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Review of the Newfoundland Lobster Fishery

by

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Abstract

Historical catch and nominal effort for the Newfoundland lobster fishery and for individual lobster fishing areas (LFA's) are reviewed along with catch rate and size composition data from research logbooks and commercial catch sampling at localized monitoring sites. Yield per recruit and egg per recruit analyses are presented for the Arnold's Cove, Placentia Bay population. An evaluation of stock-recruitment and a consideration of recruitment overfishing based on a time series of population estimates for Arnold's Cove lobsters are also presented.

Résumé

Les valeurs historiques des prises et de l'effort nominal de la pêche du homard de Terre-Neuve et de certaines zones de pêche du homard (ZPH) font l'objet d'un examen de pair avec des données sur les taux de capture et la composition par tailles des registres des pêches de recherche et des prélèvements de prises commerciales effectués à des sites de contrôle. Des analyses du rendement et de la ponte par recrue sont présentées pour la population de Arnold's Cove, dans la baie de Placentia. Une évaluation stock-recrutement et une analyse de la surpêche du recrutement reposant sur une série chronologique d'estimations de la population de homard de Arnold's Cove sont aussi présentées.

Background

The American lobster ranges from southern Labrador to north Carolina. There are intensive fisheries on coastal populations throughout its range with official landings statistics dating from the early 1870's for some areas. Offshore populations occur along the outer edge of the Continental Shelf and upper slope (at depths of about 110-145 m) from the southern Scotian Shelf off Nova Scotia southwards to Virginia. Offshore fisheries started in about 1955 and are not as intensive as those inshore.

Lobsters are distributed more or less continuously around the island of Newfoundland and along the Strait of Belle Isle portion of the Labrador coast. They occupy a narrow band of rocky bottom to depths of 30-40 m. Populations are localized. Fishing is carried out with traps in depths generally less than 15-20 m during spring to early summer with opening dates from April 20 to May 10 and closing dates from June 30 to July 15.

Landing statistics for the Newfoundland fishery start in 1874, they indicate a peak at 7938 t in 1889 followed by a collapse and a 3-year closure in the mid 1920's. The catch was processed in many small canning operations all around the coast. Early documentation indicates that virtually everything caught was processed. Lobsters were also used extensively as fertilizer in cottage farming.

Shipment of Newfoundland lobsters live to the U.S. market started in the early 1930's. By the early 1950's the transition to a live market industry was complete. At this time regulations establishing a minimum legal size (MLS) of 81 mm carapace length (CL) and protecting berried females were being enforced. Only wooden lathed traps within defined maximum dimensions and with a 1 3/4" lower spacing to allow escapement of undersize lobsters were allowed. Licences were required but available to anyone and there was no limit on the number of traps that could be used.

In Newfoundland waters all of the lobster's major life history events occur for the most part during mid-July to mid-September following the spring fishing season. It takes 8-10 years from hatching to grow to 81 mm CL (i.e. MLS) (Ennis 1978a, 1980a). At this size about 50% of the non-ovigerous females will extrude during summer (Ennis 1984a). At smaller sizes many of the ripe females will molt and extrude in the same summer (Ennis 1984b). Once extrusion has occurred for the first time and at large sizes an alternate year molt/lay sequence (i.e. a 2-year reproductive cycle) is the norm. This means that the majority of females have to survive at least one season of very intensive fishing (exploitation rates generally in excess of 85%) before they spawn. Newly extruded eggs are brooded under the female's abdomen for about a year before hatching and larval release. During the 6-10 week planktonic phase there are three molts and during the last of these metamorphosis to a postlarval stage occurs. This stage is equipped with quite remarkable swimming and behavioural capabilities designed to locate suitable settling habitat. However, the extent to which postlarval settlement originates with eggs produced in the same area is unknown.

There was a pronounced downward trend in Newfoundland lobster landings during the 1950's and 1960's from a high around 2498 t in 1955 to a low around 1238 t in 1972. By the early 1970's comparable long-term declines had occurred in most Canadian and American lobster fishing areas. Fisheries were characterized by high exploitation rates and MLS's low in relation to size at maturity, a situation constraining egg production in most populations towards the low end of the potential range. There was widespread concern with the possibility of recruitment failure due to overfishing (Anon. 1977). A major review of the lobster fishery in Atlantic Canada was conducted. Its main impact on management of the Newfoundland fishery was the implementation in 1976 of a limited entry licencing policy aimed at effort reduction.

Quite unexpectedly, the downward landings trend reversed during the 1970's. In Newfoundland landings had increased to 2592 t by 1979 (more than double the 1972 low) and reached a long-term (since 1905) high of 3207 t in 1992. Landings have been declining in recent years (2413 t in 1996), much more severely in some areas than in others.

The timing and extent of increasing landings following the early 1970's low varied between areas and regions but the pattern occurred throughout the range of the species. The phenomenon is not well understood but its widespread nature indicates a period of strong recruitment associated with favourable environmental/ecological factors. Landings peaked in Canada around 1990 but have been declining since. Declines have been widespread and substantial in some areas leading to a renewed concern with recruitment overfishing and a major review of lobster conservation in Atlantic Canada by the FRCC.

Y/R analyses done for several populations 20 years ago and for several others subsequently demonstrated that growth overfishing prevailed in Canadian and U.S. lobster fisheries. E/R analyses for a number of Canadian populations done for the FRCC review indicated E/R levels under current conditions at only 1-2% that of an unfished population. The FRCC considered the risk of recruitment failure under the current regime to be unacceptably high and recommended a 5% E/R level as a medium term target for management (Anon. 1995).

Newfoundland Lobster Landings and Nominal Fishing Effort

Official records indicate that the lobster fishery began in Newfoundland in 1874 with around 68 t landed (Fig. 1). Landings increased rapidly to a peak of 7938 t in 1889. There were a number of periods of sharp fluctuations in subsequent years but there was a distinct downward trend and by 1924 landings had declined to around 340 t. During these early years the catch was processed in many small canning operations located all around the coast. Although there were regulations defining a minimum legal size and protecting berried females, they were unenforceable and early documentation indicates that virtually everything that was caught was processed.

Following a 3-year closure (1925-27), landings increased to 2087 t in 1928, but the recovery was short lived and landings dropped sharply the following year. Shipment of live lobsters to the U.S. market where size limit and berried female regulations were strictly enforced started in the early 1930's. By the early 1950's virtually all of the landings were shipped to the U.S. and the fishery has remained a live market industry ever since. Landings increased to around 2498 t by 1955 possibly because of increased effort but more likely because of increased recruitment resulting from the degree to which the size limit and berried female regulations became enforceable. The 1955 high was followed by a period of declining landings to a low of around 1238 t in 1972. Quite unexpectedly the downward trend reversed and landings increased rapidly during the 1970's to 2592 t in 1979 and reached a long-term (since 1905) high of 3207 t in 1992. This upward trend was part of a pattern that occurred more or less throughout the range of the species. Although the phenomenon is not well understood, its widespread nature indicates a period of strong recruitment associated with favourable environmental/ecological factors. The extent to which the generally high level of recruitment was maintained by continued favourable conditions or by increased egg production at the high level of abundance or by a combination of the two is unknown. Landings have generally been declining in recent years and were down to 2413 t in 1996.

Recent landings declines have been widespread in Atlantic Canada and quite substantial in many areas. Understanding of the lobster recruitment phenomenon of the past 25 years is still quite limited and provides no basis for predicting future trends. It is unrealistic, however, to expect strong recruitment to continue indefinitely and the recent declines in landings could represent the early stages of a widespread downward trend.

Up until 1976, effort in the Newfoundland lobster fishery, in terms of both licences and the number of traps that could be fished per licence, was uncontrolled. As indicated by the number of traps fishermen stated on their licence applications that they intended to fish each year, effort increased dramatically after 1955. This measure of effort was discontinued after 1974. A limited entry licencing policy was implemented in 1976 and fishermen who were issued licences were restricted to the number of traps they had stated on their 1975 licence application that they intended to fish that year. The consensus was that the number of traps actually used (which would likely be comparable to the 1974 and earlier effort data) was substantially in excess of the number allowed as per the licencing policy. While the number of licences issued has dropped from 5992 in 1976 to 4022 in 1995, the number of traps registered increased from 741,732 in 1976 to 1,188,932 in 1992 (Fig. 1). The sharp increases in registered traps are associated with the implementation of uniform trap limits (i.e. same number for each licence) for west coast Lobster Fishing Areas (LFA's) in 1987 and for east and south coast LFA's in 1991. The number of registered traps has been declining since 1992 to 975,285 in 1995 due to trap limit reductions in west coast LFA's.

Newfoundland lobster landings and nominal effort have been available for Statistical Areas since 1953 and for three or four Statistical Sections within these areas since 1976. LFA's were established several years ago (Fig. 2); for most, boundaries coincide with the old Statistical Areas and their time series extend back to 1953. Some boundary adjustments were made on the tip of the Northern Peninsula and on the south coast which compromise the time series for LFA's 3, 11, 12, and 14C prior to 1976. The time series of landings and nominal effort (registered traps) for individual LFA's are provided in Figure 3.

Fishery Monitoring

In addition to the official fishery statistics, monitoring has included maintaining a voluntary logbook program and dockside (i.e. post cull) sampling of commercial catches throughout the fishing season annually at selected sites around the island. This started at St. Chads-Burnside, Bonavista Bay in 1968, at Arnold's Cove, Placentia Bay in 1970, at Comfort Cove, Notre Dame Bay in 1971, at Boswarlos, Port au Port Bay and Bellburns on the Northern Peninsula in 1975. It was discontinued at the two west coast sites after 1982 with the transfer of mandate to the Gulf Region of DFO. Following the return of the mandate to the Newfoundland Region, monitoring was reestablished on the west coast in 1994. Five sites were chosen for voluntary logbooks and at sea sampling of commercial catches. These were St. David's, Bay St. George; Woods Island, Bay of Islands; Rocky Harbour, Bonne Bay; River of Ponds, Northern Peninsula; and Eddies Cove West, St. John Bay.

Average seasonal catch rates and annual landings for the Statistical Sections in which they are located are presented for St. Chad's-Burnside, Arnold's Cove and Comfort Cove in Figure 4. Catch rates have ranged widely over the time series and vary considerably from year to year at each site. In general, the variability in catch rates tends to coincide with landings. They increased substantially during the 1970's and generally declined subsequently. Patterns of catch rate variation during the fishing season at each of the eight monitoring sites in recent years are depicted in Figure 5. Catch rates are usually high early in the season, even though bottom temperature and lobster catchability are low, and decline rapidly as the season progresses. Significant departures from this pattern are caused by anomalously low temperatures, delayed season opening due to ice, and the landing of large numbers of traps well in advance of the season closure.

Size frequencies from dockside commercial catch sampling at St. Chad's-Burnside, Comfort Cove and Arnold's Cove in recent years are presented in Figure 6. Most of the landings are in the recruit size range (one molt increment above MLS). Size frequencies from at-sea sampling at different times during the fishing season at various west coast sites in recent years are presented in Figure 7. These illustrate the almost complete removal of commercial lobsters from these local populations over the course of the fishing season.

Long-term Population Monitoring

Annual population estimation was initiated at the five fishery monitoring sites in the mid 1970's (Ennis et al. 1982, 1986, 1989, 1994, 1995). This involved research fishing in fall to conduct biological sampling and tag commercial lobsters. Tag returns and logbook data provided a basis for estimating standing stock and exploitation rate during the spring fishery, sampling data provided a basis for estimating recruitment to the standing stock (Ennis 1979, 1983). This population monitoring is continuing at the Arnold's Cove site. It was discontinued at the two west coast sites after 1982, at St. Chad's-Burnside after 1993, and after 1996 at Comfort Cove.

Estimated trap hauls for the season and exploitation rates show considerable inter-annual variation at the Comfort Cove, St. Chad's-Burnside and Arnold's Cove study sites (Fig. 8). No consistent patterns of variation between the two over the three time series or between the sites is evident. Exploitation rates in excess of 85-90% have occurred regularly at Comfort Cove and Arnold's Cove over the past 15-20 years. They have been increasing at St. Chad's-Burnside over this time period but reached this very high level only in recent years.

The standing stock estimates for the Arnold's Cove population are presented in Figure 9 superimposed on the landings for Placentia Bay. Estimated landings for the Arnold's Cove fishery represent approximately 5-6% of the Placentia Bay total yet fluctuations in the standing stock at Arnold's Cove closely mirrored those in Placentia Bay landings. Changes being measured in the population monitoring at Arnold's Cove reflect fluctuations in abundance on a much broader scale. Recruitment to the standing stock since the preceding fishing season ranged from 85 to 90% by number for 1993-96.

Yield Per Recruit

Y/R analyses for a number of populations including several in Newfoundland (Ennis 1978b, 1980b) have demonstrated that growth overfishing is characteristic of lobster fisheries throughout the range of the species. Results for Arnold's Cove lobsters (Fig. 10) indicate that Y/R could be increased by as much as 27% of that under current conditions (i.e. 85% exploitation rate/81 mm

MLS) by increasing the MLS to 97 mm or by 14% by decreasing the exploitation rate to 27%.

The initial reduction in landings upon implementation of a size limit increase and the subsequent increase in landings due to increased yield per recruit would depend on the magnitude of the size limit increase. They would also vary between areas depending on differences in growth rate, size at maturity, exploitation rate, etc. Assuming constant recruitment and an 80% exploitation rate, it is estimated that an increase in MLS to 89 mm CL would result in landings being reduced 50-60% below par in the year of implementation. The following year landings would be a little over par and over the next three years would increase to 27% over par and be maintained at that higher level thereafter.

Egg Per Recruit

An egg per recruit model was developed specifically for Newfoundland lobsters (Ennis and Collins 1983). Initial analyses for Arnold's Cove lobsters (Ennis 1985) indicated that egg production per female recruit (E/R) could be increased by 270% by increasing the MLS from 81 to 89 mm CL and by reducing the exploitation rate from 80 to 60% (Fig. 11). The extent to which increased egg production would result in increased recruitment, however, is unknown. More recent analyses done as part of and follow up to the FRCC review indicate that under current conditions (i.e. 85% exploitation rate/81 mm MLS) E/R is less than 1% of what it could be if the population were unfished. This could be too low to maintain high recruitment under average environmental/ecological conditions and could lead to recruitment failure under unfavourable conditions. At such a low level of egg production, the FRCC considered the risk of recruitment failure to be unacceptably high. It recommended a 5% E/R level as a medium term target towards which management should move as soon as possible.

Estimated E/R for an unfished population was generated by running the model at a 0% exploitation rate. Efforts have been ongoing to resolve uncertainties about model outputs and whether expressing E/R as a percentage of that estimated for an unfished population is a realistic representation of the relative level of egg production under current conditions. Nevertheless, the model does provide a realistic indication of the relative merit, in terms of their potential for increasing egg production, of various options that would represent comparatively small departures from the current management regime.

Analyses indicate that the E/R level could be increased from 0.9% under current conditions to 2.2% by increasing the size limit to 89 mm CL or to 1.6% by reducing the exploitation rate to 65%. Alternatively, a voluntary V-notching program, assuming a 50% rate of notching and that all are re-notched before the mark disappears, could increase the level to 2%. A maximum size limit would have no effect unless the exploitation rate was reduced. At a 65% exploitation rate and a 120 mm CL maximum size limit, the E/R level could be increased to 2.5%. The foregoing estimates are the most representative for Newfoundland lobsters currently available. They indicate that significant changes will be required in the way the fishery is managed if the target egg production level of 5% recommended by the FRCC is to be achieved. However, any measures that would lead to increased egg production would help to reduce the risk of recruitment failure.

Stock Recruitment Relationship

Along with recruitment, total annual egg production (Ennis 1991) in the Arnold's Cove population has been derived from the 1976-96 series of standing stock estimates. The best estimate of age at recruitment to the standing stock in Newfoundland lobsters is 8-10 years. Using a 9-year lag between egg production (i.e. stock) and subsequent recruitment (Fig. 12), the 21-year series of annual estimates yields 12 S-R data points. Confidence intervals for the 1976-87 standing stock estimates, from which the egg production estimates were derived, ranged from ±6.0% to ±20.4% and those for the 1985-96 standing stock estimates, from which the recruitment estimates were derived, ranged from ±5.1% to ±7.0%.

The Beverton and Holt model was fit to the data (Fig. 13). A relationship with a very steep ascending limb peaking at the low end of the range and a density-dependent effect at high levels of egg production is indicated. Habitat carrying capacity could be a factor tending to constrain recruitment at high levels of egg production.

The relationship between egg production in a given year and recruitment 9 years later is tenuous because recruitment of a particular yearclass to the standing stock will undoubtedly be spread over several years. Processes and mechanisms which determine where larvae that originate in an area eventually settle are not completely understood and the extent to which recruitment to a localized population (i.e. postlarval settlement) originates with egg production within that population is not known.

Recruitment Overfishing

Efforts to define limiting levels of exploitation beyond which the risk of recruitment overfishing is high have recently been undertaken in both Canada and the United States. In the United States, fishery management plans for species under federal jurisdiction are required to specify a threshold level beyond which the risk of recruitment overfishing is high. In the absence of definitive information, a precautionary recruitment overfishing definition for lobster has been adopted. The U.S. lobster resource is considered overfished when the fishing mortality rate exceeds the level which "results in a calculated egg production per recruit level of less than 10% of a non-fished population" (Anon. 1993).

An attempt has been made to provide an empirically based definition using Arnold's Cove E-R data combined with results of an E/R analysis (Ennis and Fogarty, in press). The approach used is based on the concept that the recruits of one generation must, on average, produce enough eggs to replace their parental generation. The threshold for replacement is represented by a line through the origin of the E-R scatterplot with slope equal to the median survival ratio derived from the data. The E/R number whose reciprocal yields the same survival ratio is determined from the E/R analysis. This identifies the exploitation rate beyond which recruitment can be expected to decline because of inadequate egg production.

For application in this analysis, our E/R model was modified to address some of the uncertainties with running it at zero exploitation rate to proxy an unfished population. Life-history sequences for large females based on limited empirical information have been incorporated. Running the earlier version of the model at zero exploitation applied growth and maturity functions derived from data on small females to the much larger sizes achieved in the model population. This overestimated egg production at zero exploitation rate and thereby underestimated the relative E/R level under the current management regime. Egg production per female recruit values for nominal exploitation rates from 0 to 100% are provided in Figure 14. Assuming a 1:1 sex ratio among recruits, the E/R number is halved to include males in the analysis.

Estimates of recruitment to the adult population were generated from the standing stock estimates (Fig. 12). The median survival ratio from the data (Fig. 15) corresponds to an E/R level of 2.5% of what it would be if the population were unfished. At a nominal 90% exploitation rate the E/R level is estimated at 4.2%. This suggests that exploitation rate may exceed 90% without risk of recruitment overfishing.

While lobster populations must be highly resilient to fishing, there are a number of factors/considerations indicating that a cautious interpretation of the results obtained from the foregoing analysis of Arnold's Cove data is warranted. In addition to the tenuousness of the stock (egg production)-recruitment relationship already mentioned, any overestimation of recruitment or underestimation of egg production will result in a high-biased estimate of the median survival ratio. Further, the approach is most appropriately applied to stock-recruitment data with no compensation involved and collected during a period when environmental conditions affecting survival are average. The high resilience of lobster populations suggests a strongly compensatory mechanism in the life cycle (Fogarty 1989, Fogarty and Idoine 1986). The Arnold's Cove E-R data were obtained during a period of strong recruitment that was at least partly associated with better than average environmental/ecological conditions. The Arnold's Cove E-R data probably provide a survival ratio that is higher than normal.

A large portion of the egg production in the Arnold's Cove population is by undersized (prerecruit) females carrying eggs for the first time (Ennis 1985, 1991). Egg viability, fertilization success, egg adhesion and hatchability may be lower for smaller lobsters. Large female lobsters tend to produce larger eggs with higher energy content than small females which probably represents a survival advantage for the larvae they produce (Attard and Hudon 1987). They found also that large females both extrude and hatch their eggs earlier in summer and there appears to be a survival advantage associated with hatching when temperature is increasing rapidly (Hudon and Fradette 1988).

Effectively then E/R numbers could be considered much lower than the model outputs. The lower the E/R number the higher the survival ratio estimated from its reciprocal and the greater the risk of recruitment overfishing when compared with the survival ratio from the E-R data. Nevertheless, egg production by sublegal females represents a buffer against exploitation that may help to prevent exploitation rates from exceeding limiting levels.

In evaluating various options for increasing egg production, model outputs clearly indicate that the most effective management measures would be any providing long-term protection from exploitation to even very small numbers of females. A factor not considered in the E/R analysis is the occurrence in some areas of small isolated pockets of mostly large lobsters. In Newfoundland waters lobsters tend to be restricted to a narrow band of rocky-bottom habitat along the shore. Areas adjacent to exposed headlands are lightly exploited because of rough seas during much of the fishing season. Such areas yield relatively small numbers of mostly large lobsters that are rarely seen in heavily exploited areas within the bays. In the Southern Gulf of St. Lawrence large lobsters are rarely taken in the commercial catch but are sometimes encountered in small numbers in research fishing during closed time. Small pockets of large lobsters may originate because of low exploitation in limited areas or possibly because some individuals have low vulnerability to capture in baited traps and avoid capture long enough to reach sizes at which entry is restricted in standard traps. Relatively small numbers of large lobsters may represent refugia that produce enough eggs to provide some of the resilience to fishing that this species exhibits. This is consistent with Fogarty's (in press) conclusion that in an area where a moderately exploited offshore population occurs, a relatively low level of recruitment subsidy through larval transport from offshore to inshore could allow an inshore population to persist at high levels of fishing mortality.

Outlook

In Newfoundland as elsewhere, lobsters are very heavily exploited and the bulk of annual landings is made up of animals that recruited since the previous year. Annual recruitment fluctuates with changes in environmental/ecological conditions; landings, therefore, will be determined largely by the vagaries of nature. Over the long term, landings can be expected to be lower, less stable, and to decline to lower levels than under a more moderate level of exploitation.

Over the past 45-50 years, major long-term trends in Newfoundland lobster landings have been part of widespread phenomena. Landings have been declining in recent years in many areas, for longer and to much lower levels in some than in others. Whether this represents the early stage of a widespread downward trend is not yet clear.

Yield per recruit analyses show that growth overfishing is occurring under the current management regime. Egg per recruit analyses show that the relative level of egg production is extremely low. While recruitment overfishing has not been demonstrated conclusively, there clearly is a high risk of recruitment failure, especially during periods when factors that influence survival to recruitment are unfavourable.

New management initiatives aimed at increasing the level of egg production will have to achieve a more moderate level of exploitation before future landings are dictated to a lesser extent by the vagaries of nature.

References

Anonymous 1997. Report of the Working Group on Homarus stocks. ICES 1977/K:11.

Anonymous 1993. American lobster. In 'Report of the 16th Northeast Regional Stock Assessment Workshop (16th SAW)'. pp. 75-107. Northeast Fisheries Science Centre Reference Document 93-18. (Woods Hole, Massachusetts)

Anonymous 1995. A conservation framework for Atlantic lobster. Fisheries Resource Conservation Council 95.R.1.

Attard, J., and C. Hudon. 1987. Embryonic development and energetic investment in egg production in relation to size of female lobster (Homarus americanus). Can. J. Fish. Aquat. Sci. 44: 1157-1164.

Ennis, G. P. 1978a. Growth curves for Newfoundland lobsters from data on molt increment and proportion molting. CAFSAC Res. Doc. 78/29. 11 p.

1978b. Yield per recruit assessments for Newfoundland lobster stocks. CAFSAC Res. Doc. 78/31. 18 p.

1979. Estimates of abundance and recruitment to the standing stock for a Newfoundland population of the lobster, Homarus americanus, with a method of estimating its natural mortality. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 175: 2225-228.

1980a. Recent and current Canadian research on growth of lobsters in the wild. pp. 9-15. In: V. C. Anthony and J. F. Caddy (eds.). Proceedings of the Canada-U.S. Workshop on Status of Assessment Science for NW Atlantic Lobster (Homarus americanus) Stocks, St. Andrews, N.B., Oct. 24-26, 1978. Can. Tech. Rep. Fish. Aquat. Sci. 932, St. Andrews, Canada.

1980b. Further yield per recruit analyses for Newfoundland lobsters. CAFSAC Res. Doc. 80/39. 14 p.

1983. Annual variations in standing stock in a Newfoundland population of lobsters. N. Amer. J. Fish. Manage. 3:26-33.

1984a. Comparison of physiological and functional size-maturity relationships in two Newfoundland populations of lobsters Homarus americanus. Fish. Bull. 82: 244-249.

1984b. Incidence of molting and spawning in the same season in female lobsters, Homarus americanus. Fish. Bull. 82: 529-530.

1985. An assessment of the impact of size limit and exploitation rate changes on egg production in a Newfoundland lobster population. N. Am. J. Fish. Manage. 5: 86-90.

1991. Annual variation in egg production in a Newfoundland population of the American lobster, Homarus americanus. pp. 291-299. In: A. Wenner and A. Kuris (eds.). Crustacean Egg Production. A. A. Balkema/Rotterdam/Brookfield.

Ennis, G. P., and P. W. Collins. 1983. A computer program to assess egg production per recruit in a lobster (Homarus americanus) population. Can. Tech. Rep. Fish. Aquat. Sci. 1198.

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: 45 p.

1989. Fisheries and population biology of lobsters (Homarus americanus) at St. Chad's-Burnside, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1651: 44 p.

Ennis, G. P., P. W. Collins, G. Dawe, and W. R. Squires. 1994. Fisheries and population biology of lobsters (Homarus americanus) at Bellburns on the Northwest Coast of Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1997: 31 p.

1986. Fisheries and population biology of lobsters (Homarus americanus) at Arnold's Cove, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1438: 34 p.

1995. Fisheries and population biology of lobsters (Homarus americanus) at Boswarlos, Port au Port Bay, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 2103: 20 p.

Ennis, G. P., and M. J. Fogarty. A recruitment overfishing reference point for the American lobster, Homarus americanus. Marine and Freshwater Res. (in press)

Fogarty, M. J. 1989. Lobster recruitment processes. The Lobster Newsletter. 2: 2.

Fogarty, M. J. Implications of migration and larval exchange in American lobster stocks: Spatial structure and resilience. Can. Spec. Pub. Fish. Aquat. Sci. (in press)

Fogarty, M. J., and J. S. Idoine. 1986. Recruitment dynamics in an American lobster (Homarus americanus) population. Can. J. Fish. Aquat. Sci. 43: 2368-2376.

Hudon, C., and P. Fradette. 1988. Plantonic growth of larval lobsters (Homarus americanus) off Iles de la Madeleine (Quebec), Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 45: 868-878.

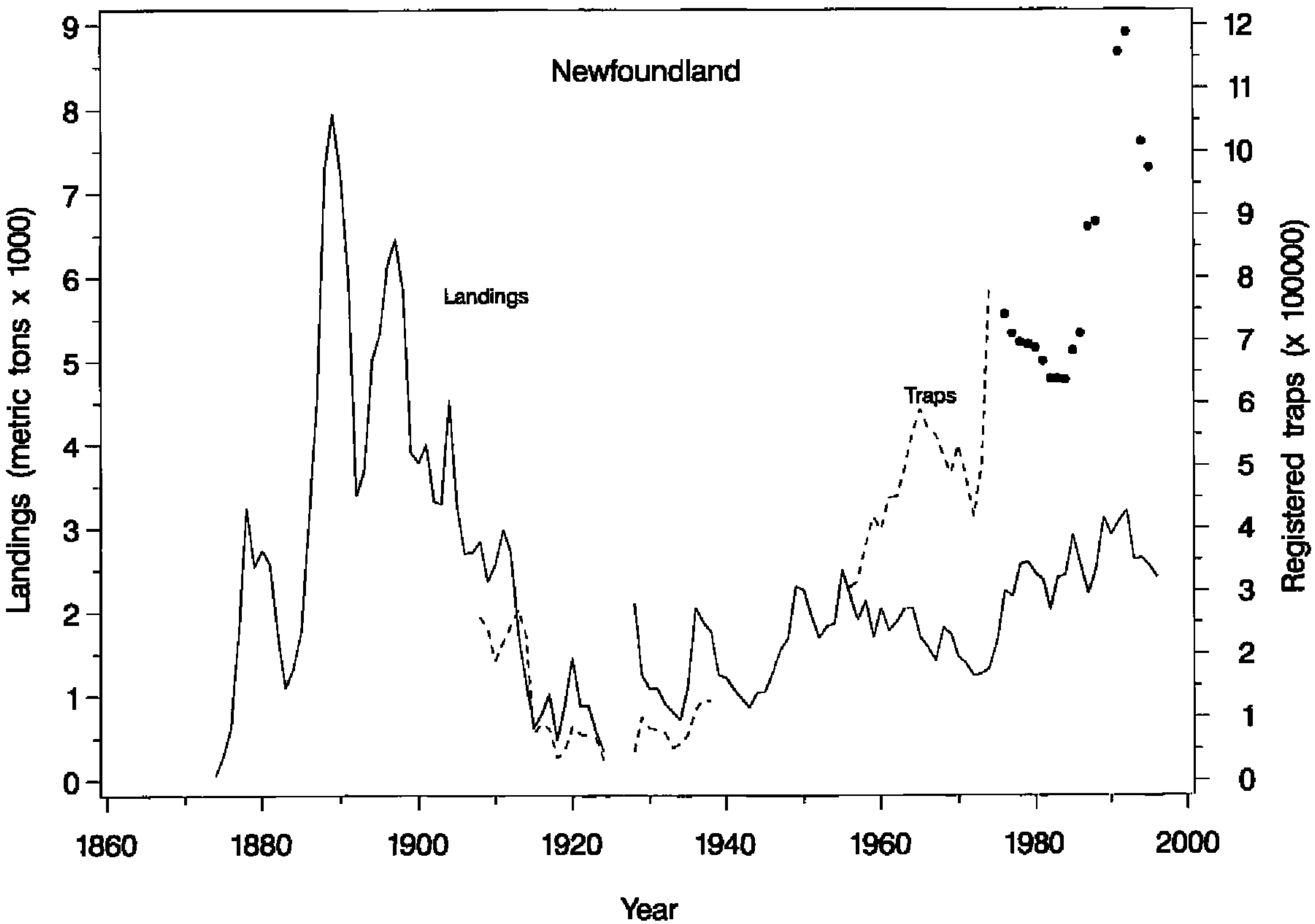


Fig 1. Historical landings and effort for the Newfoundland lobster fishery.

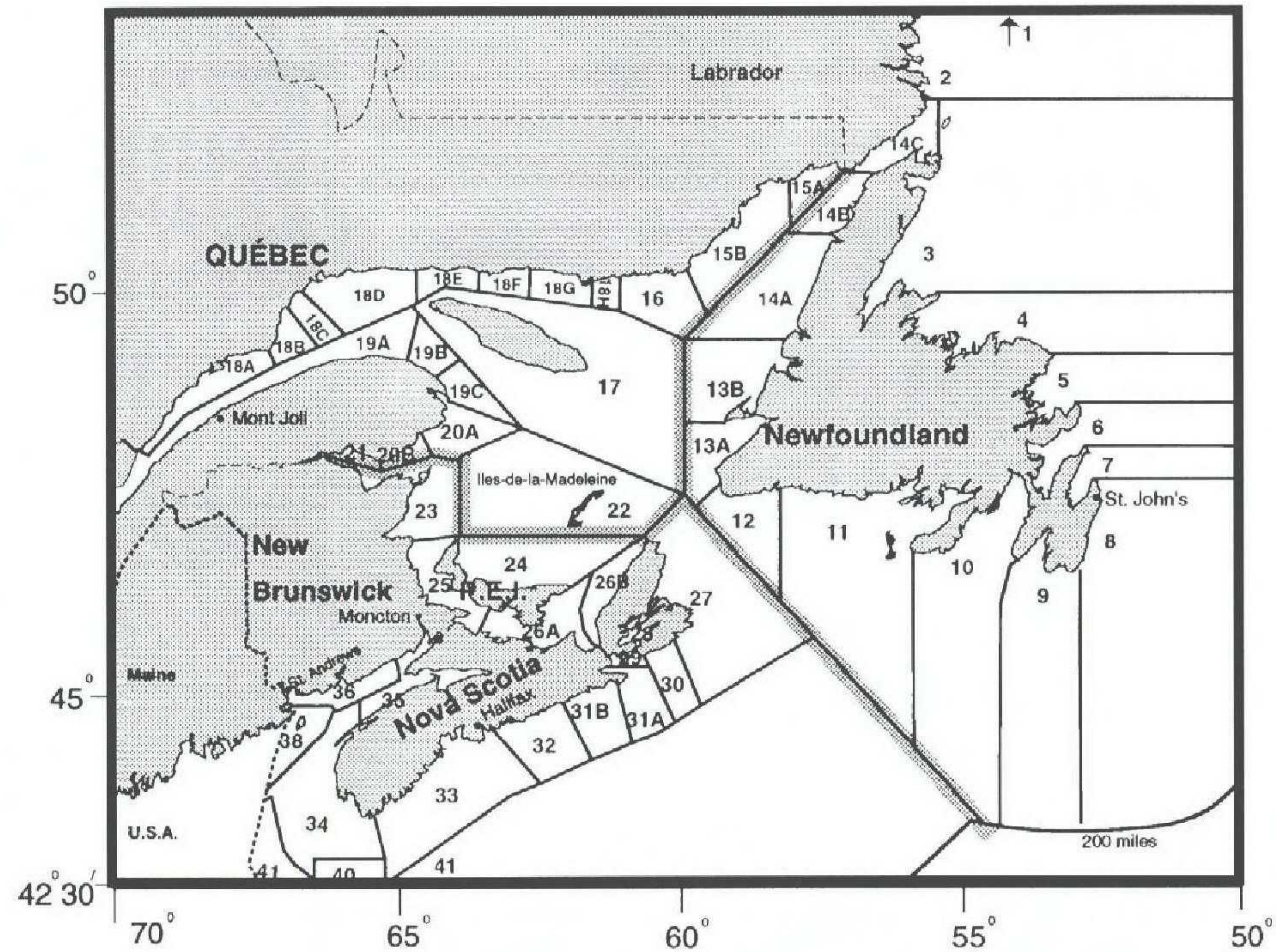


Fig 2. Lobster fishing areas (LFA's) of Atlantic Canada.

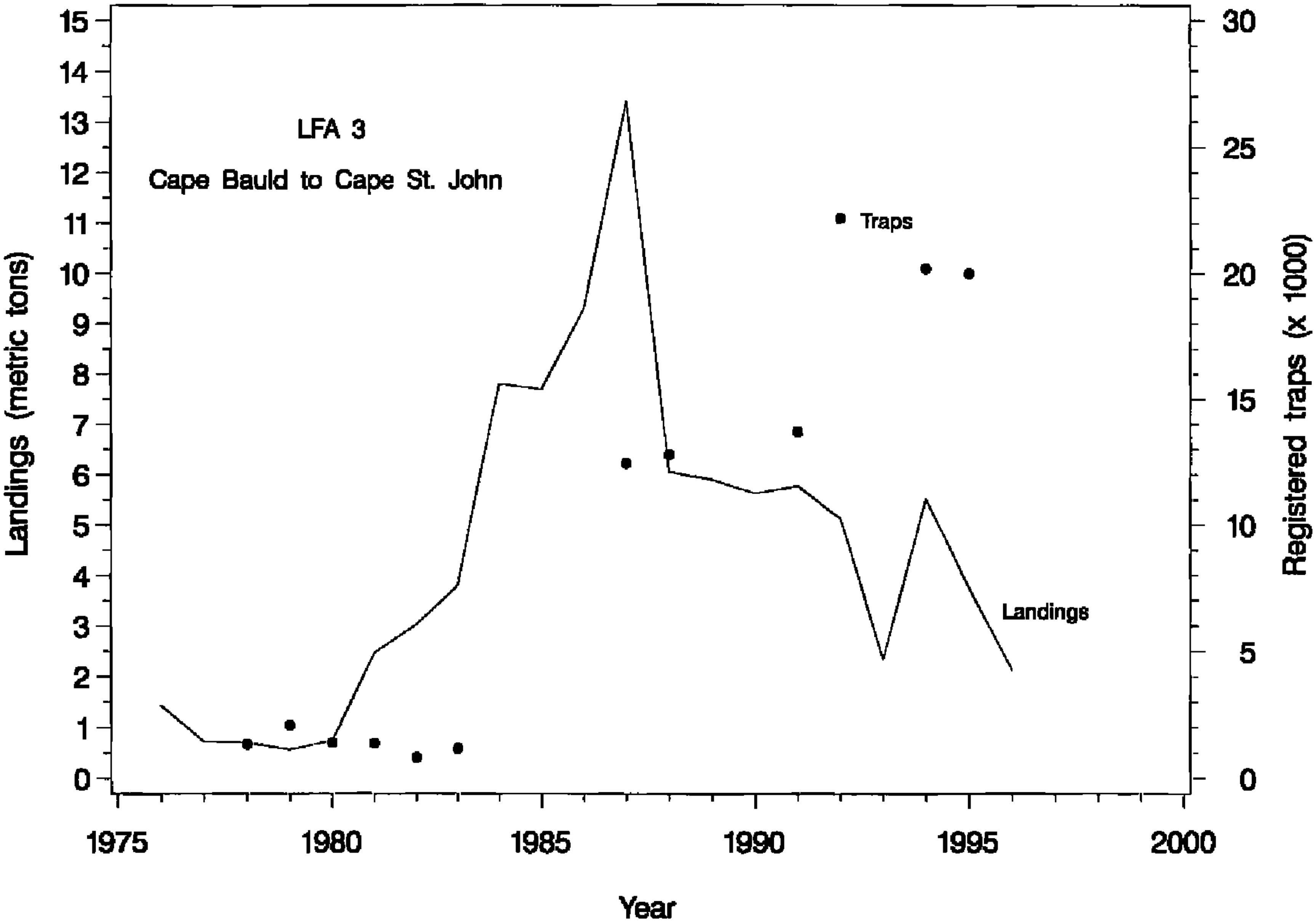


Fig 3. Landings and effort for Newfoundland lobster fishing areas.

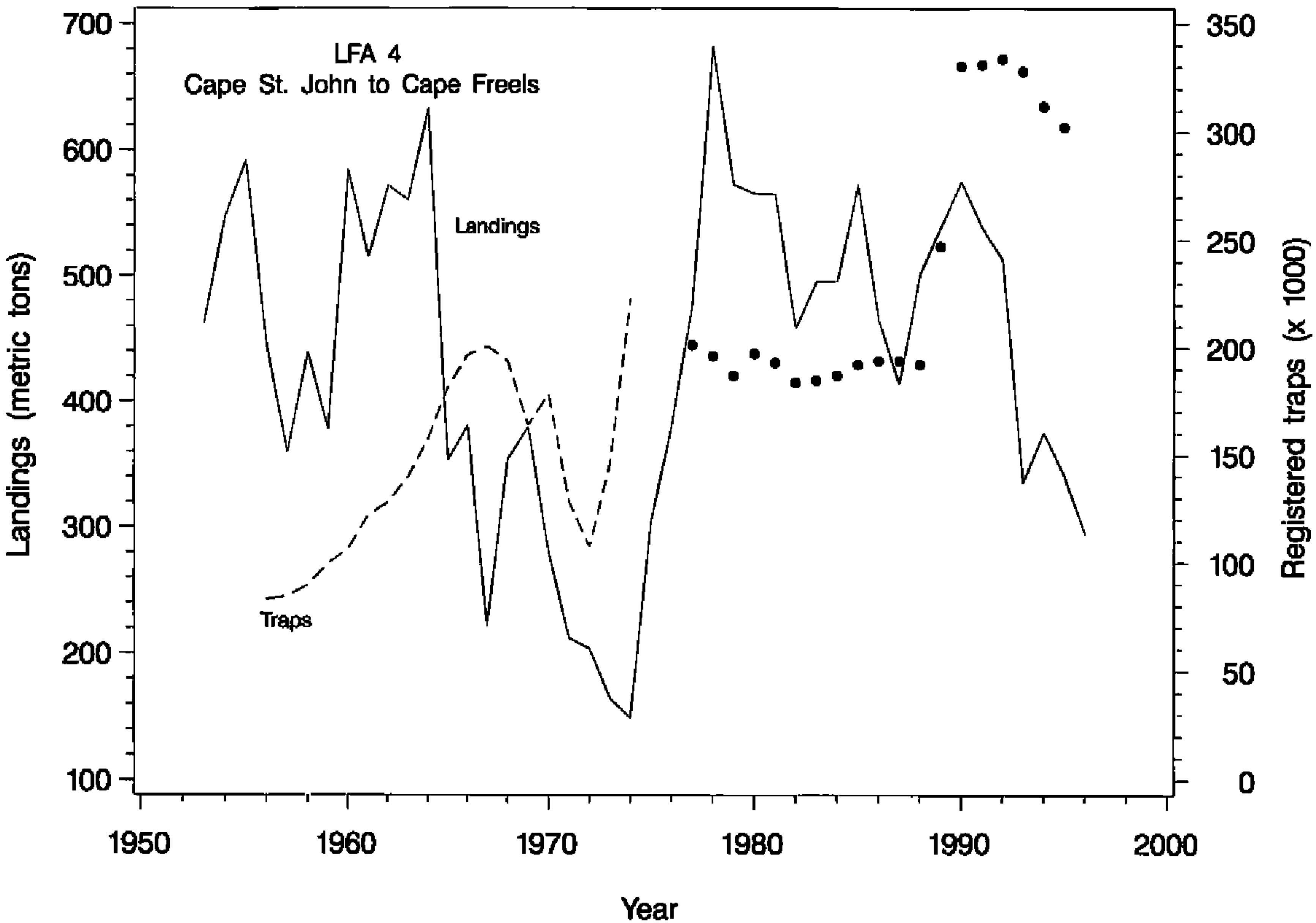
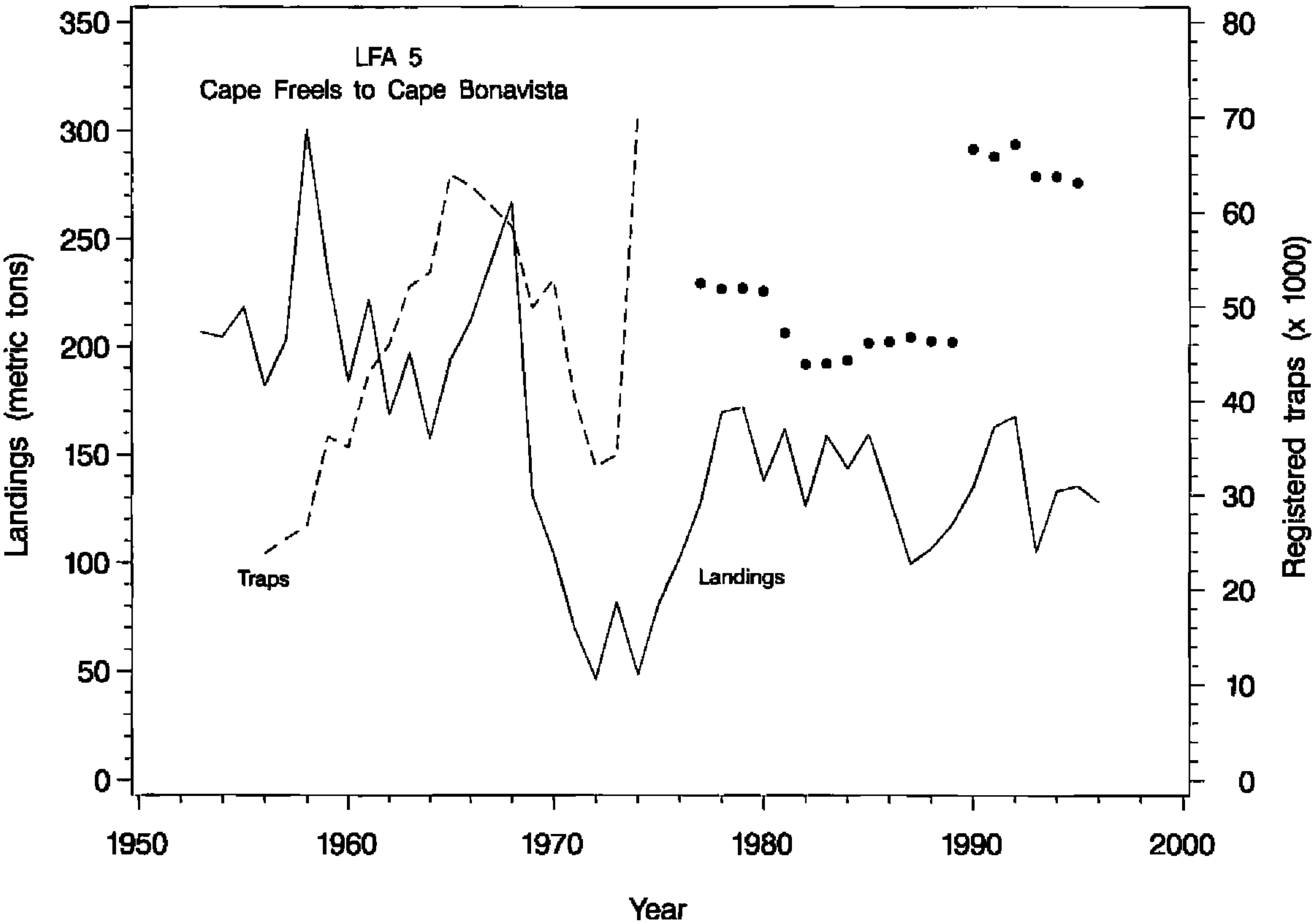


Fig 3. continued...



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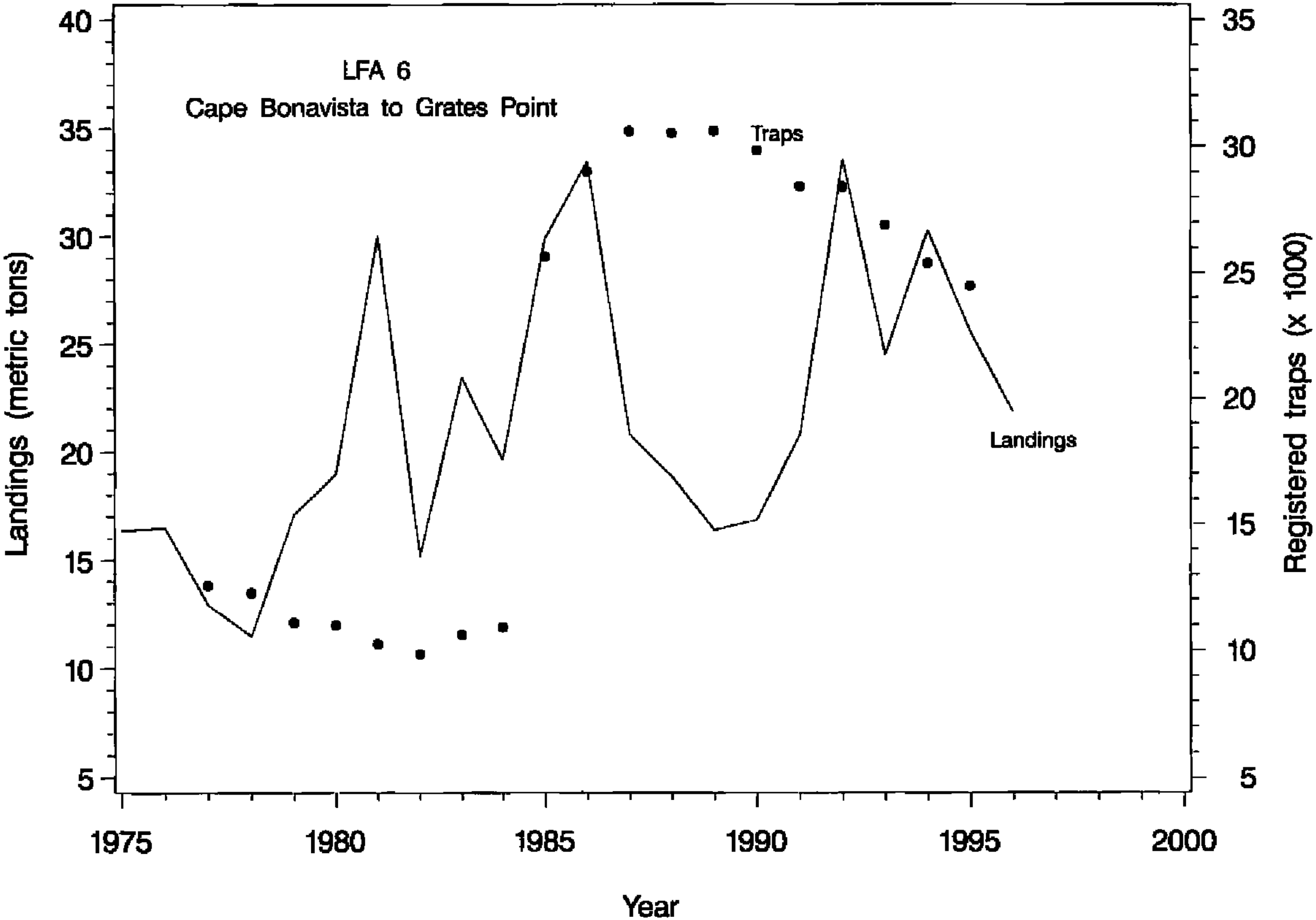

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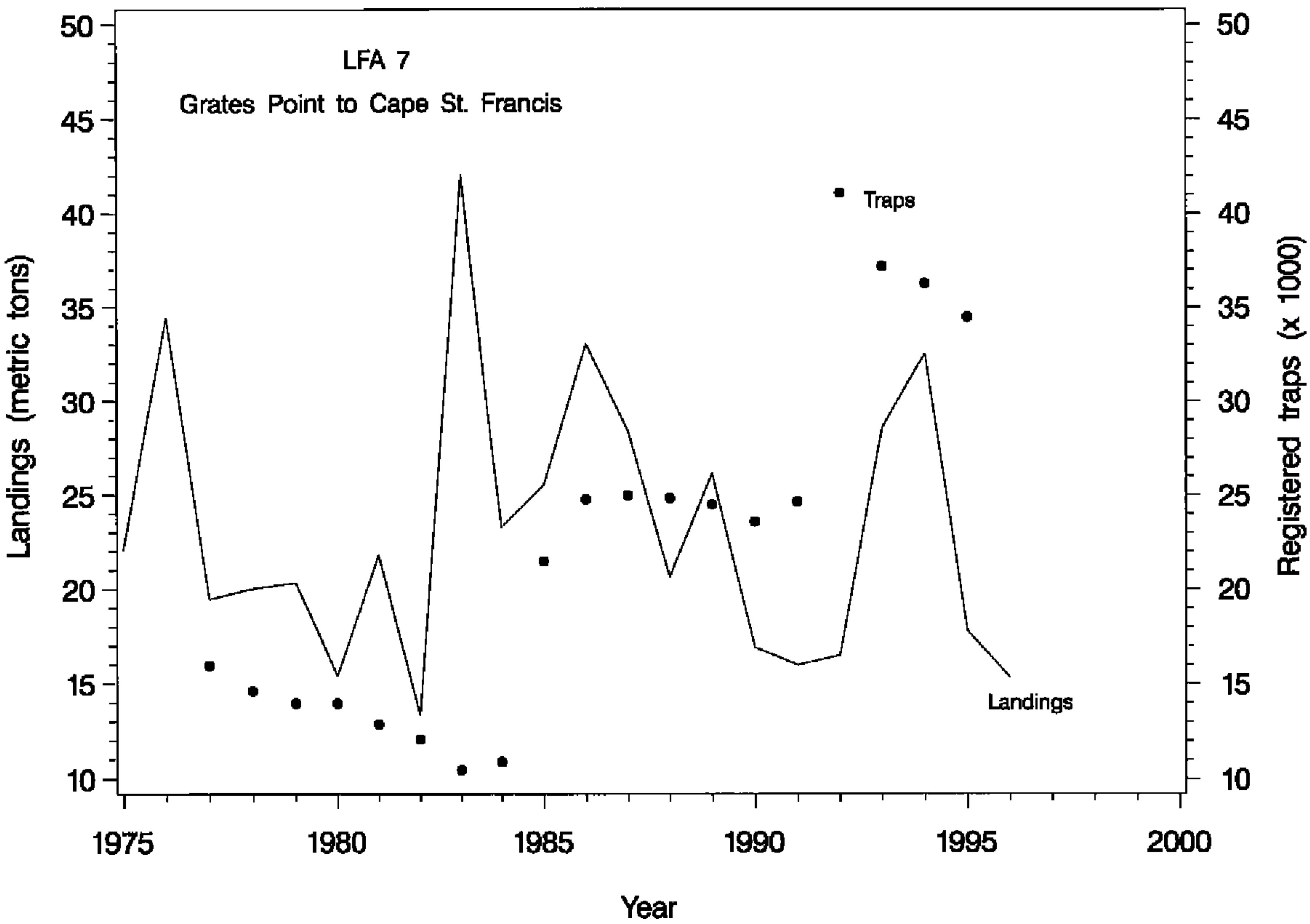

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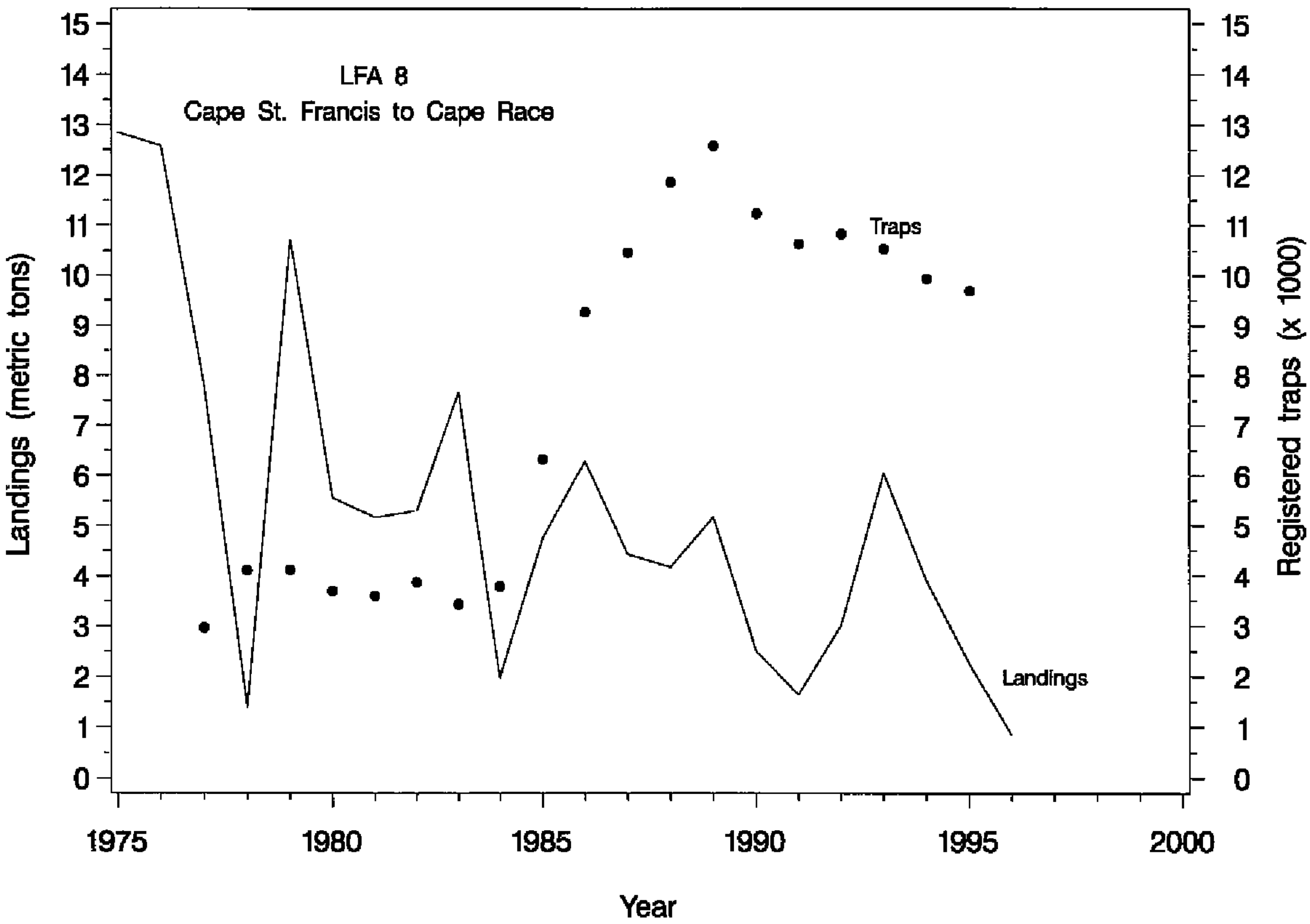

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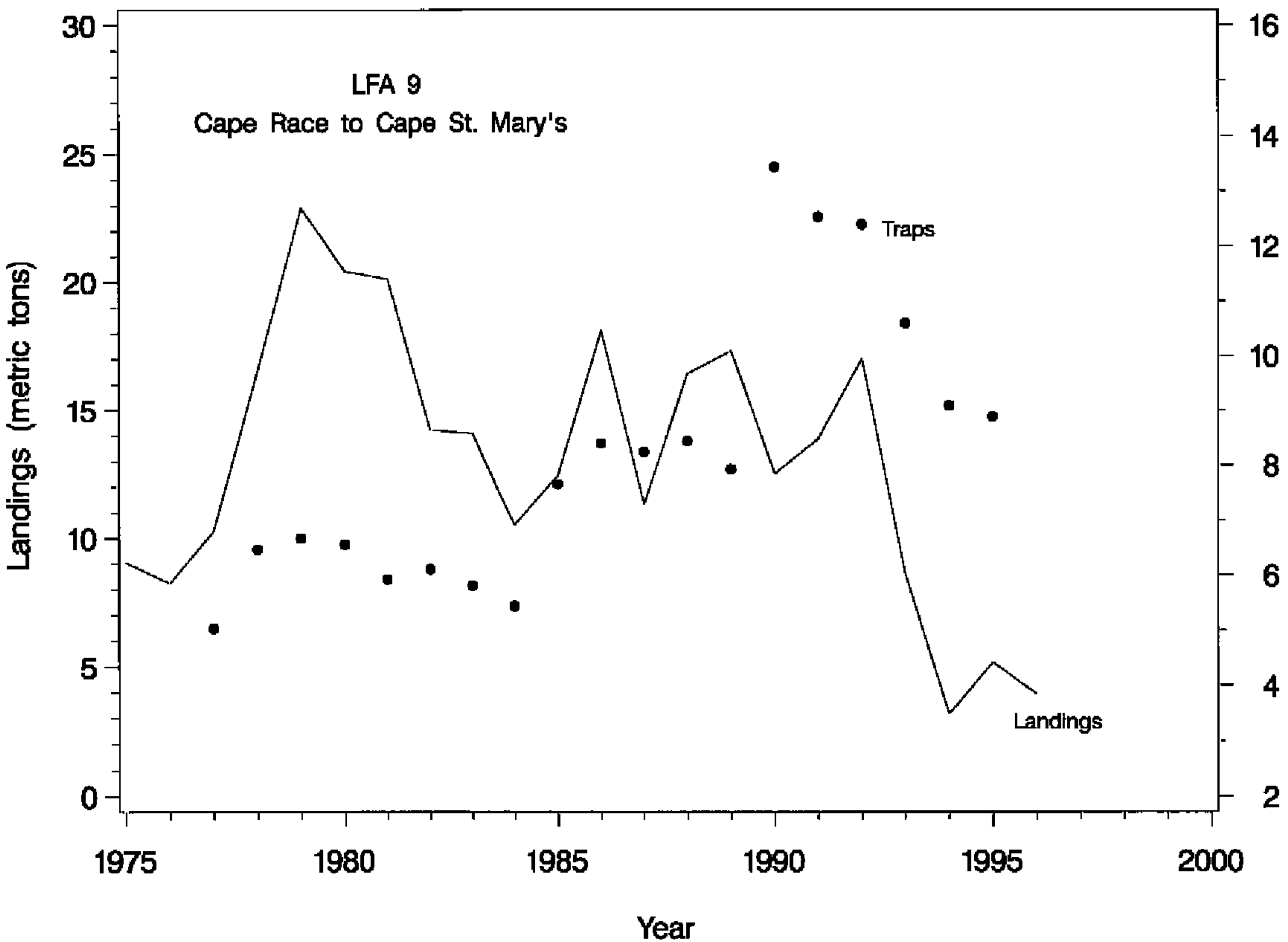

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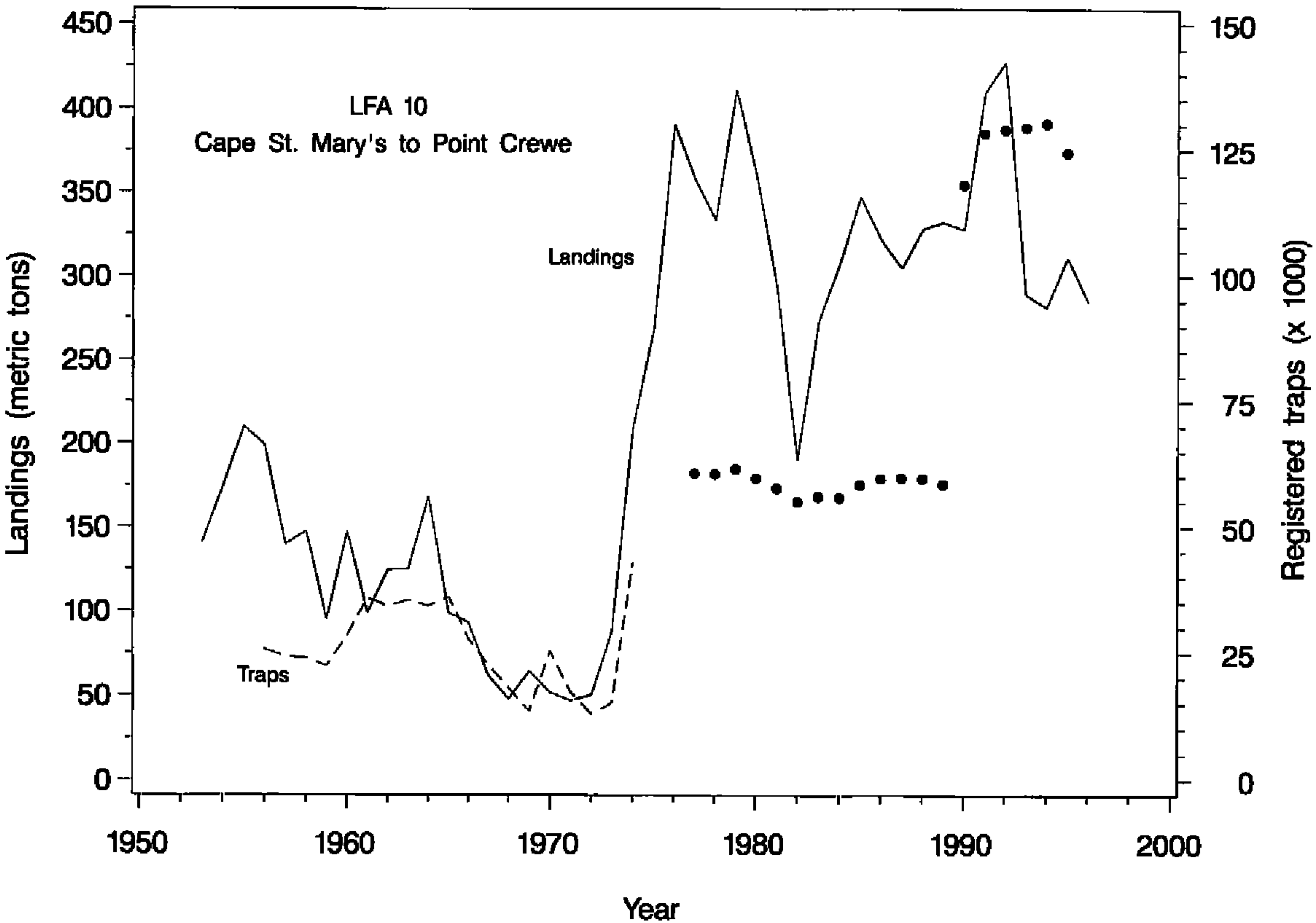

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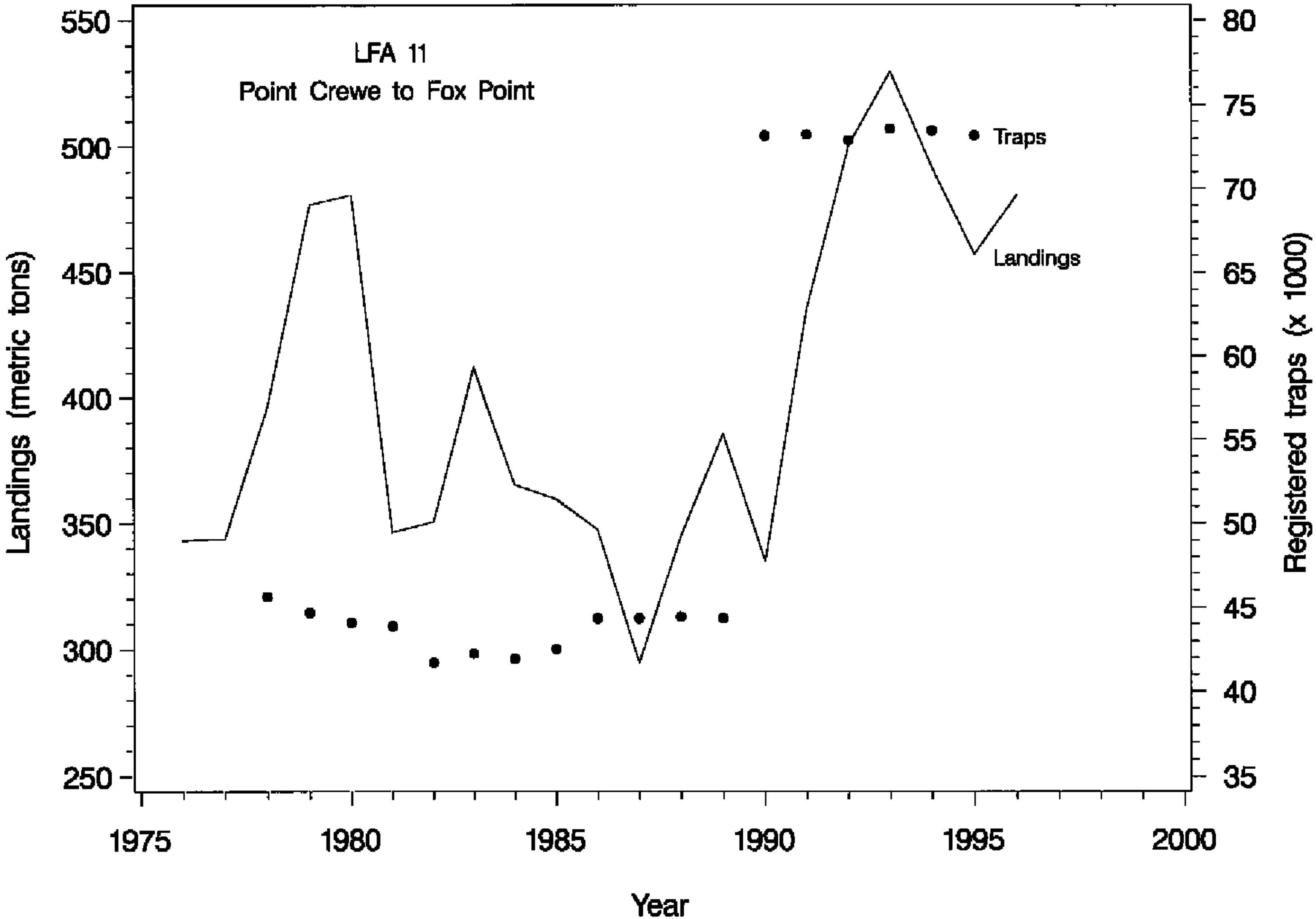

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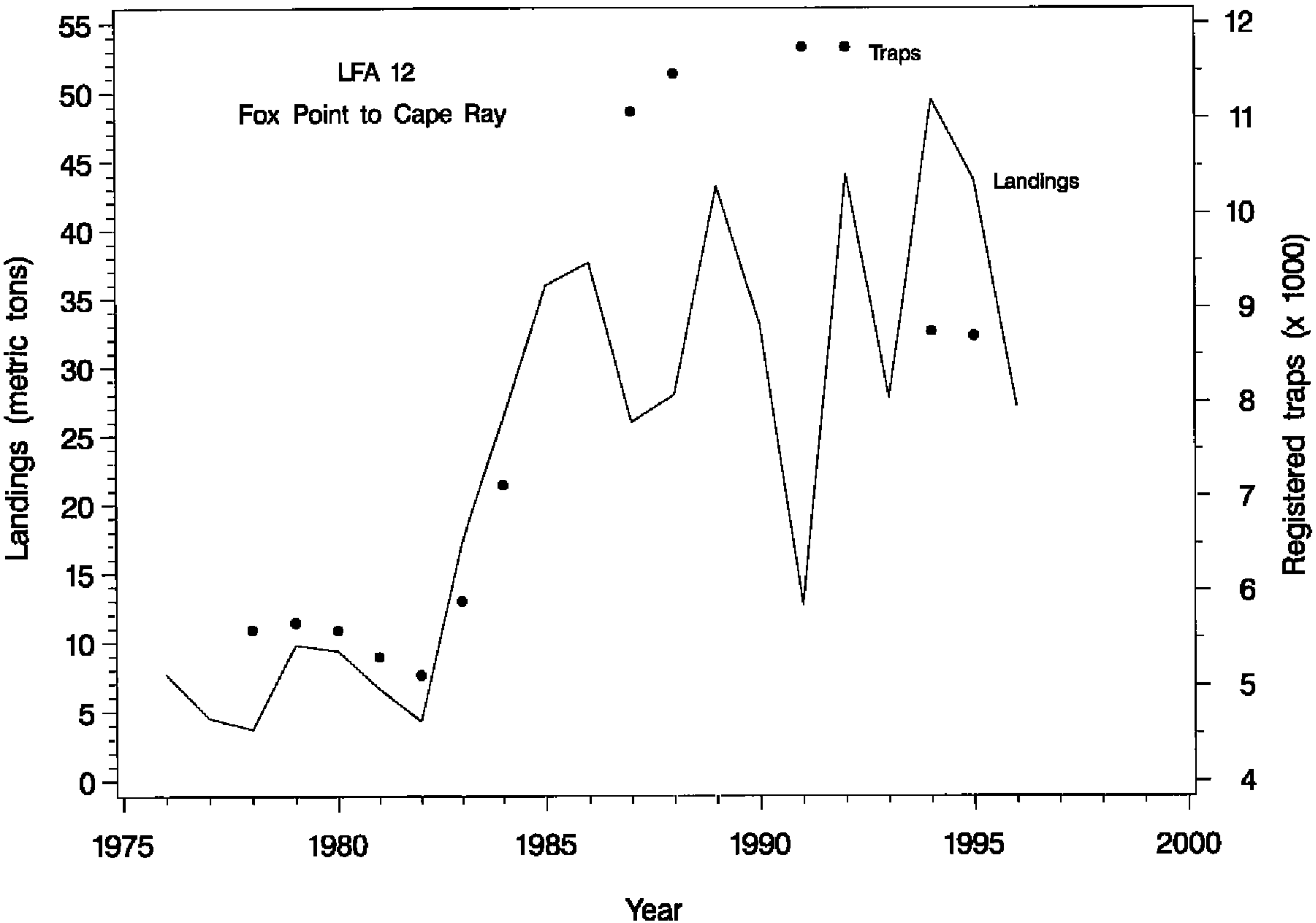

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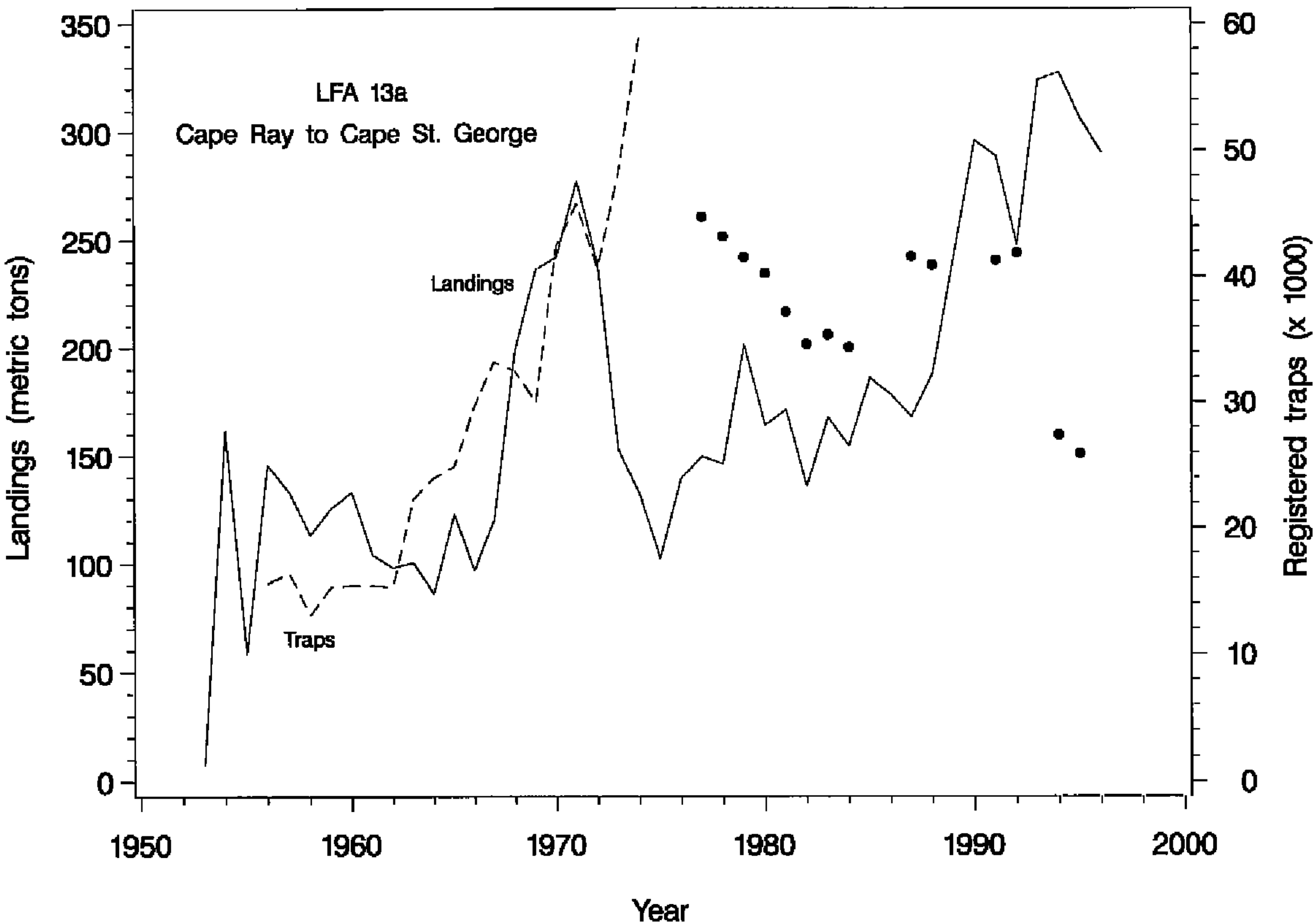

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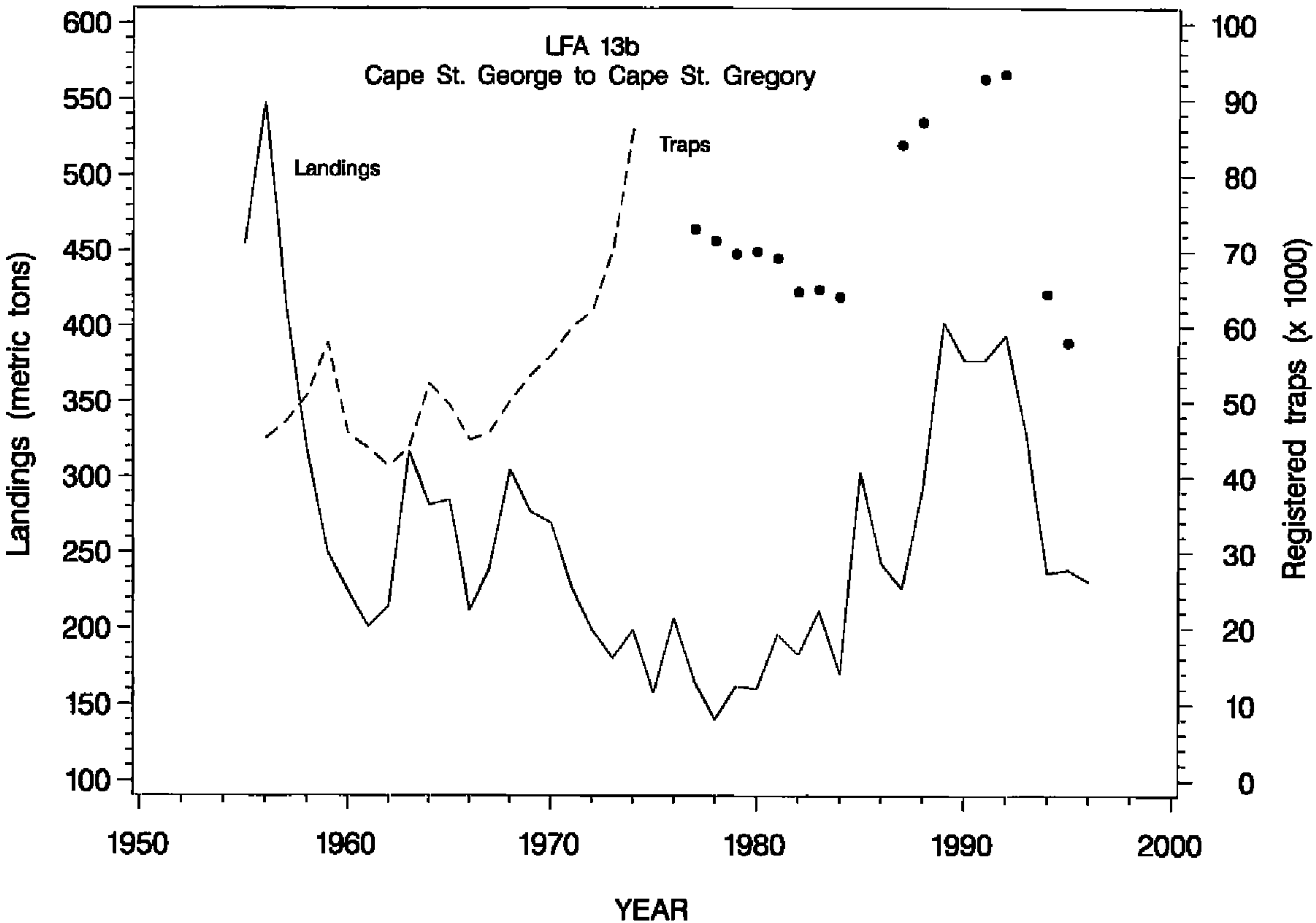

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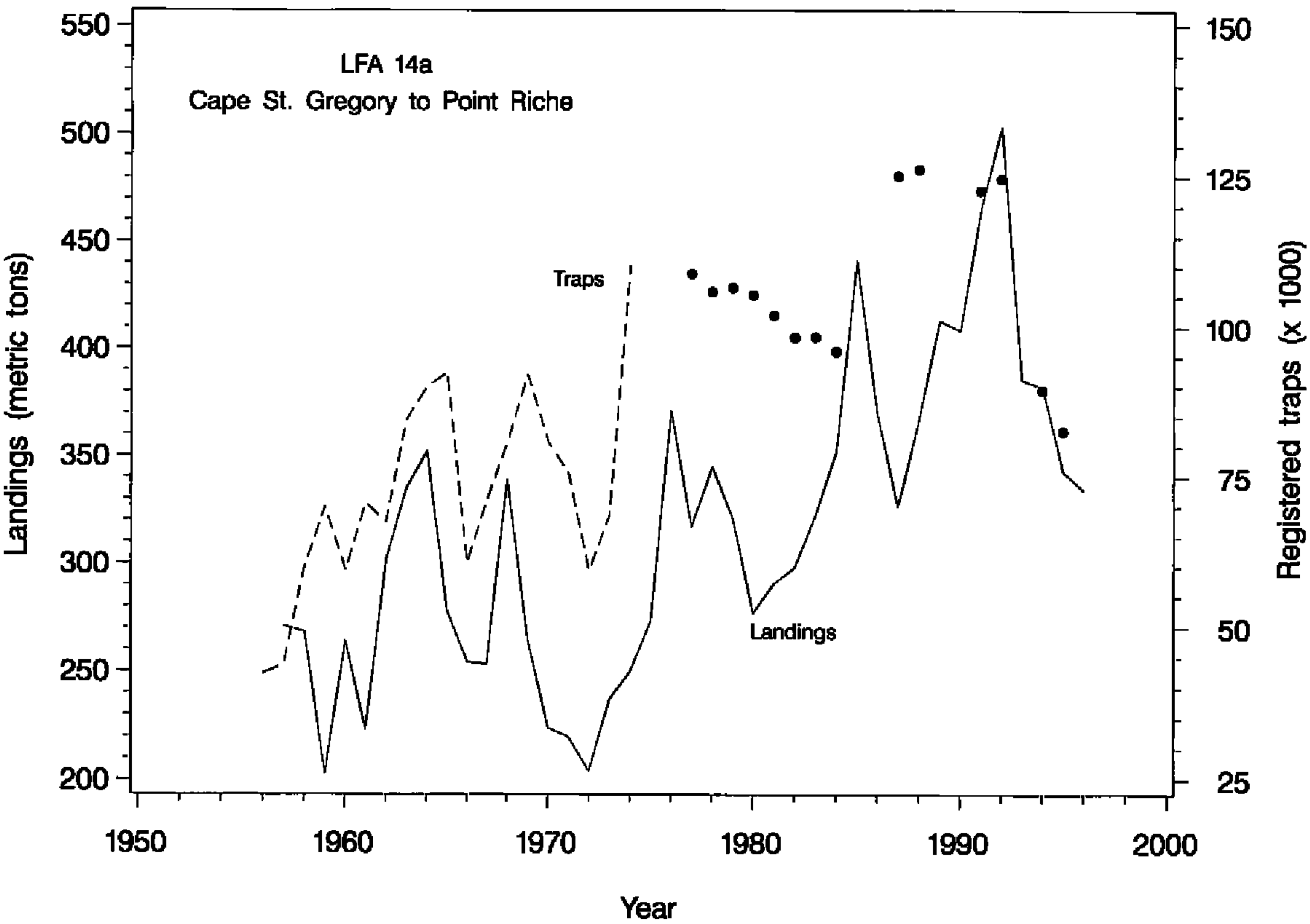

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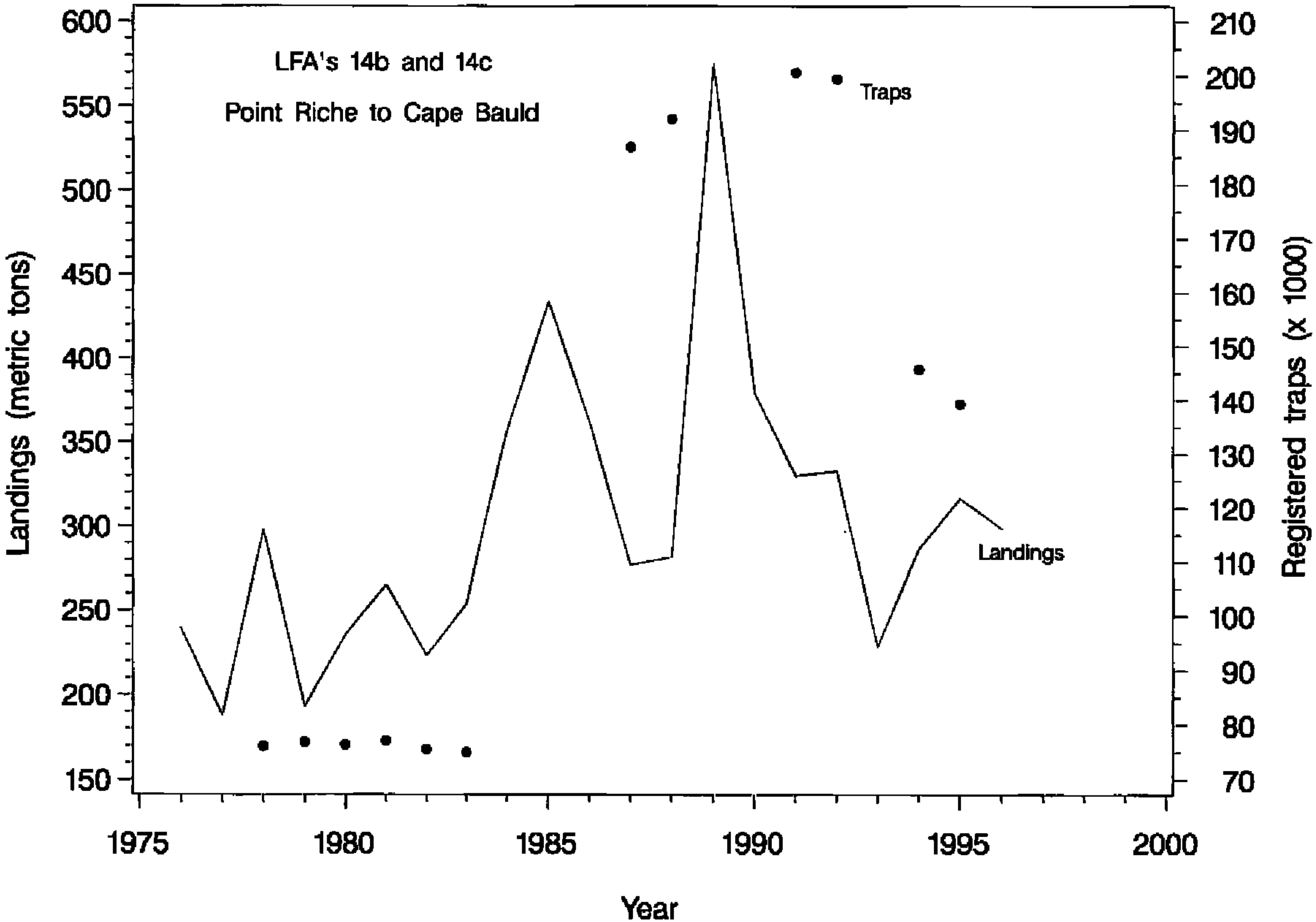

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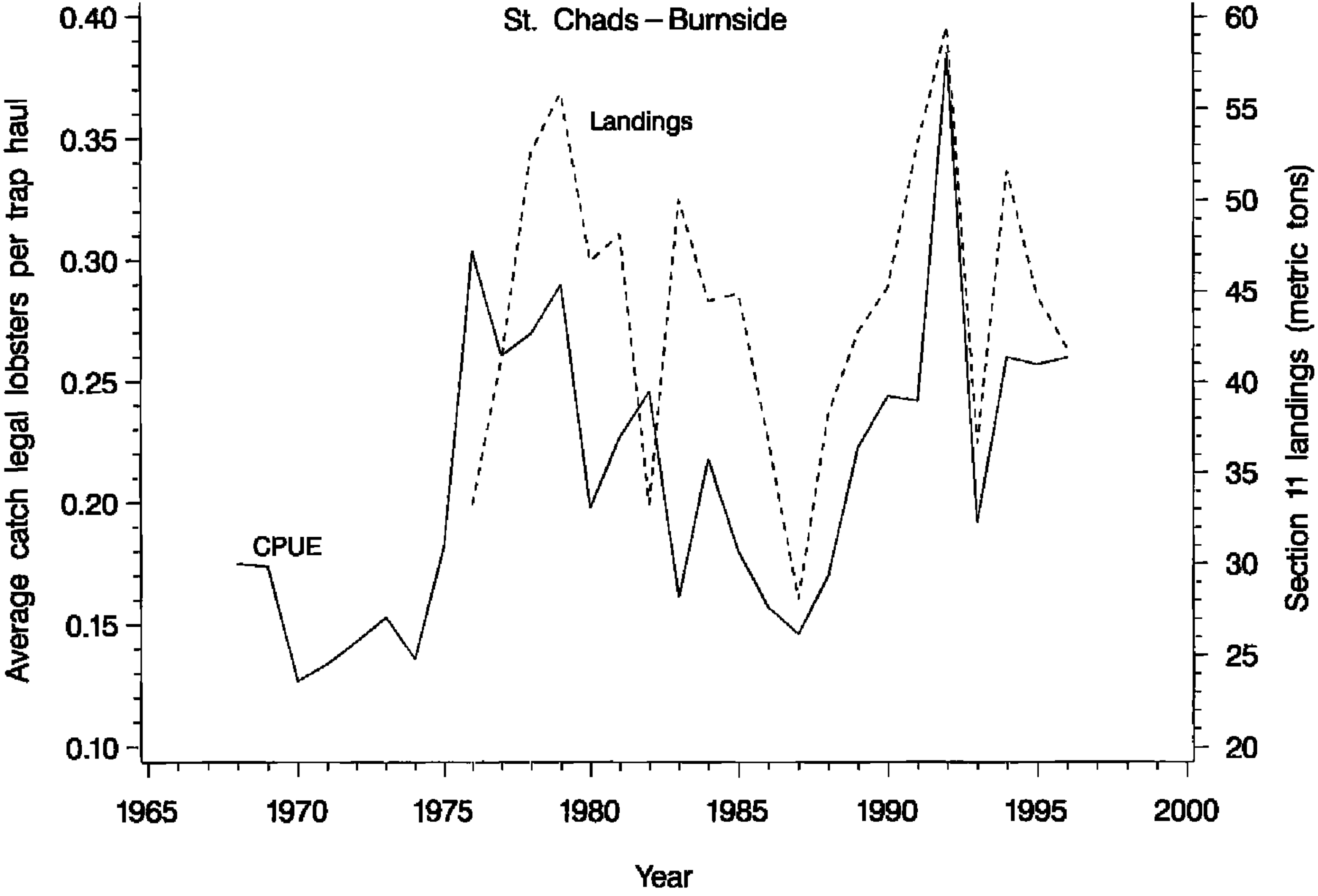
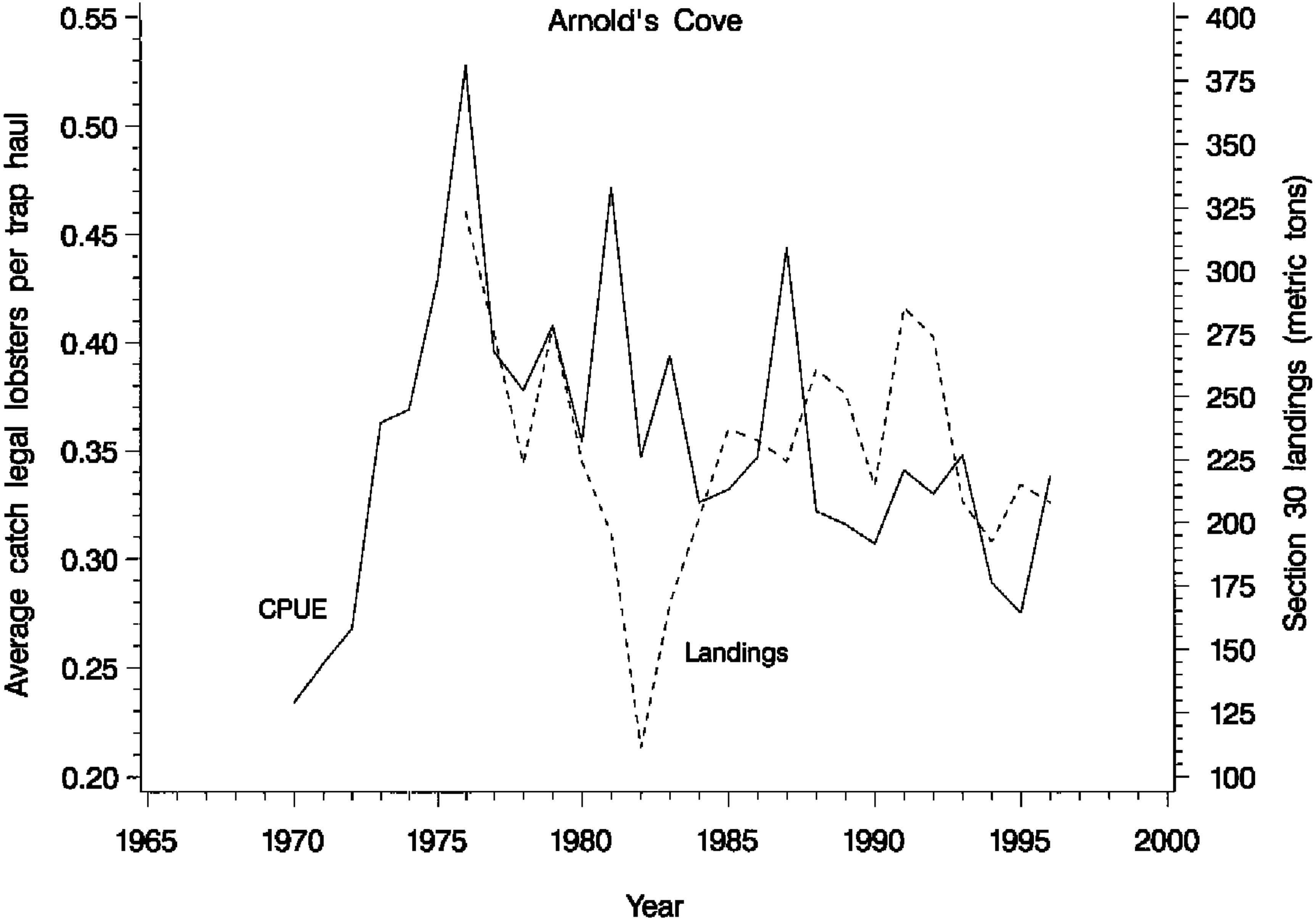


Fig 4. Average seasonal catch rates at St. Chads – Burnside, Arnold's Cove, and Comfort Cove along with annual landings for the Statistical Sections in which each is located.



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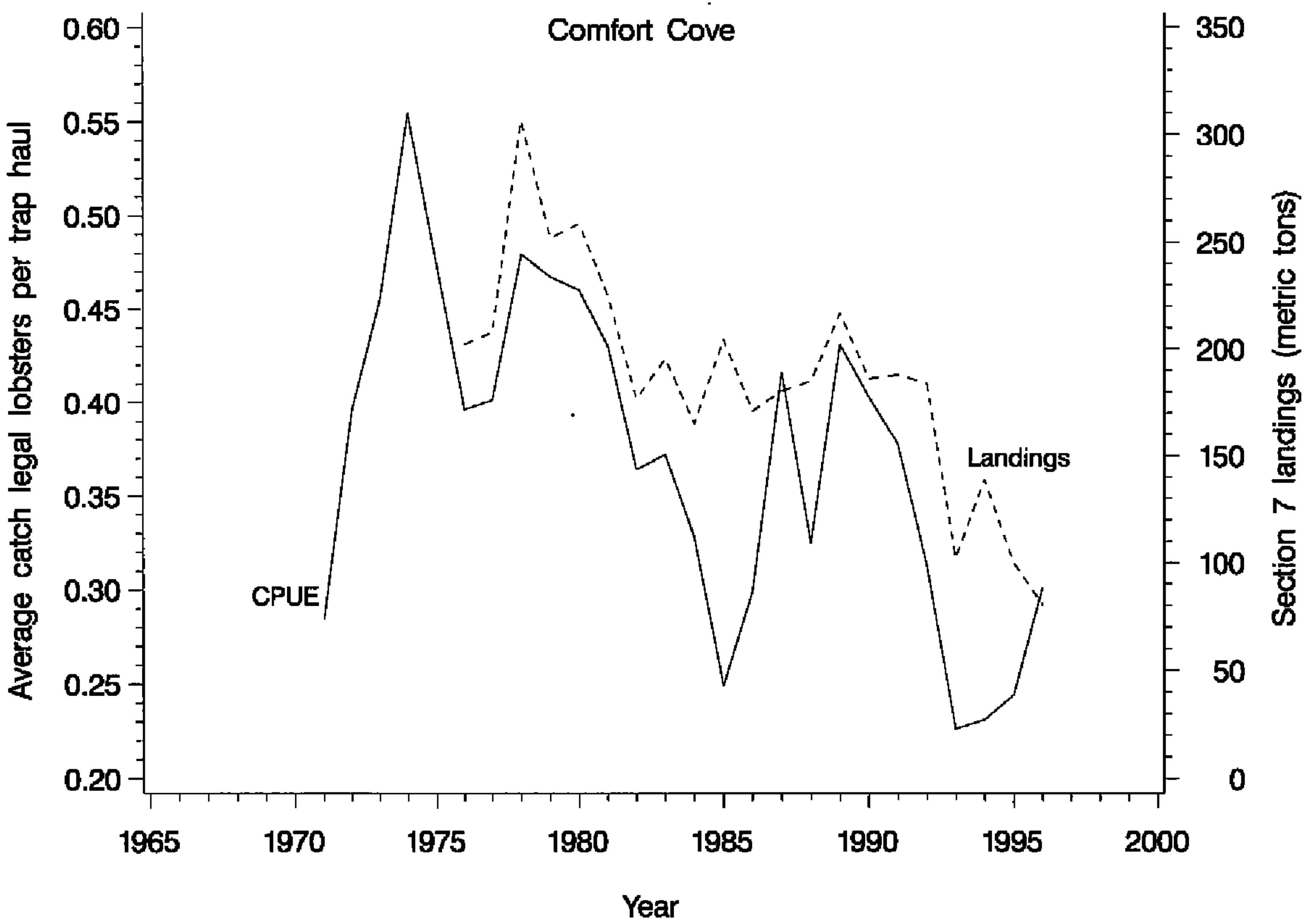

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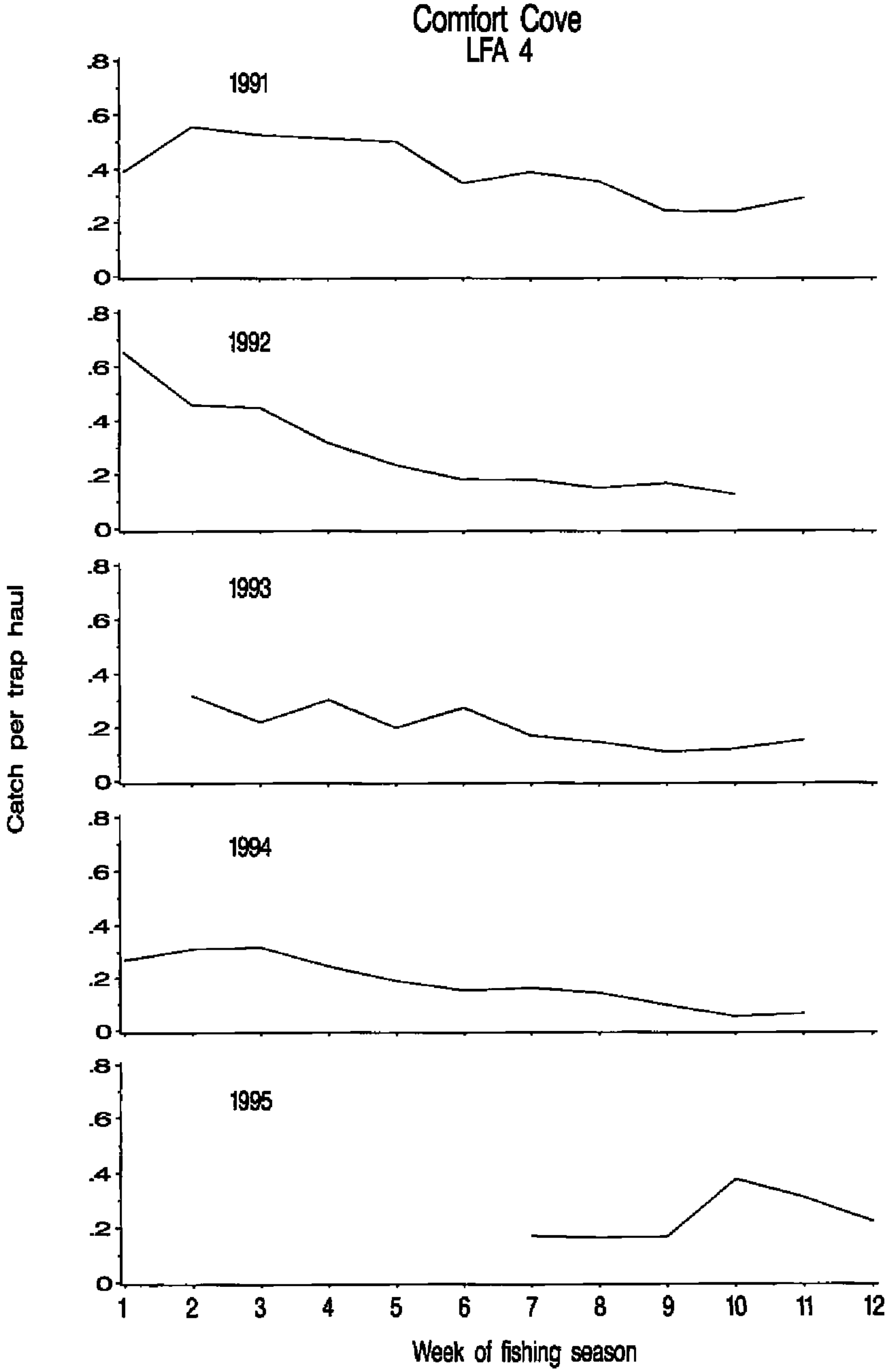


Fig. 5. Catch rates during the fishing season at lobster fishery monitoring sites.

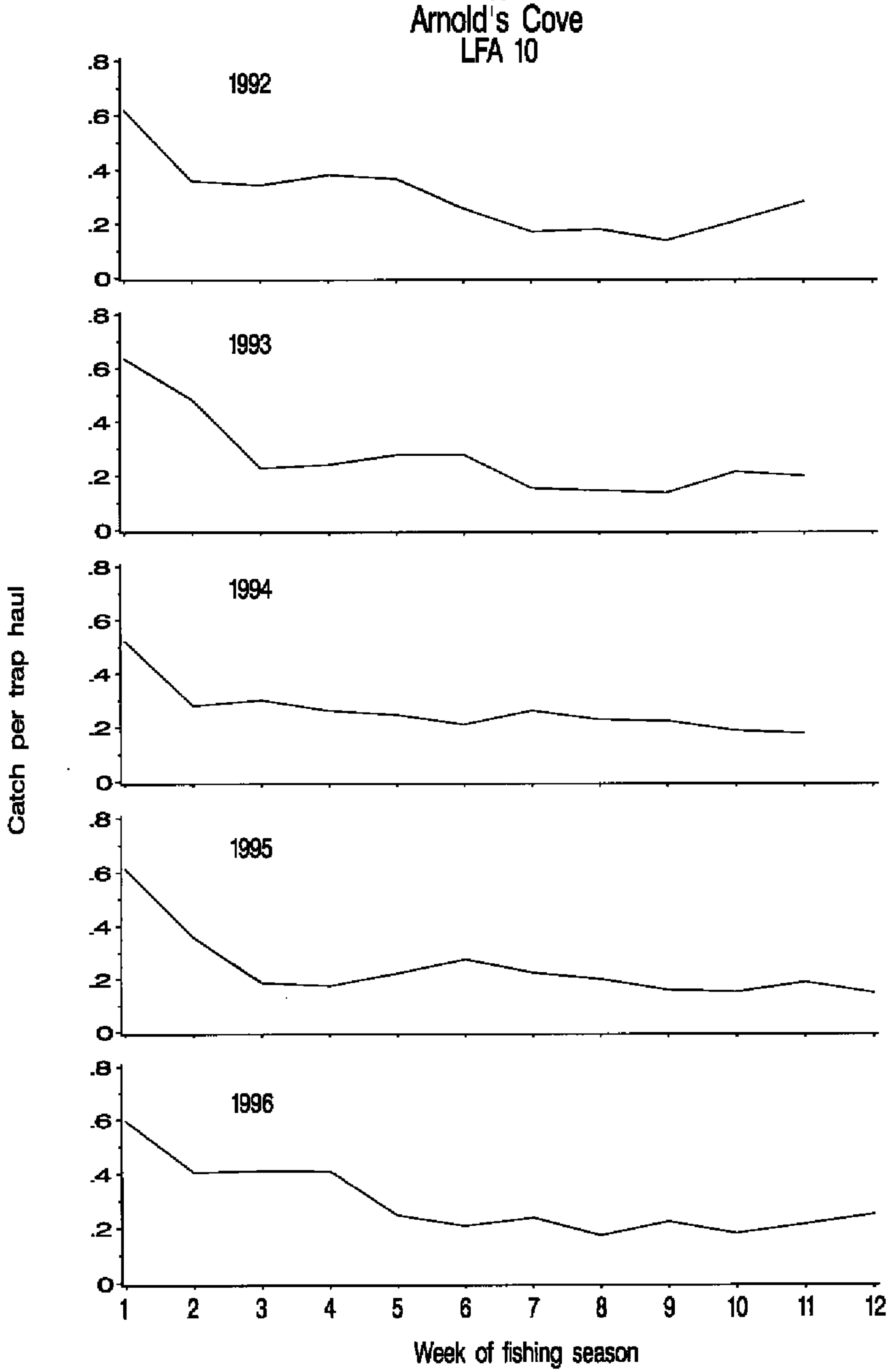
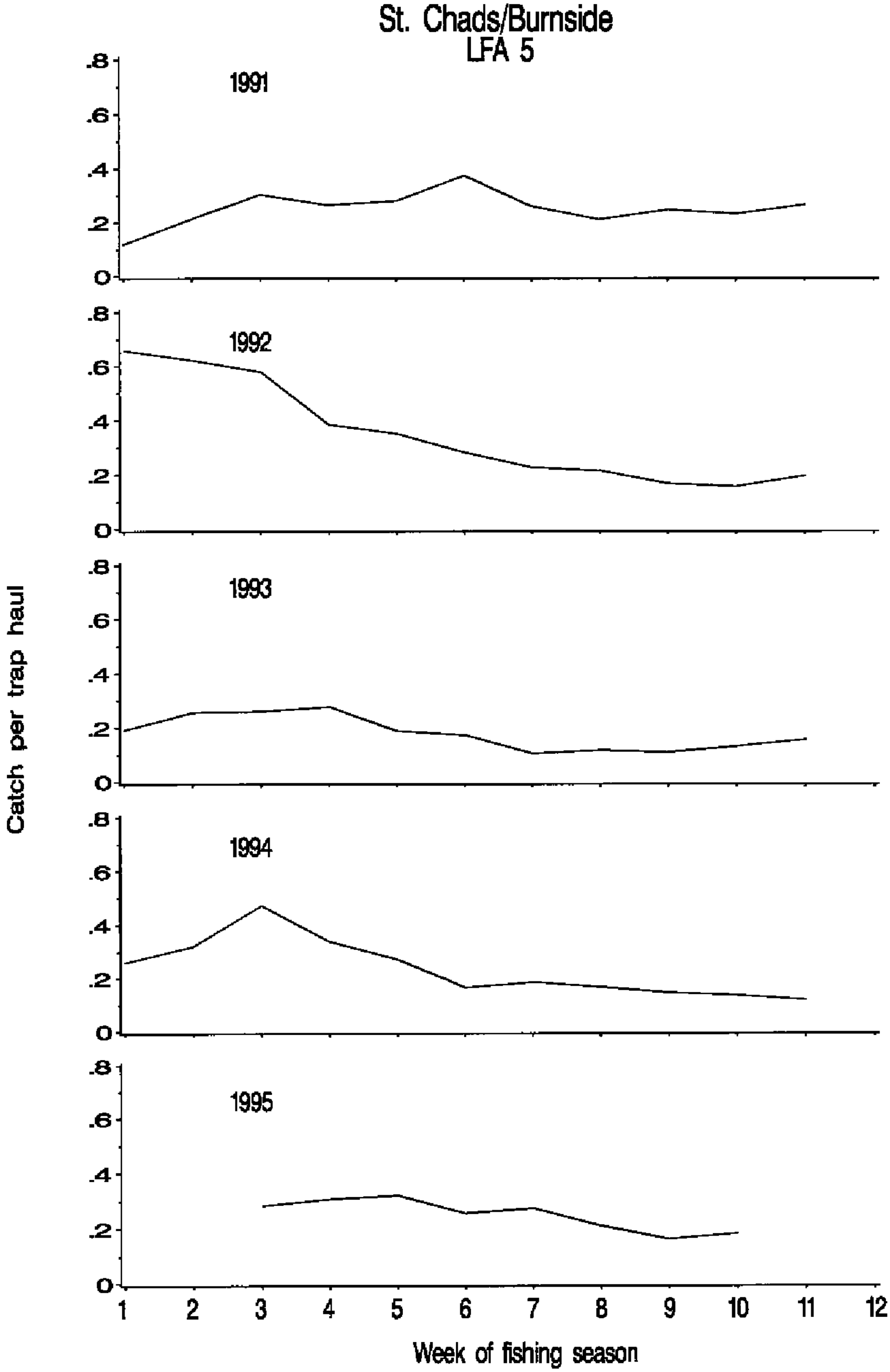


Fig. 5. continued...



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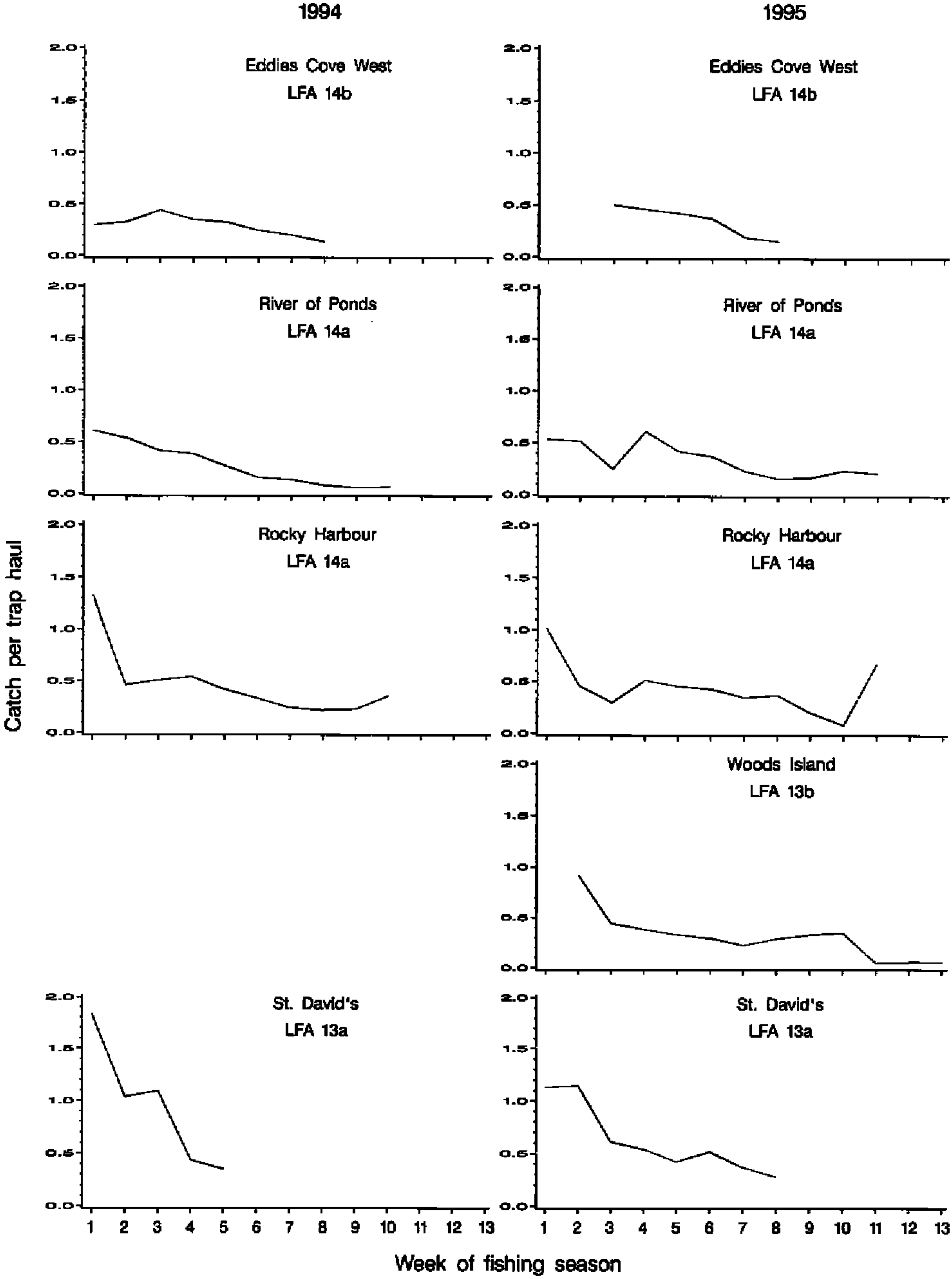

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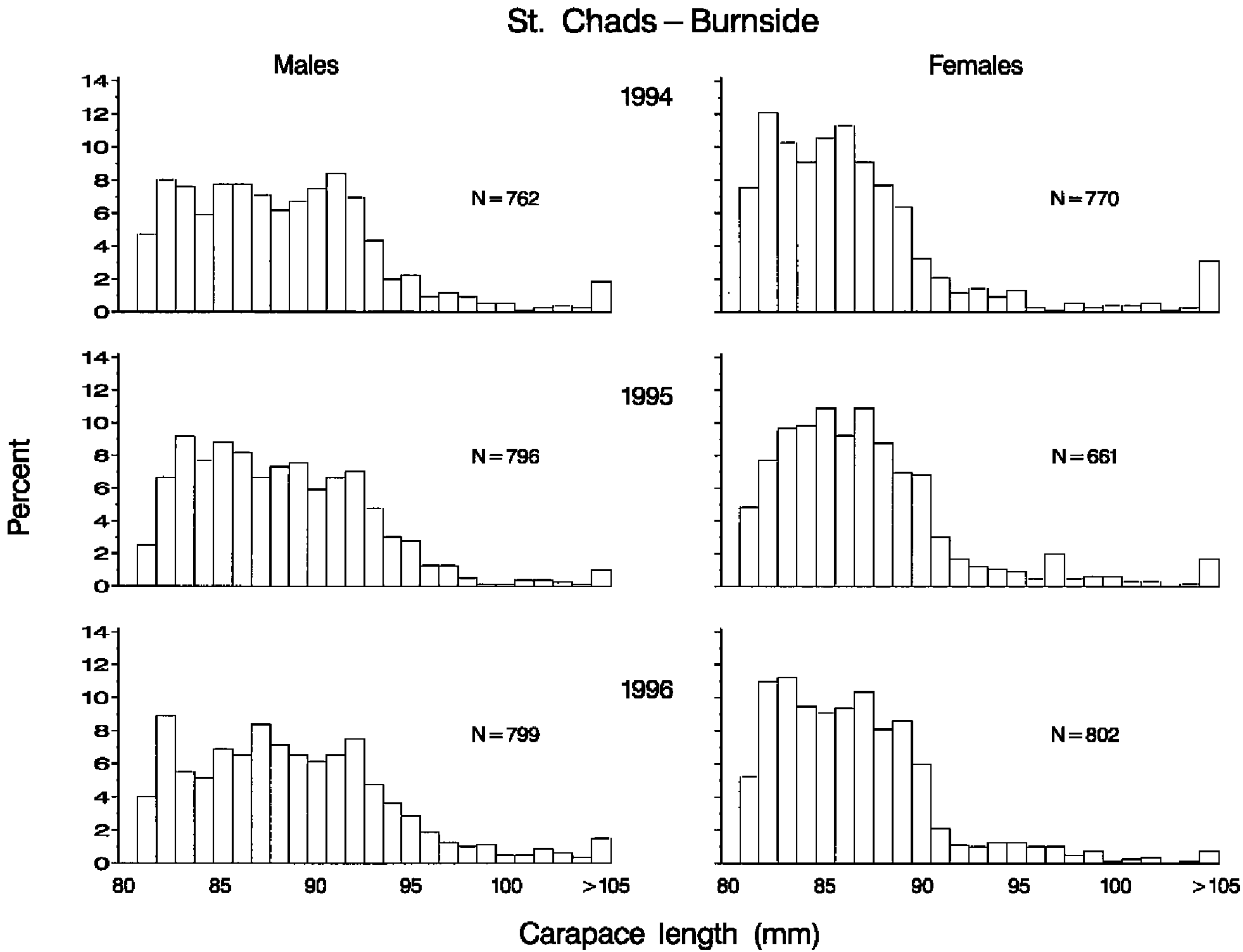


Fig 6. Size frequencies from commercial sampling at St. Chads – Burnside, Comfort Cove and Arnold's Cove in recent years.

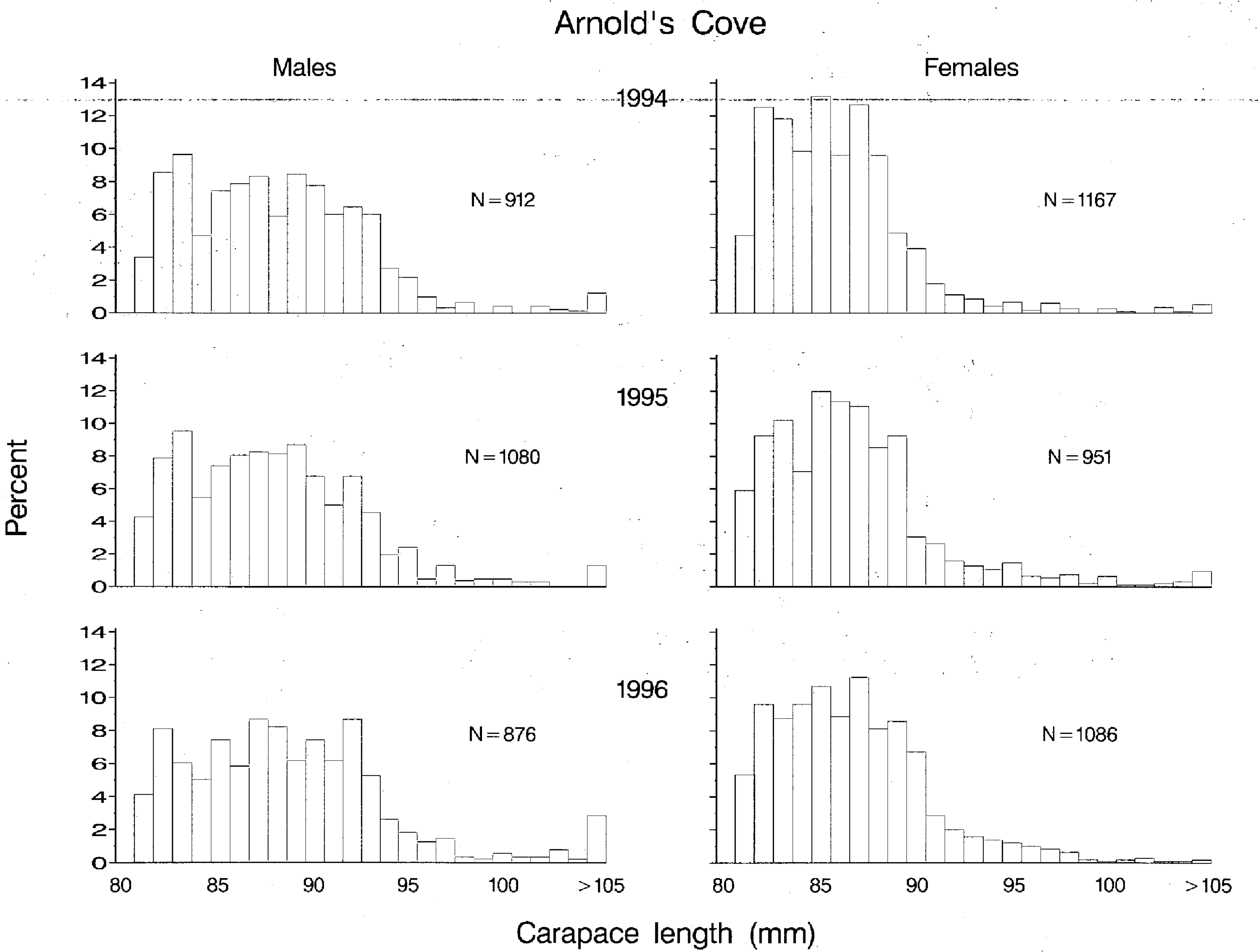
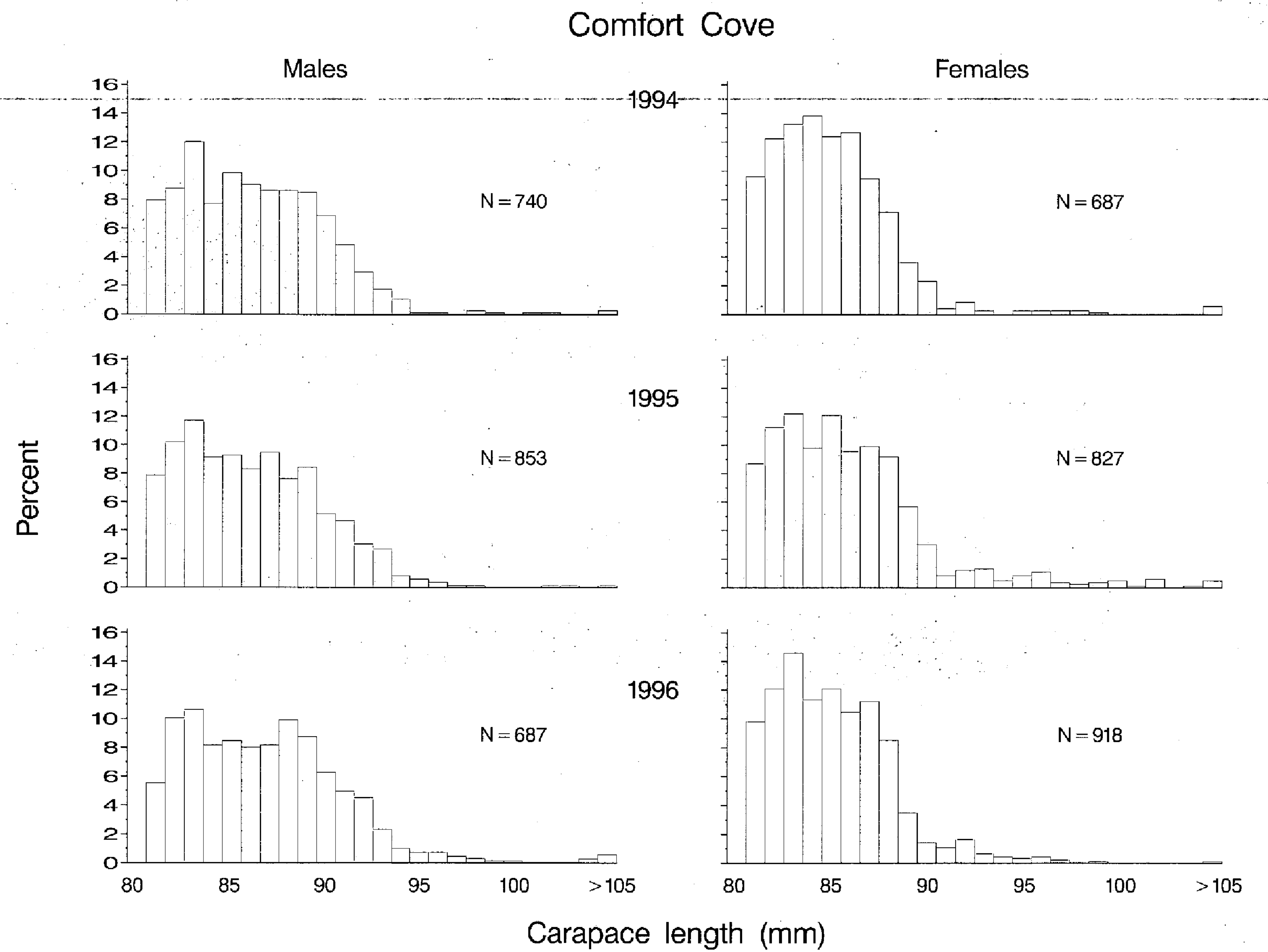


Fig 6. continued...



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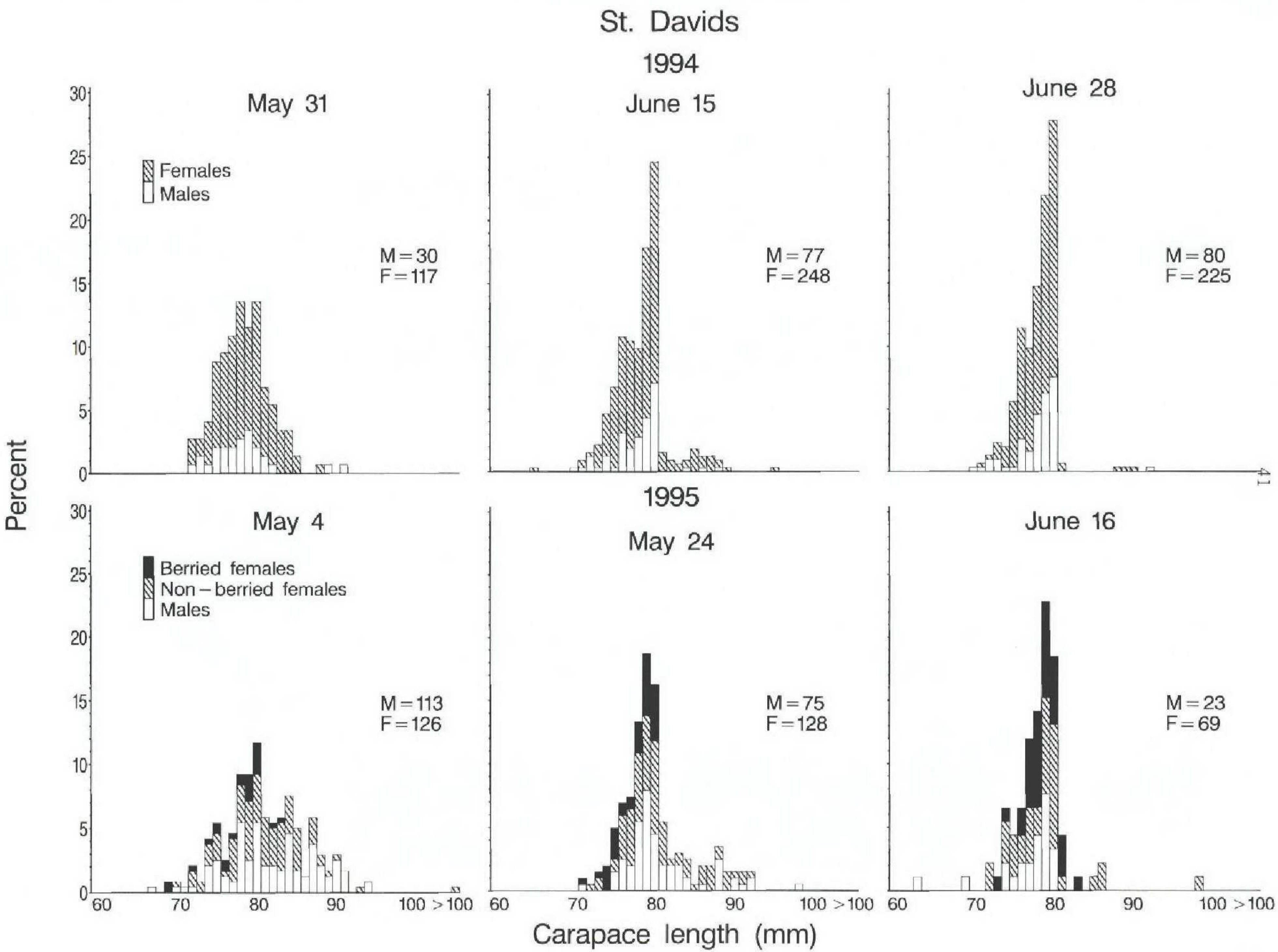


Fig 7. Size frequencies from at-sea sampling of commercial catches at 4R lobster fishery monitoring sites in recent years.

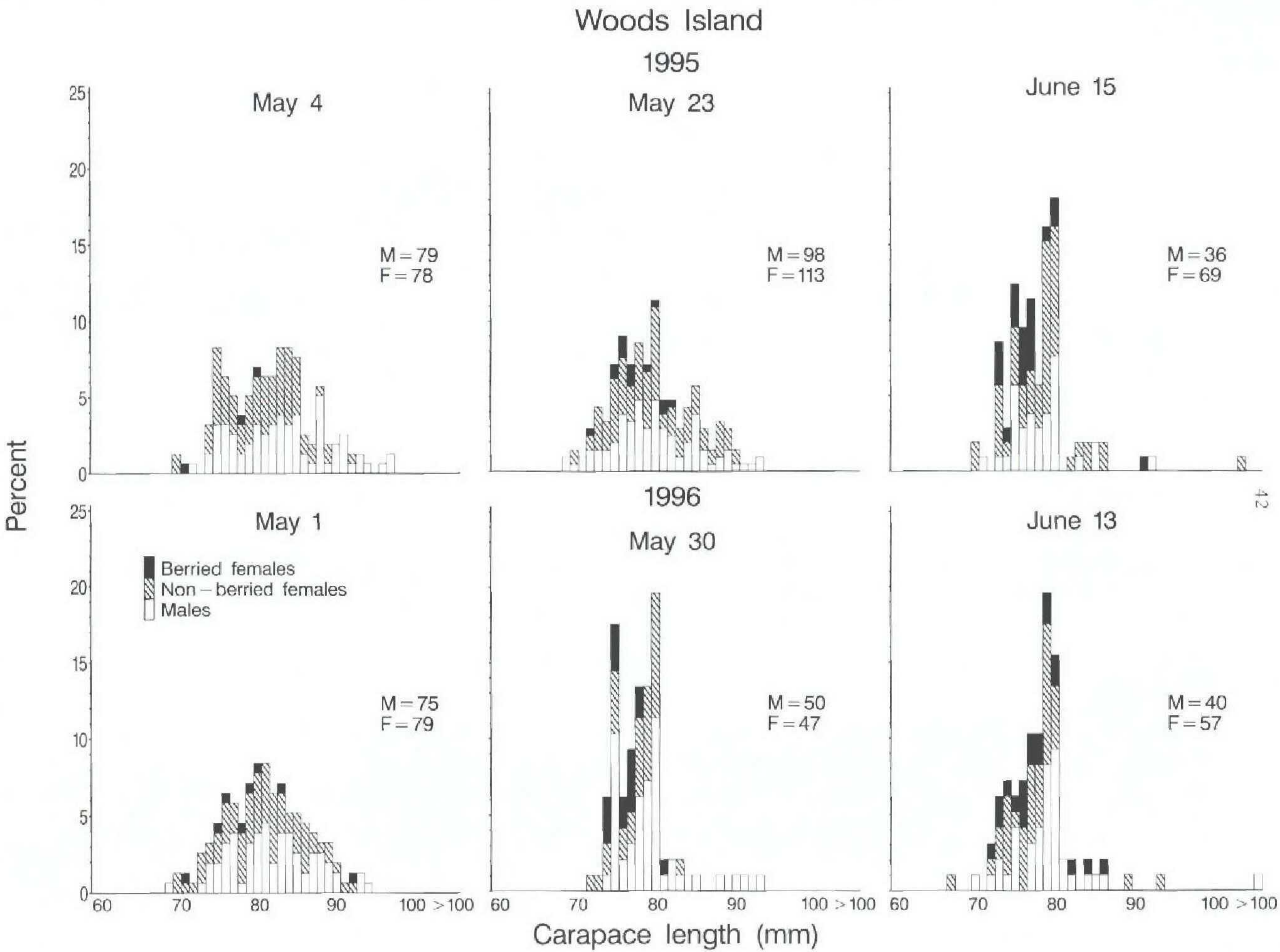
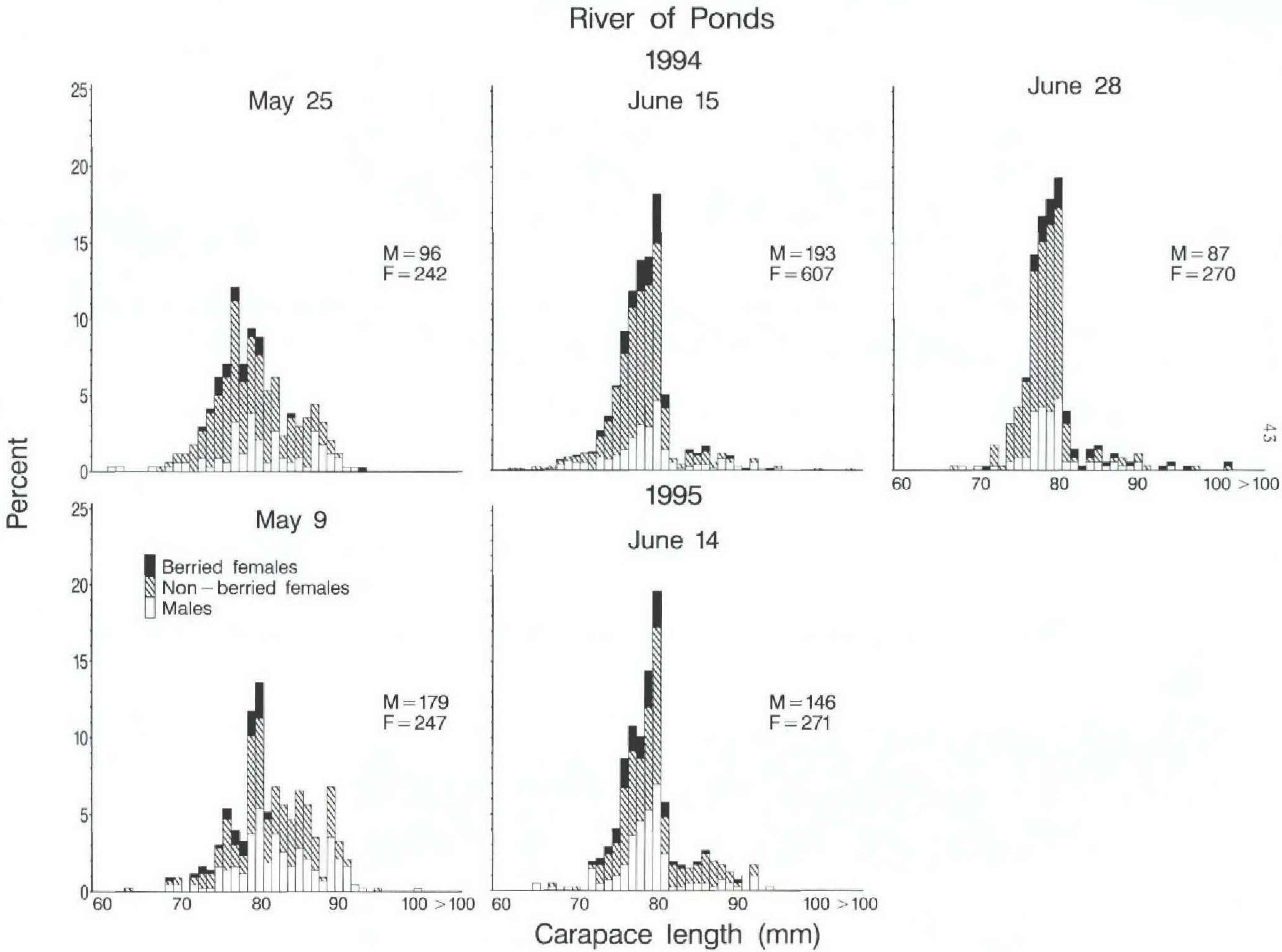


Fig 7. continued...



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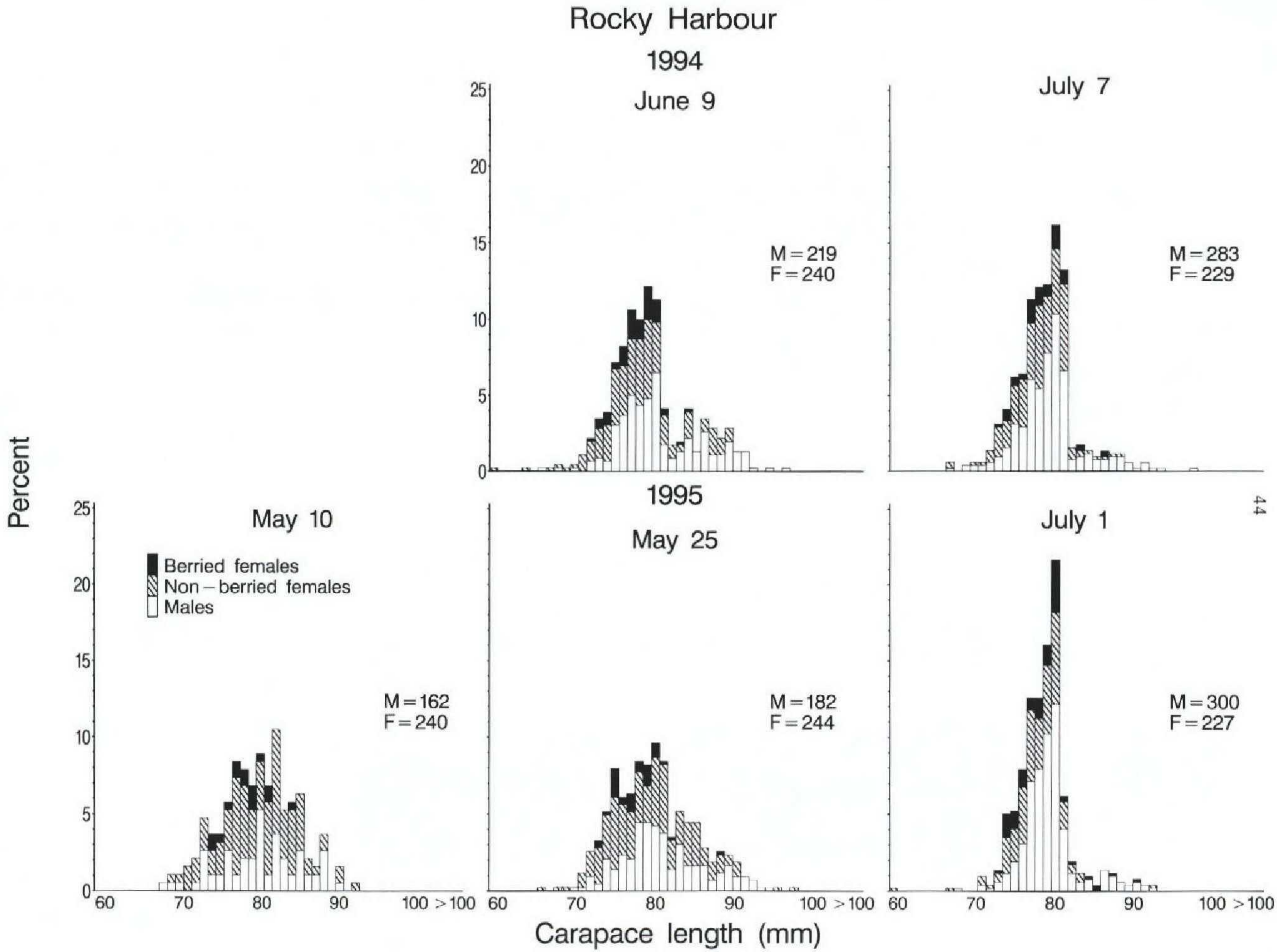

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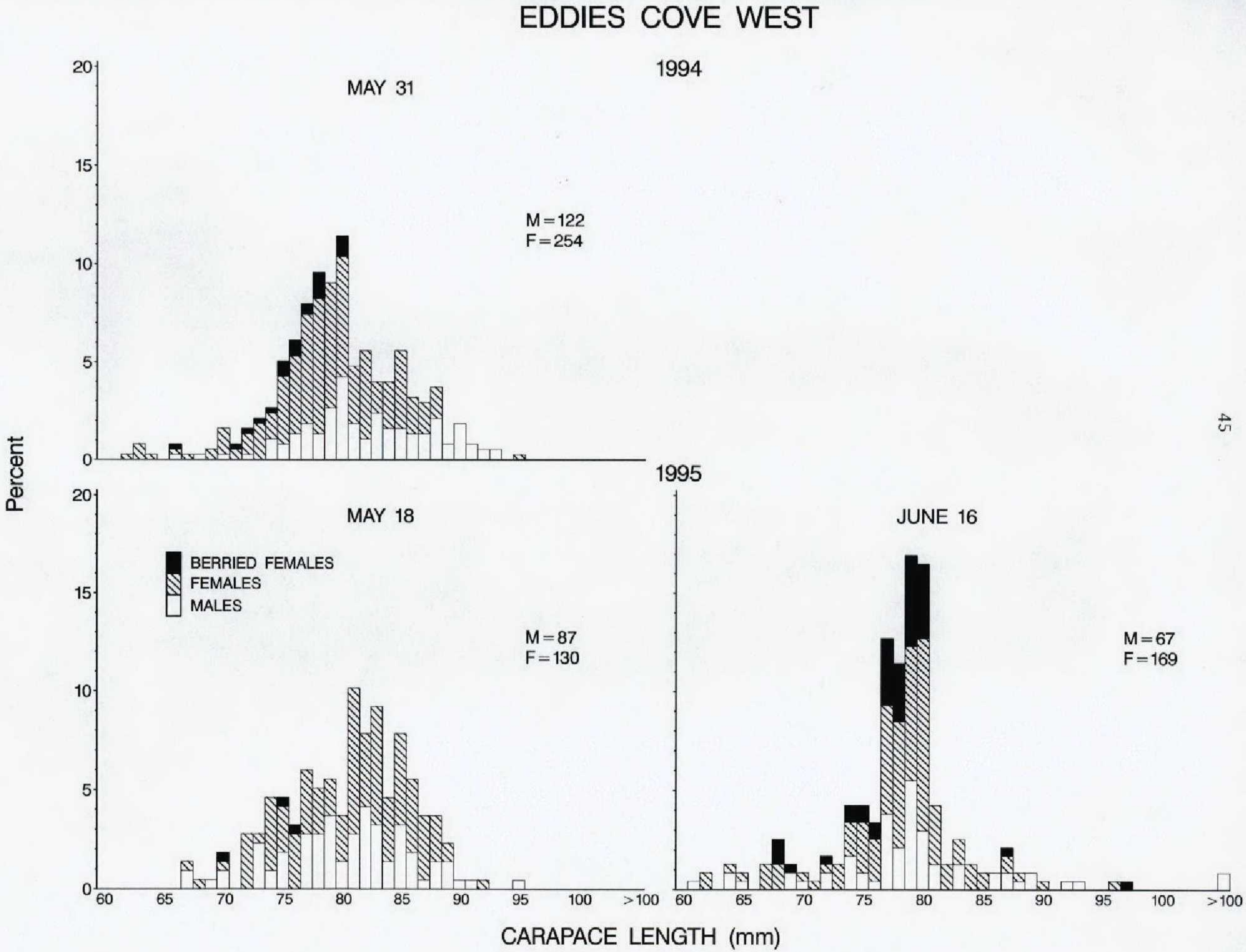

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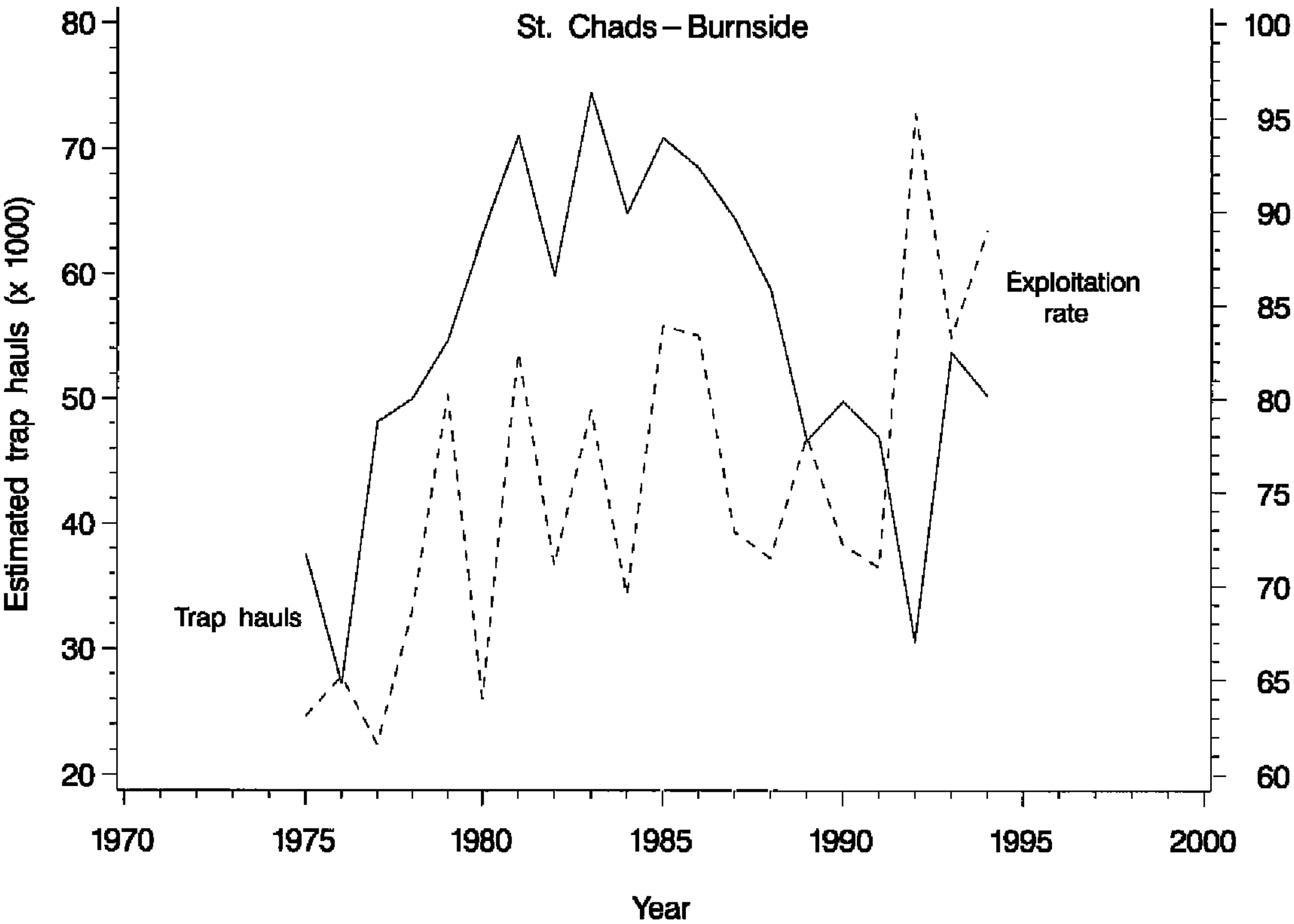
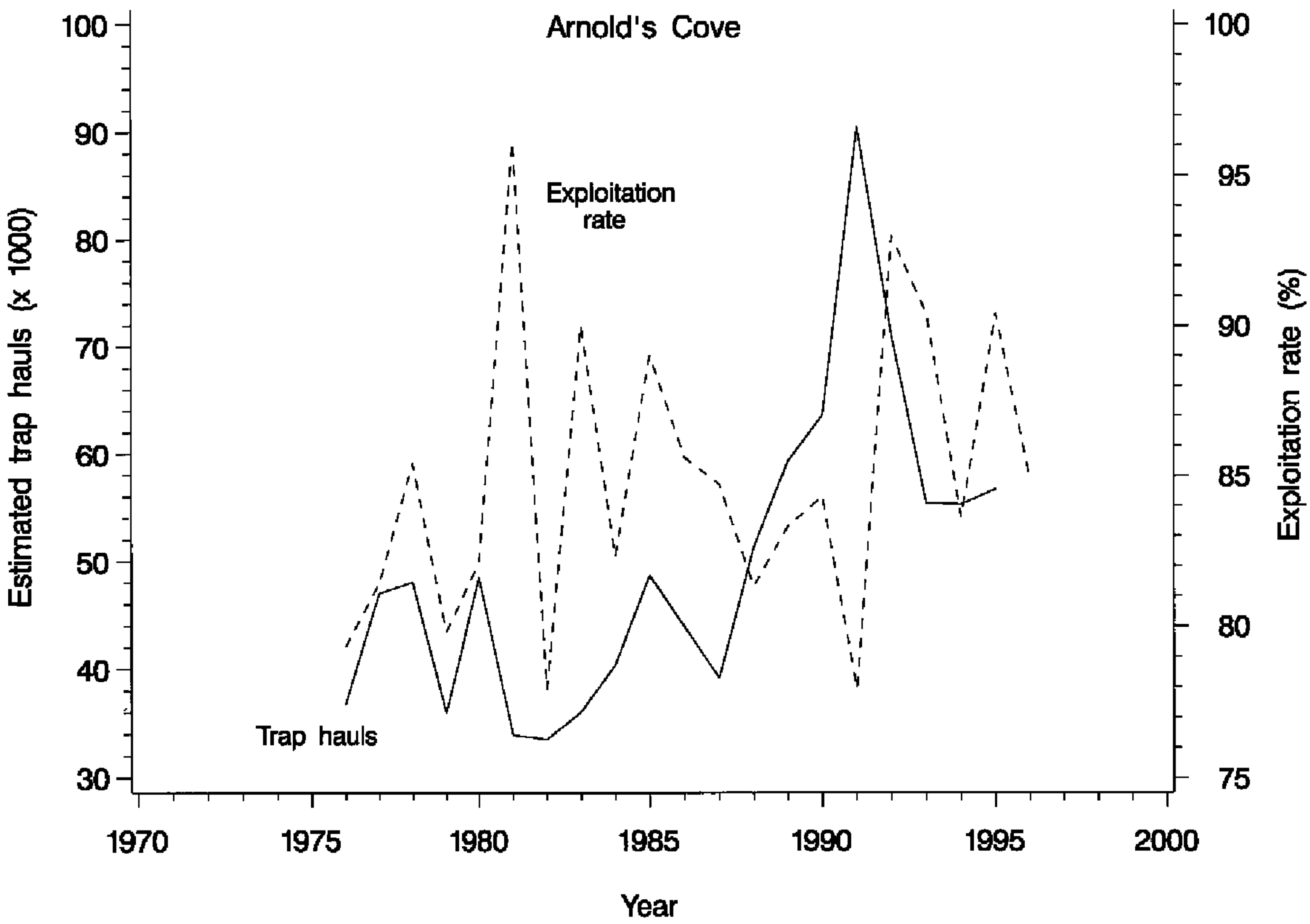


Fig 8. Estimated trap hauls for the season and exploitation rates at St. Chads – Burnside, Arnold's Cove and Comfort Cove.



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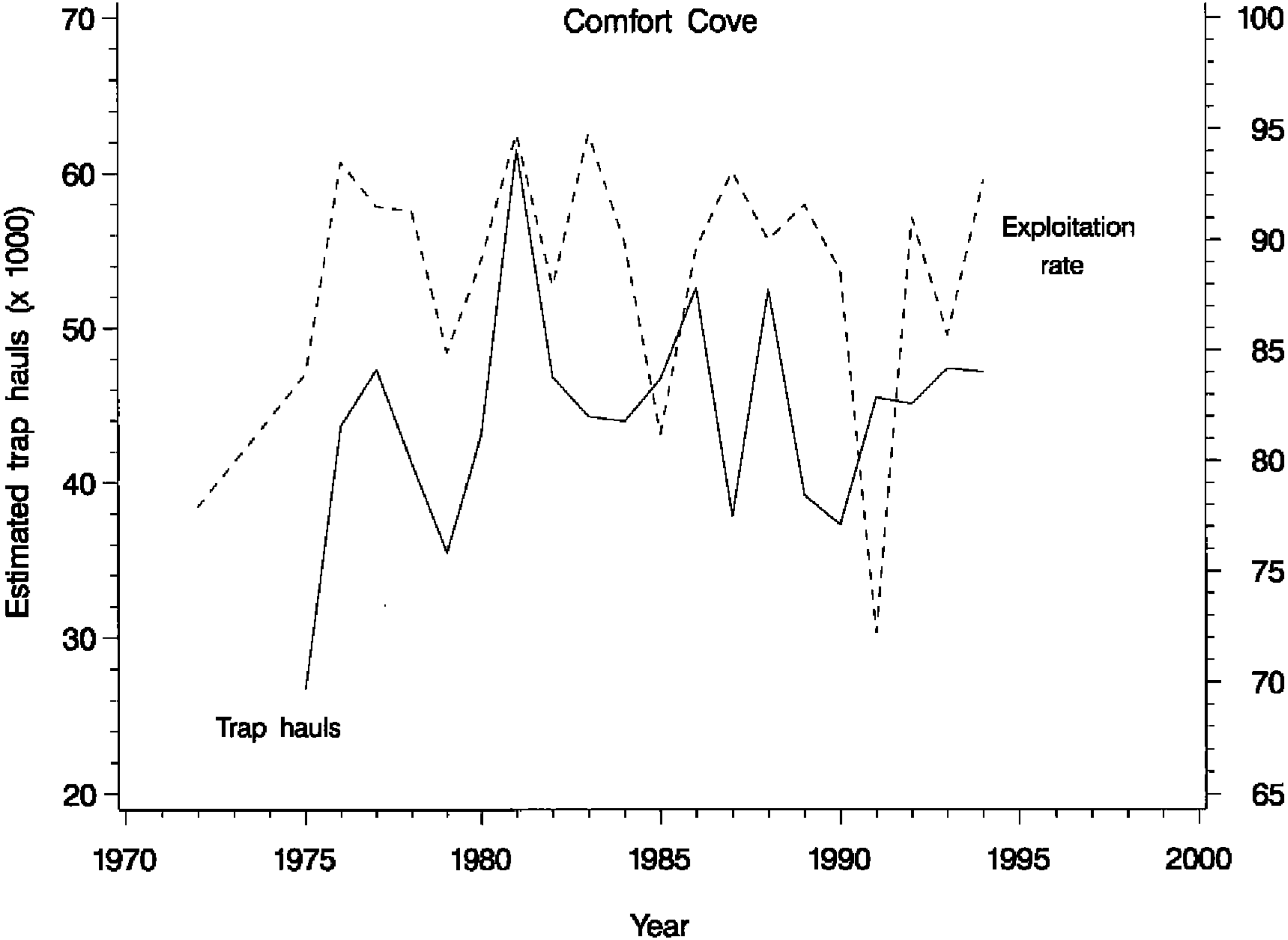

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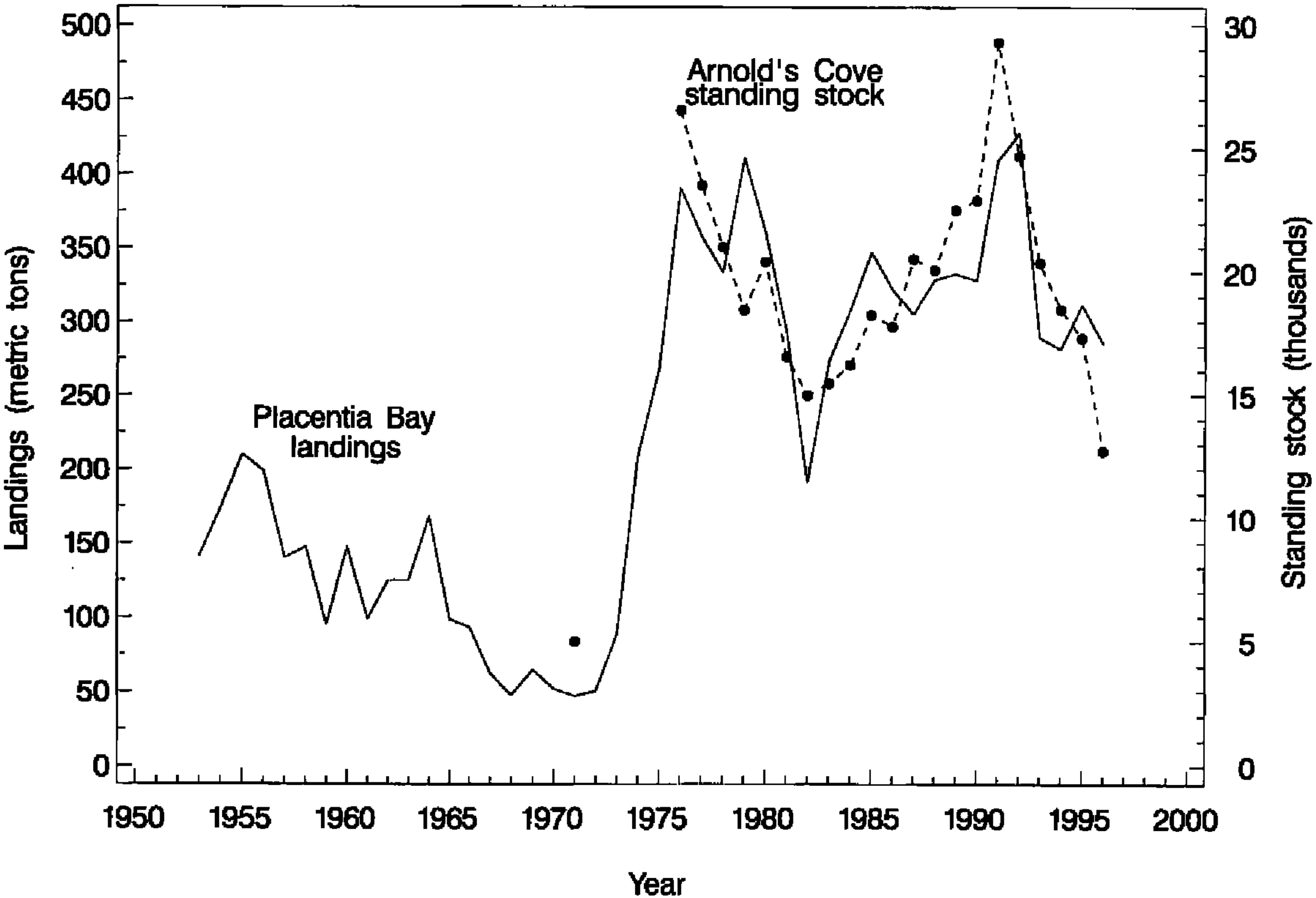

Fig 9. Placentia Bay lobster landings, 1953–96, with standing stock estimates for the Arnold's Cove population for 1971 and 1976 to 1996 superimposed.

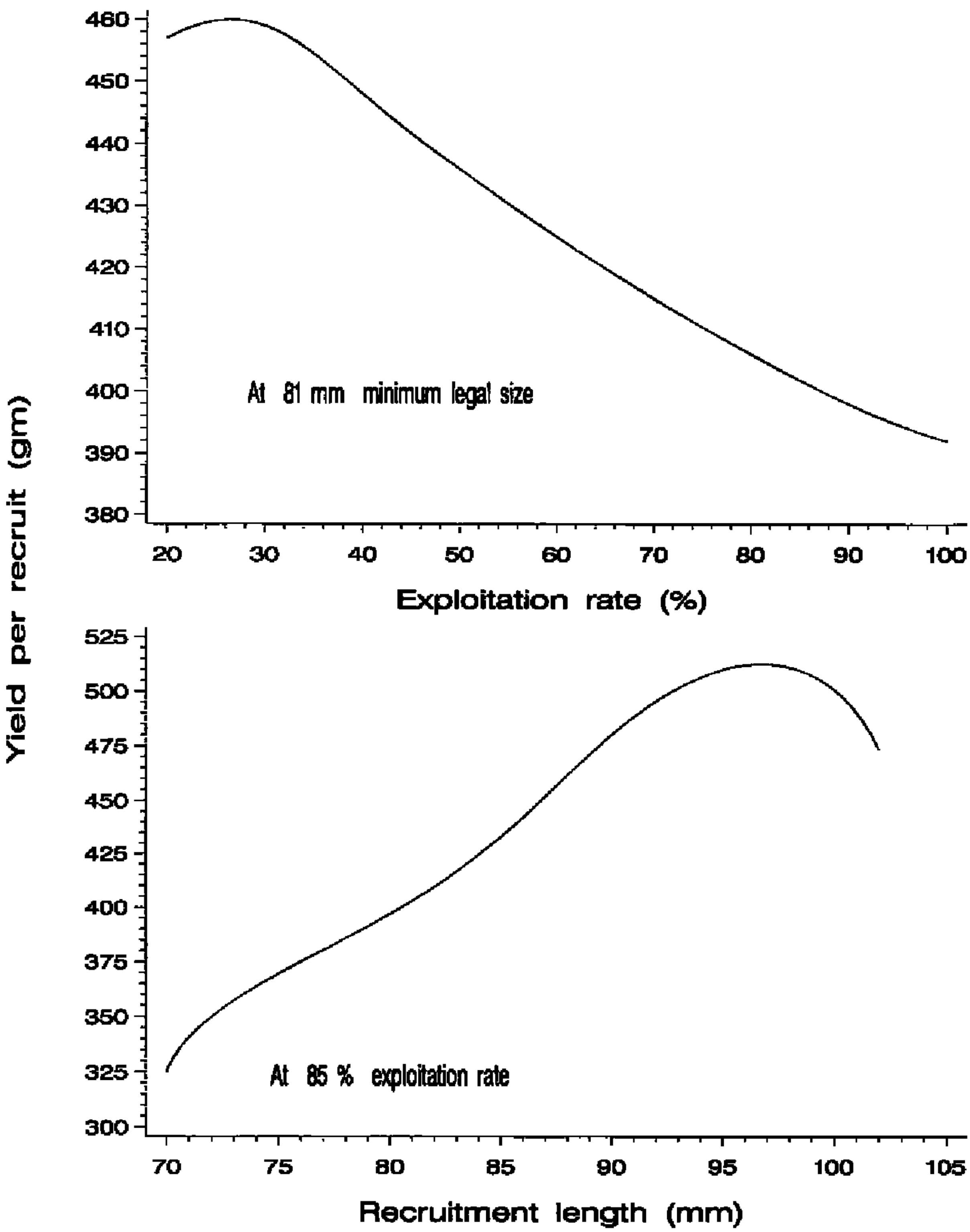

Fig 10. Yield per recruit analyses for the Arnold's Cove lobster population.

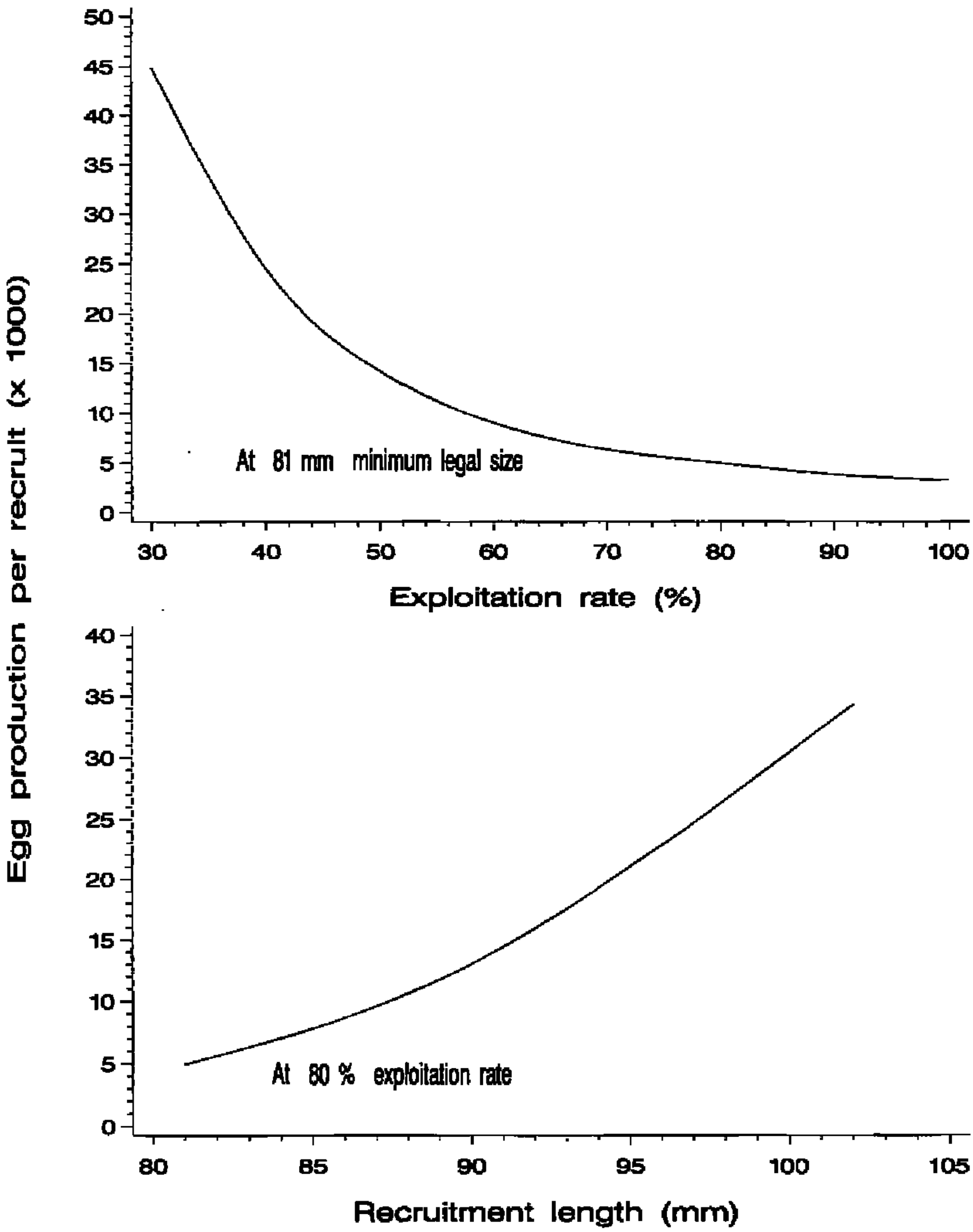

Fig 11. Egg per recruit analyses for the Arnold's Cove lobster population.

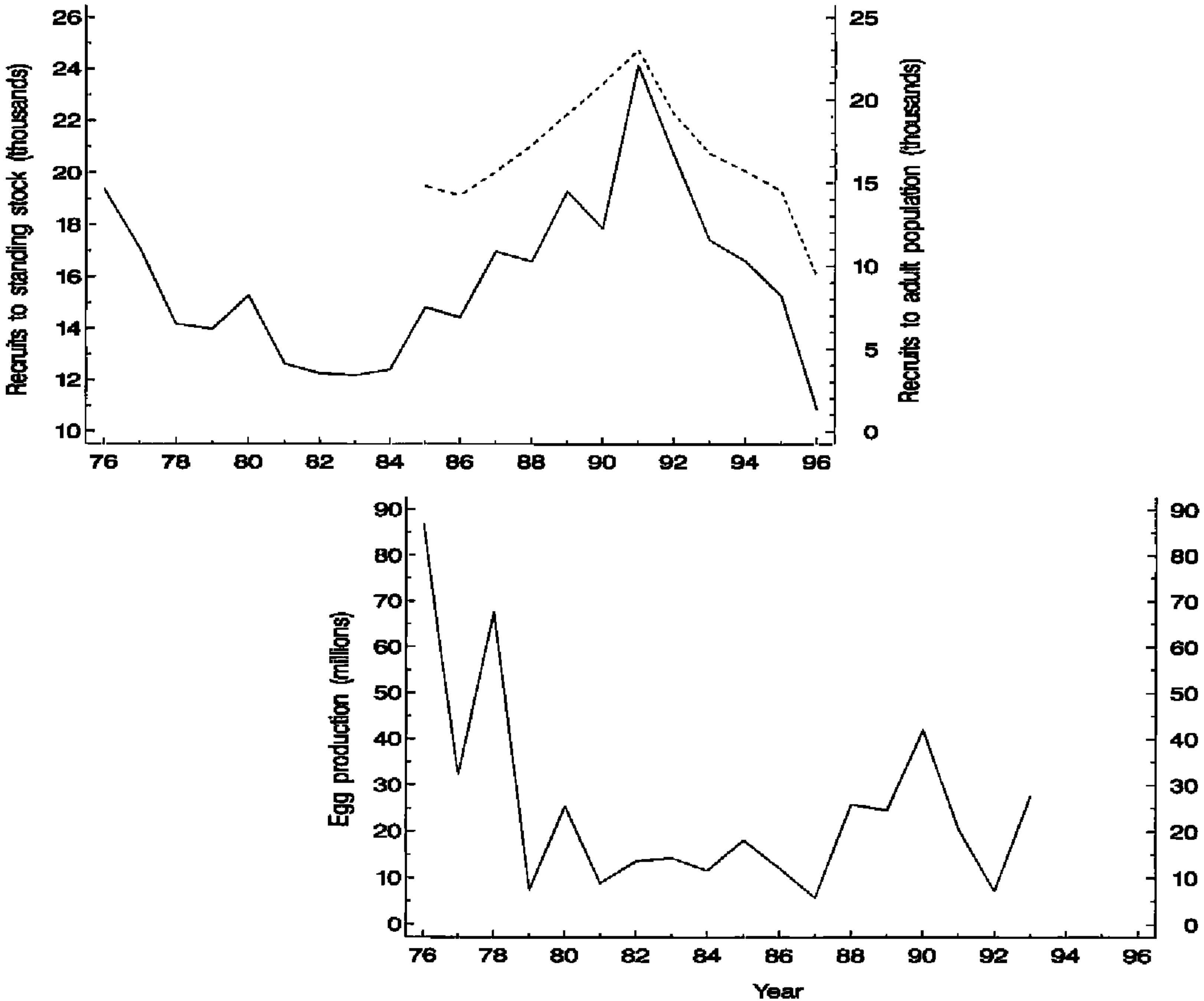

Fig 12. Estimates of recruits to the standing stock, 1976–96 and recruits to the adult population 1985–96 (top), and egg production, 1976–93 offset 9 years to right (bottom), in the Arnold's Cove lobster population.

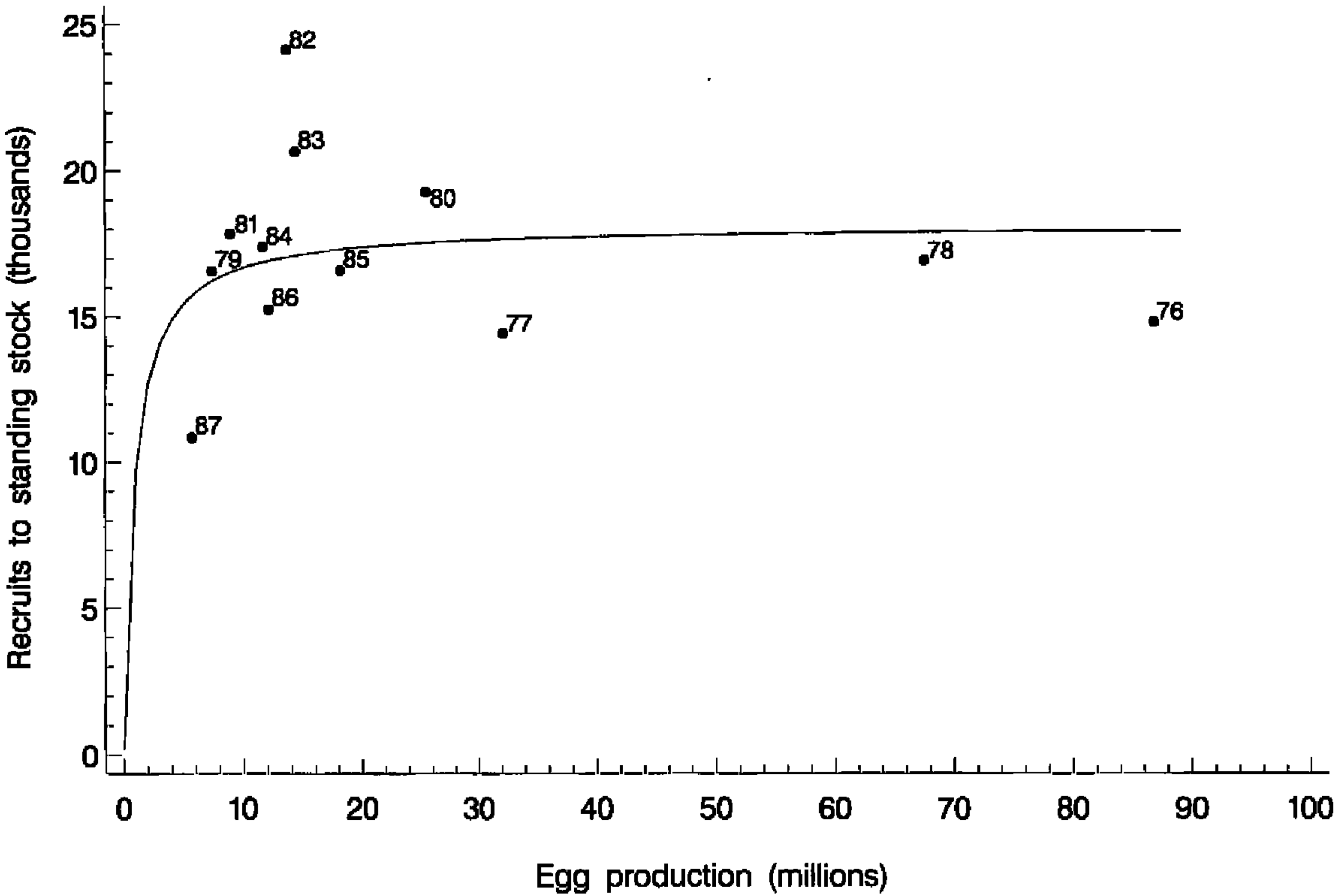

Fig 13. Estimates of egg production for 1976 to 1987 and recruits to the standing stock 9 years later for the Arnold's Cove lobster population fitted to the Beverton and Holt stock–recruitment model. Numbers adjacent to the data points indicate the yearclass.

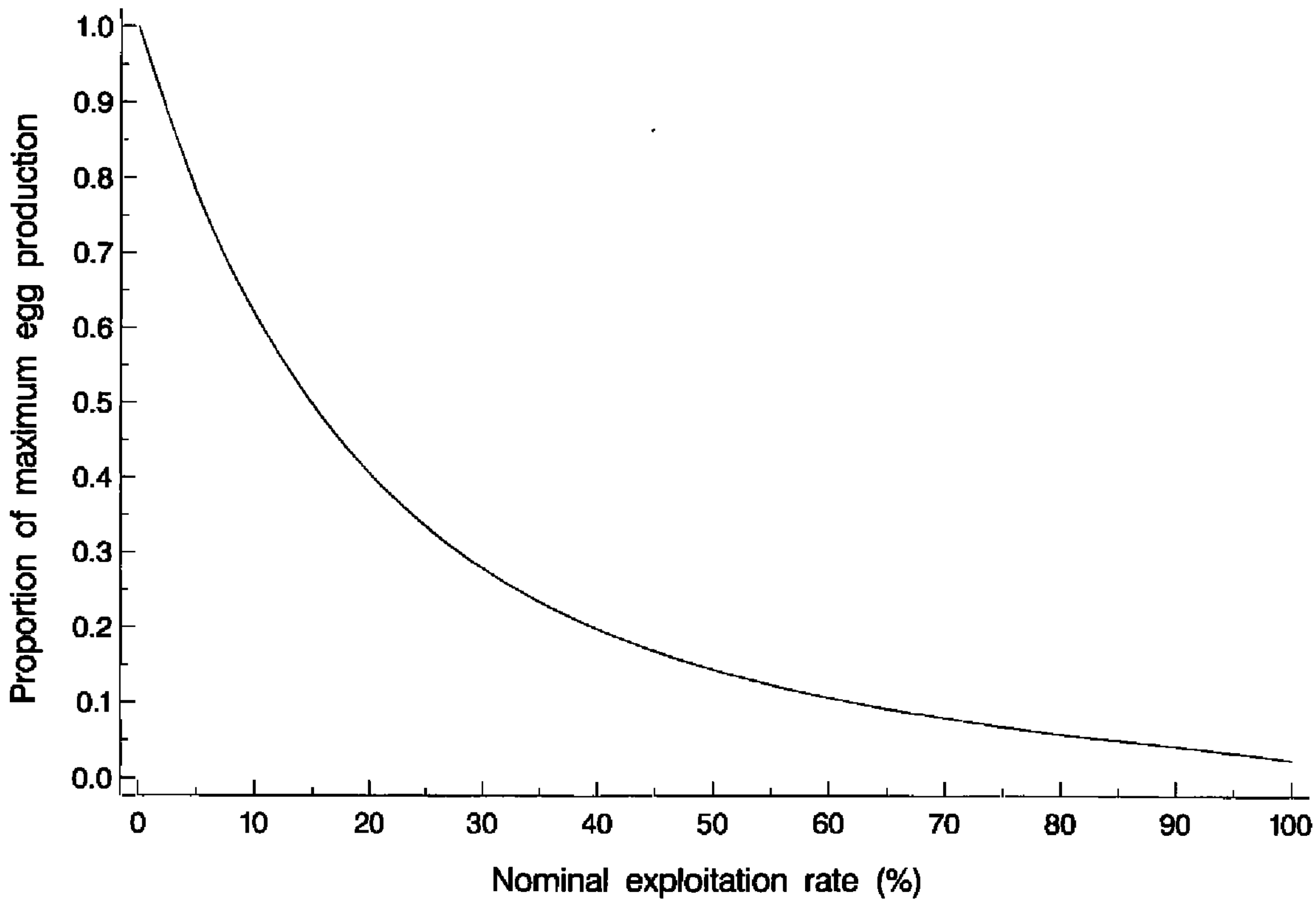

Fig 14. The relationship between egg production per recruit (E/R) expressed as a proportion of the maximum and nominal exploitation rate for the Arnold's Cove lobster population. Assuming a 1:1 sex ratio, the E/R value was halved.

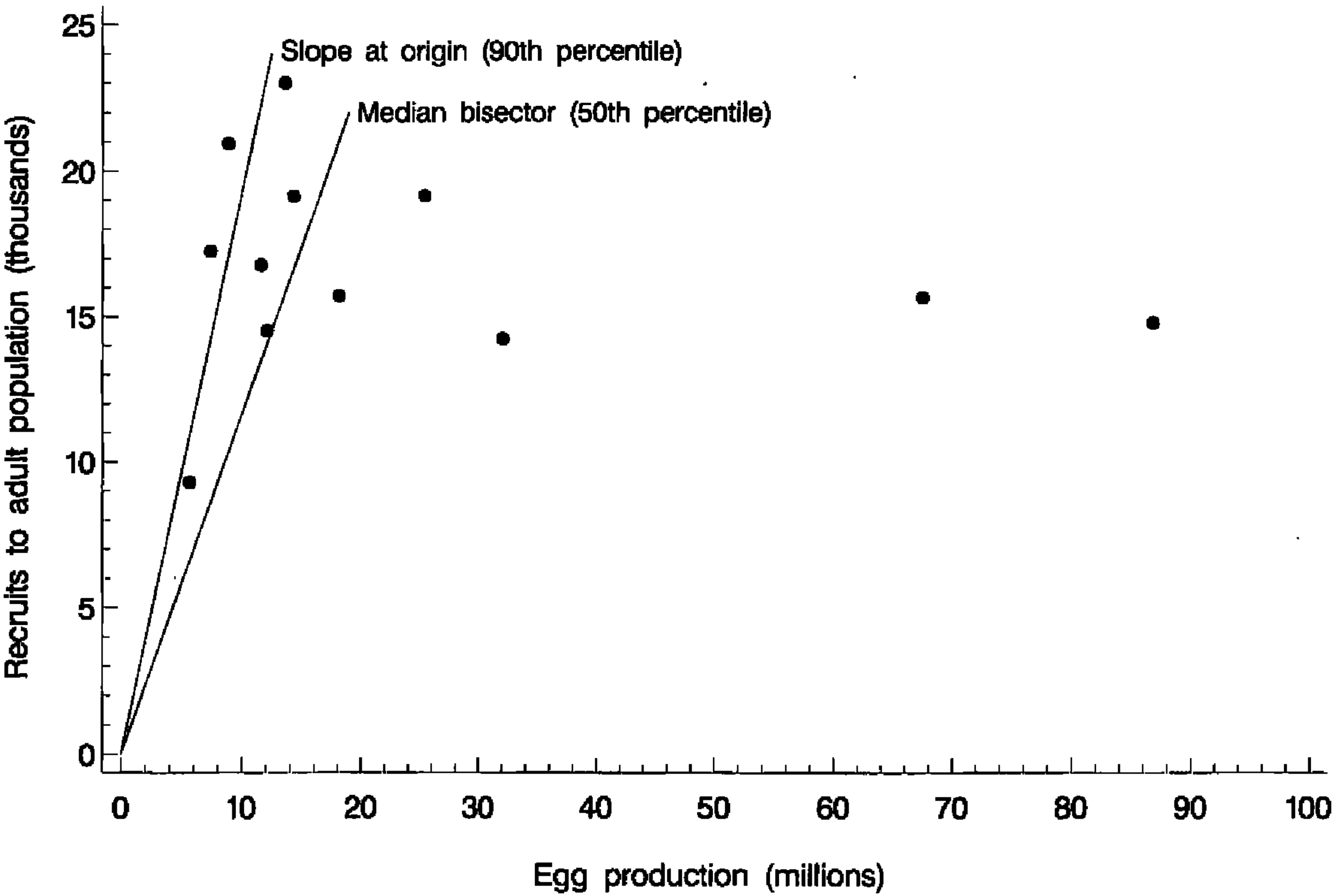

Fig 15. Estimates of egg production (E) for 1976 to 1987 and recruitment (R) to the adult population 9 years later for the Arnold's Cove lobster population. Lines through the origin of the scatterplot with slopes equal to the median survival ratio and the 90th percentile survival ratio are shown.