes of lobsters which can enter and escape from the trap. Proportion molting would be overestimated at smaller sizes, for example, if the old-shelled lobsters are undersampled because they escape from the trap more readily than the larger new-shelled lobsters. At larger sizes proportion molting would be underestimated if the larger new-shelled lobsters are undersampled because entrance ring size excludes them or makes entry more difficult. Behavioural interactions between lobsters in and around a trap may also affect size selectivity.

Another factor which may introduce a bias in the estimates of proportion molting for females is the possibility of some variation in catchability related to ovigerous condition. Of the 397 old-shelled females in the sample represented in Fig. 8, 321 (81%) are ovigerous and of the 1816 new-shelled females, 78 (4.3%) are ovigerous; in total, ovigerous specimens make up 18% of the female sample. Molting and egg-laying are likely to have a significant effect on catchability, at least over the short term. It is assumed here, however, that sufficient time has elapsed between the time of these events and the time of sampling for catchability to have become equalized.

To what extent the estimates of proportion molting presented here are biased because of these factors is not known. Any bias that is present should be consistent from year to year, so that any variation in estimates of proportion molting for a given size group should reflect real changes.

Growth curves. Growth curves were generated by combining molt increment and proportions molting data as described by Ennis (1978, 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:

$$\ell_t = 102.1\ [1-e^{-0.3701(t-3.6113)}]$$ for males and

$$\ell_t = 99.0\ [1-e^{-0.3417(t-4.2504)}]$$ for females.

Growth curves derived from these equations are presented in Fig. 9. How closely these curves approximate the real situation is unknown. However, the $L\infty$ values are obviously too low. Despite very high exploitation rates and the small minimum legal size limit, animals larger than these sizes are commonly observed.

It is clear that at the larger sizes (say beyond 95 mm CL) these curves underestimate growth rate, at the smaller sizes it is felt that they approximate the real situation reasonably well.

Temperature conditions and proportions molting. Robinson (1979) introduced the use of accumulated degree-days (determined by adding successive mean daily temperatures) as a means of illustrating the importance of temperature conditions to growth rate of lobsters in an area. According to Aiken (1980), at a temperature of 5°C lobsters will progress slowly through the molt stages to D_0 and stop, but will continue slowly through premolt and can complete ecdysis in temperatures as low as 0°C provided molt stage D_1 has been reached before the temperature drops to 5°-6°C. In the Comfort Cove area lobsters are trappable at temperatures below 0°C and it is assumed that some physiological progress towards molting in late July-August does occur over the 0°-5°C temperature range that commonly lasts well into June in this area. Accumulated degree-days (above 0°C) from May 1 to July 15 ranged from 42 in 1974 to 379 in 1979 (Table 3). Unfortunately the thermographs were usually not maintained beyond July 15, the last day of the commercial fishing season. Temperature conditions between July 15 and the molting period (which starts around the end of July) will undoubtedly influence the proportion molting in a given year, however, it is felt that temperature conditions during the period May 1 to July 15 exert just as great or possibly even greater influence and can be used as a good indicator of year to year variation in temperature conditions over the period that temperature is a factor in determining proportion molting.

Proportions molting in both male and female prerecruit and recruit size groups varied substantially from year to year, especially in the recruit size group where proportion molting was consistently lower than in the prerecruit size group (Table 3). In both size groups males consistently had a higher proportion molting.

In the prerecruit size group proportion molting increased with increasing degree-days up to ∿ 250 (Fig. 10) beyond which it tended to fluctuate, suggesting that beyond a certain level, factors other than temperature become more important than they are at lower temperature levels. In the recruit size group, except for anomalously low values for males in 1978 and for females in 1977, proportion molting continued to increase with increasing degree-days.

It is clear that temperature conditions during the period preceding the molting season vary substantially from year to year resulting in variation in proportions molting and hence annual growth within the population.

Petersen estimates of standing stock

Assumptions of the Model. Estimates of population size using the Petersen method are valid only insofar as the seven assumptions of the model are met. A consideration of the extent to which these assumptions are met in the present study follows.

1. N is constant. Tagging studies (Ennis, unpubl. data) in the area of Comfort Cove and elsewhere in Newfoundland indicate that lobsters have rather restricted movements and practically all tag recaptures have been within the tagging areas. The Comfort Cove lobster grounds include about 10.8 miles (17.4 km) of shoreline along which lobsters are restricted to a narrow band of rocky bottom that generally does not extend more than 150 m from shore. There are no physical barriers to movement of lobsters into or out of the study area, however, tagging has been conducted throughout the area and there have been no recoveries from outside despite nearby fishing activity. In this area, molting, spawning and hatching occur during late July to late August. Hence there are no changes to the size of the commercially legal lobster population as a result of these activities between the fall (October) tagging period and the spring (April 20 - July 15) fishing season. Natural mortality is unlikely to be a factor either. Although no direct estimates were available the consensus reached by the ICES Working Group on *Homarus* stocks was that natural mortality can be expected to be less than 10% annually (Anon. 1977). Attempts to estimate natural mortality (this paper) indicate that for commercial sizes it may be close to 0%. At any rate it is expected that most natural mortality in lobsters would be associated with annual molting activity and in addition, there is no reason to suspect that it would be different for tagged and untagged animals. In conclusion, there appears to be no serious violation of the assumption that population size is constant.

2. No tag loss. Some tags are lost during the 6 month period between tagging in the fall (October) and the commercial fishing season (April 20 - July 15) the following spring. Estimates of tag loss are available from the use of highly visible secondary marks during the fall tagging in Comfort Cove for the years 1976-79. We have no evidence that these bands are lost and it is highly unlikely that both bands, plus the tag, would be lost from the same animal. Fishermen were canvassed at intervals during each fishing season to obtain data on recaptured lobsters with secondary marks only. The estimate of tag loss ranged from 0.3% to 2.8% (Table 4). The four years' data were pooled to get a mean estimate of 1.7% which was used to determine the number of tagged lobsters left in the population at the beginning of the fishing season.

3. Tagging does not affect catchability. In the present study there is no basis for testing this assumption. Presumably any affect of catching, handling, etc. at the time of tagging on subsequent catchability would be short term and tagging was done well in advance of the fishing season. There is no a priori reason to suspect that catchability of tagged lobsters during the fishing season is affected by the tagging or by the presence of the tag. In addition, because of the nature of the tag (attached externally to the carapace) and the tagging operation itself (lobsters were tagged and released immediately after the trap was hauled), it is highly unlikely that there is any mortality associated with tagging.

4. In the second sample tagged animals are randomly distributed throughout the population. An unbiased estimate of population size is possible if there is uniform mixing of tagged and untagged animals in the population. In the present study the tagging operation itself ensured a high degree of mixing. The traps used to catch the lobsters for tagging were distributed throughout the area and each trap was moved repeatedly during the tagging period. In addition, lobsters move about quite extensively within localized areas and it is quite likely that considerable mixing would be achieved during the 5-6 month period between tagging in the fall and the beginning of the fishing season the following spring. It is considered that in this study uniform mixing of tagged lobsters has been achieved to the extent that no significant bias is present.

5. All animals have the same probability of being caught in the first sample. A comparison of sex ratios of commercial lobsters (≥ 81 mm carapace length, non-ovigerous) taken in traps in the fall and during the fishing season the following spring indicates that females are undersampled in the fall. In the fall samples males outnumber females by around 2 to 1 whereas in spring the sexes are usually very close to being equally represented (Table 2). This is not readily explained and it is not clear if it is due to increased catchability of males or reduced catchability of females. To test the importance of this, estimates of N were derived for males and females separately and combined. In 6 out of 7 estimates N was lower when males and females were combined. The difference ranged from 0.3 to 11% of the estimate obtained when males and females were treated separately and added together. In one estimate N was higher by 3.9%. To eliminate any possible bias, the estimate of N and subsequent calcuations using N were derived for males and females separately. Size frequency distributions from these same fall and following spring samples were compared to determine if there was any difference in catchability related to size for either sex between fall and spring. While there was no obvious difference in the size frequencies, in five out of six comparisons there were significantly smaller proportions in the recruit size range (i.e. more larger lobsters) in fall than in spring for the males; however, for the females this was true in only one out of six comparisons (Table 5). In the case of males there is a slight tendency for larger animals to be caught in the fall; however, it is considered that any bias in the estimate of N resulting from this would be very slight. Because of the small numbers of larger lobsters tagged, it would be unrealistic to try to remove this bias by estimating the numbers of smaller and larger lobsters separately as was done for males and females. For this reason this possible bias is being ignored in the estimates presented here.

6. All animals in the second sample are correctly classified as tagged or untagged. The carapace strap tag is attached along the mid-dorsal line of the carapace and is very conspicuous. Since the catch per trap haul is generally quite low (mean CPUE is less than 1 commercial lobster per trap haul) and all lobsters caught are handled individually, it is extremely unlikely than any tagged lobsters in the catch would be missed.

7. All tags are reported on recovery. To ensure that all recaptured tags were returned, field staff met with each fisherman in the area periodically throughout the fishing season. Rewards were paid in cash as the tags were collected or in a lump sum at the end of the season. It is felt that this procedure eliminated non-reporting of tags as a bias.

Conclusion regarding assumptions. Where violations of the assumptions could be identified, corrections were made to eliminate bias in the estimates. Some assumptions could not be tested but as far as can be judged there are no violations which would introduce serious bias. It appears that the estimates are reliable, however, 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.

Estimates of N. The number of commerical lobsters or standing stock present on the Comfort Cove grounds at the beginning of each fishing season was estimated using Chapman's (1951) modified version of the Petersen method. This is as follows:

$$N = \frac{(M+1)\ (n+1)}{m+1}$$

where

M = number of marked animals from the first sample;
n = number of animals examined for marks in the second sample; and
m = number of marked animals in the second sample.

The data on which the estimates are based are provided in Table 6. As explained above, estimates of N were derived for males and females separately and then added. Variance was also estimated for males and females separately, using the formula

$$v = \frac{(M+1)\ (n+1)\ (M-m)\ (n-m)}{(m+1)^2\ (m+2)}$$

and added. A normal distribution is assumed and 95% confidence limits were derived according to

$$N \pm 1.96 \sqrt{v_m + v_f} \qquad \text{(see Seber 1973, p. 59-62)}$$

Confidence limits ranged from ±13 to ±21%. There is some overlap in 95% confidence limits for the series of estimates however, it is clear that there was a substantial increase in standing stock from 11,250 animals in 1972 to 22,587 in 1978 (Fig. 11).

With exploitation rates in the Comfort Cove area as high as 93.5% (Table 1) it is obvious that recruitment has to be the major factor in determing the size of the standing stock in any given year. The upper limits of the recruit size ranges (81-92 mm for males; 81-90 mm for females) and the lower limits of the prerecruit size ranges (70-80 mm for males; 71-80 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, Fig. 11A) 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 varied from 79 to 91% (Table 7). The cause of increased recruitment during the 1970's cannot be determined with certainty. Better than average environmental conditions for survival of lobster larvae to settlement stage and beyond may have prevailed during the late 1960's and early 1970's. Another possibility is improved conditions for growth and survival of prerecruits because of low levels of recruit abundance, as indicated by commercial landings during the early 1970's.

The number of prerecruits in the population the preceding year (Fig. 11A) was estimated by dividing the number of recruits in the current year by the proportion molting in the prerecruit size range the preceding year times the survival rate (i.e. 90%-annual natural mortality assumed to be 10%). The number of commercial lobsters remaining in the population following exploitation in the preceding year (Fig. 11A) which would make up the majority of non-recruit lobsters the following year (Fig. 11A) ranged between 1000 and 3000 and had very little, if any, impact on annual variation in standing stock. There was annual variation in proportion molting in both the prerecruit and recruit size ranges (Fig. 11B). It varied more extensively for recruits than for prerecruits but, in general, variation in standing stock tended to coincide with variations in proportion molting the preceding year. Obviously, it is variation in proportion molting in the prerecruit size range that would have significant impact on standing stock the following year.

From the comparisons it is quite clear that recruitment is the key factor involved in annual variation in the abundance of commercial lobsters and in any given year this is determined by numbers and proportion molting in the prerecruit size range the preceding year.

Leslie estimates of standing stock

Assumptions of the Model. Only two of the four assumptions of the Leslie model are considered here. The others have been dealt with considering the assumptions of the Petersen model.

1. Catchability remains constant. In the present study this assumption is violated. Over the fishing season (April 20-July 15) temperature on the lobster grounds increases from around 0°C to as much as 14°C in some years (Fig. 5) and catchability of lobsters increases with increasing temperature (McLeese and Wilder 1958). There may be other factors having very subtle effects on catchability over this period, however, temperature is clearly the factor having the major effect. Increased catchability over the fishing season would result in overestimates of population size, using the Leslie model. To correct for this, we have adjusted all observed CPUE's to a standard

temperature of 4°C. This was done using the temperature-catchability relationship of McLeese and Wilder (1958). Their Fig. 4 was replotted with the index of catchability adjusted to catch per trap haul instead of catch per 100 trap hauls. This relationship indicates zero catchability at around 3°C, however, in the Comfort Cove area lobsters are caught at temperatures as low as -1°C. Using parallel rulers the regression line was elevated on the graph (without changing the slope) until the index of catchability at -1°C was a positive number. The equation $y = .0704x + .095$ (y = catch per trap haul and x = °C) was derived for this line.

McLeese and Wilder (1958) suggest that the slope of the relationship depends on stock density. We are more inclined to suggest that the elevation (or intercept) of the line, and not the slope, depends on stock density and have assumed here that the slope of their temperature-catchability relationship is representative of the species. This is a tenuous assumption, but in the absence of any other basis for adjusting the CPUE data for varying catchability, it was decided to accept it as being valid. In the present application the intercept of the line is not important. The observed CPUE's are adjusted to a 4°C standard by multiplying with a correction factor determined by dividing the index of catchability at 4°C by that at the observed temperature (both from the temperature-catchability relationship $y = .0704x + .095$).

2. Fishing effort is constant. Fishing effort in terms of trap hauls per one week period varied tremendously over the course of each fishing season. In the 1977 season, for example, it varied from 299 to 2924 trap hauls. Several population estimates were derived for each of different years; one estimate was based on all weekly CPUE values regardless of fishing effort applied and others were derived after varying numbers of CPUE values represented by high and low effort levels had been omitted. The omission of points had very little effect on the estimate, however, the estimates provided are based on the arbitrary omission of points (as indicated in Fig. 12) in order to meet the assumption as closely as possible.

3. Population is totally available to the fishery. 4. No natural mortality or recruitment. The consideration of assumption one of the Petersen model indicates that there are unlikely to be any serious violations of these assumptions.

Estimates of N. Commercial catch data are not available for all Comfort Cove area lobster fishermen. Catches are available only for the three or four fishermen who maintained records of their daily catch and effort throughout the fishing season. Weekly catches for all fishermen were estimated by multiplying the weekly catch of these three or four fishermen by the factor obtained by dividing the total number of tags returned for the fishing season by the number returned by three or four fishermen. A near identical estimate of population size was obtained using only accumulated catches of the 3 or 4 fishermen and multiplying this estimate by the correction factor. The former procedure was used so that confidence limits could be derived.

Population size estimates and confidence limits were obtained as described by Ricker (1975). The data and analyses are presented in Table 8 and Fig. 12. Confidence limits about the estimates ranged from -7.9 to -17.4% and from +12.6 to + 38.2%. The Leslie estimates were consistently lower than the Petersen estimates (by 6.1-19.7%) but showed the same trend over the period (Fig. 13).

Mortality estimates

In addition to exploitation rates estimated from tag return data, two different models were used in an attempt to estimate total mortality. One was the Gulland (1969) model

$$Z = \log e \left(\frac{N_{t+1}}{N_t}\right)$$

In this instance N_t is the number of male recruits in the standing stock which was obtained as already described. N_{t+1} was calculated as described by Ennis (1979). The method was applied to males only because ovigerous females are not included in the estimate of standing stock and in the case of females the calculation of N_{t+1} would be confounded. In most cases the estimate of Z (expressed as a percent) was very close to the exploitation rate estimated for time t (Table 9). In only one case (i.e. 1975) did total mortality, as estimated above, minus the expoitation rate for time t give a positive number. This indicates that the method, as proposed by Ennis (1979), is not sufficiently precise to estimate the annual natural mortality rate but tends to support the consensus that for commercial size lobsters natural mortality is very low.

The other model used to estimate total mortality was that of Beverton and Holt (1957)

$$Z = K \left(\frac{L\infty-\ell}{\ell-\ell_c}\right)$$

where ℓ is the mean length of lobsters caught and ℓc is the length at which lobsters are first fully exposed to fishing which in this case is equal to the minimum legal size of 81 mm CL. The von Bertalanaffy parameters used were those obtained as described in the section on growth. The estimates of total mortality obtained using this model were substantially lower than the estimates of exploitation rate (Table 9). This further substantiates the earlier conclusion that the growth equations derived do not reflect the real situation.

The data presented in Table 9 indicate differences in some years between exploitation rates estimated for males and females separately. Further analyses show wide variation in estimates of exploitation rate between sexes at the same size and between different sizes within each sex (Table 10). The differences were tested for statistical significance using X_c^2 from 2x2 contingency table.

Exploitation rates were higher for males in 39 of the 48 male/female comparisons. Of these 39, 32 were tested statistically; 8 were significant at the 1% level and 6 at the 5% level. Of the 9 comparisons where exploitation rates were higher for females, 4 were tested and none were found to be significant (Table 11). In all 13 male/female comparisons where all sizes were combined for individual years and where all years were combined for the different size groups, the males had higher exploitation rates. All of these comparisons were tested; seven were significant at the 1% level and two at the 5% level.

Exploitation rates in the 81-85 mm size groups were compared with those in the 86-90, 91-95 and 96-100 mm size groups. In 17 of 21 comparisons for males, the larger size group had the higher exploitation rate. Of these 17, 16 were tested and only three found to be significant. Three of the four cases where the smaller size groups had the higher exploitation rate were tested but none were significant (Table 12). In the 20 comparisons for females, the larger size groups had the higher exploitation rate in ten cases but in only one case was the difference significant. In only one of the ten cases where the smaller size groups had the higher exploitation rate was the difference significant (Table 12). The data suggest that exploitation rates tend to be higher for males and for larger sizes, at least for the males. If these differences are real it means that the estimates of exploitation rate for the Comfort Cove fishery are biased upwards because, compared to the commercial catch samples, males predominate in the tagged samples and among the tagged males there is a higher proportion of larger animals. However, because of the inconsistency and variability of the results, no definite conclusions can be drawn regarding differences in exploitation rate between males and females and between different sizes.

GENERAL DISCUSSION AND CONCLUSIONS

The catch and effort data that are available for the lobster fishery in Notre Dame Bay are not amenable to analysis using surplus yield models which would give a reliable indication of MSY and associated fishing effort. Possibly suitable data are only available for the period 1953-73. In addition to the absence of comparable data from around 1874 when official records indicate lobster fishing began in Newfoundland, there were substantial changes in the nature of the fishery and in regulatory measures and their enforcement over the first 80 years (see Templeman 1941). Recent yield per recruit assessments (Ennis 1978b, 1980c) clearly indicate that current exploitation rates are considerably in excess of those that would maximize yield per recruit at the current minimum legal size. In addition, egg production, and presumably subsequent recruitment to the stocks, is substantially less under current conditions than that which would occur with an exploitation rate and minimum legal size that would maximize yield per recruit. There is no 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.

Examination of Fig. 2A shows that landings comparable to the 1978 peak of 1.38 million lbs were taken in the 1950's and 1960's at considerably lower levels of effort in terms of the number of traps in use. There has been a substantial increase in effort in Notre Dame Bay since 1972. Observations at Comfort Cove indicate that exploitation rates have increased substantially as well. Presumably exploitation rates throughout Notre Dame Bay during the 1950's and 1960's were substantially lower than in recent years which means that lobster abundance would have had to be higher for landings comparable to the 1978 peak to have been taken. Another indication of this is the fact that the tremendous increase in the number of traps in use in recent years has reduced catch rates to the point where in many areas effort has been spreading to low or marginally productive areas that were not fished or fished very lightly in the past. For Notre Dame Bay it seems likely that the contribution to recent landings from this source is significant. Landings of approximately

1.3 million lbs were obtained in Notre Dame Bay in 1955 and in 1960 with 97,000 and 103,000 traps in use, respectively (Fig. 2a). It has been suggested that an "optimum" level of effort (in terms of the number of traps in use) or a level towards which management should aim is around 110,000 traps. This compares with approximately 209,000 traps which the 1980 licence holders were registered to use, which is likely to be substantially below the number actually used. This level has been agreed to and recommended by the Newfoundland Lobster Advisory Committee. A reduction in effort to this level would likely result in a substantial reduction in exploitation rates throughout Notre Dame Bay. At current levels of abundance this would result in decreased landings. Over time, however, reduced exploitation rates would allow a gradual increase in abundance to levels that prevailed during the 1950's and early 1960's, thereby allowing landings comparable to recent levels at substantially lower levels of fishing effort. If this situation could be achieved, there would be a substantial improvement in the economics of the fishery.

The reduced level of landings in Notre Dame Bay in the years between the 1955 and 1960 peaks probably resulted from a natural fluctuation in abundance. Even under an ideal fisheries management regime, natural fluctuations in abundance of lobsters (and hence landings) will occur. At Comfort Cove as much as 91% of the standing stock was recruited since the preceding fishing season. Dramatic fluctuations in landings from year to year are inevitable in a fishery that is so heavily dependent on recruitment. The dramatic decline from landings of 1.39 million lbs in 1964 to .33 million lbs in 1974 in Notre Dame Bay appears to have resulted from reduced levels of recruitment combined with recruitment overfishing over the period and illustrates the kind of instability that can be expected at high levels of fishing effort. Far greater stability in landings than the present management regime allows can be achieved. The key is a lower level of exploitation which will allow an increase in the abundance of non-recruit lobsters in the standing stock which will provide a buffer against annual fluctuations in recruitment.

The observations at Comfort Cove show that recruitment increased over the 1973-1980 period despite increased fishing effort. The dramatic increase in landings in Notre Dame Bay from 1974 to 1978 indicates that recruitment increased throughout the Bay. The cause of this increased recruitment cannot be determined with certainty. Environmental conditions for survival of lobster larvae to settlement stage or for survival and growth of postlarval and early juvenile stages may have been much better than average during the late 1960's. 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 1970's. Whatever the cause or causes of increased recruitment during the mid to late 1970's, landings since 1978 indicate that the level of recruitment has declined. Landings can be expected to continue to decline until a period of increased recruitment comes along and at current levels of fishing effort it is possible that a decline to levels below 1974 could occur over just a few years.

The yield per recruit assessments (Ennis 1978) for Comfort Cove lobsters show that even at substantially lower than current rates of exploitation, yield per recruit will be increased by increasing the minimum legal size. At any given level of recruitment, total yield could be increased by such action. Yield per recruit could be maximized by increasing the minimum legal size and/or decreasing the exploitation rate. In the case of Comfort Cove lobsters, maximum yield per recruit would be at least 28% greater than that being achieved at the present size limit and exploitation rate. The increased egg production that would also result from an increase in size limit could be a critical consideration in the near future if levels of fishing effort are not reduced substantially. Reference was made earlier to the fact that much of the increased effort in recent years has been spreading to low or marginally productive areas that were not fished or fished very lightly in the past. While lobsters may be relatively scarce in such areas, in the absence of heavy exploitation they would grow to large sizes and fecundity increases exponentially with size. In addition, the majority of females would lay eggs several times before being caught and many might never be caught. It is not unlikely that in the past at least, these "refugia" supplied a substantial proportion of the annual egg production in the population as a whole.

It is quite clear that management of the lobster fishery in Notre Dame Bay, and throughout Newfoundland, could be improved dramatically. Total yields could be increased and the cost of fishing as well as the magnitude of year to year fluctuations in landings could be reduced. If the current management regime continues, however, all that can be expected is a long term downward trend in landings characterized by sharp annual fluctuations.

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Table 1. Counts of lobster traps on the fishing grounds at Comfort Cove, estimated number of trap hauls and exploitation rates for each season, 1971-80.

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Trap counts	703	644	-	-	-	854	1,064	1,304	1,034	-
Trap hauls	-	23,247	-	-	26,719	43,647	47,282	41,269	35,467	43,151
Exploitation rate (%)	-	77.9	-	-	83.9	93.5	91.5	91.3	84.9	89.1

Table 2. Comparison of sex ratios in commercial landings at Comfort Cove, 1975-80 and in commercial lobsters taken in sampling the preceding fall.

	Commercial landings				Preceding fall sampling			
Year	No. males	No. females	M:F	P	No. males	No. females	M:F	P
1975	1017	760	1:0.75	<.005	573	283	1:0.49	<.005
1976	1365	1146	1:0.84	<.005	502	258	1:0.51	<.005
1977	1319	1260	1:0.96	>.10	614	295	1:0.48	<.005
1978	1469	1389	1:0.95	>.10	617	340	1:0.55	<.005
1979	1422	1541	1:1.08	>.025	583	382	1:0.66	<.005
1980	1726	1962	1:1.14	<.005	568	271	1:0.48	<.005

Table 3. Accumulated degree-days (above 0°C during May 1 to July 15) and proportions molting in the prerecruit and recruit size ranges at Comfort Cove, 1974-80.

Year	Accumulated degree-days	Prerecruit size range		Recruit size range	
		Males	Females	Males	Females
1974	42.1	75.5	64.2	41.8	22.2
1975	247.7	93.0	88.1	73.0	50.0
1976	339.5	90.4	76.1	90.3	63.2
1977	308.2	95.0	83.3	78.8	36.0
1978	306.2	85.0	77.2	44.2	73.1
1979	379.1	93.2	81.7	85.7	64.3
1980	176.2	86.6	80.9	67.5	45.0

Table 4. Estimates of tag loss between tagging in the fall and the fishing season the following spring at Comfort Cove, 1977-80.

Year	No. of fishermen canvassed	No. of tags returned	No. of lobsters observed with secondary marks only	% tags lost
1977	24	428	9	2.1
1978	18	379	1	0.3
1979	13	353	10	2.8
1980	15	371	7	1.9
All years	-	1531	27	1.7

Table 5. Comparisons of proportions in recruit size range in fall tagging sample and commercial catch sample the following spring.

	Males					Females				
	Fall		Spring			Fall		Spring		
Fall/ Spring	Total	Proportion in recruit size range	Total	Proportion in recruit size range	χ^2_c [1,2]	Total	Proportion in recruit size range	Total	Proportion in recruit size range	χ^2_c
1974/1975	380	.839	1017	.920	18.94**	91	.912	760	.922	0.02
1975/1976	381	.885	1365	.925	5.68*	138	.928	1146	.905	0.51
1976/1977	442	.855	1319	.923	17.35**	122	.893	1260	.930	1.70
1977/1978	492	.884	1469	.914	3.59	161	.938	1389	.911	0.97
1978/1979	454	.881	1422	.928	9.11**	239	.833	1541	.897	8.15**
1979/1980	439	.875	1726	.933	15.44**	125	.864	1962	.885	0.33

[1]Chi square (2 x 2 contingency table) corrected for continuity

[2]$\chi^2_{.05}$ = 3.84, 1 df.*; $\chi^2_{.01}$ = 6.63, 1 df.**

Table 6. Data from which Petersen estimates of population size were obtained.

Year	Number lobsters tagged preceding fall			Number tagged lobsters in population at beginning of fishing season			Number tagged lobsters returned during fishing season			Exploitation rate (%) M/F combined	Number tagged lobsters returned by fishermen who provided catch data		Number lobsters caught by fishermen who provided catch data	
	M	F	Total	M	F	Total	M	F	Total		M	F	M	F
1972	357	127	484	351	125	476	268	103	371	77.9	82	36	1469	1465
1975	265	88	353	261	86	347	231	60	291	83.9	64	13	1918	1433
1976	160	60	220	157	59	216	149	53	202	93.5	41	12	2464	2068
1977	376	112	488	370	110	480	340	99	439	91.5	136	40	3890	3717
1978	368	133	501	362	131	493	331	119	450	91.3	119	35	3478	3289
1979	298	201	499	293	198	491	261	156	417	84.9	102	63	3136	3398
1980	363	113	476	357	111	468	325	92	417	89.1	114	32	3251	3696

Table 7. Estimates of the percent recruits in standing stock.

Year	Standing stock estimate M	Standing stock estimate F	Percent in recruit size range[1] M	Percent in recruit size range[1] F	Percent molters recruits in size range[2] M	Percent molters recruits in size range[2] F	Number recruits in standing stock M	Number recruits in standing stock F	Percent recruits in standing stock M/F combined
1975	7784	8658	92.0	92.2	73.4	96.4	5255	7698	78.8
1976	9240	9661	92.5	90.5	94.9	98.4	8106	8606	88.4
1977	10,537	10,066	92.3	93.0	97.1	99.1	9447	9277	90.9
1978	10,524	12,063	91.4	91.1	95.2	98.7	9156	10,847	88.6
1979	8986	10,508	92.8	89.8	80.8	98.5	6735	9289	82.2
1980	10,124	12,547	93.3	88.5	96.9	99.1	9148	11,008	88.9

[1]Based on commercial catch sampling

[2]Based on shell condition sampling preceding fall

Table 8. Data from which Leslie estimates of population size were obtained.

Week of fishing season	1972 Observed CPUE[1]	1972 Average Temp (°C)[2]	1972 CPUE adjusted to 4°C	1972 Cumulative catch[3]	1975 Observed CPUE[1]	1975 Average Temp (°C)[2]	1975 CPUE adjusted to 4°C	1975 Cumulative catch[3]
1								
2								
3					0.557			
4					0.396			
5					-			
6	0.622	0.32	1.995	176	-			
7	0.520	0.80	1.295	1456	0.656	2.90	0.827	5219
8	0.470	-	-	-	0.603	3.00	0.742	6098
9	0.474	-	-	-	0.500	4.35	0.470	7175
10	0.331	5.25	0.268	7168	0.534	5.67	0.407	8432
11	0.316	6.48	0.216	8351	0.458	7.17	0.288	9642
12	0.168	5.65	0.129	8955	0.359	5.37	0.286	10898
13	0.129	6.33	0.090	9156	0.318	14.25	0.109	11862
14					0.347	14.43	0.118	12428

Table 8. (Cont'd.)

Week of fishing season	1976 Observed CPUE[1]	1976 Average Temp (°C)[2]	1976 CPUE adjusted to 4°C	1976 Cumulative catch[3]	1977 Observed CPUE[1]	1977 Average Temp (°C)[2]	1977 CPUE adjusted to 4°C	1977 Cumulative catch[3]
1	0.602	0.30	1.957	519				
2	0.552	0.63	1.497	2005	0.071	-1.07	1.361	1
3	0.587	2.85	0.748	4416	0.244	-0.82	2.468	93
4	0.499	3.18	0.590	7379	0.482	-0.27	2.391	954
5	0.384	2.25	0.572	10075	0.412	0.22	1.406	2659
6	0.288	2.92	0.361	11470	0.550	0.85	1.339	5202
7	0.358	6.05	0.259	12705	0.478	2.35	0.692	8552
8	0.336	4.67	0.299	14338	0.441	3.03	0.539	11808
9	0.255	5.50	0.200	15230	0.424	3.43	0.475	13993
10	0.243	5.38	0.193	15967	0.322	6.58	0.217	15404
11	0.225	5.48	0.176	16743	0.274	7.35	0.169	16797
12	0.147	7.55	0.089	17130	0.269	9.88	0.128	18006
13	0.106	5.15	0.087	17239	0.195	12.18	0.077	18769
14								

Table 8. (Cont'd.)

Week of fishing season	1978 Observed CPUE[1]	1978 Average Temp (°C)[2]	1978 CPUE adjusted to 4°C	1978 Cumulative catch[3]	1979 Observed CPUE[1]	1979 Average Temp (°C)[2]	1979 CPUE adjusted to 4°C	1979 Cumulative catch[3]
1								
2					0.438			
3					-			
4	0.082	-0.98	1.189	13	0.714	0.70	1.866	25
5	0.273	-0.92	3.404	383	0.449	0.58	1.246	305
6	0.771	2.62	1.040	2478	0.666	1.25	1.372	2605
7	0.669	4.17	0.649	6186	0.544	1.05	1.214	6542
8	0.608	4.38	0.568	9856	0.402	3.57	0.438	10038
9	0.463	7.47	0.281	12759	0.301	6.27	0.212	12518
10	0.385	7.27	0.239	15132	0.266	9.77	0.128	14085
11	0.353	6.35	0.246	17204	0.227	10.42	0.103	15194
12	0.318	6.30	0.223	18744	0.200	10.70	0.089	15964
13	0.203	5.47	0.159	19578	0.133	9.45	0.066	16404
14								

Table 8. (Cont'd.)

1980				
Week of fishing season	Observed CPUE[1]	Average Temp (°C)[2]	CPUE adjusted to 4°C	Cumulative catch[3]
1	0.212	-0.48	1.306	50
2	0.570	-0.22	2.703	881
3	0.563	0.38	1.743	2401
4	0.502	0.10	1.855	4485
5	0.564	0.38	1.746	6973
6	0.538	1.72	0.939	9219
7	0.587	2.30	0.861	11460
8	0.451	3.88	0.462	13544
9	0.399	3.18	0.472	15395
10	0.351	3.22	0.411	17012
11	0.304	3.97	0.306	18380
12	0.293	4.42	0.272	19448
13				
14				

1Number of commercial lobsters per trap haul
2Mean of daily temperature (from Fig. 5) for the period.
3Estimated by multiplying the weekly catches of those fishermen who provided log records by the factor obtained by dividing their tag returns for the season into the total for all fishermen (Table 6).

Table 9. Estimates of exploitation rate from tag returns and total mortality from two different models (see text for details) at Comfort Cove, 1975-80.

Year	Exploitation rate		Gulland Model	Beverton and Holt Model	
	Males	Females	Males	Males	Females
1975	88.5	69.8	89.0	64.7	65.0
1976	94.9	89.8	88.3	64.3	63.9
1977	91.9	90.0	87.5	62.5	64.3
1978	91.4	90.8	77.4	60.5	58.9
1979	89.1	78.8	88.9	62.5	56.8
1980	91.0	82.9	-	62.8	55.1

Table 10. Estimates of exploitation rates for different size groups of male and female lobsters at Comfort Cove, 1975-80. Numbers in ( ) are numbers of tagged lobsters present at the start of the fishing season.

	Males							Females						
	Carapace length (mm) groups							Carapace length (mm) groups						
Year	81-85	86-90	81-90	91-95	96-100	91-100	All sizes	81-85	86-90	81-90	91-95	96-100	91-100	All sizes
1975	86.1	84.7	85.3	92.3	93.8	92.7	88.5	70.0	72.2	70.5	100	20.0	50.0	69.8
	(86)	(111)	(197)	(39)	(16)	(55)	(261)	(60)	(18)	(78)	(3)	(5)	(8)	(86)
1976	85.9	92.2	89.1	92.9	100	93.3	94.9	89.7	84.0	87.0	80.0	-	80.0	89.8
	(64)	(64)	(128)	(28)	(2)	(30)	(157)	(29)	(25)	(54)	(5)		(5)	(59)
1977	84.3	94.8	89.8	97.9	88.2	96.4	91.9	73.2	95.7	83.5	100	100	100	90.0
	(121)	(134)	(255)	(93)	(17)	(110)	(370)	(56)	(47)	(103)	(9)	(3)	(12)	(110)
1978	89.5	89.4	89.4	94.8	100	95.6	91.4	86.8	95.7	90.2	100	50.0	83.3	90.8
	(105)	(160)	(265)	(77)	(14)	(91)	(362)	(76)	(46)	(122)	(4)	(2)	(6)	(131)
1979	89.3	85.8	87.1	92.7	75.0	90.6	89.1	82.7	79.0	80.9	71.4	61.5	67.7	78.8
	(84)	(141)	(225)	(55)	(8)	(63)	(293)	(81)	(81)	(162)	(21)	(13)	(34)	(198)
1980	85.2	92.1	89.3	92.3	100	93.8	91.0	80.1	88.4	84.2	80.0	60.0	73.3	82.9
	(108)	(164)	(272)	(65)	(15)	(80)	(357)	(52)	(43)	(95)	(10)	(5)	(15)	(111)
All yrs	86.6	89.8	88.5	94.4	93.1	94.2	90.9	80.2	86.5	82.9	82.7	57.1	73.8	83.3
	(568)	(774)	(1342)	(357)	(72)	(429)	(1800)	(354)	(260)	(614)	(52)	(28)	(80)	(695)

Table 11. χ^2_c values[1,2] obtained from comparison of exploitation rates for males and females in the same size groups. The analysis was not performed when the number of tagged lobsters in either group to be compared was less than 10.

Year	Carapace length (mm) groups						
	81-85	86-90	81-90	91-95	96-100	91-100	All sizes
1975	4.63*	0.93	7.01**	-	-	-	15.43**
1976	0.03	0.58	0.02	-	-	-	1.08
1977	2.36	0.02	2.20	-	-	0.03	0.18
1978	0.10	1.02	0.002	-	-	-	0.001
1979	0.99	1.26	2.35	4.31*	-	6.46*	8.99**
1980	0.23	0.21	1.30	0.44	-	3.99*	4.99*
All yrs	6.22*	1.78	10.79**	7.75**	15.97**	31.77**	28.67**

[1]Chi square (2 x 2 contingency table) corrected for continuity
[2]$\chi^2_{.05} = 3.84$, 1 df.*; $\chi^2_{.01} = 6.63$, 1 df.**

Table 12. χ_c^2 values[1,2] obtained from comparison of exploitation rates for different size groups within each sex. The analysis was not performed when the number of tagged lobsters in either group to be compared was less than 10.

	Males			Females		
	Carapace length (mm) groups compared			Carapace length (mm) groups compared		
Year	81-85/ 86-90	81-85/ 91-95	81-85/ 96-100	81-85/ 86-90	81-85/ 91-95	81-85/ 96-100
1975	0.004	0.49	0.19	0.01	-	-
1976	0.72	0.35	-	0.04	-	-
1977	6.52*	9.43**	0.004	7.85**	-	-
1978	0.03	1.01	0.61	1.61	-	-
1979	0.30	0.15	-	0.16	0.73	1.94
1980	2.56	1.32	1.41	0.53	0.14	-
All years	2.93	13.4**	1.85	3.78	0.05	6.89**

[1]Chi square (2 x 2 contingency table) corrected for continuity
[2]$\chi^2_{.05}$ = 3.84, 1 df.*; $\chi^2_{.01}$ = 6.63, 1 df.**

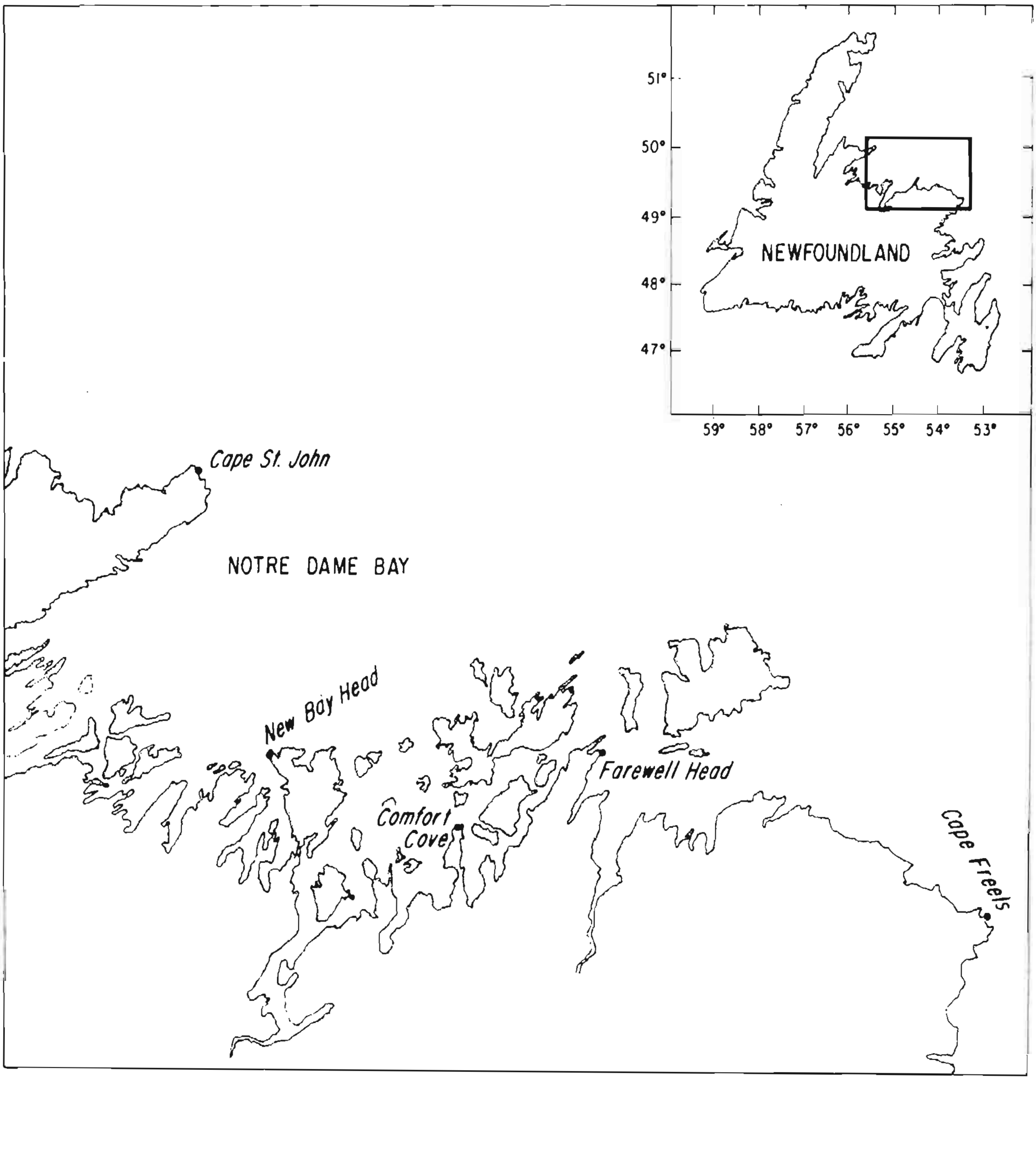

Fig. 1. Map of Notre Dame Bay, Newfoundland.

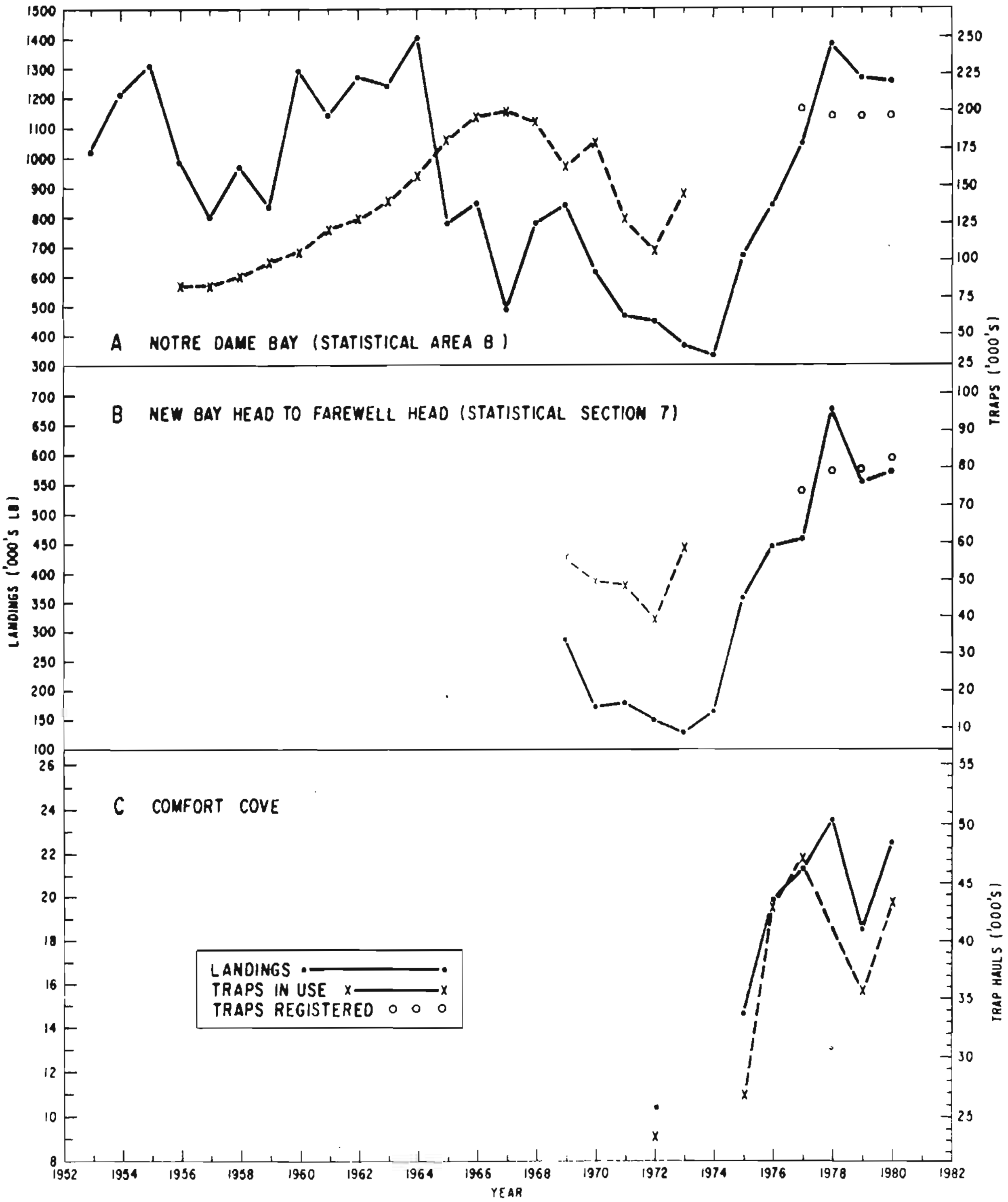

Fig. 2. History of lobster landings and effort in (A) Notre Dame Bay, (B) Statistical Section 7, and (C) Comfort Cove area (see text for details).

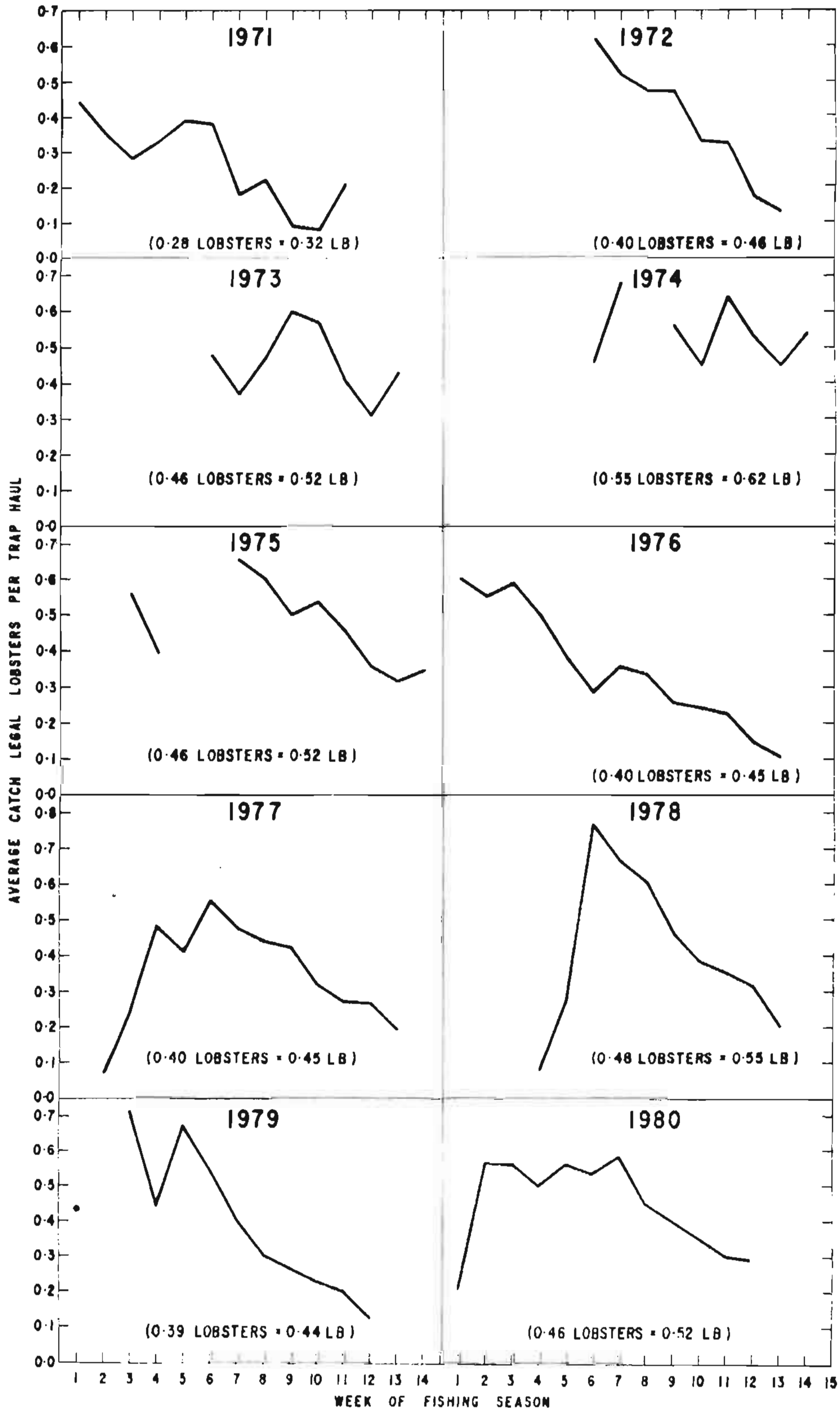

Fig. 3. Average weekly CPUE (number of commercial lobsters per trap haul) throughout the 1971 through 1980 fishing seasons at Comfort Cove.

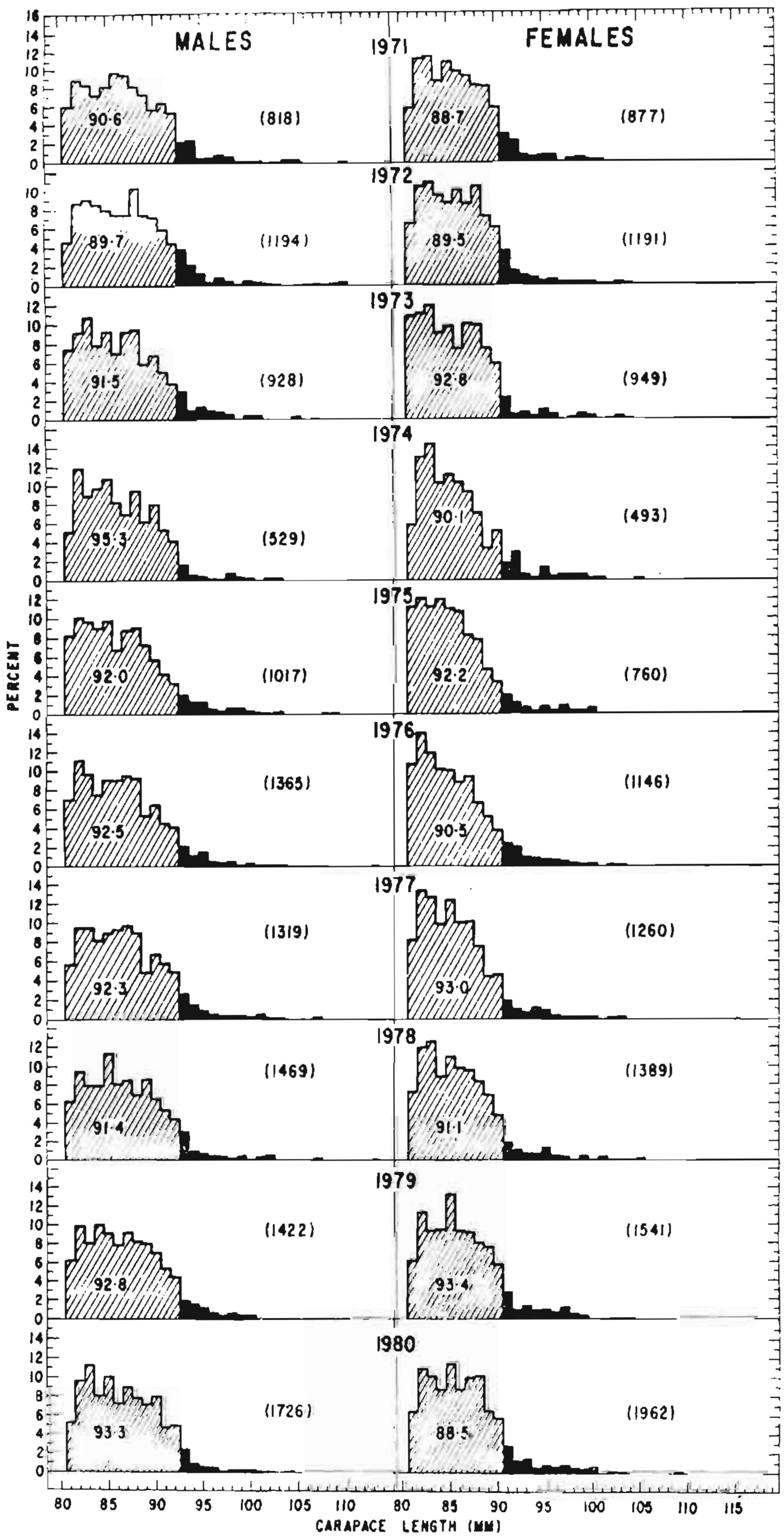

Fig. 4. Size frequency distributions of lobsters landed at Comfort Cove during the 1971 through 1980 fishing seasons. Hatched areas and the numbers included represent proportions within the recruit size ranges.

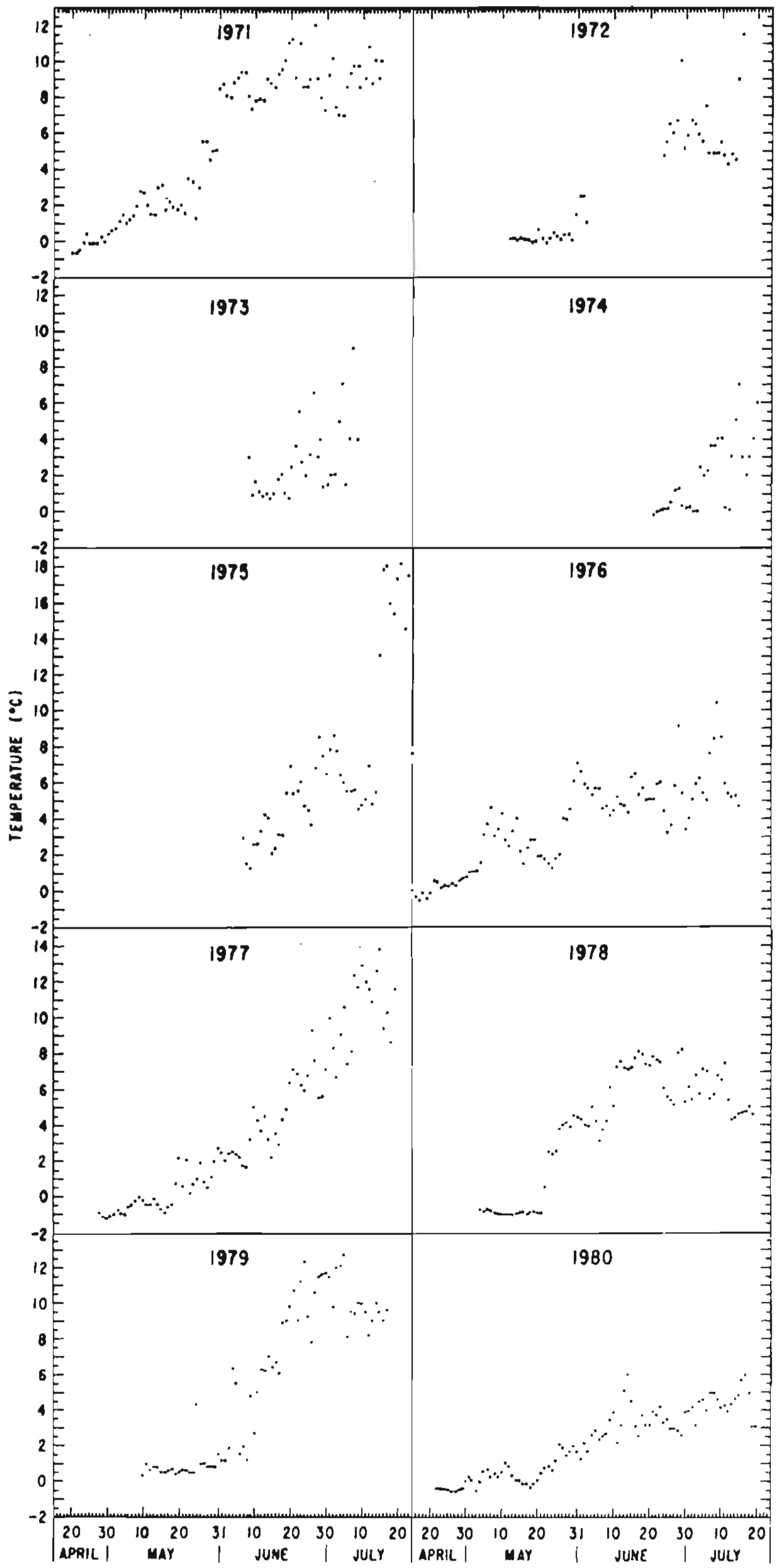

Fig. 5. Daily temperatures (°C) at a depth of 9 m on the lobster grounds at Comfort Cove during April-July from 1971 to 1980.

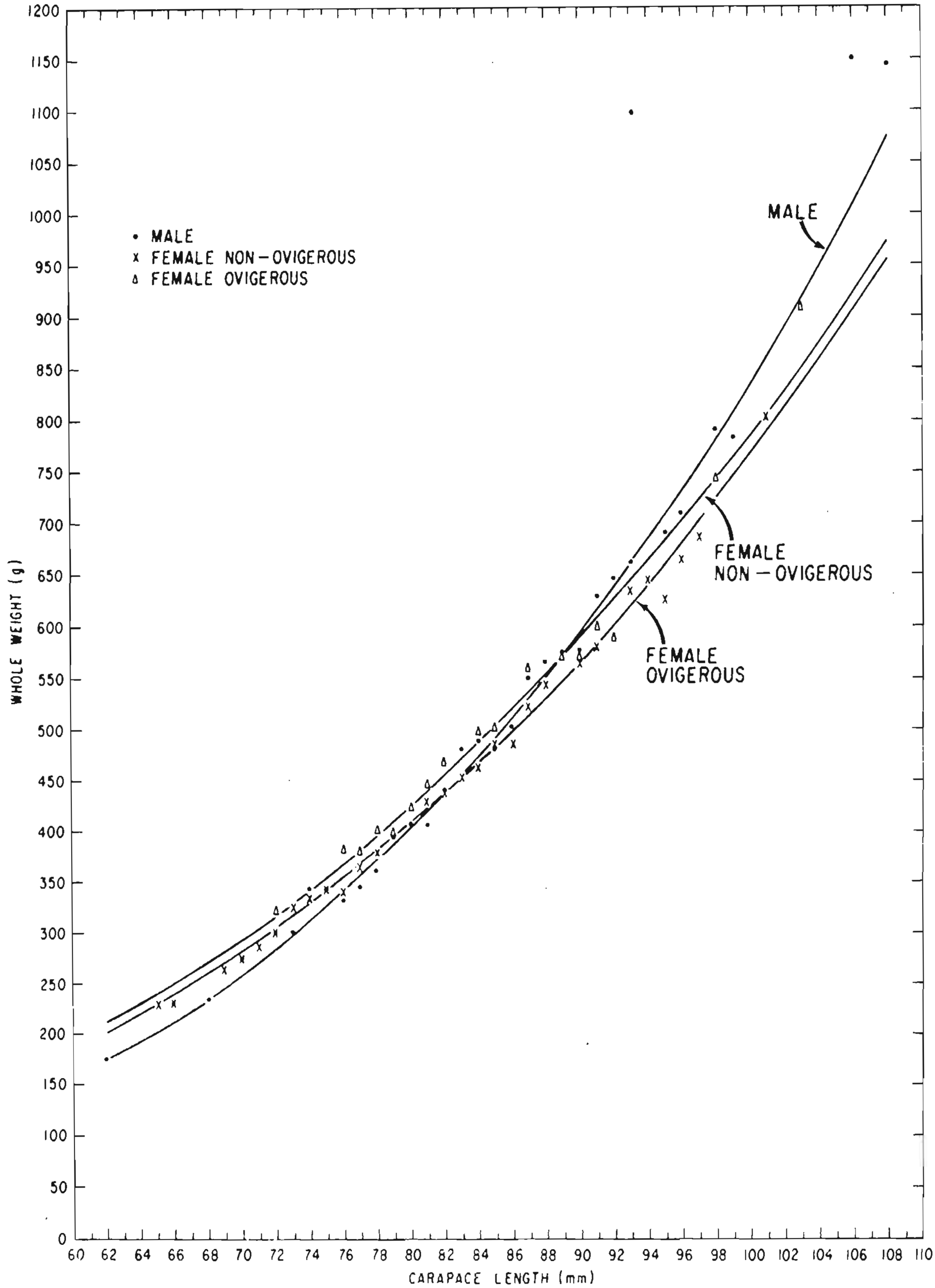

Fig. 6. Carapace length-whole weight relationships for Comfort Cove lobsters.

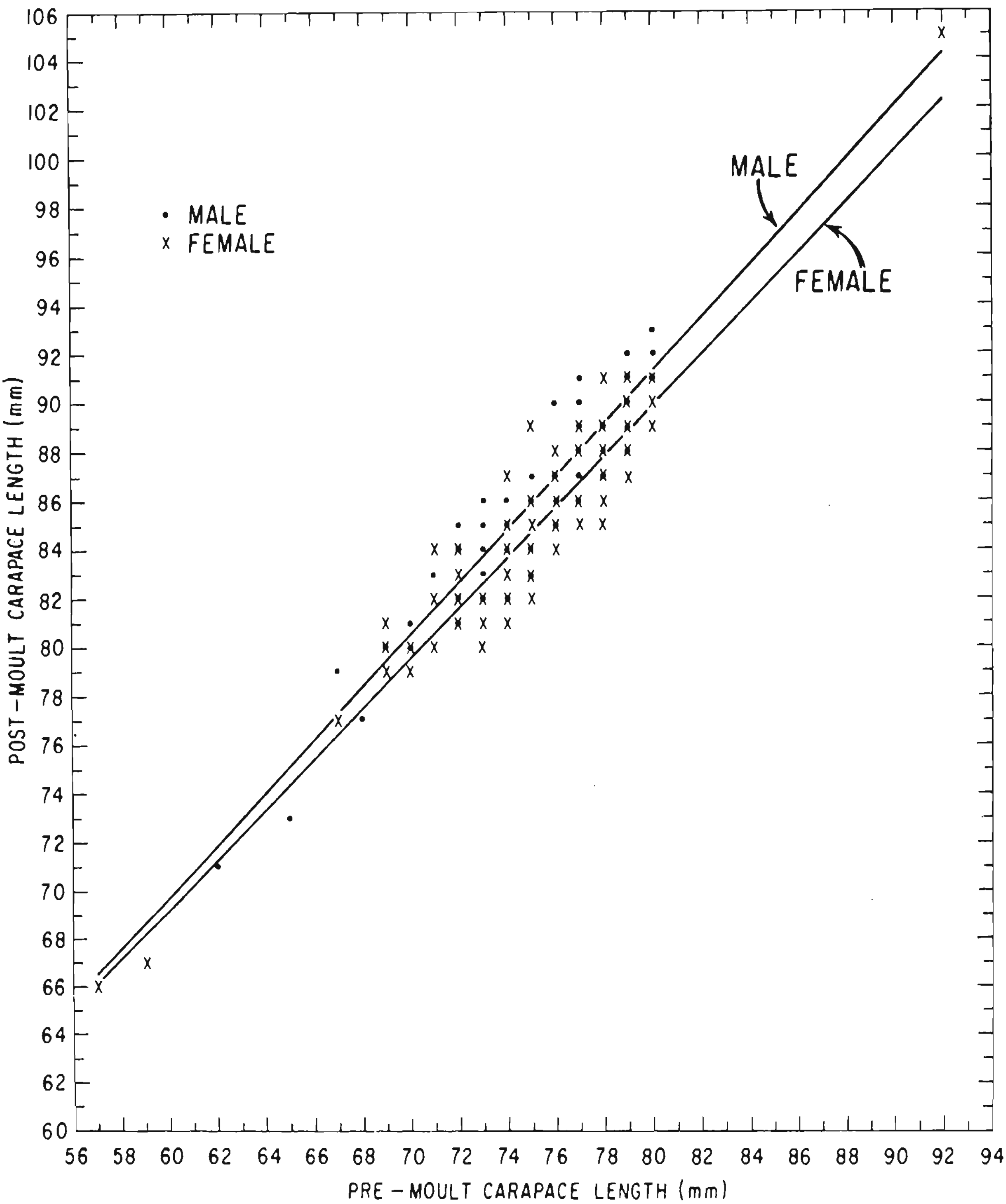

Fig. 7. Premolt-postmolt carapace length relationships for Comfort Cove lobsters.

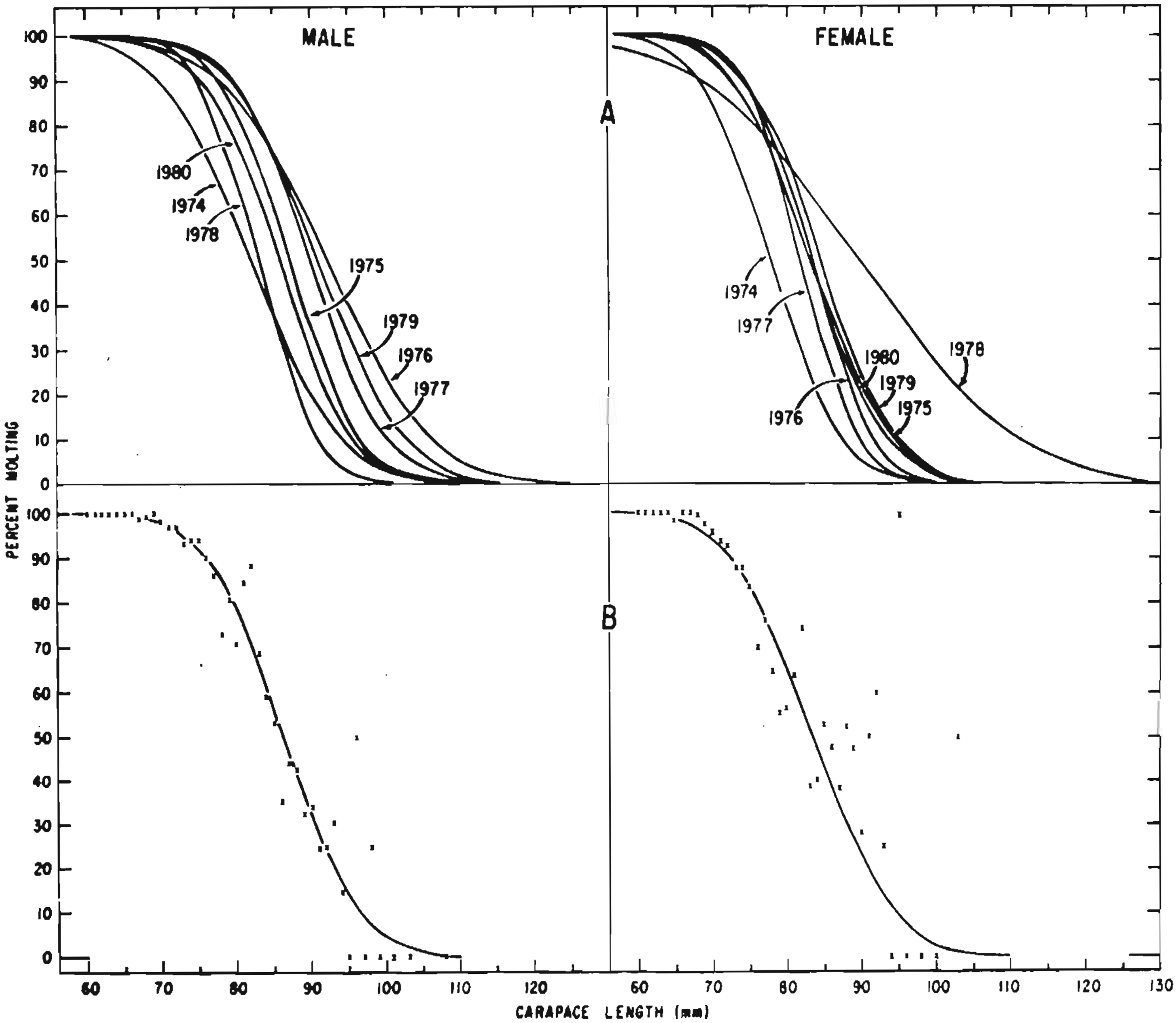

Fig. 8. Carapace length - proportion molting relationships for Comfort Cove lobsters. A-relationship for each year 1974 to 1980, B-relationship for all years combined.

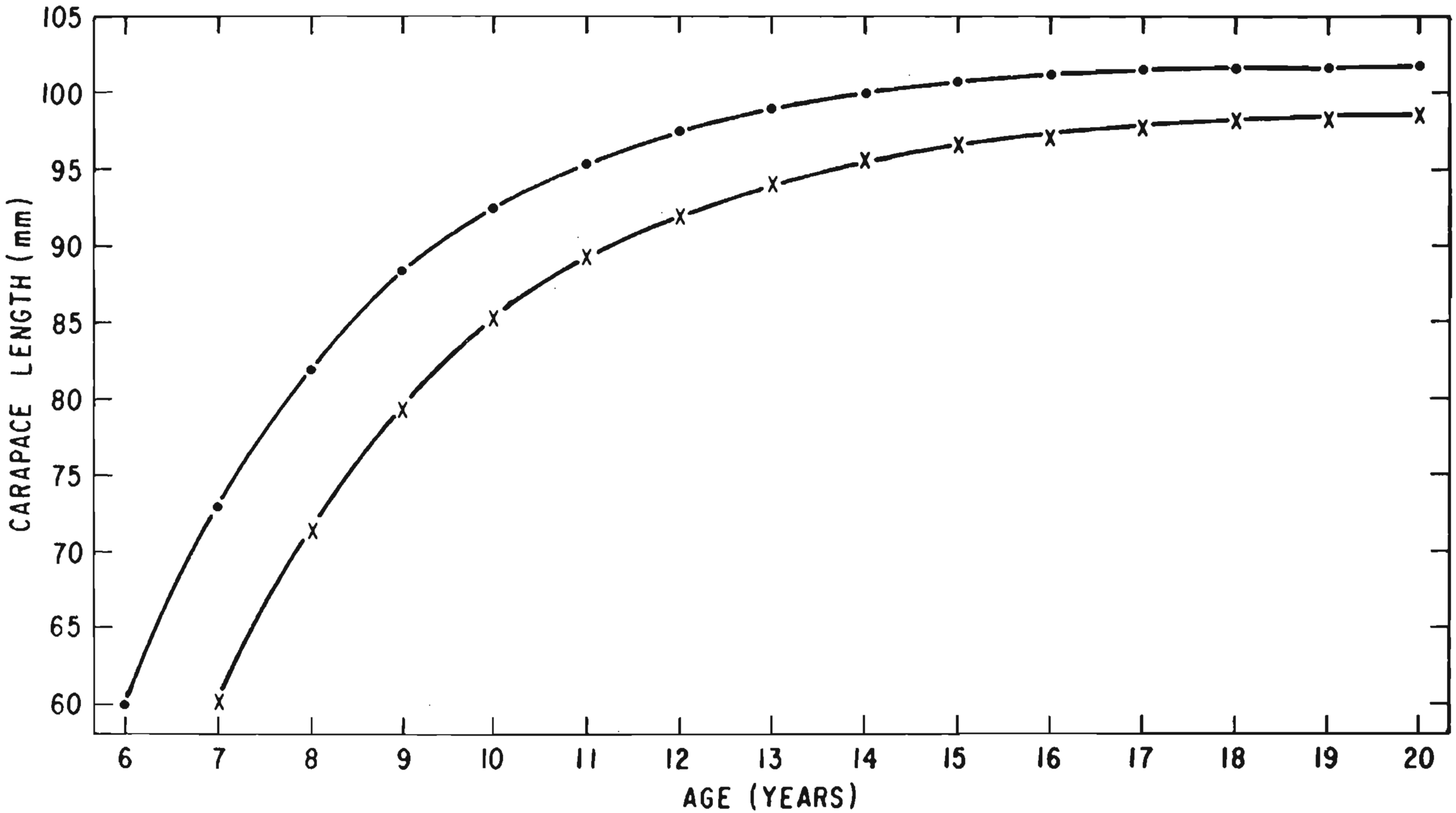

Fig. 9. Growth curves for Comfort Cove lobsters - · males, x females.

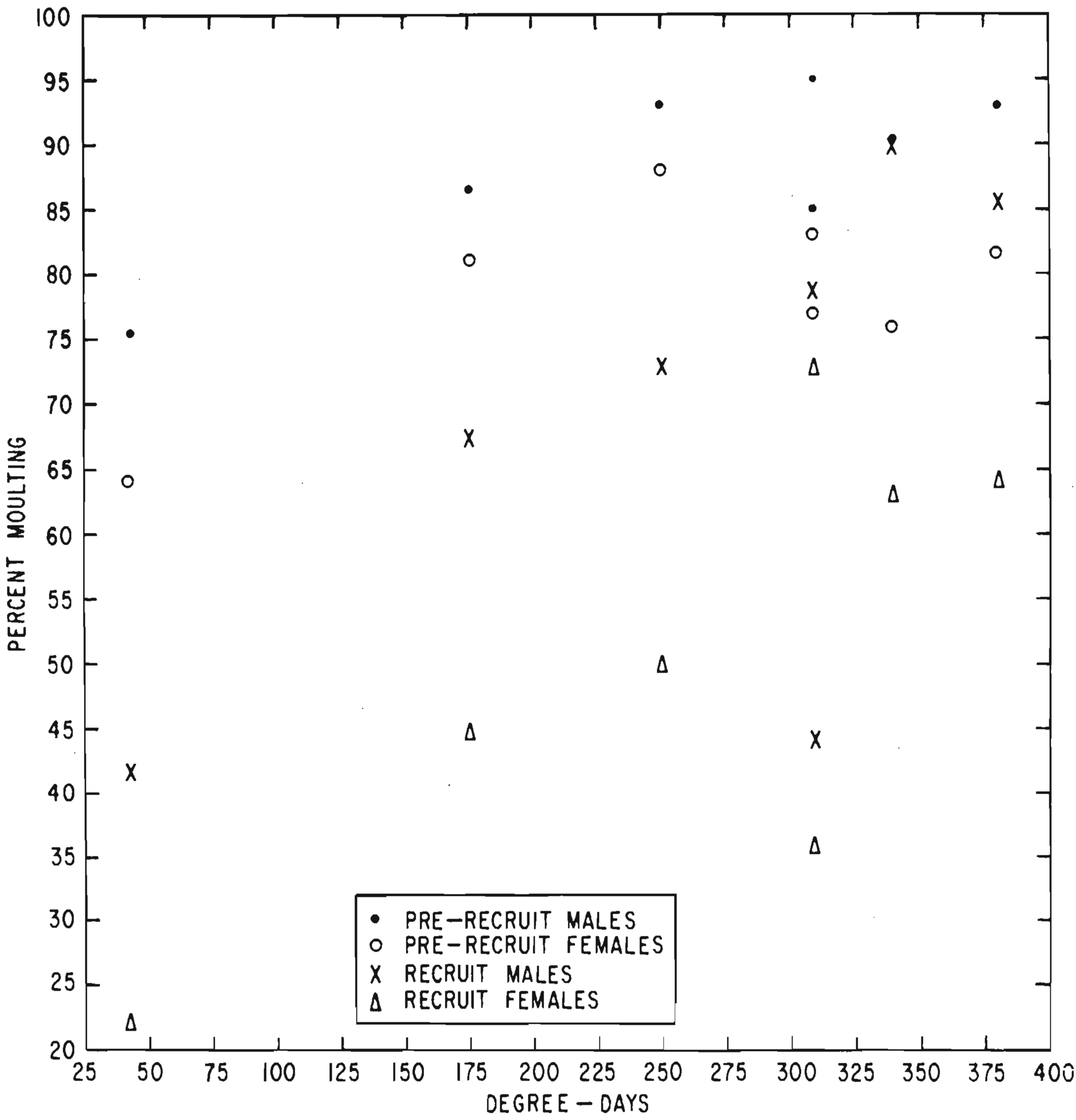

Fig. 10. Annual proportions molting in Comfort Cove lobsters in relation to accumulated degree - days (above 0°C) over the period May 1 to July 15.

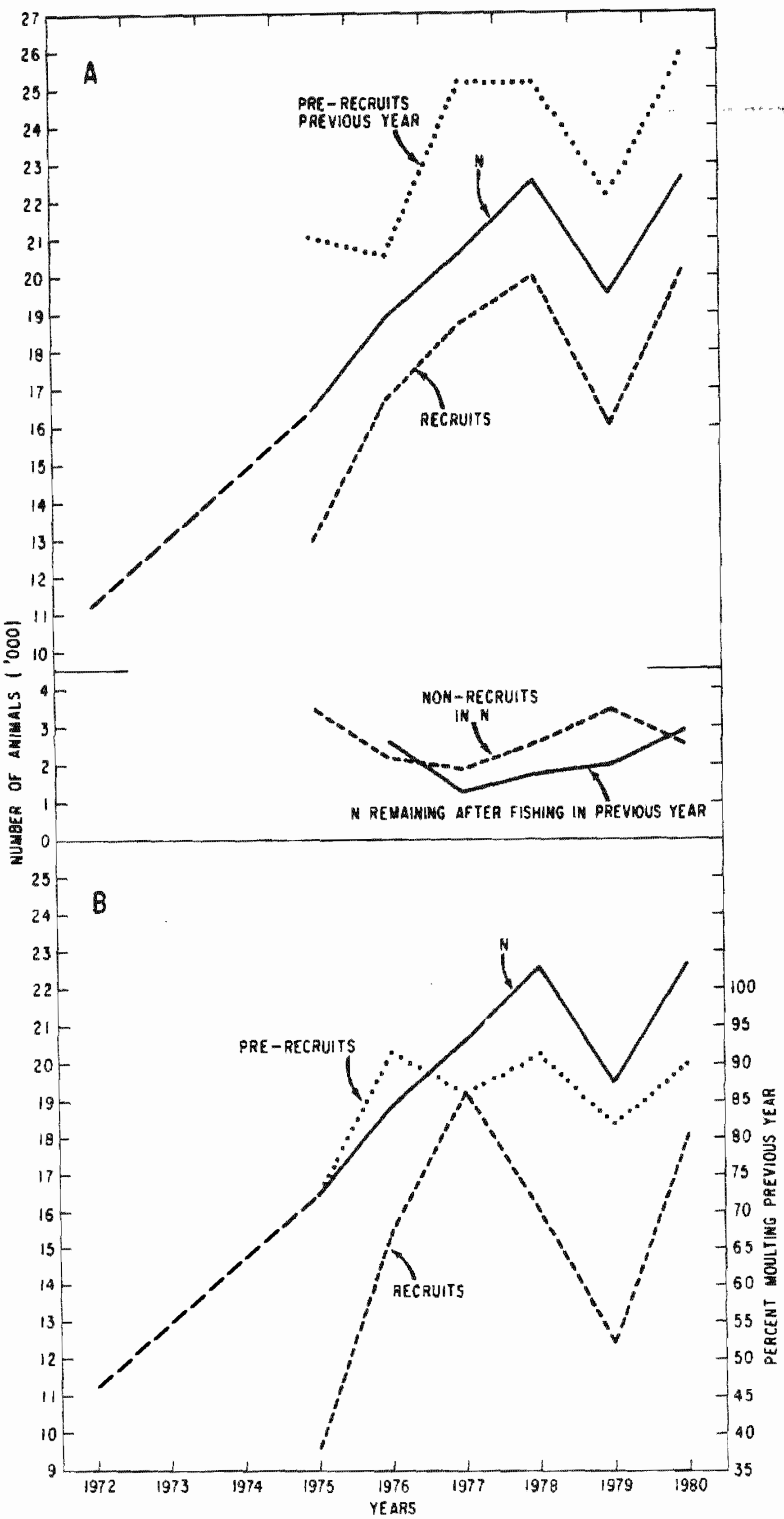

Fig. 11. Estimates of the standing stock of lobsters at Comfort Cove for 1972 and 1975-80. A-in relation to estimates of the components of the standing stock and prerecruit abundance the preceding year; and B-in relation to estimates of proportions molting in the prerecruit and recruit size ranges the preceding year.

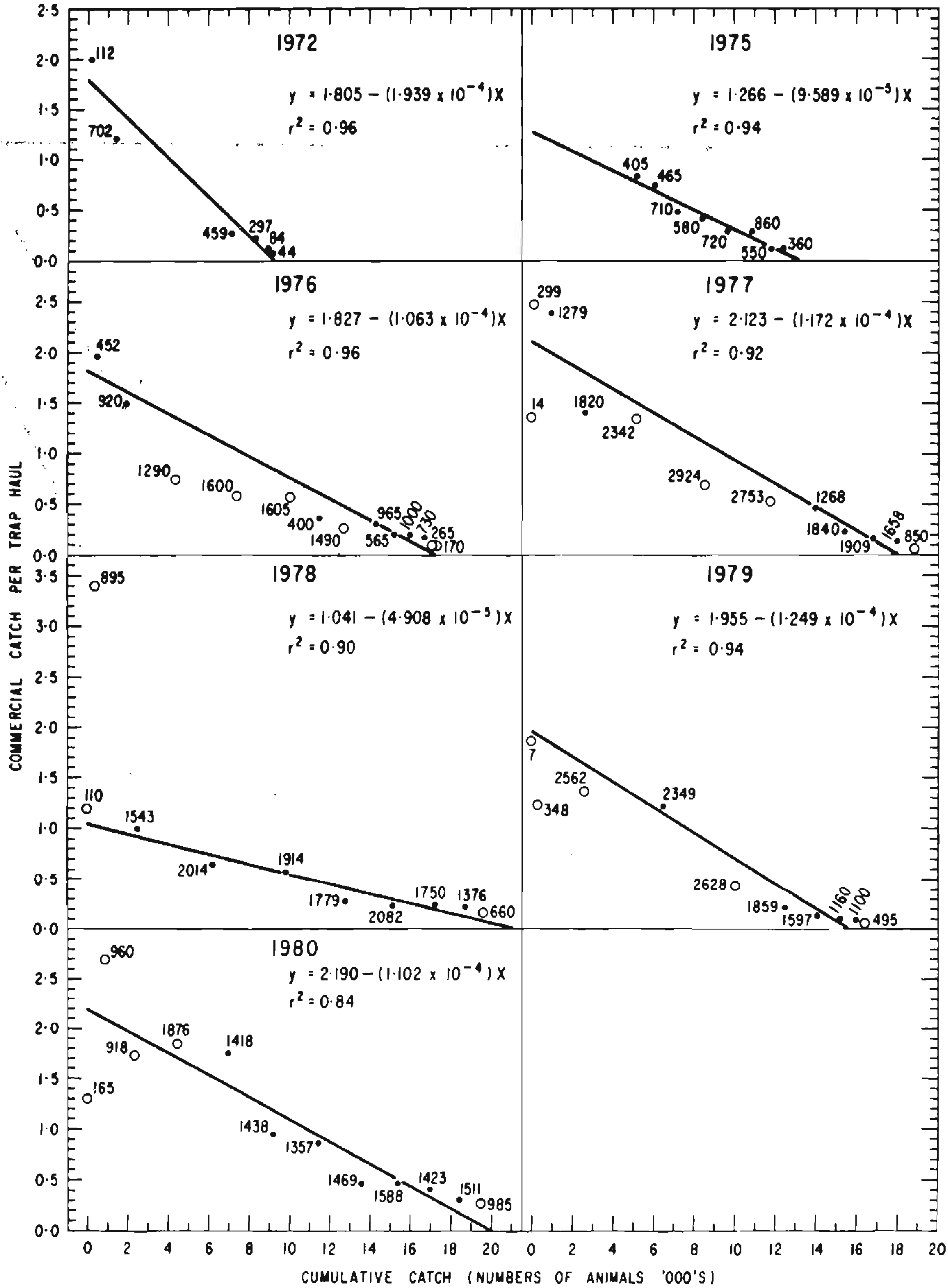

Fig. 12. Leslie analyses of Comfort Cove lobster data for 1972 and 1975 to 1980. Circled points were not used in the regressions. Numbers adjacent to points are total trap hauls on which the observed CPUE is based.

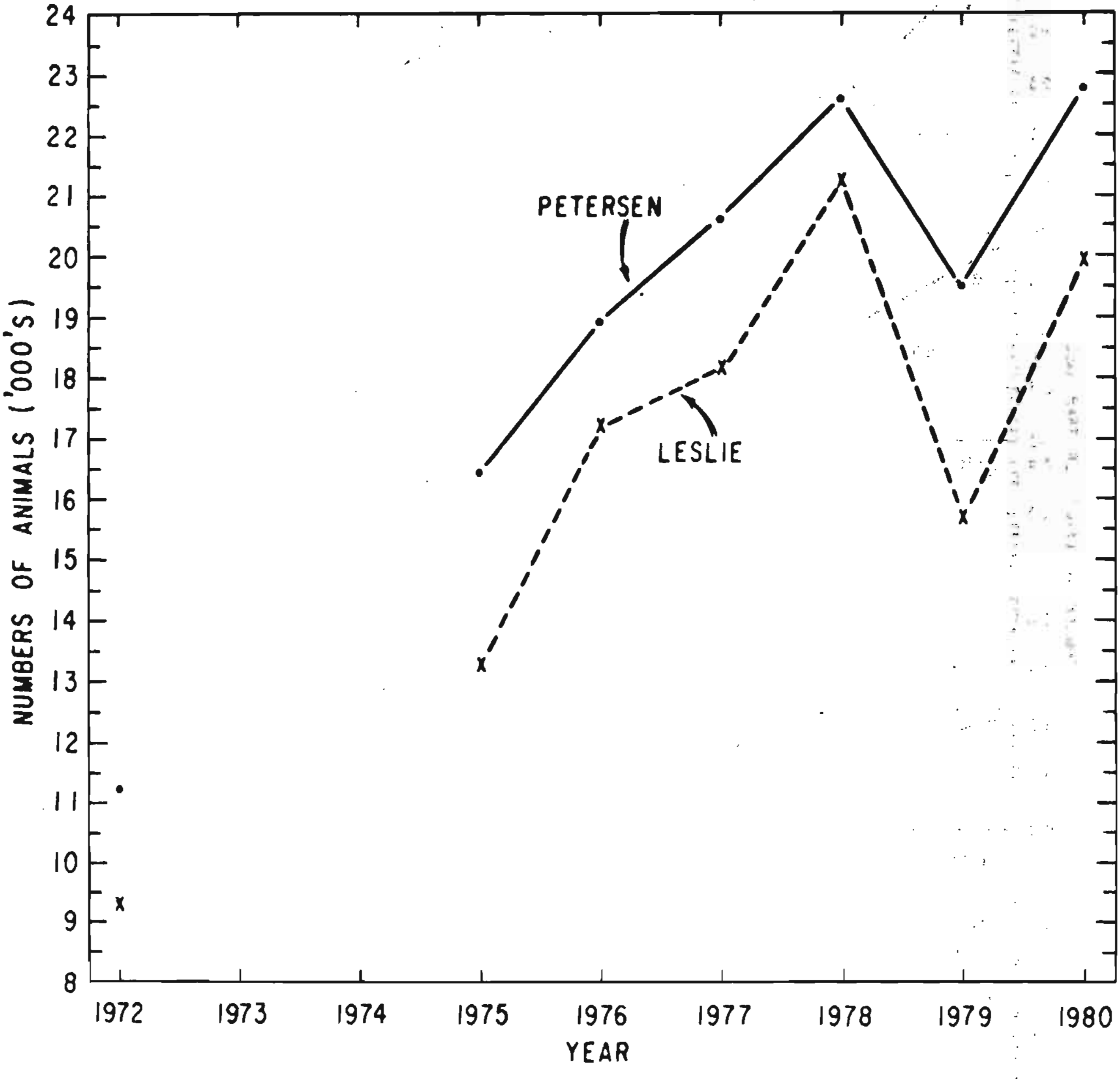

Fig. 13. Petersen and Leslie estimates of the standing stock of lobsters at Comfort Cove for 1972 and 1975 to 1980.