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Monitoring Fluctuations in Pelagic Fish Availability with Seabirds

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Abstract

The present results are generated from long-term monitoring schemes of seabird prey harvests off Newfoundland. They are focused on pelagic fish and squid harvests by northern gannets (*Sula bassana*) and common murres (*Uria aalge*). Over a 16-year period from 1977–1992, there have been increases in diversity and interannual shifts in the prey harvests of gannets off the northeast coast of Newfoundland. Shifts are associated with cold summer sea surface temperatures. During these cold conditions, summer residents, squid (*Illex illecebrosus*), mackerel (*Scomber scombrus*) and Atlantic saury (*Scomberesox saurus*), did not migrate into the region, as indicated by their scarcity in avian prey harvests. The maturity of capelin (*Mallotus villosus*) appeared to be delayed by cold water. During 1990 and 1991, capelin moved into the inshore regions 4 or more weeks later than usual, and gannets made their largest harvests of capelin in August, when capelin would usually be offshore. The gannets' harvests of capelin were significantly inversely correlated with sea surface temperatures. There appeared to have been relatively little of the gannets' usual pelagic prey available in August of 1990 and 1991, when cod and salmon were taken in significant numbers.

The percentage of gravid females taken by murres, which feed their chicks almost exclusively on female capelin, on Funk Island during August in 1991 was 48% compared to 4% in 1990. This finding is consistent with the hypothesis that capelin matured much later in 1991, though capelin landed by both murres and gannets in August were significantly larger in 1991 than in 1990. The relative scarcity of 2- and 3-year (110 -140 mm fork length) capelin in the prey harvests of murres in 1991 is consistent with the high incidences of small capelin in inshore regions in 1992. More than 50% of the capelin landed by gannets, which feed close to the surface, were males, suggesting that the smaller, but deeper diving murres either selectively preyed on female capelin or found them easier to capture.

As shown by significant associations between the landings of fisherpersons and gannets, the birds' harvests of squid and mackerel reflect abundance/availability around the colony, at a larger scale near the gannets' maximum foraging range (e.g. ~100 km), and for the entire region, i.e. from Labrador to the Grand Bank and St. Pierre Bank. The correlations are higher at larger spatial scales.

Résumé

Les renseignements donnés ici découlent d'un programme d'óbservation à long terme des captures de proie des oiseaux de mer au large de Terre-Neuve. Ils portent essentiellement sur les captures de poisson pélagique et d'encornet par les fous de Bassan (Sulla bassana) et les marmettes communes (Uria aalge). De 1977 à 1992, soit en seize ans, on a observé un accroissement dans la diversité et les variations interannuelles des captures de proie des fous de Bassan évoluant au large de la côte nord-est de Terre-Neuve. Les variations sont associées aux basses températures estivales de la surface de l'eau. En effet, quand l'eau est froide, ses résidants estivaux tels que l'encornet (Illex illecebrosus), le maquereau (Scomber scombrius) et le balaou de l'Atlantique (Scomberex saurus) se tiennent à l'écart de la région, comme le révèle leur rareté dans les captures des oiseaux prédateurs. Par ailleurs, la maturation du capelan (Mallotus villdosus) semble avoir été retardée par l'eau froide. En 1990 et 1991, le capelan est arrivé dans les eaux côtières au moins quatre semaines plus tard qu'à l'accoutumée et les fous de Bassan ont capturé leur plus grande récolte de capelan en août, époque où ce poisson se trouverait normalement dans les eaux du large. Une corrélation inverse significative a été établie entre les captures de capelan par les fous de Bassan et les températures superficielles de la mer. Il semble que les poissons pélagiques qui sont habituellement la proie des fous de Bassan étaient relativement peu nombreux en août 1990 et 1991, périodes où l'on a capturé des quantités notables de morue et de saumon.

Le pourcentage de femelles pleines capturées par les marmettes communes - qui nourrissent leurs petits presque exclusivement de capelans femelles - sur l'ile Funk en août 1991 s'établissait à 48 p. 100, comparativement à 4 p. 100 en 1990. Cette constatation renforce l'hypothèse d'une maturation plus tardive du capelan en 1991, quoique le capelan capturé par les fous de Bassan et par les marmettes communes en août était considérablement plus gros en 1991 qu'en 1990. La rareté relative des capelans de 2 et 3 ans (longueur à la fourche de 100 à 140 mm) parmi les captures de proie des marmettes communes en 1991 est compatible avec la forte incidence de petits capelans dans les eaux côtières en 1992. Plus de 50 p. 100 du capelan capturé par les fous de Bassan, qui se nourrissent à entendre que les marmettes communes, qui sont plus petites mais plongent plus profondément, ont soit sélectionné les femelles comme proies, soit trouvé celles-ci plus faciles à capturer.

Comme le révèlent des associations significatives entre les prises des pêcheurs et celles des marmettes communes, les captures d'encornet et de maquereau par les marmettes reflètent l'abondance ou la disponibilité de ces poissons dans la colonie, ainsi qu'à plus vaste échelle, plus précisément à la limite de l'aire de ravitaillement des marmettes ($\sim$100 km) et dans toute la région, soit du Labrador aux Grands Bancs de Terre-Neuve et au banc de Saint-Pierre. Les corrélations sont encore plus grandes sur de plus vastes échelles spatiales.

Introduction

Dietary, energetics and behavioural data derived from seabirds are used in multi-species assessments of fish abundance (e.g. Bailey et al. 1991), and marine birds and mammals are sometimes taken into account when fisheries' quotas are considered (Croxall 1989). Seabirds are currently being incorporated in multi-species approaches by ICES (Anon. 1991).

Prey harvests by seabirds have been quantified in meso- and mega-scale community energetics models (Cairns et al. 1990a; Furness 1990; Diamond et al. 1992; Montevecchi et al. 1992a), and these models can be incorporated as subroutines of natural mortality in VPA models (Cairns 1992). In turn dietary, behavioural and reproductive behaviour data can be used to derive natural indices of prey abundance that can also be incorporated into assessment models (e.g. Barrett et al. 1990; Hatch and Sanger 1992; Lilly 1991).

Most seabirds feed on pelagic fish, crustaceans and squid (Montevecchi 1992; Rice 1992), and in the northwest Atlantic, capelin are the primary prey of vertebrate food webs, including seabirds (Brown and Nettleship 1984), cod (Lilly 1991) and marine mammals (Carscadden 1984; Whitehead and Carscadden 1985). Seabirds consume hundreds of thousands of tonnes of capelin and other prey each year (Brown and Nettleship 1984; Cairns et al. 1989, 1990b), and many depend on capelin for successful reproduction. The consumption levels of marine mammals are probably of equivalent or greater levels (Lavigne et al. 1985; D. Renouf pers. comm.). To assess the question of how seabirds can be used to monitor the status of marine fish stocks, interannual variability in seabird diet and the abundance/availability of prey stocks must be compared over appropriate geographic scales. For example, if seabird diet reflected only small scale changes around a colony, then these data would only be of limited use in monitoring the status of the prey over its entire range.

The present results are generated from long-term and from relatively recently established monitoring schemes of seabird prey harvests in the northwest Alantic (e.g. Montevecchi et al. 1987; Montevecchi and Berutti 1991) and are focused on pelagic fish, especially capelin harvests by gannets and murres, and on mackerel, Atlantic saury and squid by gannets.

Prey Harvest by Gannets on Funk Island

From 1977 through 1992, food samples were collected in July, August and September from gannets at the colony on Funk Island (Figure 1). Limited samples were also obtained from gannets at Cape St. Mary's, Baccalieu Island and Great Bird Rock, Magdalen Islands (Figure 1). Food samples were collected by approaching birds at roosts and within the colony. Gannets regurgitate food to chicks and often regurgitate loads before fleeing or taking flight. Chicks also regurgitate food when approached by researchers. The samples obtained from adults were often fresh, i.e. eyes intact, and almost always identifiable to species in the field. Fresh samples were weighed with Pesola spring scales, and their fork or mantle lengths measured. Fresh samples have also been analyzed for organic and amino acid composition and energy densities (Montevechi et al. 1984; Montevecchi and Piatt 1984). The frequencies of prey in the annual harvests of gannets were converted to biomass on the basis of the mean masses of individual prey items, and biomass data were in turn converted with mean energy densities to energy harvests. Comparisons of the percentage of biomass of different prey in different years were correlated with commercial catches in i) the colony vicinity (Funk Island region; 3Ki), ii) larger meso-scale regions around the colony within avian foraging ranges (North-East Newfoundland; 3Khi3La), and iii) the fishing regions of Labrador, Newfoundland and St. Pierre et Miquelon (Newfoundland; 2J3KLMNOP Figure 1). Seabird data were analayzed with commercial landings for August and for the entire year. Sea surface temperatures (SSTs) and salinities for different months obtained from hydrographic station 27 (47°32.8'N 52°35.2'W), which was established in 1946 and which lies 2 km east of St. John's in the inshore branch of the Labrador Current (Figure 1), were correlated with annual prey harvests. Station 27 has been attended by research vessels entering and leaving St. John's Harbour approximately twice monthly since 1950, providing coverage in all seasons. In a comparison of temperature and salinity measurements from station 27 with data collected at moorings and cross-shelf transects from Hamilton Bank off southern Labrador to the northern Grand Bank, Petrie et al. (1988) concluded that ocean climate signals were highly correlated over the entire region and were well represented by station 27 (see also Myers et al. 1988, 1990).

Diversity in the prey harvests of gannets increased through the sampling period, and there was a marked change in the gannets' prey harvests during 1990 and 1991 (Figure 2). In these years capelin dominated the gannets' prey landings during August sampling periods. Furthermore, cod (*Gadus morhua*) and salmon (*Salmo salar*), which previously had been extremely rare in the diet, were significant components of the gannets' prey harvests. The appearance of capelin, cod and salmon in the diets in August appears to be linked to cold summer SSTs. The June and July average surface (0–10 m) temperatures in 1991 are the lowest on record (Figure 3). The percentage of capelin in the gannets' prey harvests is significantly negatively correlated with the mean surface temperature June and July at station 27 (Figure 4, $r = -0.915$, $p < 0.00001$). The length of capelin taken by gannets was significantly longer in 1991 than in 1990 (Table 1). There were significant correlations between avian and human harvests of mackerel and squid (Figures 5 and 6), and these relationships were stronger at larger geographic scales and higher in comparisons of annual commercial harvests compared to commercial harvests during August. Prey harvests by gannets also indicated high availability of Atlantic saury, a thermally sensitive warm water species (Dudley et al. 1985; Scott and Scott 1988), during the mid to late 1980s (Montevecchi and Berutti 1991); no saury were landed by gannets in 1990 and 1991.

Capelin Harvests by Murres on Funk Island

In 1990 and 1991, food-carrying adult murres were captured out of the air with dip nets attached to poles as they delivered fish to chicks in the colony. This method of capturing murres produces virtually no disturbance in the colony. Capelin and birds were measured and weighed.

Murres preyed almost exclusively on female capelin, and those taken in 1991 were significantly longer and heavier and included a higher proportion of gravid females (48%) compared to 1990 (4%; Figure 7, Table 1). This finding is consistent with the hypothesis that capelin matured later in 1991. The mean lengths of capelin taken by murres and by gannets were not significantly different from one another in either 1991 or 1990, though the gannets preyed on a significantly higher proportion of males (Table 1).

Timing of Egg-laying by Murres at Cape St. Mary's

Since 1980, ten census plots of common murres have been surveyed at Cape St. Mary's (Piatt and McLagen 1987), these are longest term, regularly censused plots of capelin-dependent seabirds in the northwest Atlantic. Population data suggest that the population has declined in recent years (Piatt et al. 1991). Median egg laying dates (inferred from eggs observed on plots and back calculated from departure dates). were only slightly later than usual in 1991 and 1990 at Cape St. Mary's (Figure 8). In contrast, the Funk Island population, approximately 80% of the breeding population of murres in the northwest Atlantic (Montevecchi and Tuck 1987), appears to be behaving differently than the murres at Cape St. Mary's. During August of 1990 and 1991, 100,000s of common murres were present on Funk Island; these were the only years during the time series that began in 1977 when this order of magnitude of birds was present in August, indicative of the latest breeding years during this period. Usually, most of murres depart Funk Island by the end of July (Tuck 1960). We do not know what controls variation in egg-laying date among murres breeding in Newfoundland and Labrador, but it is evident that seabirds in different oceanographic regions are subjected to different environmental influences.

Discussion

From 1977 through 1991, gannets have exhibited marked changes in their prey harvests during August on Funk Island. We interpret these changes as shifts in the pelagic food web on the northern Newfoundland shelf (see also Burger and Cooper 1984; Crawford et al. 1985). Major shifts are associated with unusually cold summer SSTs. During these cold conditions, summer residents, squid, mackerel and Atlantic saury, did not migrate into the region, and the maturity of capelin appeared to be delayed in 1991, when they came into inshore regions about 4 or more weeks later than usual. This made them available in August when they would usually be offshore and out of the range of breeding seabirds attached to inshore colonies. There appeared to have been relatively little of the gannets' usual prey available in August of 1990 and 1991, when cod and salmon were taken in significant numbers. Neither of these species are shoaling fish and probably are not optimal prey for gannets.

The harvests of squid and of mackerel by fisherpersons and by gannets showed significant correlations at different spatial and temporal scales. These findings support contentions that dietary data from seabirds are useful in predicting fishery conditions in local areas around breeding colonies (e.g. Monaghan et al. 1991), and also in larger meso- and mega-scale regions around colonies (e.g. Hislop and Harris 1985).

The dramatic shift in the prey harvest of gannets on Funk Island was also seen in the capelin harvest by the murres there. Murres fed almost exclusively on female capelin (see also Barrett and Furness, 1990; Burger and Piatt 1990) and may have actively selected female capelin, as indicated by the significantly higher percentage of male capelin preyed on by gannets which feed need the surface in areas accessible to murres. Male and female capelin often segregate into gender specific schools with schools of mature females being found much nearer the surface than schools of males and spent females (e.g. Erikstad and Vader 1989). The percentage of gravid female capelin taken by murres in 1991 (48%) was more than 10 times that landed in 1990 (4%). Futhermore, the later egg-laying and breeding chronology by murres also suggests that capelin was not available early in the season. The scarcity of 2- and 3-year (110 -140 mm fork length) capelin in the prey harvests of murres in 1991 compared to 1990 might be taken to suggest weak younger age classes and is consistent with the appearance of small capelin in inshore regions in 1992.

Seabirds that breed at colonies on the northeast coast of Newfoundland are exposed to different environmental conditions than birds that breed at Cape St. Mary's, which is situated in a region somewhat less directly influenced by the Labrador Current. These influences are probably reflected in the later breeding chronologies of seabirds on the northeast coast, and also in the widespread reproductive failures of surface-feeding seabirds in the northwest Atlantic in 1991 and 1992, when black-legged kittiwakes (*Rissa tridactyla*) nesting at Cape St. Mary's fared better than conspecifics on the northeast coast (Montevecchi et al. 1992b).

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Table 1. Characteristics of capelin caught by murres and gannets on Funk Island during August, 1990 and 1991.

Capelin	1990	1991	χ^2 Comparison
MURRES			
% female	100	96[a]	$P > .05$
% gravid	4	48[b]	$P < .001$
fork length (mm)	138	152[c]	$P < .001$
weight (g)	11.5 (spent)	15.2 (spent)	$P < .001$
		21.7 (gravid)	$P < .001$
		18.4 (all)	$P < .001$
GANNETS			
% female	–	44[a]	
% gravid	–	3[b]	
fork length (mm)	139	152[c]	$P < .001$
Murre/Gannet Comparisons			a,b $P < .001$
			c $P > .05$

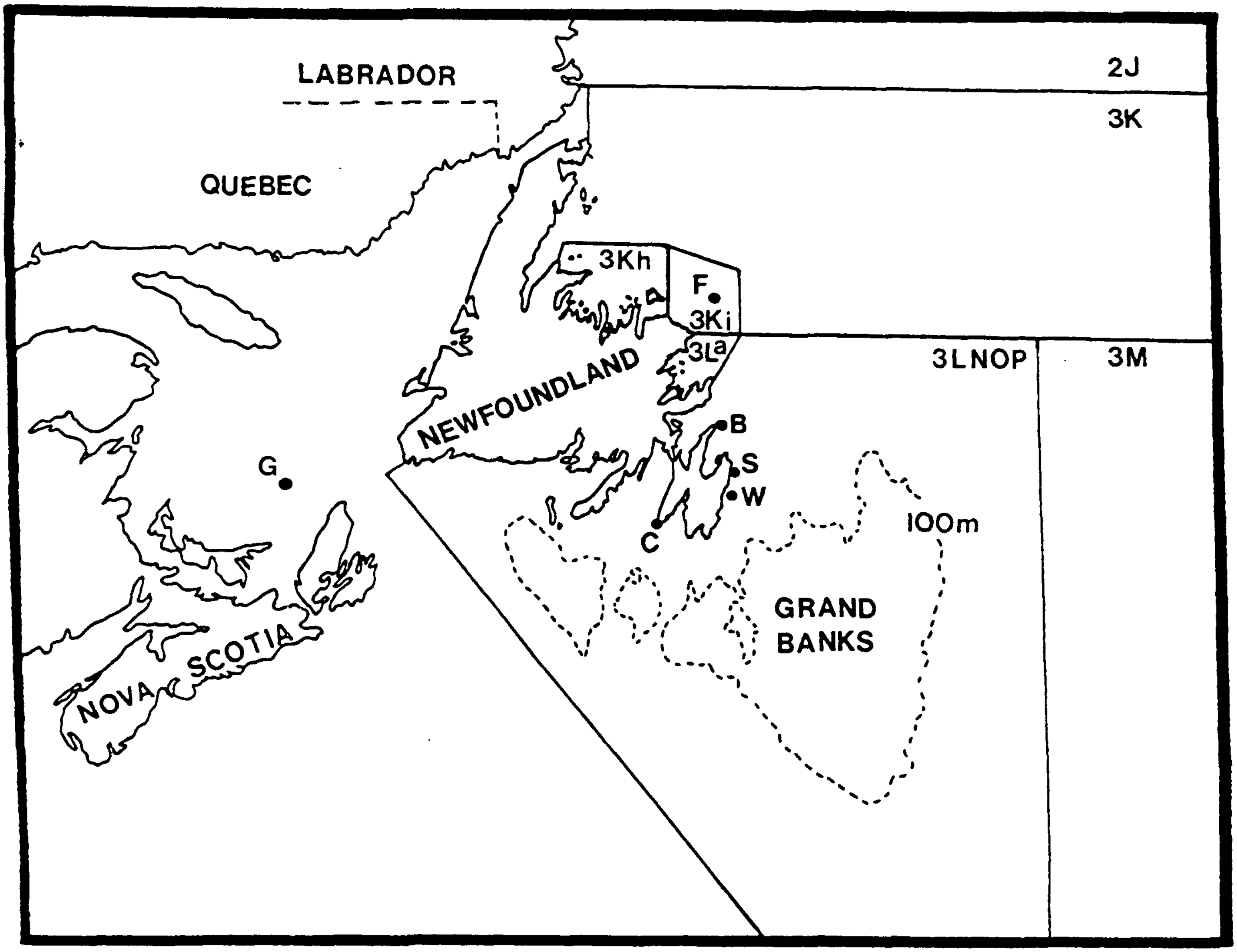

Figure 1. Location of Funk Island (F) and fisheries areas around island from which commercial prey harvests of squid and mackerel are compared with the prey harvests of gannets. 3Ki = Funk Island Region; 3Khi3La = North-East Newfoundland; all area east of bold lines = Newfoundland. Baccalieu Island (B), hydrographic station 27, Cape St. Mary's (C) and Great Bird Rock (G; Magdalen Islands) are also shown.

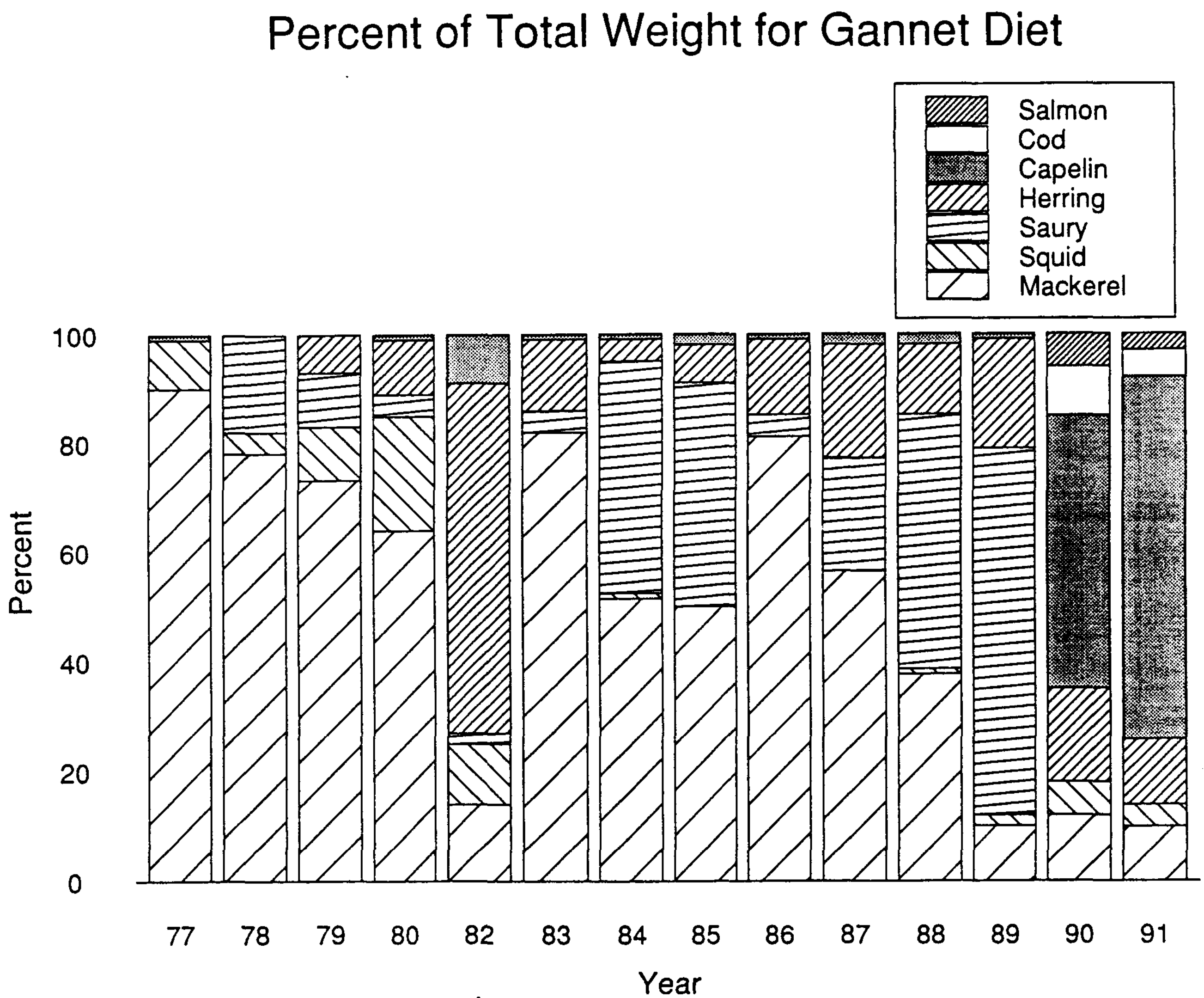

Figure 2a. The percentage of various food items by weight in the prey harvests of gannets on Funk Island, 1977-1991.

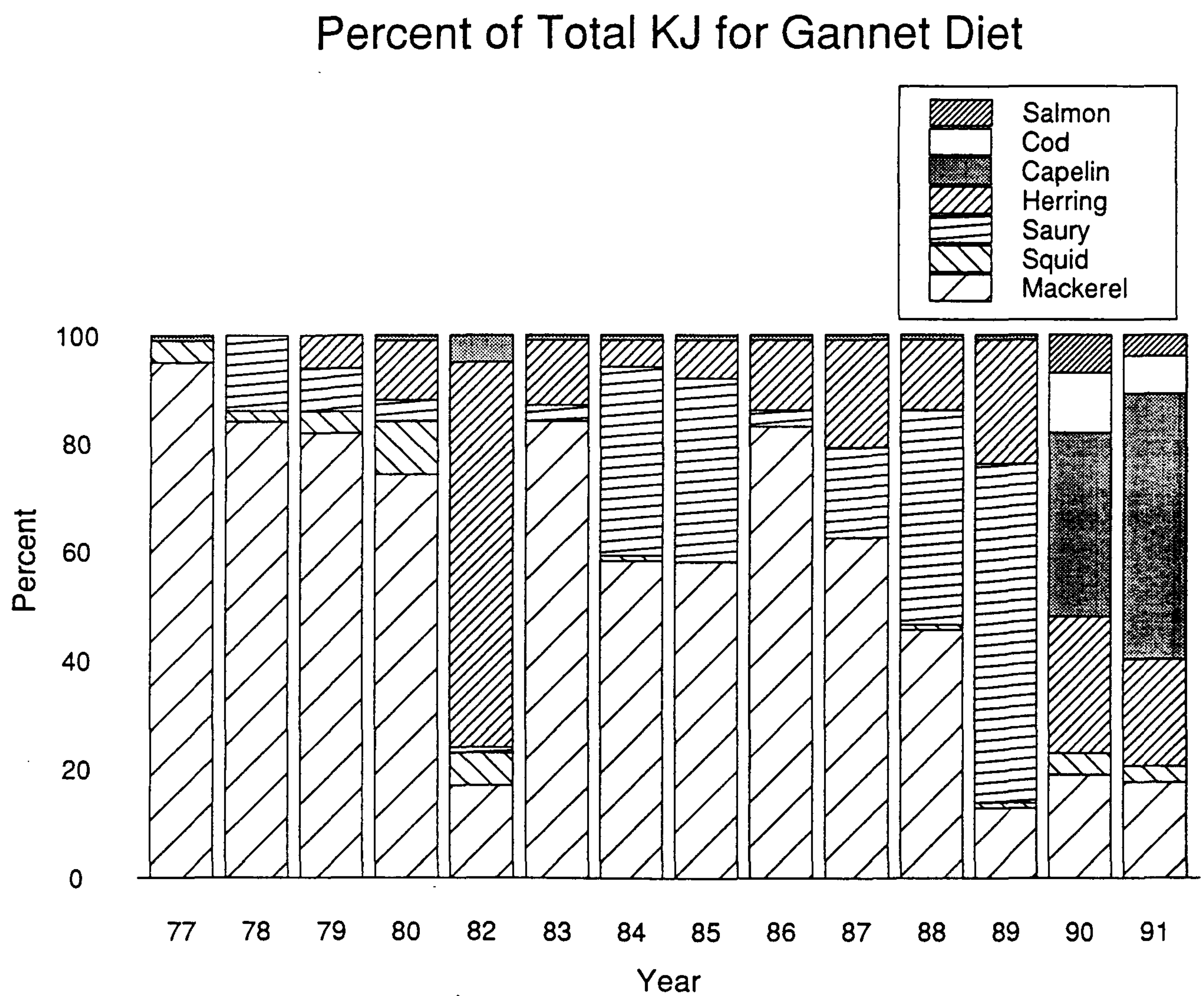

Figure 2b. The percentage of various food items by energy (kJ) in the prey harvests of gannets on Funk Island, 1977-1991.

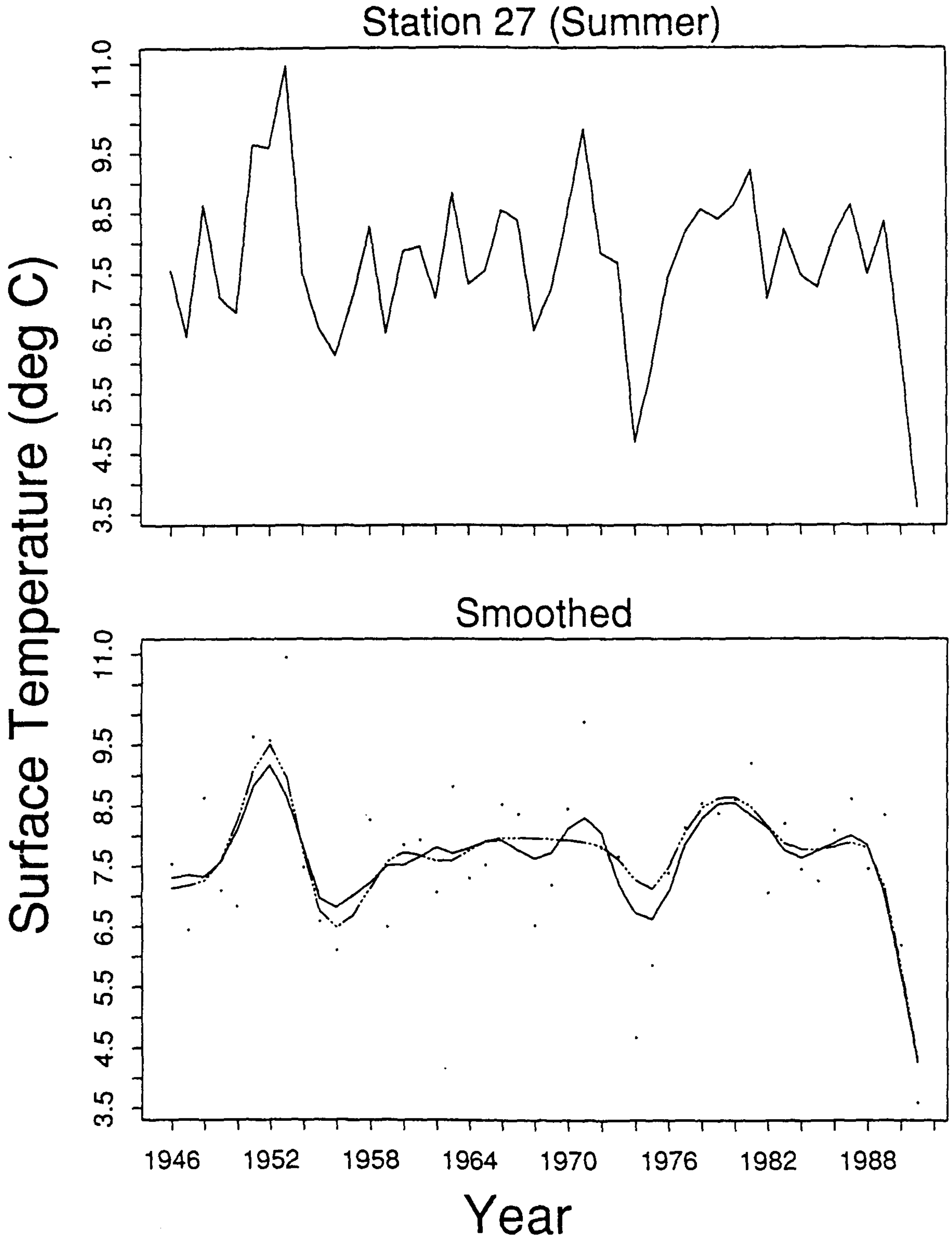

Figure 3. Time series of average June and July SSTs (0–10 m) at station 27 from 1946 though 1991 (Upper). The lower plot shows two smoothed versions of the time series; individual data points are also plotted. The solid line is the lowess smoother, a robust locally weighted regression (Cleveland 1979), with a window size of 6 months on each side. The broken line is a series of means of running medians. The results are produced by applying a method known as 4(3RSR)2H twice (Tukey 1977).

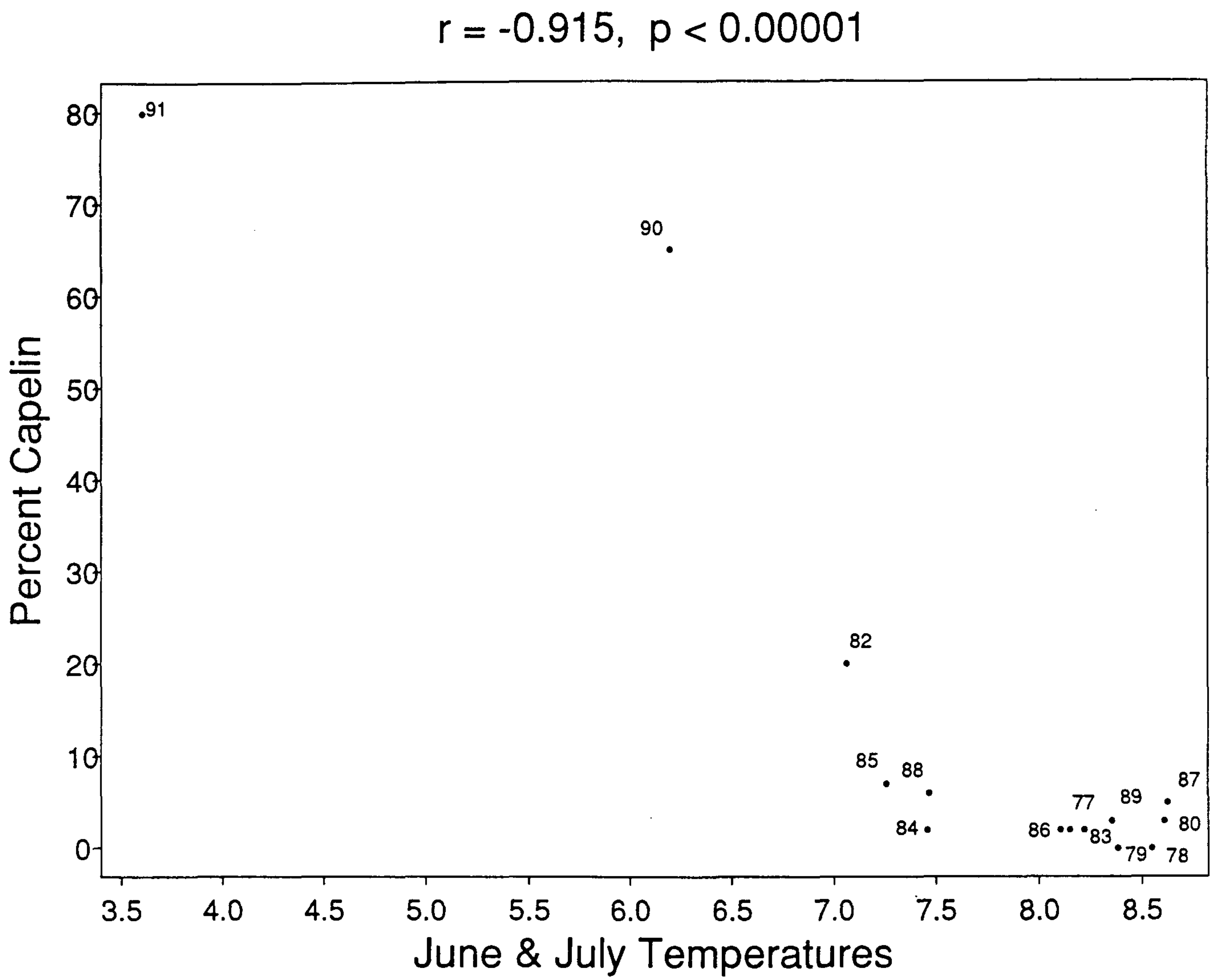

Figure 4. The relationship between percentage of capelin in the prey harvests of gannets and the average SSTs (0–10m) at station 27 in June and July, 1977 - 1991 ($r = -0.915$, $p < 0.00001$).

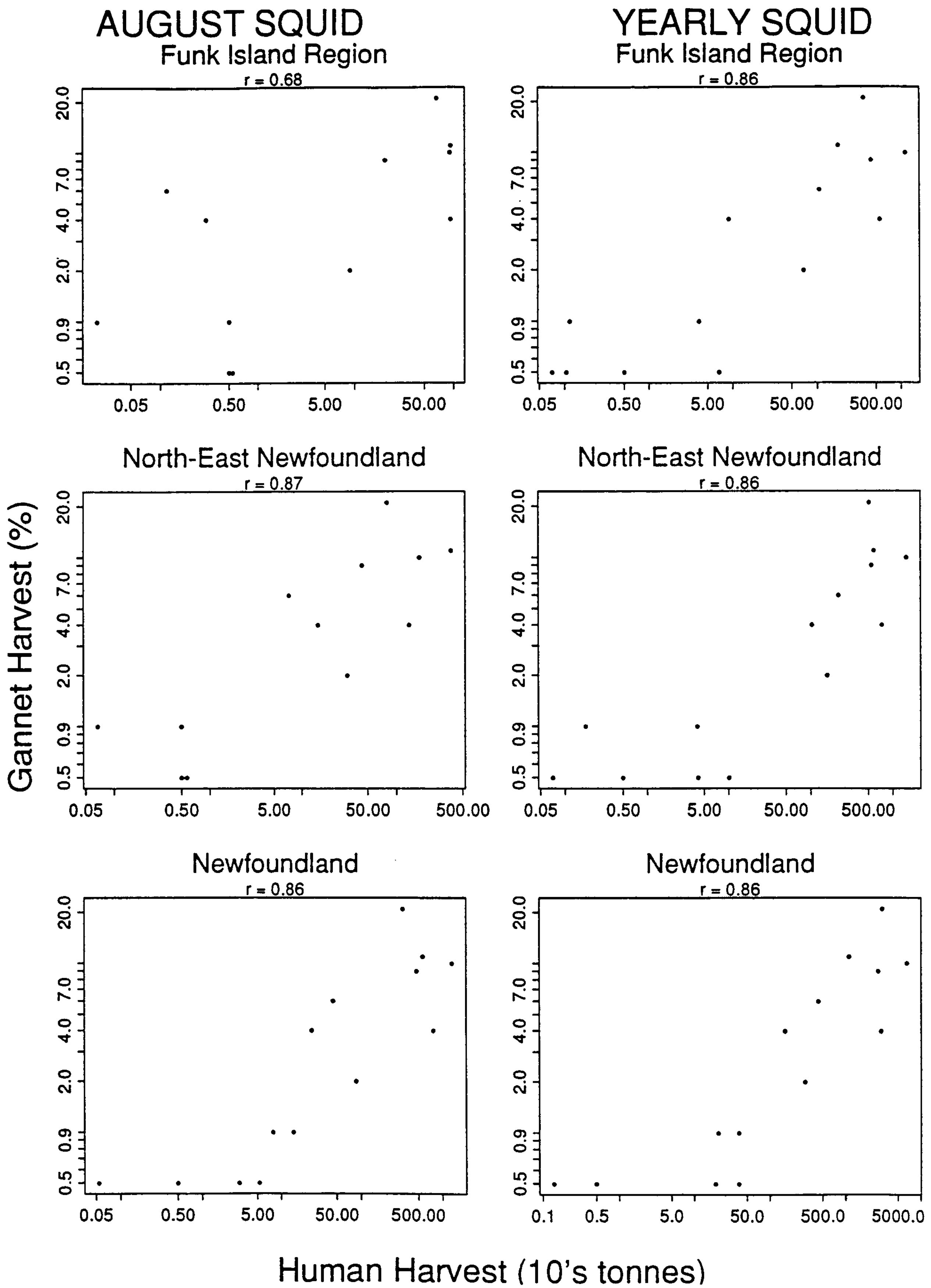

Figure 5. Relationships between the log of the percentage of short-finned squid in the prey harvests of gannets and log commercial catch in i) the Funk Island Region (NAFO area 3Ki), ii) North-East Newfoundland (3Khi3La) and iii) Newfoundland (2J3KLMNOP), 1977–1991.

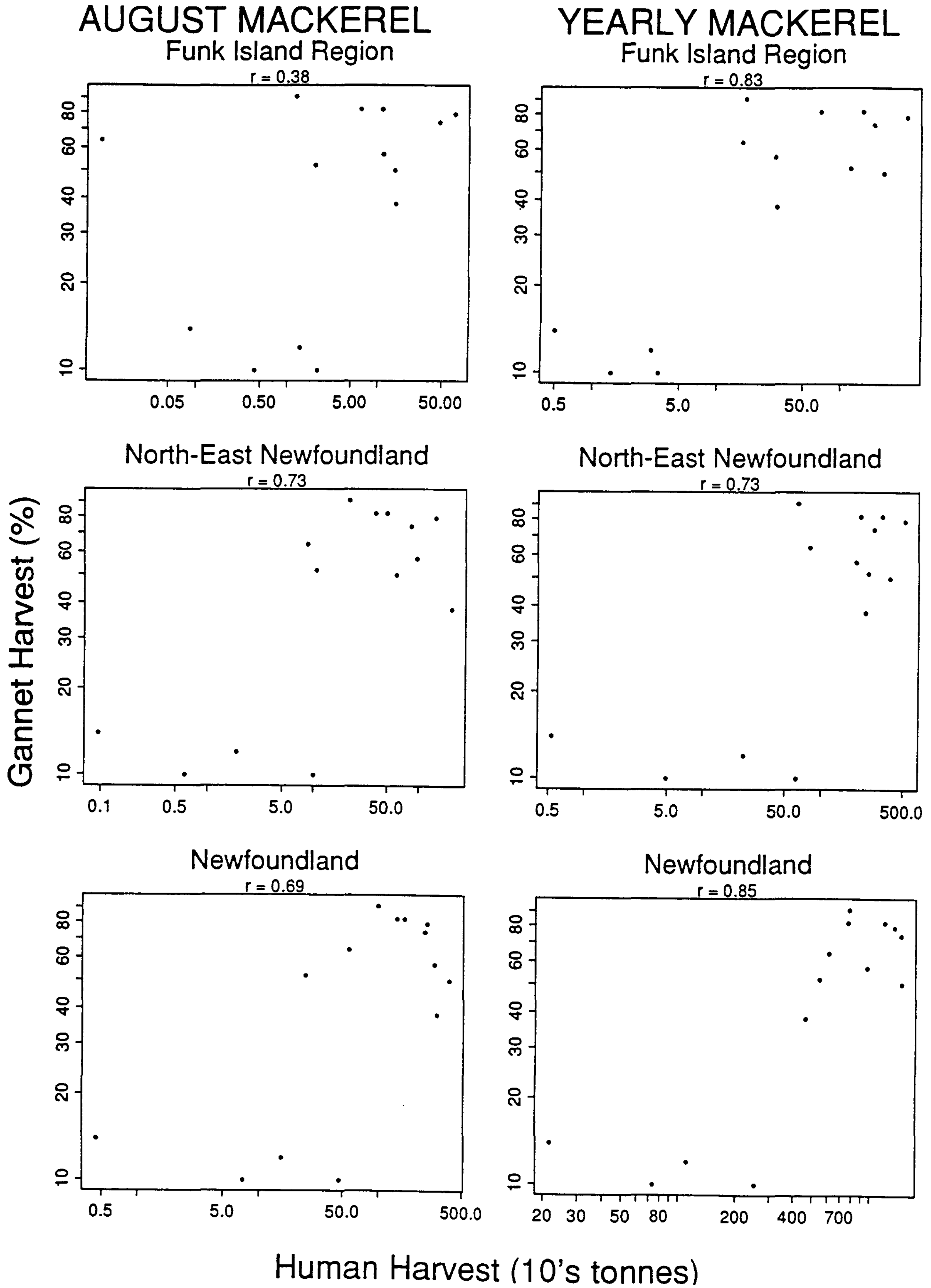

Figure 6. Relationships between the log of the percentage of mackerel in the prey harvests of gannets and log commercial catch in i) Funk Island Region (NAFO area 3Ki), ii) North-East Newfoundland (NAFO areas 3KhiLa), and iii) Newfoundland (NAFO Division 2J3KLMNOP).

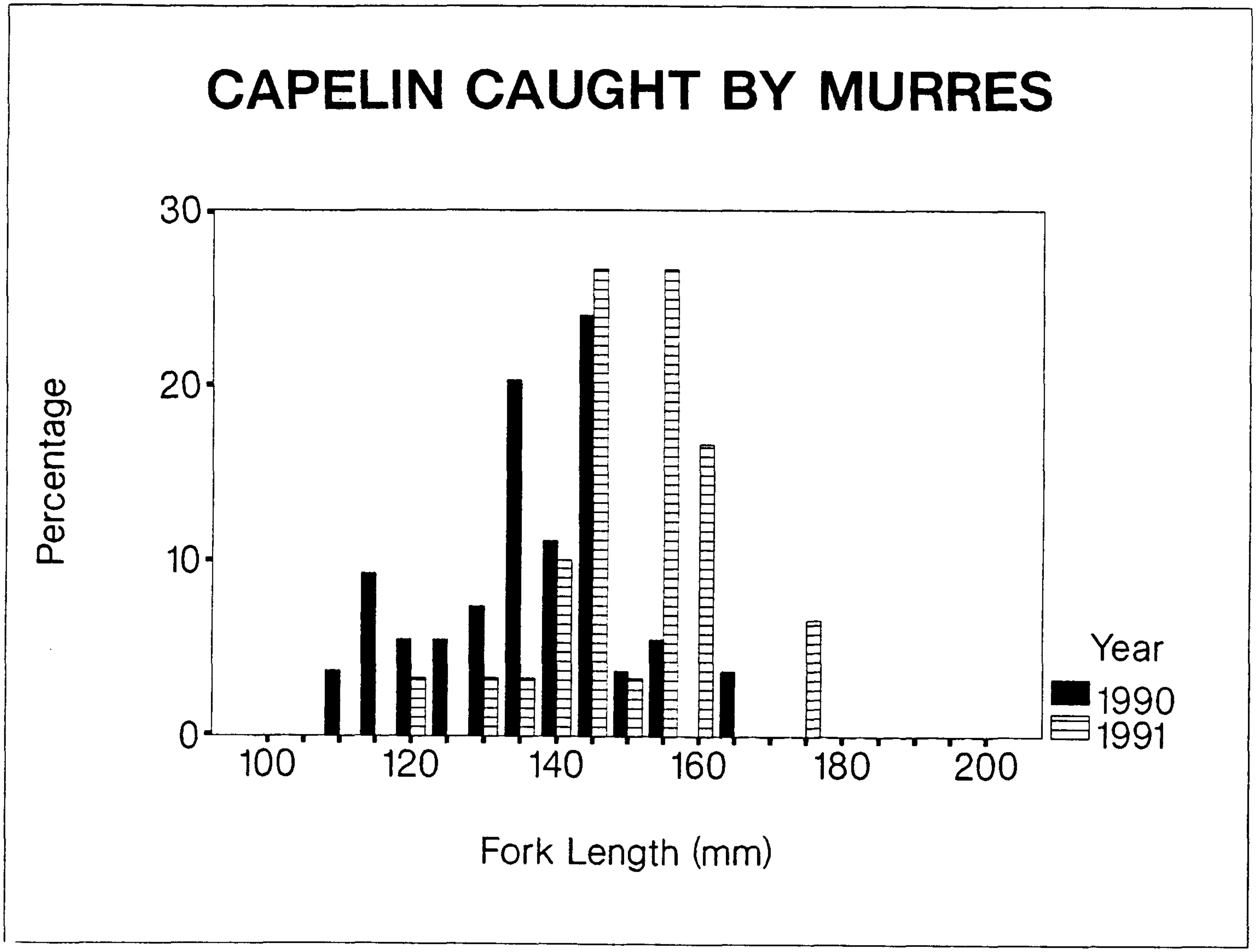

Figure 7. Length distribution of capelin caught by murres on Funk Island during August, 1990 and 1991.

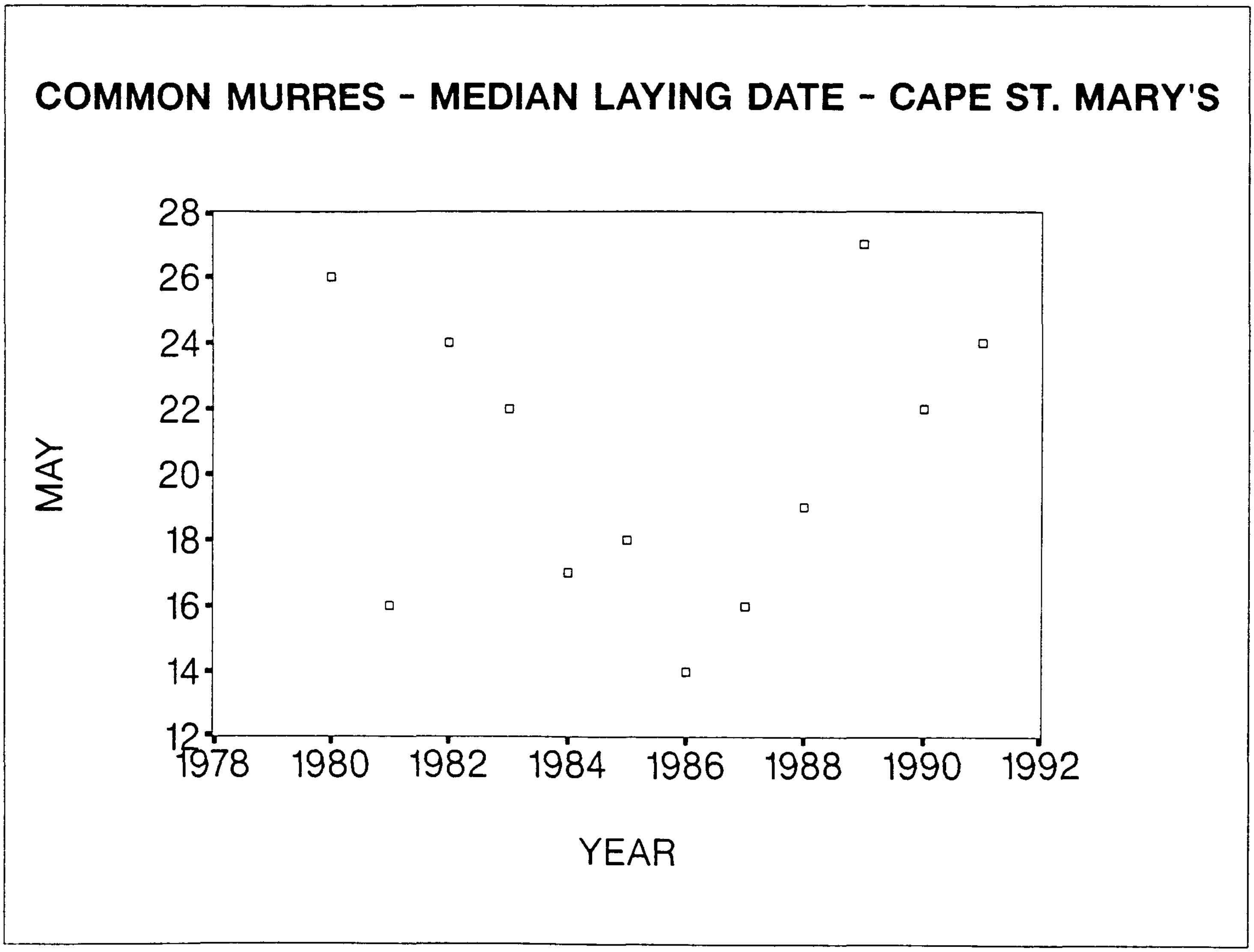

Figure 8. Median laying dates of common murres at Cape St. Mary's, Newfoundland, 1980–1991 (from J.F. Piatt and F. Shahood, unpubl. data).