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# Timing, location, and volume of herring spawn deposition at Fisherman's Bank, Prince Edward Island, 1987-1990


David K. Cairns[1], Shoukry N. Messieh[1,2], Elmer Wade[1], Paul A. MacPherson[3], and G. Clarence J. Bourque[1]

[1]Science Branch
Department of Fisheries and Oceans
Box 5030
Moncton
New Brunswick E1C 9B6

[2]Present address:
Habitat Ecology Lab
Department of Fisheries and Oceans
Bedford Institute of Oceanography
Box 1006
Dartmouth
Nova Scotia B2Y 4A2

[3]Mur-Mac Marine Services
6162 Duncan Street
Halifax
Nova Scotia B3L 1K2



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# TIMING, LOCATION, AND VOLUME OF HERRING SPAWN DEPOSITION AT FISHERMAN'S BANK, PRINCE EDWARD ISLAND, 1987-1990

by

David K. Cairns[1], Shoukry N. Messieh[1,2], Elmer Wade[1],

Paul A. MacPherson[3], and G. Clarence J. Bourque[1]

[1]Science Branch
Department of Fisheries and Oceans
Box 5030
Moncton
New Brunswick E1C 9B6

[2]Present address:
Habitat Ecology Lab
Department of Fisheries and Oceans
Bedford Institute of Oceanography
Box 1006
Dartmouth
Nova Scotia B2Y 4A2

[3]Mur-Mac Marine Services
6162 Duncan Street
Halifax
Nova Scotia B3L 1K2

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**This report is dedicated to the memory of V. Bruce MacLeod,**

**fisherman and friend.**

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## ABSTRACT

The timing, location, and volume of spawn deposition by Atlantic herring (*Clupea harengus*) was investigated at Fisherman's Bank (46°01'N, 62°16'W), a fall spawning ground in the southeastern Gulf of St. Lawrence. Spawn volume was estimated through counts of eggs collected by divers (1987) and from measurements of bed thickness made with a remote video camera (1988-1990). Geostatistic analysis was used to estimate egg quantity and to map the distribution of eggs within beds in 1988-1990. Herring spawned primarily on cobble and bedrock substrates in depths between nine and 23 m. Vegetation on the spawning grounds was generally sparse or absent. Bottom temperatures during the spawning period varied from 6 to 20°C, and showed no clear trend with date. From four to seven spawnings were identified in each year from 1987 to 1990. Spawnings occurred from 20 August to 16 September, and magnitude and timing of spawning were not clearly linked to trends in catch rate or to landings of the commercial fishery. Estimated volume of deposited eggs was 11,417, 11,814, 17,189, and 13,504 $m^3$ in 1987, 1989, and 1990, respectively. Underwater video measurements of spawn thickness coupled with geostatistical analysis provide a valid and efficient means of estimating deposition of herring spawn.

## RÉSUMÉ

La phénologie, le placement, et le volume de la déposition des oeufs par le hareng de l'Atlantique (*Clupea harengus*) furent étudiés à Fisherman's Bank (46°01'N, 62°16'O), un fond de frai automnal du sud-est du Golfe du Saint-Laurent. Le volume des oeufs déposés fut estimée en 1987 à l'aide des décomptes des oeufs ramassés par les plongeurs. En 1988-1990 les estimés étaient calculés à partir de l'épaisseur du banc, qui était mesurée avec un appareil vidéo à distance. L'analyse géostatistique fut employée en 1988-1990 pour estimer la quantité d'oeufs à l'intérieur des frayères et pour cartographier leur distribution. Le fraie de hareng a été localisé principalement sur les fonds de cailloux ou sur la roche mère dans les profondeurs entre neuf et 23 m. La végétation sur les frayères étaient généralement dispersée ou absente.

Les températures au fond variaient entre 6 et 20°C, et elles ne montraient pas de tendances claires avec la date. De quatre a sept dépositions d'oeufs ont été notées annuellement de 1987 à 1990. Les fraies ont eu lieu du 20 août au 16 septembre, et la quantité d'oeufs et la date de leur déposition n'étaient pas reliées d'une façon claire aux tendances dans les prises par unité d'effort ou aux débarquements de la pêche commerciale. Le volume d'oeufs déposés a été estimé à 11,417, 11,814, 17,189, et 13,504 $m^3$, en 1987, 1988, 1989, et 1990, respectivement. Les mesures d'épaisseurs faites à partir de caméras vidéos sous-marins et l'analyse géostatistique fournissent un moyen fiable et efficace pour estimer la quantité d'oeufs de hareng.

## INTRODUCTION

Populations of herring (*Clupea harengus*), like those of most pelagic fishes, are difficult to estimate. In the southern Gulf of St. Lawrence, herring stock assessments have traditionally relied on sequential population analysis (Claytor et al. 1990). This method has met with reasonable success in autumn-spawning herring of the southern Gulf, but its accuracy is constrained by uncertainties in abundance trends and seasonal spawning affinities.

Herring are demersal spawners, and their eggs are the only sessile stage of the herring life cycle. This suggests that measurements of egg deposition might serve to indicate size or abundance trends of the stock that produced the eggs. In British Columbia, spawning bed surveys began in the 1930s, and are now a major part of herring assessments (Schweigert and Stocker 1988). The first spawning bed survey in eastern Canada was conducted in 1962 at a spring bed at Blanchard Point, Bay of Chaleur (Tibbo et al. 1963). Subsequently, surveys were conducted in 1981, 1983, and 1984 at the spring spawning grounds at Escuminac in eastern New Brunswick (Pottle et al. 1981; Messieh et al. 1983, 1985a, 1985b; Messieh 1987, 1988) and in 1985-1990 at Fisherman's Bank, a fall spawning ground off southeastern Prince Edward Island (PEI). Results of 1985 and 1986 surveys at Fisherman's Bank were reported by Messieh (1986, 1987, 1988), Messieh et al. (1987), Lambert and Messieh (1989), and Messieh and Rosenthal (1989).

Spawning bed surveys produce spatially distributed data. Such data can be analysed by classical statistics or by geostatistics, a spatial analysis tool derived from the mining industry. Unlike classical statistics which requires that sample points be randomly distributed and independent, geostatistics accepts any distribution of sample points and makes use of spatial structure to generate estimates and to map distributions. Geostatistical theory is described by Clark (1979), Armstrong et al. (1992), Rossi et al. (1992), and Simard et al. (1992). Recent geostatistical applications in fisheries include analysis of spatial distribution in a herring school (Conan et al. 1988), snow crab (*Chionoecetes opilio*) biomass estimates (Chiasson et al. 1991), mapping and estimation of northern shrimp (*Pandalus borealis*) biomass (Simard 1991, Simard et al. 1992), and estimation of egg deposition in a herring spawning bed (Hopkins and Morrison 1991).

This report describes the timing, location, and volume of herring spawn deposition and characterizes timing and habitat choice of spawning in terms of temperature, current regime, and substrate type at Fisherman's Bank during the 1987-1990 spawning seasons. We also present results of a search for spawning beds at Milne Bank near the eastern tip of Prince Edward Island, where herring concentrations had been reported by local fishermen.

## STUDY AREA AND METHODS

### BATHYMETRIC DESCRIPTION

Fisherman's Bank (46°01'N, 62°16'W) is an underwater dome located 16 km east of the southeastern tip of PEI (Fig. 1). The bank measures 3.1 x 5.3 km within the 20 m contour, and rises to 9 m depth at its shallowest point. A broad shelf 25-30 m deep lies between Fisherman's Bank and PEI. Water depths to the east are about 45 m, but an elongated promontory known as the Ridge extends northeast from Fisherman's Bank (Fig. 1). Depths on the Ridge are about 24-32 m.

Milne Bank (46°23'N, 62°55'W) lies 9 km southeast of East Point, PEI (Fig. 1). This bank is 9 m deep at its shallowest point and measures 10 x 3.5 km at the 18 m contour.

### LOGISTICS AND PHYSICAL MEASUREMENTS

In 1987, surveys were carried out on the CSS *Navicula*, a 20 m Department of Fisheries and Oceans (DFO) research vessel. Surveys in 1988 and 1989 were conducted on a 13.5 m chartered lobster boat, supplemented in 1989 by a 12 m DFO vessel. In 1990 the *Navicula* and an 8.5 m DFO vessel were used. Base ports were Georgetown and Murray Harbour (1.5 and 1 h steam from Fisherman's Bank, respectively).

A detailed bathymetric chart was prepared from 618 depth soundings made with an Eagle Fish I.D. echosounder (Eagle Electronics, Catoosa, Oklahoma) in August - September 1990. Readings were made with the sounder's transducer mounted within 30 cm of the surface during Phase I (Offsets A and B), Phase II, and Phase III sampling, as well as at special stations located around the periphery of the Phase I sampling area.

Loran locations of soundings were converted to latitudes and longitudes by the formulas given in Appendix A. Heights and times of tidal minima and maxima were calculated from tables using Pictou as a reference port and Murray Harbour as a secondary port. Mean tidal range and mean water level at Murray Harbour is 1.2 and 1.0 m, respectively (Canadian Hydrographic Service 1989). Tide height was estimated for each sounding by linear interpolation between the preceding and subsequent high and low tides. Calculated tide height was subtracted from raw depths to give depth of water relative to chart datum.

Bottom contours were drawn by the Surfer contouring package (Anon. 1987). The contouring grid was prepared by octant search and a kriging algorithm using a 100 m x 100 m grid size. Duplicate sample points were averaged. The grid was smoothed by a cubic splining process that doubled the density of grid points. Cubic splining also provided additional smoothing during contour generation. The contour map generated by Surfer was digitized in Autocad (Anon. 1988) to form a base map for figure preparation. Field locations were transferred to the map with the aid of regression functions that calculated Autocad screen units from latitudes and longitudes.

Substrate and vegetation characteristics were recorded on camera drops at Fisherman's Bank in 1988-1989. Observers characterized the bottom as sand (1), gravel (2), gravel/cobble (2.5), cobble (3), cobble/bedrock (3.5), or bedrock (4). Density of macrophytic vegetation was visually estimated as none (<1% of bottom covered), sparse (1-5%), light (6-35%), moderate (36-55%), heavy (66-95%) and continuous (>95%). These categories were coded 1 to 6, respectively.

Substrate and vegetation types were contoured with the Surfer package using the numeric category codes. The procedure followed that of bathymetric contouring, except that the contouring grid was prepared by normal search and cubic splining was not applied. Contour lines were drawn only in areas within 250 m of sample points. Contour lines were drawn at integer values + 0.5. Thus the area between the 2.5 and 3.5 lines on substrate maps contained cobble, and the area between 1.5 and 2.5 contours on vegetation maps contained sparse vegetation.

Surface and bottom temperatures were recorded irregularly at Fisherman's Bank in 1987-1989 with a Vemco time-locked electronic thermometer (Vemco Ltd., Armdale, Nova Scotia). In 1990 bottom temperatures were obtained on camera drops by reading an alcohol thermometer mounted above the egg ruler (Fig. 2). Surface temperatures in 1990 were obtained from the *Navicula*'s continuous temperature readout, and on the 8.5 m vessel from the temperature readout of an Eagle Fish I.D. Plus echosounder. Temperatures from the alcohol and echosounder thermometers were corrected by regression equations derived by comparing their readings with those of a laboratory mercury thermometer.

Bottom temperatures were contoured by the Surfer contouring package following the procedure used for bottom types.

Events which occur at night (fishing, spawning) are referred to by the date of the first half of the night. Thus a spawning on the night of 26-27 August is listed under 26 August.

Landings and catch rates for the Fisherman's Bank gillnet herring fishery were calculated from data provided by the Prince Edward Island Area Office of DFO, which maintains daily records of landings and active fishing vessels for the purpose of quota enforcement.

EGG ESTIMATES: EGG COUNT METHOD

Spawning bed surveys in 1987 were based on measurements of egg density (eggs $m^{-2}$). Spawning beds were located by examining the seafloor with a DeepSea Power & Light underwater video camera (Model DVC-500LX) (20 cm long x 6 cm diameter) with an 8 mm f1.6 lens giving a $47^{o}$ diagonal field of view in water (R&D Lyons Ltd., Halifax, Nova Scotia). The rated minimum illumination was 3 lux. The camera was mounted on a bracket attached to a length of angle aluminum (Fig. 2) and lowered to the bottom by its 60 m long signal-transmission cable. The image was viewed on a black and white monitor aboard the vessel. The camera was equipped with lights but ambient light on the seafloor was adequate for a clear image until about 30 min before sunset.

Sampling stations were arbitrarily chosen from a 193 m grid which extended across the bank. Once a bed was identified, additional stations on the 193 m grid were examined with the video camera for presence of eggs, and a map of bed boundaries was prepared. Stations within the bed were then arbitrarily chosen for sampling. Where time permitted, stations were examined by divers who collected all eggs from two or four 0.0625 $m^2$ quadrats which were arbitrarily chosen near the descent point. Eggs were collected into mesh bags by air-lifts operated from SCUBA tanks, or, in the case of heavy depositions, by peeling the egg mat from the substrate. Egg samples were preserved in 4% formalin for transport to the laboratory.

Where time was insufficient for diving, stations were examined by video camera. Bed thickness was categorized as heavy, medium, light, and very light.

Egg samples were cleaned of gravel and debris, then dried in an oven at $60^{o}C$ until a constant weight was attained (about 16 h). Five subsamples of about 1000 eggs each were taken from each quadrat and weighed and counted. The total number of eggs per quadrat was estimated by applying the mean number of eggs $g^{-1}$ from the subsamples to the entire weight of the quadrat sample.

Total area of the spawning bed was determined from maps of the bed boundary drawn by eye on the basis of stations with and without eggs. Mean egg density (eggs $m^{-2}$) was the mean of the mean density of each sampling station. In the case of beds in which no egg counts were made, stations judged on the video monitor to have heavy, medium, light, and very light depositions were assigned the mean egg count of these categories as measured in the bed where egg counts were made. Total eggs per bed was the product of bed area and mean egg density.

In all years eggs were collected for maturity staging by a MacDougall-Bourque dredge (Fig. 2) which was dragged on the bottom for several minutes while the vessel drifted. Eggs were stored on ice for transport to shore. A dissecting microscope was used to stage eggs from the surface of the egg mat according to the scheme of Baxter (1971). Date of spawning was estimated from egg maturities, assuming that the eggs passed through one maturity stage per day.

## EGG ESTIMATES: EGG VOLUME METHOD

### *Sampling protocol*

Volume estimates in 1988-1990 were derived from egg bed thickness measurements made by plunging a sharpened ruler into the eggs until it reached the substrate. The underwater camera was used to monitor the depth of penetration of the ruler into the eggs. Several camera mounting systems were used (Fig. 2). In 1988 the vertical aluminum mount, with the camera focused on the ruler at its tip (Fig. 2A), was used at times of light tidal current. When strong currents made it difficult to hold this device upright the camera was mounted on a tripod made of angle aluminum (Fig. 2B). The camera focused on a leg which terminated with the ruler. In 1989 the tripod (Fig. 2C) was constructed of thin rods to reduce water resistance and allow the camera to hang vertically in the water. Finally, the tripod used in 1990 added a vane to orient the camera while drifting (Fig. 2D).

Spawning bed surveys in 1988-1989 proceeded in three stages: exploratory surveys (Phase I), bed delineation (Phase II), and volume estimation by random sampling (Phase III). In 1990 an additional phase (IV) was added to intensify sampling for geostatistical analysis. At each camera station the vessel stopped at pre-determined Loran TDs where the survey crew lowered the camera to the bottom. The camera was hauled clear of the bottom for a few seconds and then dropped until at least three clear measurements were obtained. Five measurements were taken at each Phase III and IV station.

Surveys in 1988 and 1989 were based on the 193 m grid used in 1987. In 1990 a new 200 m grid was used with $46^{o}00$'N, $62^{o}18$'W as its base point. In 1988-1989 and in 1990 twin arrays of Phase I stations were established, each of which used every second point of the 193 or 200 m grid (Fig. 3). These arrays were diagonally offset from each other by 273 m in 1988-1989 and by 283 m in 1990. Phase I arrays contained about 65 stations in 1988-1989, and about 90 stations in 1990. The greater number in 1990 was due to the extension of the grid into deeper water. Each array could be completed within a day, given good weather and no equipment problems.

Phase I surveys alternated between the two offset arrays. When spawn was discovered in Phase I surveying, the boundaries of the bed were delineated in a Phase II survey which examined nearby stations on the 193 or 200 m grid. The survey proceeded by examining all stations that were immediate neighbours of a station where eggs were found. If any of these stations had eggs, additional stations were examined until all known egg sites were bounded by stations without eggs. In 1988 and 1989 immediate neighbours were considered those in cardinal compass directions from the station with eggs. In 1990 stations immediately northeast, southeast, southwest, and northwest of the station with eggs were also examined.

After completion of Phase II sampling, a sampling zone was established by drawing a rectangle around the spawning bed. This sampling zone included a 193 or 200 m margin around all stations known to have eggs. Phase III sampling points were randomly chosen within the sampling zone. In 1988 sample points were chosen by randomly selecting points along the northern and western margins of the sample zone. Any point falling within 25 m of a previously existing point was rejected. Lines were projected perpendicularly from these points, and sampling stations were designated as the intersections of the north-south and east-west lines. In 1989 lines were set up 24 m apart on north-south and east-west axes. Lines were randomly chosen from these sets, and the intersections of selected lines were sampling stations. In 1990 Phase III sampling stations were selected by establishing cells at the intersections of a 40 m grid within the sampling zone. Sampling stations were randomly selected from these cells, with each cell having an equal probability of being chosen.

The area of the sampling zone was the sum of the sampling areas around each potential sample point. Thus total sampling area consisted of the area inside the rectangle within which stations were randomly selected, plus the area of a strip around the edge of this box whose width was half the distance between potential sampling points. This peripheral strip was 12.5 m wide in 1988, 12 m wide in 1989, and 20 m wide in 1990.

Phase IV sampling, introduced in 1990, took advantage of the lack of requirement in geostatistics for randomness in sample selection. Phase IV points were chosen arbitrarily after the completion of Phase III sampling. Locations were selected to increase sample intensity in dense parts of the bed or to improve delineation of bed boundaries.

### *Egg volume analysis*

Egg volume estimates from 1988-1990 Phase III surveys were analysed in a 1-stage sampling regime in which each sample point was the mean of the measurement points at the station (Cochran 1977). Under this scheme means and variances are calculated by the conventional formulas for simple random sampling. Volume of egg deposition was calculated as the product of mean egg thickness and total sampling area.

Geostatistical analysis of spawn measurements was based on mean values of thickness measurements at each station. Because geostatistics does not require random selection of sample points, data from all survey phases were used in estimates of mean and standard deviation of egg thickness.

Geostatistical analysis began by creating variograms, which plot the association among sample values at various inter-point (lag) distances. Variograms were calculated by GEOEAS, developed by the U.S. Environmental Protection Agency (Englund and Sparks 1990). Nugget, sill, and range values were determined by applying a spherical model to these variograms (see Englund and Sparks 1990 for definitions and Armstrong et al. 1992 for discussion of models). GEOEAS cannot calculate variograms for data sets with more than 180 points. Individual beds did not have more than 180 sample points, but in both 1989 and 1990 the number of sample points used in kriging of the whole bank exceeded this limit. Hence variograms for whole-bank analysis were created from randomly chosen subsets of 180 points.

Point and block kriging was performed by COKRI, a program written in the Matlab language (Marcotte 1991). Egg thickness estimates were made by ordinary point kriging at the intersection points of 51 by 51 grids. COKRI also generated kriged standard deviations on the same grid. Point kriging used 15 sample points within a search radius of 6 km. Areas where egg thickness was greater than zero and greater than 0.1 cm were estimated through summation of the points on the 51 x 51 grid where point kriged estimates exceeded these values. Point kriged estimates and standard deviations were contour mapped by Surfer using the matrices generated by COKRI. Block kriging was performed by COKRI on the sample zone of each spawning bed, and on quarter sections of some sample zones with large numbers of sample points. The search radius for block kriging was 6 km and the total data set was used.

Mean egg densities (eggs $m^{-2}$) estimated in 1987 were converted to egg thicknesses by a linear regression equation. Input data for the regression were 11 measurements of egg thicknesses made in 1986 (Messieh et al. 1987) and 32 measurements made in 1987 (present study). Because 0 egg density necessarily produces 0 egg thickness, the regression was forced through the origin. This regression was also used to convert egg densities from 1985 and 1986 (Messieh 1986, Messieh et al. 1987) to volume estimates.

## RESULTS

### FISHERMAN'S BANK

*Physical measurements*

Most of Fisherman's Bank has a cobble substrate, although there are extensive areas of bare bedrock, especially at the shallow western end (Fig. 4). Gravel and sandy substrates are found only on the periphery of the bank.

Most of Fisherman's Bank has little benthic vegetation, with most bottom falling into the category of light, sparse, or no vegetation (Figs. 5-6). Vegetated seafloor was more extensive in 1988 than in 1989. In 1988 beds of laminarians and other algae occupied much of the northeastern part of the bank, but these beds were much reduced in 1989. There was no clear relation between the density of vegetative cover and depth (Figs. 7-8).

Surface temperatures in 1988-1990 were between 14 and 22$^{o}$C, and generally decreased during the survey period (Fig. 9). Surface temperatures varied within days only by 1 or 2$^{o}$C. Temperatures were generally lower on the bottom than at the surface. Bottom temperatures were spatially heterogeneous and varied by as much as 11$^{o}$C on the same day (Fig. 9, Appendix B). Bottom temperatures also varied rapidly with time; e.g. the bottom in the southeastern part of Fisherman's Bank warmed from 12-13$^{o}$C at 1100 on 7 September 1990 to 17-18$^{o}$C 3.5 hours later (Appendix B). Bottom temperatures showed no consistent seasonal trends, although bottom waters appeared to become warmer in the first few days of September 1988 (Fig. 9).

Bottom temperatures were not closely linked with depth, although on 19 September 1990 waters below 22 m were 4 to 6$^{o}$C colder than the average bottom temperatures of shallower waters (Fig. 10).

*Relation between egg density and thickness*

Egg density and thickness measurements were related by the equation: thickness = 0.259 density ($N$=43, $R^2$=0.89), where thickness is in cm and density is in millions of eggs $m^{-2}$ (Fig. 11).

*Timing and location of spawning*

Four spawning beds were discovered in field surveys conducted between 28 August and 18 September 1987 (Fig. 12). Estimated spawning dates ranged from 23 August to 9 September. The last bed was located by a milt patch visible in the water. Four beds located during surveys between 31 August and 20 September 1988 were estimated to have been spawned between 5 and 12 September. In 1989, surveys from 31 August to 19 September revealed five spawning beds, although the first of these (estimated spawn date of 28 August) could not be re-located on subsequent surveys. Subsequent spawnings occurred until 12 September. Surveys in 1990 ran from 22 August to 20 September. Seven beds were located, with estimated spawn dates from 20 August to 16 September.

Spawnings occurred from depths of 9 m (the shallowest point of the bank) to about 23 m (Figs. 13-16; see Appendix C for Phase I sampling locations). Comparisons of spawning locations in 1985-1990 show that spawning occurred in all parts of the bank except the south-central portion (Fig. 16). The most frequently used area is the shallow western region; spawning occurred within the 10 m contour there in five of six years. Spawning was generally not repeated at the same site within the same year. Contour maps prepared from whole-bank kriging show that peak egg thicknesses varied greatly among beds, with a maximum of 3.5 cm in 1989 and 2.5 cm in 1990 (Figs. 17-19).

*Volume estimates*

Spawning beds surveyed in 1987 were estimated to contain $4.56 \times 10^{12}$ eggs (Table 1). Total egg volume, calculated from egg densities via the regression equation (Fig. 11), was 11,814 $m^3$ (Table 1). Spawning was spread over four beds, each containing from 10 to 35% of total spawn (Table 1).

Volume estimates for 1988-1990 are presented in Table 2; sample locations, kriged contour plots, and variograms for each bed are found in Figs. 20-29.

Frequent inclement weather in 1988 prevented intensive surveys in all but one spawning bed. In this bed (Bed 1), 11 designated Phase III stations at the south end of the sample area could not be visited because of bad weather (Fig. 20). Without these stations location of sample sites cannot be considered random, and estimation of spawn volume by classical statistics is therefore inappropriate. Contours derived from geostatistics indicated two main clusters of eggs in the north and central portions of this bed. The variogram showed a range of 0.5 km. Mean kriged egg depth within the sample zone was 0.113 cm (N=86, SD=0.055) (Table 2). One of the remaining beds discovered in 1988 (Bed 2) was likely small as spawn was located at only one station on the 400 m grid (Fig. 13). Two other beds (3 and 4) covered sizable areas and may have been similar in size or larger than Bed 1.

Bed 1 in 1989 could not be measured because no trace of eggs was found in Phase II sampling (Fig. 14). The bed was less than 0.5 cm thick at the single Phase I sampling site where eggs were found, and total volume was probably small.

Classical statistics, using 80 Phase III sample points (Fig 21), estimated an egg volume of 5,326 $m^3$ for Bed 2, 1989 (Table 2). Geostatistics, using these points plus 26 others from Phase I and II surveys, indicated a volume of 5,589 $m^3$. The contour plot indicated one main and two smaller concentrations of eggs (Fig. 21D). Because of the method of choosing random points in 1988-1989, there is a an east-west void in the sampling area. The absence of data in this strip and along the southern and eastern margins increased kriging standard deviations in these areas (Fig. 21E).

Eighty Phase III points were available for classical analysis of Bed 3, 1989, and 16 additional points were used in geostatistics (Fig. 22). The volume estimate by classical statistics was much higher than that of geostatistics (13,894 vs. 8,103 $m^3$). Most of the Phase III points fell in narrow corridors which covered only a small part of the sampling area. The contour chart from kriging analysis (Fig. 22B,D) shows areas of high egg density within the corridors covered by Phase III sampling. However, the Phase I and II samples lying between the Phase III corridors had low egg thicknesses, leading geostatistics to assign a relatively low mean to this area and lowering the total volume estimate.

Forty and 45 points were used in classical and geostatistical analysis of Bed 4, 1989, respectively (Table 2, Fig. 23). Volume estimates by the two methods were 2,792 and 2,352 $m^3$, respectively (Table 2). Eggs were clustered in two mounds whose margins reached the edge of the sample area (Fig. 23D), which suggests that some eggs lay outside the sample area and that total bed volume was underestimated.

Volume estimates for Bed 5, 1989, by classical statistics (63 points, 1,375 $m^3$) were higher than those of geostatistics (75 points, 1,145 $m^3$) (Table 2). Contouring showed the bed to be in contact with the edge of the sampling area (Fig. 24) which suggests that a substantial portion of the bed may have lain outside it and that spawn volume was underestimated.

The first bed deposited in 1990 was discovered at two Phase I (Appendix C13, C14) and two Phase II stations (Fig. 15A), but no eggs were found in the area two days later (Fig. 12). Egg deposits at sampling stations were 0.2 cm or thinner and total egg volume was probably small.

In Bed 2, 1990, classical and geostatistical analysis used 30 and 74 sample points, respectively (Table 2). The large number of geostatistical points stems from intensive Phase IV sampling on and near the spawn deposit (Fig. 25). Classical analysis produced a spawn volume estimate only one third as large as geostatistics (901 vs. 2,711 $m^3$). The difference between these estimates stems from the large difference in the number of sample points within the bed. Only five of the randomly placed points used by classical statistics had eggs, but 25 points with eggs were available to geostatistics (Fig 26A).

Bed 3, 1990, was discovered at one Phase I sampling station where egg thickness was 0.2 cm (Fig. 15, Appendix C18). No eggs were found at nearby Phase I stations, nor at the same station four days later (Fig. 12, Appendix C19 and C20). Total spawn volume was likely small.

Thirty and 50 sample points were used in classical and geostatistical analysis of Bed 4, 1990, respectively (Table 2). The classical statistical estimate was much lower than the geostatistical estimate (161 vs. 360 $m^3$). This difference reflects an accumulation of eggs estimated by geostatistics to have occurred around a single sampling point where egg thickness was 2.2 cm (Fig. 26B,D). The classical estimate is low because random Phase III sampling did not contact this concentration; no Phase III points had egg thicknesses greater than 0.4 cm.

Classical and geostatistical analysis used 30 and 60 points, respectively, to estimate egg volumes of Bed 5, 1990 (Table 2, Fig. 27). The classical estimate was lower than the geostatistical estimate (1,896 vs. 2,251 $m^3$).

Bed 6, the largest bed found in 1990, was analysed classically with 40 points and geostatistically with 106 points (Table 2). Kriged contours based on intensive sampling throughout the sampling area indicated a two-peaked structure (Fig. 28D). Classical estimates of volume were higher than geostatistical estimates (10,620 vs. 7,839 $m^3$).

For Bed 7, 1990, 15 points were used in classical statistical analysis and 20 points were used in geostatistics (Table 2, Fig. 29). Classical statistics gave lower estimates than did geostatistics (287 and 344 $m^3$). Because of the small number of sample points where eggs were found the variogram was poorly defined.

*Egg deposition, fisheries landings and fisheries catch rate*

Reported herring landings from Fisherman's Bank fluctuated from 2,955 to 10,315 t in 1985-1990 in response to varying markets and quota limits (Fig. 30). Estimated spawn deposition varied between 11,417 and 17,189 $m^3$ in 1985-1987 and 1989-1990 (Tables 1 and 2, geostatistical estimates used for 1989-1990).

A comparison of spawning activity with commercial landings reveals that spawning only approximately corresponded to the timing of the fishery (Fig. 31). In 1986 (data from Messieh et al. 1987) a large portion of landings were made after the single massive spawning recorded that year. In 1990, by contrast, the largest spawning occurred after the fishery was closed due to attainment of the quota. Catch rates, expressed as nightly catch per boat, did not show obvious or consistent peaks during spawning events (Fig. 31). It is widely believed by fishermen that herring spawning depends on lunar phase. However, spawning occurred during all lunar phases at Fisherman's Bank in 1985-1990 (Fig. 31).

*Block kriging of sampling zones as a whole and by quarters*

Variograms were calculated for quarter sections of the sampling zones of three beds for which the greatest number of sampling points was available (Beds 2 and 3, 1989; Bed 6, 1990). In eight of these 12 quarters the variogram showed spatial structure suitable for model fitting (Figs. 21F, 22F, 28F). Block kriging was performed in these quarters; in the remaining quarters the arithmetic mean was calculated (Table 3). Ratios of the mean of quarterly means to the estimate from kriging the entire sample zone ranged from 0.92 to 1.04. The mean of all ratios was 1.00.

MILNE BANK

The camera survey conducted on Milne Bank on 21 and 22 September 1988 revealed no herring spawn (Fig. 32). Spiny dogfish (*Squalus acanthias*) were frequently seen on the camera monitor. The substrate at all stations was sand, which is unsuitable for herring spawning. One fisherman told us that a small amount of rocky bottom exists on Milne Bank, so the possibility that herring spawn there cannot be completely excluded.

## DISCUSSION

TIMING, LOCATION, AND PHYSICAL ENVIRONMENT OF SPAWNING

Herring spawned at Fisherman's Bank in 1985-1990 on cobble and bedrock substrates at depths of 9-23 m (Figs. 4 and 16). The shallowest part of the bank was the area most frequently used, although most other points on the bank received spawn at least once during the six year period. Herring typically spawn on vegetation or on hard substrates (e.g. Drapeau 1973, Messieh 1987), presumably because fine particles might bury their eggs. Sand was present only on the margins of the bank and was not used for spawning. Spring-spawning herring in the Gulf of St. Lawrence often deposit their eggs on benthic algae (Messieh 1988), but most eggs at Fisherman's Bank lay directly on the substrate because bottom flora is sparse or absent over most of the bank (Figs. 5-6).

Messieh (1977, 1987) proposed that timing of herring spawning is influenced by water temperature, a view challenged by Chadwick and Claytor (1989) who argued that spawning is triggered by large scale cues such as photoperiod. Bottom temperature records at Fisherman's Bank (Figs. 9-10, Appendix B) show no clear seasonal trends. In addition, bottom temperatures may vary by as much as 11°C over short distances and time scales. Given this variability and lack of seasonal trend, temperature is unlikely to be a proximate trigger of spawning.

SURVEY DESIGN AND DATA ANALYSIS

*Diving vs. underwater video*

The original spawning bed surveys at Fisherman's Bank in 1985 were based on counts of eggs contained in samples collected by divers (Messieh 1986). In 1986 and 1987 both diver collections and underwater video observations were used (Messieh et al. 1987, present study). Since 1988, surveys have relied solely on underwater video equipment. The shift from diving to video-based surveys has been motivated by the need for large numbers of sample stations to reliably discover, delineate, and measure spawn depositions. Survey crews can check about 12 stations per hour using video equipment, but a diving team can at best sample two stations per hour.

Because underwater video cameras can measure thickness of the egg mat but not collect samples, the shift from diving to video surveys required adoption of an analysis system based on spawn volumes rather than egg density. Regression of egg density and thickness (Fig. 11) allows interconversion of density and volume estimates and thus continuity of the spawn estimate time series (Fig. 30).

*Classical statistics vs. geostatistics*

The choice between determination of mean spawn thickness by classical statistics or geostatistics depends on field survey efficiency and on the validity of statistical models. In our surveys bed edges were delineated on a 193 or 200 m grid, and sampling zones were established with a 193 or 200 marginal strip to ensure that the entire bed is included. In most cases the actual bed was much smaller than the sampling zone, and consequently most of the sampling zone (often more than two thirds) was devoid of eggs. When stations are placed randomly, only a minority of them typically fall within the egg bed. The paucity of stations inside the egg bed makes estimates vulnerable to high sampling error.

Because geostatistics does not require random station placement, additional stations can be placed by the operator at sites which will intensify coverage in egg-rich parts of the bed or better define the bed boundary. This means that most sampling effort can be placed within the bed, rather than at null points outside it.

Fisheries survey data are typically spatially autocorrelated. Such data sets pose problems to both classical and geostatistics. The non-independence of sample points violates assumptions of classical statistics, and the non-stationarity typical of most survey results violates assumptions of geostatistics (Simard et al. 1992). In the present study we have reanalyzed three egg beds by dividing sample zones in four equal parts and block kriging egg thickness with them. The mean of quarterly means differed by no more than 8% from the mean derived from kriging the sample zone as a whole, and the mean of the ratios between results given by the two methods was 1.00 (Table 3). This comparison is subject to a small sample size and to the fact that block kriging was possible in only eight of the 12 quarter zones. Nevertheless the similarity of results suggests that non-stationarity is not a major source of error in our geostatistical estimates.

*Other sources of error*

Our surveys depend on a rapid discovery of eggs and completion of intensive bed sampling before hatching. If eggs are not discovered because a bed falls between sample points of the exploratory (Phase I grid), total spawn deposition will be underestimated. We believe that non-discovery of egg beds is unlikely to be a significant source of error in spawn deposition estimates because bed sizes are typically much larger than the spaces between exploratory sample points (compare Figs. 3 and 16). It is possible to miss small beds, but these are unlikely to contribute significantly to total biomass. In 1988, surveys could not be completed on several important beds because of consistently bad weather, and a total estimate for spawn deposition was not possible for that year. Several beds in 1989 and 1990 were not surveyed because eggs could not be relocated after the first contact (Table 2). These beds were likely very small, and their contribution to total spawn deposition was probably negligible.

Contouring of point kriging estimates showed that two beds in 1989 (4 and 5, Figs. 23 and 24) had high egg densities at the boundary of the sampling zone. This suggests that the bed extended outside the edge of the sampling zone and that egg volumes for the bed are underestimated. A rough estimate of the extent of error may be made by assuming that one third and one half of eggs lay outside the sampling zone in Beds 4 and 5, respectively (Figs. 23D and 24D). If this is the case total spawn deposition for the year would be underestimated by 8% (see Table 2). In 1990 Phase II sampling was extended to points northwest, northeast, southeast, and southwest of egg locations. This reduced the chances of inappropriate positioning of sampling zones, and no beds in that year showed significant egg thicknesses at sampling zone boundaries (Figs. 25-29).

Egg volume estimates presented in this report are not corrected for losses due to predation, although predatory fish are abundant on and near the spawning beds and may consume substantial quantities of eggs (Messieh et al. 1987). If losses increase with time since deposition, then volume estimates will vary with the delay between spawn deposition and thickness measurements. Most of our Phase III and IV surveys, which supplied the bulk of the data points for geostatistical estimates, were made between three and five days after the estimated spawning date (Fig. 12). Because of time needed to locate and delineate the bed it is difficult to standardize survey timing more closely than this.

If herring spawn at a site for several days in a row some thickness measurements might preceed completion of spawning. This would downwardly bias estimates of total deposition. If spawning at a site occurs over several days, eggs sampled from the surface of the bed should show a reversal or at least constancy of maturity stages in the several days following bed initiation. However, in nearly all cases egg maturity stages showed a steady progression (Fig. 12), suggesting that spawning at a particular site took place over a single night.

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## LITERATURE CITED

Anon. 1987. Surfer information manual, Version 3.11. Golden Software Inc., Golden, Colorado.

Anon. 1988. Autocad reference Manual, Version 10. Autodesk Inc., Sausalito, California.

Armstrong, M., D. Renard, J. Rivoirard, and P. Petitgas. 1992. Geostatistics for fish survey data. Centre de Géostatistique, École des mines, Fontainebleau, France.

Baxter, I.G. 1971. Development rates and mortalities in Clyde herring eggs. Rapp. Proc.-V. Reun. Cons. Inter. Explor. Mer. 160:27-29.

Canadian Hydrographic Service. 1989. Canadian tide and current tables. Vol. 2, Gulf of St. Lawrence. Department of Fisheries and Oceans, Ottawa.

Chadwick, E.M.P., and R.R. Claytor. 1989. Run timing of pelagic fishes in Gulf of St. Lawrence: area and species effects. J. Fish. Biol. (Suppl. A):215-223.

Chiasson, Y., M. Hébert, E. Wade, C. Gallant, P. DeGrâce, P. Mallet, and M. Moriyasu. 1991. La pêche au crabe des neiges (*Chionoecetes opilio*) dans le sud-ouest du golfe du Saint-Laurent en 1990: état de la ressource et l'estimation de la biomasse. CAFSAC Res. Doc. 91/27.

Clark, I. 1979. Practical geostatistics. Elsevier, London.

Claytor, R.R., E.M.P. Chadwick, and H.M.C. Dupuis. 1990. Assessment of Atlantic herring in NAFO Division 4T, 1989. CAFSAC Res. Doc. 90/73.

Cochran, W.G. 1977. Sampling techniques. John Wiley, New York.

Conan, G.Y., U. Buerkle, E. Wade, E.M.P. Chadwick, and M. Comeau. 1988. Geostatistical analysis of spatial distribution in a school of herring. ICES CM 1988/D:21.

Drapeau, G. 1973. Sedimentology of herring spawning grounds on Georges Bank. ICNAF Res. Bull. 10:151-162.

Englund, E., and A. Sparks. 1990. GEO-EAS (Geostatistical environmental assessment software) user's guide. U.S. Environmental Protection Agency, Las Vegas, Nevada.

Hopkins, P., and J.A. Morrison. 1991. Evaluation of geostatistical methods for the estimation of total egg numbers in a herring spawning bed. ICES CM 1991/H:43.

Lambert, T.C., and S.N. Messieh. 1989. Spawning dynamics of Gulf of St. Lawrence herring. Can. J. Fish. Aquat. Sci. 46:2085-2094.

Marcotte, D. 1991. Cokriging with Matlab. Computers Geosci. 17:1265-1280.

Messieh, S.N. 1977. The regularity of spawning time of Atlantic herring in the Gulf of St. Lawrence. ICES CM 1977/H:25.

Messieh, S.N. 1986. Herring spawning bed survey in Fisherman's Bank, P.E.I., in fall 1985. CAFSAC Res. Doc. 86/78.

Messieh, S.N. 1987. Some characteristics of Atlantic herring (*Clupea harengus*) spawning in the southern Gulf of St. Lawrence. N. Atl. Fish. Org. Sci. Council Stud. 11:53-61.

Messieh, S.N. 1988. Spawning of Atlantic herring in the Gulf of St. Lawrence. Am. Fish. Soc. Symp. 5:31-48.

Messieh, S.N., P.A. MacPherson, and C. Bourque. 1987. Herring spawning bed survey in Fishermans Bank, P.E.I., - fall 1986. CAFSAC Res. Doc. 87/41.

Messieh, S.N., R.A. Pottle, P.A. MacPherson, and C. Bourque. 1985a. Herring spawning bed survey in Miramichi Bay, NB in spring 1984. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 85/40.

Messieh, S.N., R.A. Pottle, P.A. MacPherson, and T. Hurlbut. 1983. Herring spawning bed survey in Miramichi Bay, N.B. in spring 1983. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 83/70.

Messieh, S.N., R.A. Pottle, P.A. MacPherson, and T. Hurlbut. 1985b. Spawning and exploitation of

Atlantic herring (*Clupea harengus*) at Escuminac in the southwestern Gulf of St. Lawrence, spring 1983. J. Northw. Atl. Fish. Sci. 6:125-133.

Messieh, S.N., and H. Rosenthal. 1989. Mass mortality of herring eggs on spawning beds on and near Fisherman's Bank, Gulf of St. Lawrence, Canada. Aquat. Living Resour. 2:1-8.

Pottle, R.A., P.A. MacPherson, S.N. Messieh, and D.S. Moore. 1981. A scuba survey of a herring (*Clupea harengus*) spawning bed in Miramichi Bay, N.B. Can. Tech. Rep. Fish. Aquat. Sci. No. 984.

Rossi, R.E., D.J. Mulla, A.G. Journel, and E.H. Franz. 1992. Geostatistical tools for modeling and interpreting ecological spatial dependence. Ecol. Monogr. 62:277-314.

Schweigert, J.F., and M. Stocker. 1988. Escapement model for estimating Pacific herring stock size from spawn survey data and its management implications. N. Am. J. Fish. Manage. 8:63-74.

Simard, Y. 1991. Comparison of kriging estimates of northern shrimp biomass obtained from two different trawlers in the Sept-Iles fishing grounds in 1990. CAFSAC Res. Doc. 91/80.

Simard, Y., P. Legendre, G. Lavoie, and D. Marcotte. 1992. Mapping, estimating biomass, and optimizing sampling programs for spatially autocorrelated data: case study of the northern shrimp (*Pandalus borealis*). Can. J. Fish. Aquat. Sci. 49:32-45.

Tibbo, S.N., D.J. Scarratt, and P.W.G. McMullon. 1963. An investigation of herring (*Clupea harengus* L.) spawning using free-diving techniques. J. Fish. Res. Board Can. 20:1067-1079.

Table 1.
Numbers and volume of eggs deposited by herring at Fisherman's Bank, 1985-1987. 1985 data from Messieh (1986), 1986 data from Messieh et al. (1987), and 1987 data from present study.

| Bed number | Estimated spawn date | Bed area ($km^2$) | Number of stations | Number of quadrats | Mean egg density (eggs $m^{-2}$) | Total number of eggs ($10^6$) | Mean egg thickness (cm) | Egg volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| 1985 | | | | | | | | |
| 1 | 31 Aug | 0.286000 | 7 | 7 | 2,590,000 | 740,740 | 0.671 | 1,920 |
| 2 | 31 Aug | 0.488800 | 13 | 13 | 240,000 | 17,312 | 0.062 | 304 |
| 3 | 4 Sep | 0.239000 | 6 | 6 | 4,714 | 1,127 | 0.001 | 3 |
| 4 | 16 Sep | 0.247000 | 26 | 26 | 7,940,000 | 1,961,180 | 2.059 | 5,085 |
| 5 | 16 Sep | 0.559500 | 6 | 6 | 2,830,000 | 1,583,385 | 0.734 | 4,105 |
| Mean | | 0.364060 | 11.6 | 11.6 | 2,720,943 | 880,749 | 0.705 | 2,283 |
| Total | | 1.820300 | 58 | 58 | | 4,403,744 | | 11,417 |
| 1986 | | | | | | | | |
| 1 | 3 Sep | 1.100000 | 29 | 29 | 3,800,000 | 4,180,000 | 0.985 | 10,837 |
| 1987 | | | | | | | | |
| 1 | 23 Aug | 0.186364 | 5 | 0 | 2,380,000 | 443,546 | 0.617 | 1,150 |
| 2 | 26 Aug | 0.795454 | 22 | 0 | 1,980,000 | 1,574,999 | 0.513 | 4,083 |
| 3 | 1 Sep | 0.482727 | 14 | 0 | 2,300,000 | 1,110,272 | 0.596 | 2,878 |
| 4 | 9 Sep | 0.615455 | 16 | 38 | 2,320,000 | 1,427,856 | 0.601 | 3,702 |
| Mean | | 0.520000 | 14.3 | 9.5 | 2,245,000 | 1,139,168 | 0.582 | 2,953 |
| Total | | 2.080000 | 57 | 38 | 8,980,000 | 4,556,673 | | 11,814 |

Table 2.
Egg volume and area of herring spawning beds at Fisherman's Bank, 1988-1991. A dash indicates that data are unavailable.

| Year and bed | Estimated spawn date | Area of sampling zone ($km^2$) | Classical statistics: Number of stations | Classical statistics: Egg thickness (cm) Mean | Classical statistics: Egg thickness (cm) SD | Classical statistics: Egg thickness (cm) CV | Classical statistics: Egg volume ($m^3$) | Geostatistics: Number of stations | Geostatistics: Egg thickness (cm) Mean | Geostatistics: Egg thickness (cm) SD | Geostatistics: Egg thickness (cm) CV | Geostatistics: Egg volume ($m^3$) | Geostatistics: Egg thickness >0 Area ($km^2$) | Geostatistics: Egg thickness >0 Mean egg thickness (cm) | Geostatistics: Egg thickness ≥0.1 cm Area ($km^2$) | Geostatistics: Egg thickness ≥0.1 cm Mean egg thickness (cm) | Ratio of volume estimates, classical: geostatistical |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | | | | | | | | | | | | | | | | | |
| 1 | 5 Sep | 0.844690 | | - | | | | 86 | 0.113 | 0.055 | 0.49 | 950 | 0.844690 | 0.113 | 0.323519 | 0.243 | - |
| 2 | 6 Sep | | | - | | | | | - | | | | | | | | |
| 3 | 8 Sep | | | - | | | | | - | | | | | | | | |
| 4 | 12 Sep | | | - | | | | | - | | | | | | | | |
| 1989 | | | | | | | | | | | | | | | | | |
| 1 | 28 Aug | | - | | | | | | | | | | | | | | |
| 2 | 29 Aug | 1.277830 | 80 | 0.417 | 1.028 | 2.47 | 5,326 | 106 | 0.437 | 0.094 | 0.22 | 5,589 | 1.194587 | 0.448 | 0.837685 | 0.623 | 0.95 |
| 3 | 3 Sep | 1.223080 | 80 | 1.136 | 1.652 | 1.45 | 13,894 | 96 | 0.663 | 0.138 | 0.21 | 8,103 | 0.620567 | 1.243 | 0.490342 | 1.564 | 1.71 |
| 4 | 9 Sep | 0.258290 | 40 | 1.081 | 1.567 | 1.45 | 2,792 | 45 | 0.911 | 0.156 | 0.17 | 2,352 | 0.206188 | 1.120 | 0.158476 | 1.446 | 1.19 |
| 5 | 12 Sep | 0.500240 | 63 | 0.275 | 0.611 | 2.22 | 1,375 | 75 | 0.229 | 0.052 | 0.23 | 1,145 | 0.423898 | 0.265 | 0.228785 | 0.465 | 1.20 |
| Mean | | 0.814860 | 66 | 0.727 | 1.215 | 1.90 | 5,847 | 81 | 0.560 | 0.110 | 0.21[a] | 4,297 | 0.611310 | 0.769 | 0.428822 | 1.024 | 1.36 |
| Total | | 3.259440 | 263 | | | | 23,387 | 322 | 2.239 | | | 17,189 | 2.445240 | | 1.715289 | | 1.36 |
| 1990 | | | | | | | | | | | | | | | | | |
| 1 | 20 Aug | | - | | | | | | | | | | | | | | |
| 2 | 28 Aug | 1.081600 | 30 | 0.083 | 0.195 | 2.34 | 901 | 74 | 0.251 | 0.073 | 0.29 | 2,711 | 1.080353 | 0.283 | 0.943541 | 0.318 | 0.33 |
| 3 | 2 Sep | | - | | | | | | | | | | | | | | |
| 4 | 3 Sep | 0.409600 | 30 | 0.039 | 0.097 | 2.46 | 161 | 50 | 0.088 | 0.035 | 0.40 | 360 | 0.265665 | 0.144 | 0.104250 | 0.322 | 0.45 |
| 5 | 11 Sep | 0.537600 | 30 | 0.353 | 0.803 | 2.28 | 1,896 | 60 | 0.419 | 0.115 | 0.28 | 2,251 | 0.466085 | 0.485 | 0.309828 | 0.711 | 0.84 |
| 6 | 13 Sep | 1.289600 | 40 | 0.824 | 0.915 | 1.11 | 10,620 | 106 | 0.608 | 0.074 | 0.12 | 7,839 | 1.289600 | 0.594 | 1.026325 | 0.734 | 1.35 |
| 7 | 16 Sep | 0.193600 | 15 | 0.148 | 0.346 | 2.34 | 287 | 20 | 0.178 | 0.046 | 0.26 | 344 | 0.147675 | 0.235 | 0.074284 | 0.439 | 0.83 |
| 8[b] | | 0.150600 | 15 | 0.000 | | | 0 | | | | | | | | | | |
| Mean | | 0.702400 | 29 | 0.289 | | | 2,773 | 62 | 0.309 | 0.069 | 0.19[a] | 2,701 | 0.649876 | 0.348 | 0.491646 | 0.505 | 1.03 |
| Total | | 3.512000 | 145 | | | | 13,864 | 310 | | | | 13,504 | 3.249378 | | 2.458229 | | 1.03 |

[a] $\frac{\Sigma(\text{CV of bed estimate x bed estimate})}{\text{total estimate}}$

[b] Sampling area established but no eggs found in Phase III sampling.

Table 3.
Comparison of egg thickness estimates (cm) by kriging the sampling zone as a whole and by quarters.

| Year and bed | Northwest quarter | | | | Northeast quarter | | | | Southeast quarter | | | | Southwest quarter | | | | Mean of quarterly means | Whole bed mean | Mean of quarterly means:whole bed mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Mean | SD | CV | N | Mean | SD | CV | N | Mean | SD | CV | N | Mean | SD | CV | | | |
| 1989 | | | | | | | | | | | | | | | | | | | |
| 2 | 22 | 0.526 | 0.098 | 0.19 | 22 | 0.647 | 0.227 | 0.35 | 30 | 0.167 | 0.185 | 1.11 | 34 | 0.459* | 0.934 | 2.03 | 0.450 | 0.437 | 1.03 |
| 3 | 27 | 0.705* | 1.432 | 2.03 | 22 | 0.561 | 0.302 | 0.54 | 25 | 0.538 | 0.317 | 0.59 | 25 | 0.639 | 0.233 | 0.36 | 0.611 | 0.663 | 0.92 |
| 1990 | | | | | | | | | | | | | | | | | | | |
| 6 | 24 | 0.628* | 0.919 | 1.46 | 28 | 0.797 | 0.125 | 0.16 | 24 | 0.407* | 0.542 | 1.33 | 32 | 0.710 | 0.086 | 0.12 | 0.635 | 0.608 | 1.04 |
| Mean | | | | | | | | | | | | | | | | | | | 1.00 |

*Arithmetic mean.

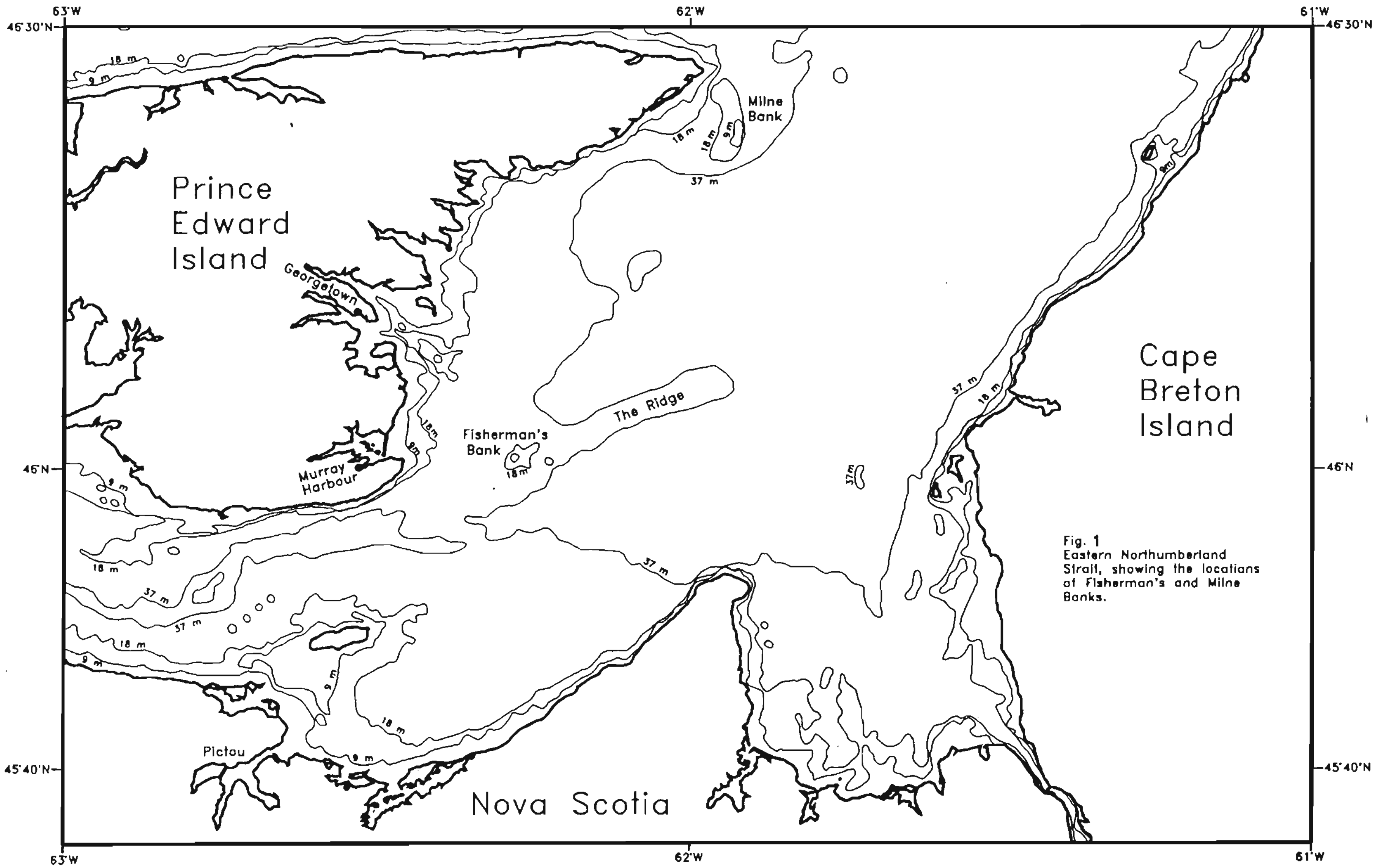



Fig. 1
Eastern Northumberland Strait, showing the locations of Fisherman's and Milne Banks.

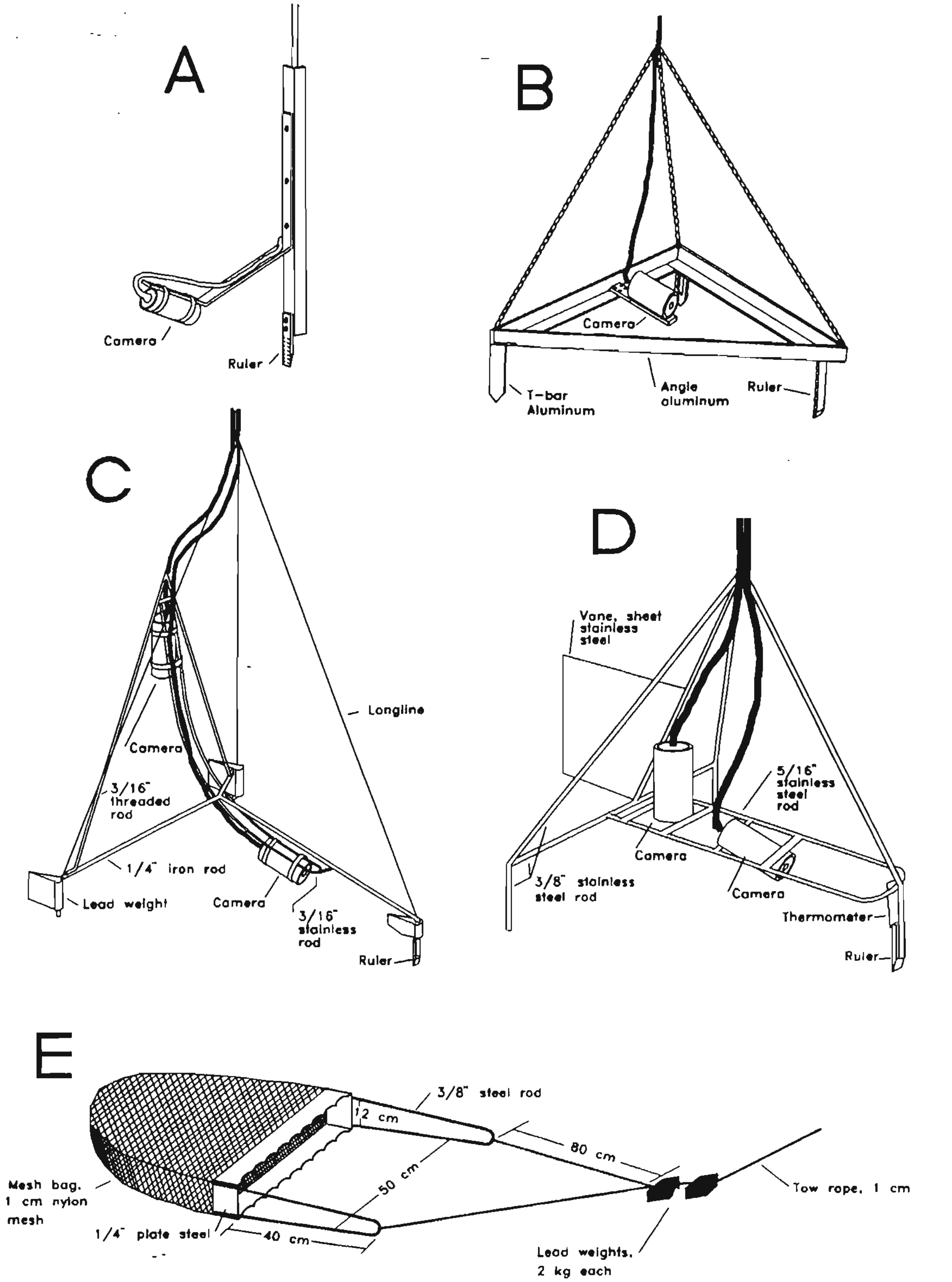



Fig. 2
Sampling devices used in spawning bed surveys at Fisherman's Bank, 1987–1990. (A) Vertical angle aluminum camera mount, 55 cm long, used in 1987 and 1988. (B) Angle aluminum tripod, 77 cm along the base with 25 cm legs, used in 1988. (C) Iron rod tripod, 68 cm on the base and 72 cm high, used in 1989. (D) Stainless steel rod tripod, 78 cm on the base and 80 cm high, used in 1990. (E) The MacDougall–Bourque dredge used for gathering egg samples.

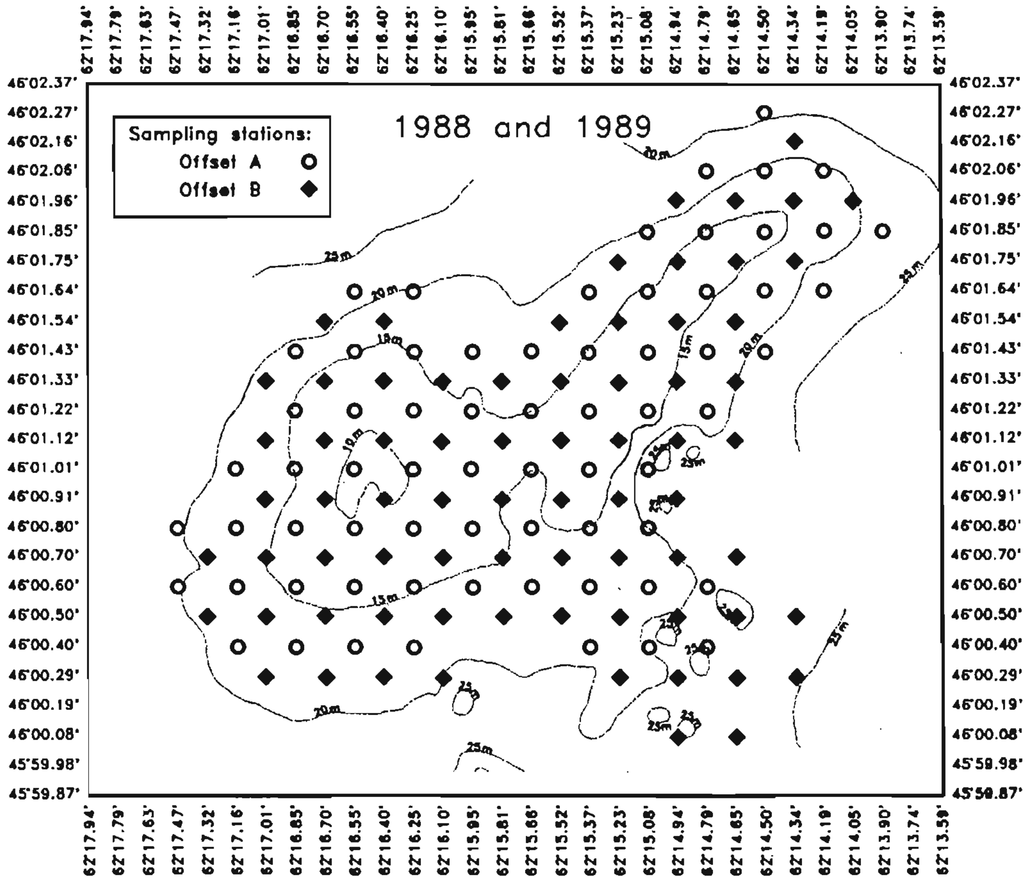



**Fig. 3**
Offset A and B stations used in Phase I sampling at Fisherman's Bank, 1988 and 1989. The stations are set on a 193 m grid.

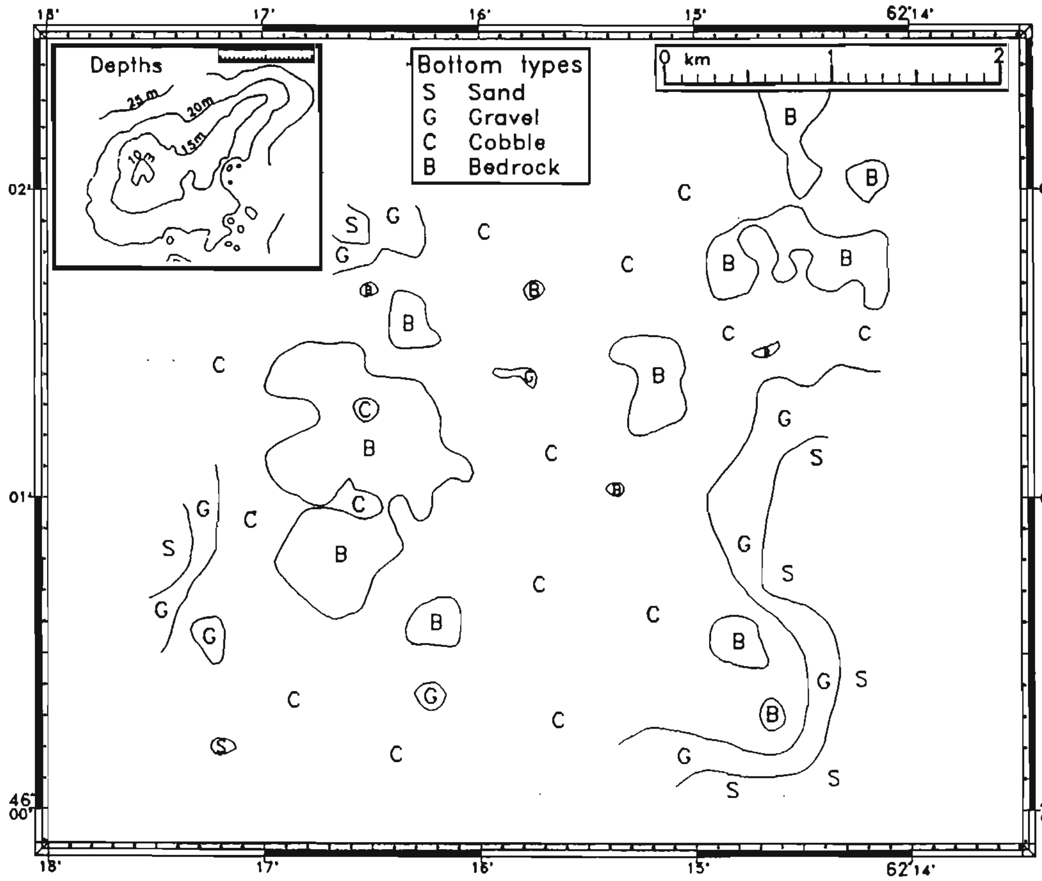



**Fig. 4**
Bottom types at Fisherman's Bank, from 1074 observations in 1988 and 1989.

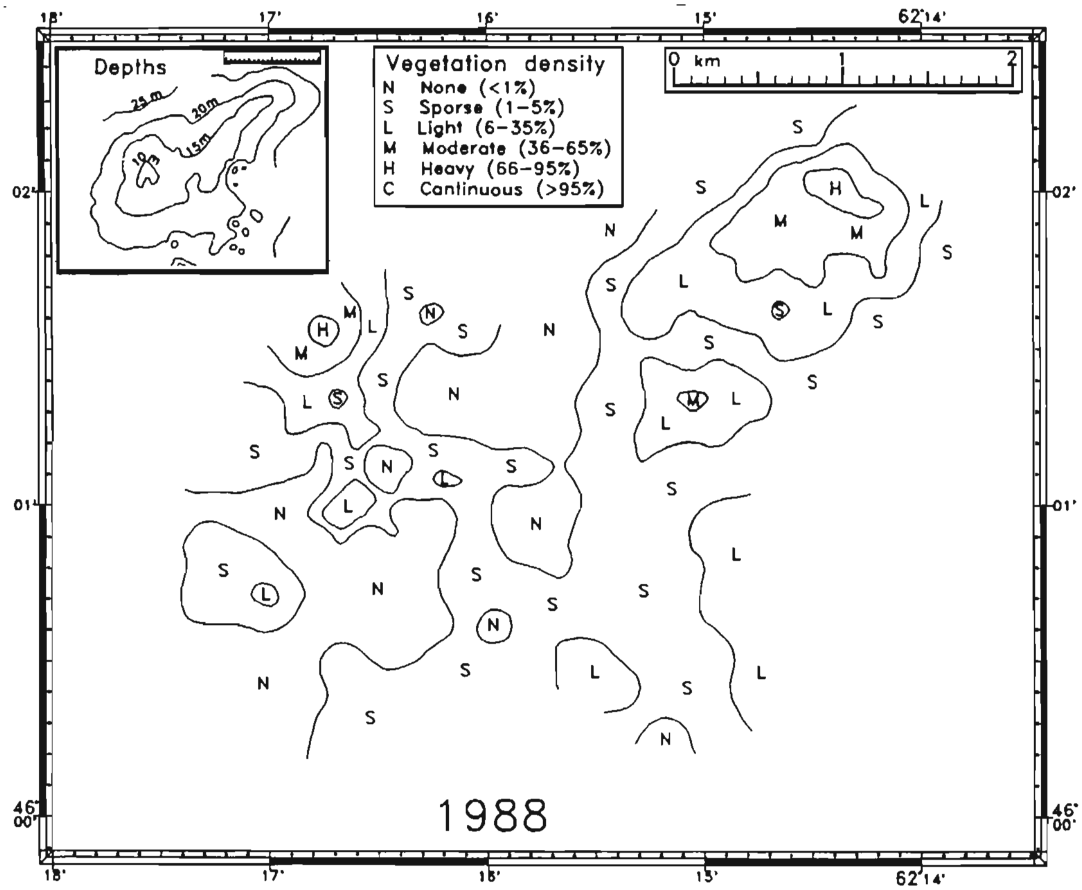



Fig. 5 Density of bottom vegetation at Fisherman's Bank from 493 observations in 1988.

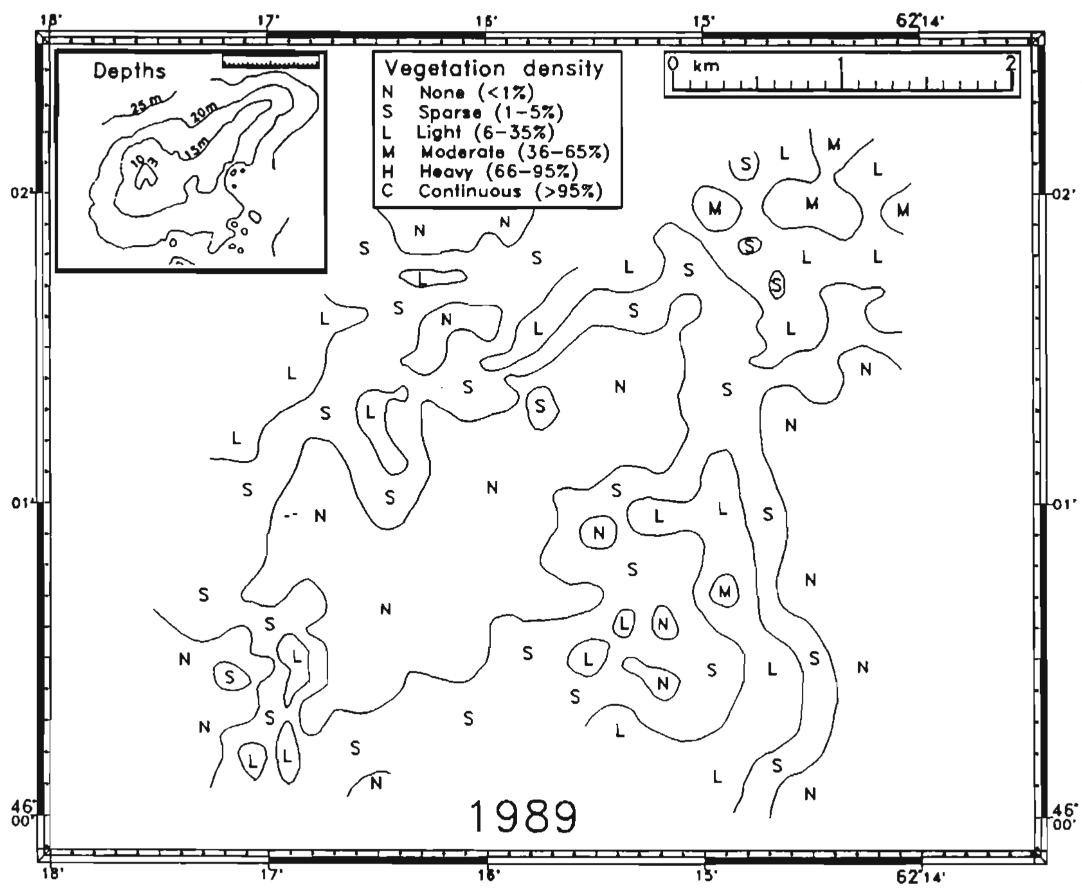



Fig. 6 Density of bottom vegetation at Fisherman's Bank from 598 observations in 1989.

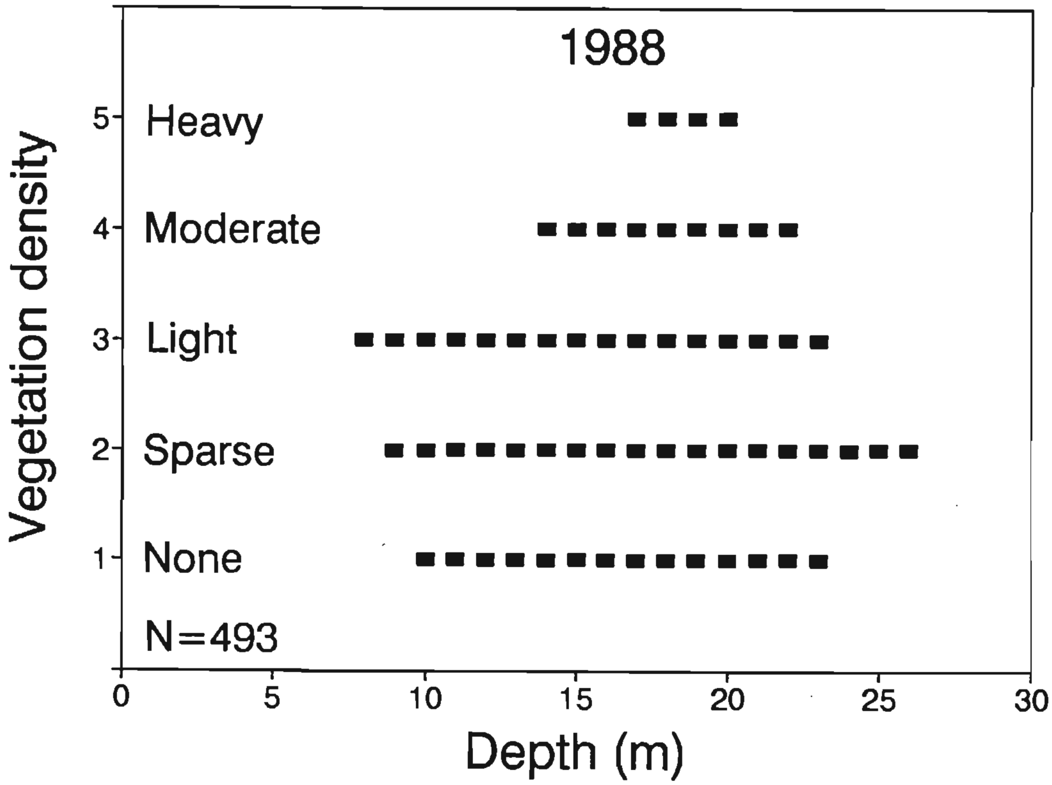



Fig. 7.
Relation between vegetation density and water depth at Fisherman's Bank, 1988.

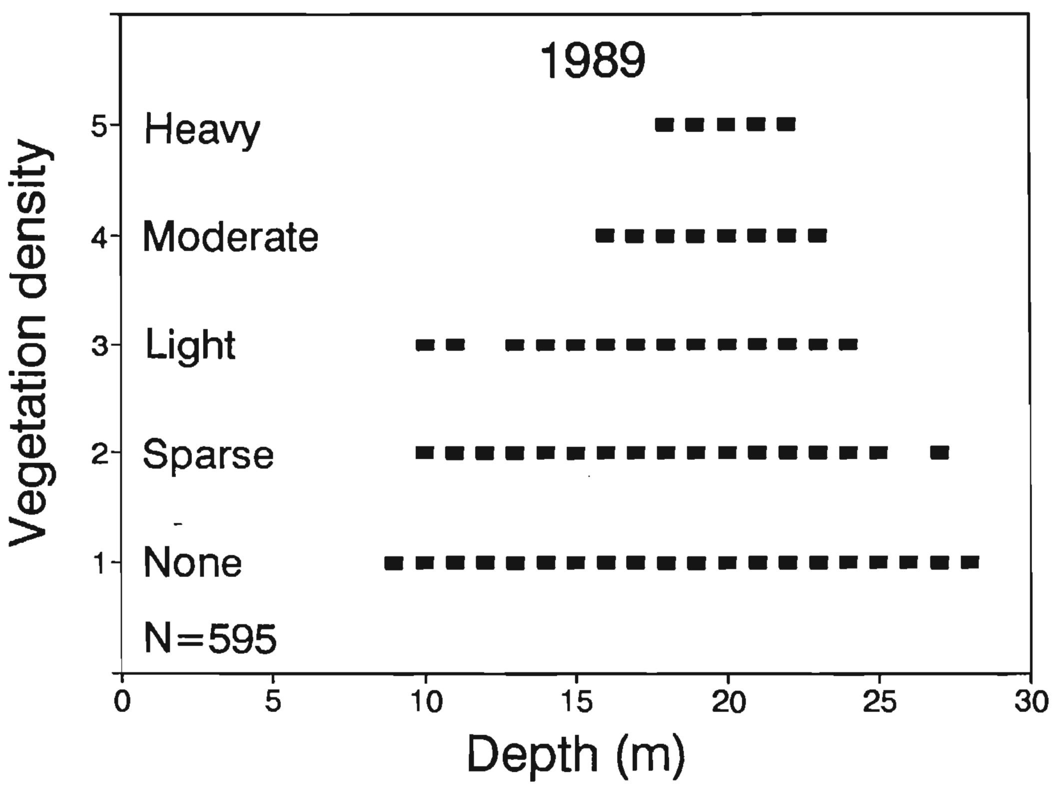



Fig. 8.
Relation between vegetation density and water depth at Fisherman's Bank, 1989.

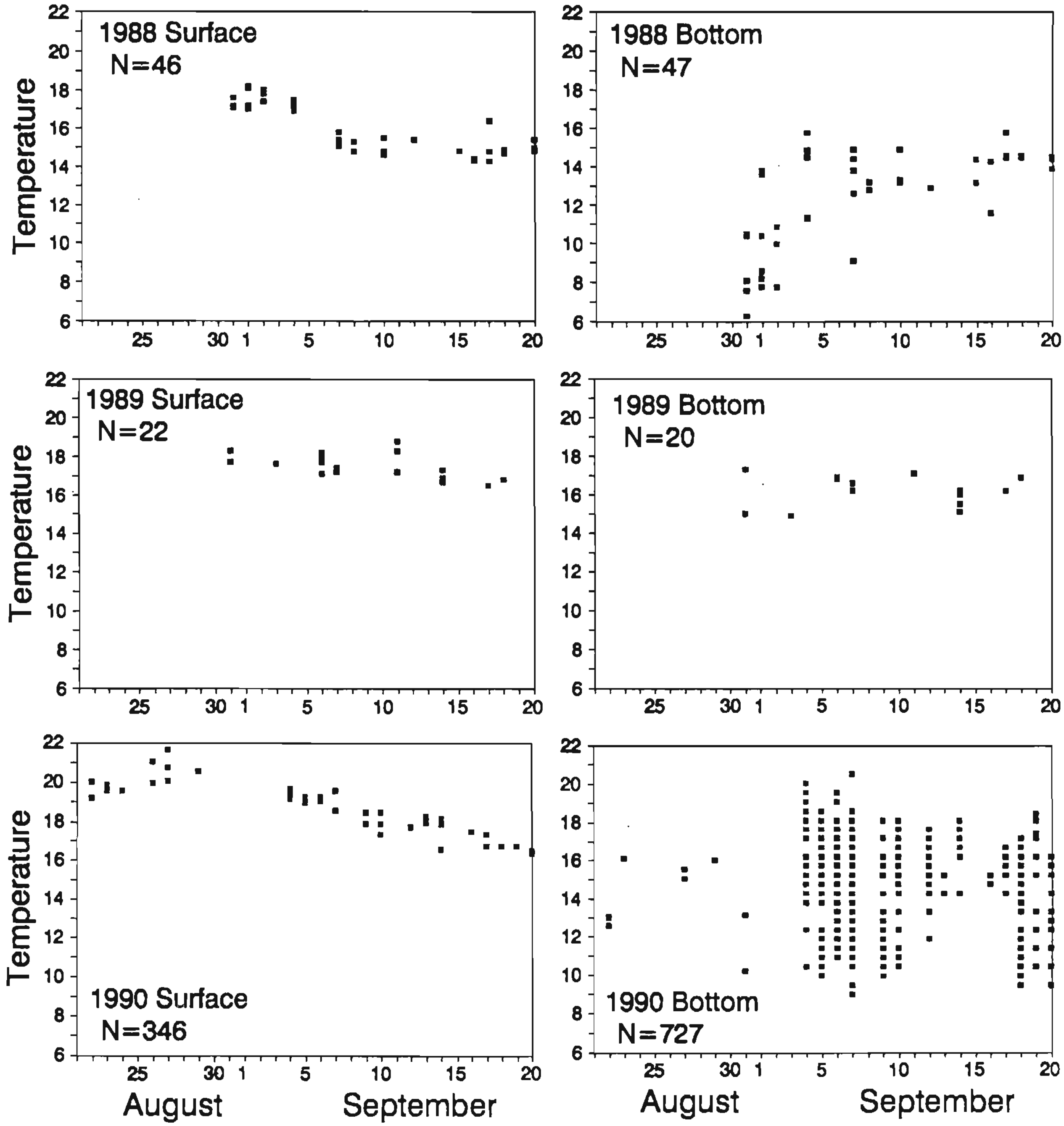



Fig. 9
Surface and bottom temperatures (°C) at Fisherman's Bank, 1988-1990.

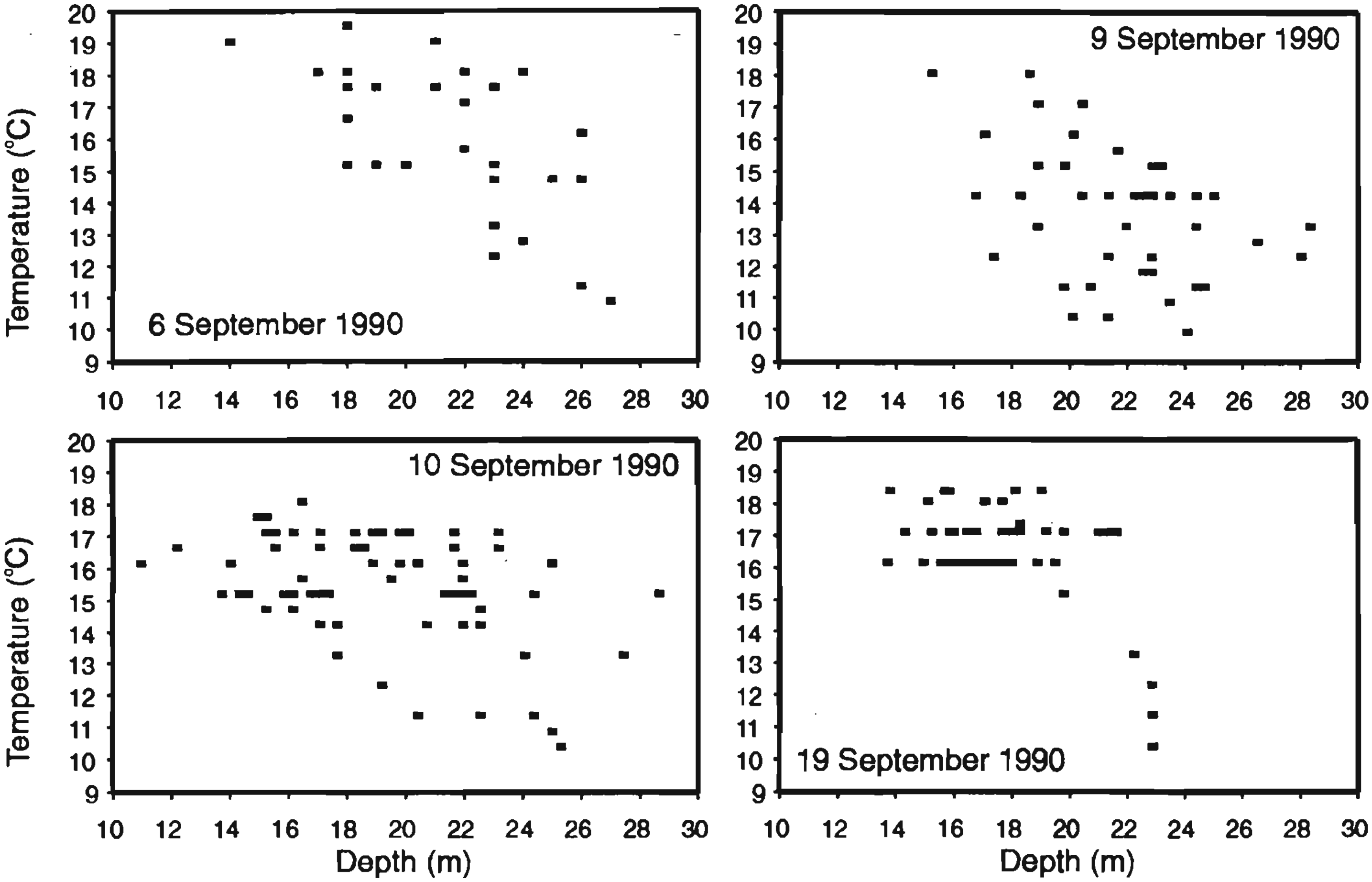



Fig. 10
Relation between bottom temperature and water depth at Fisherman's Bank on four days in 1990.

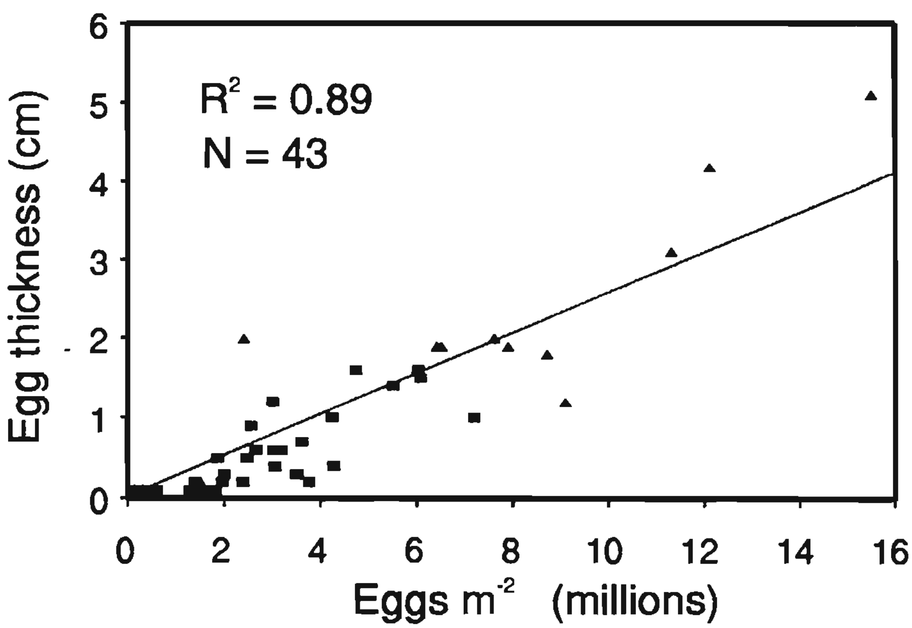
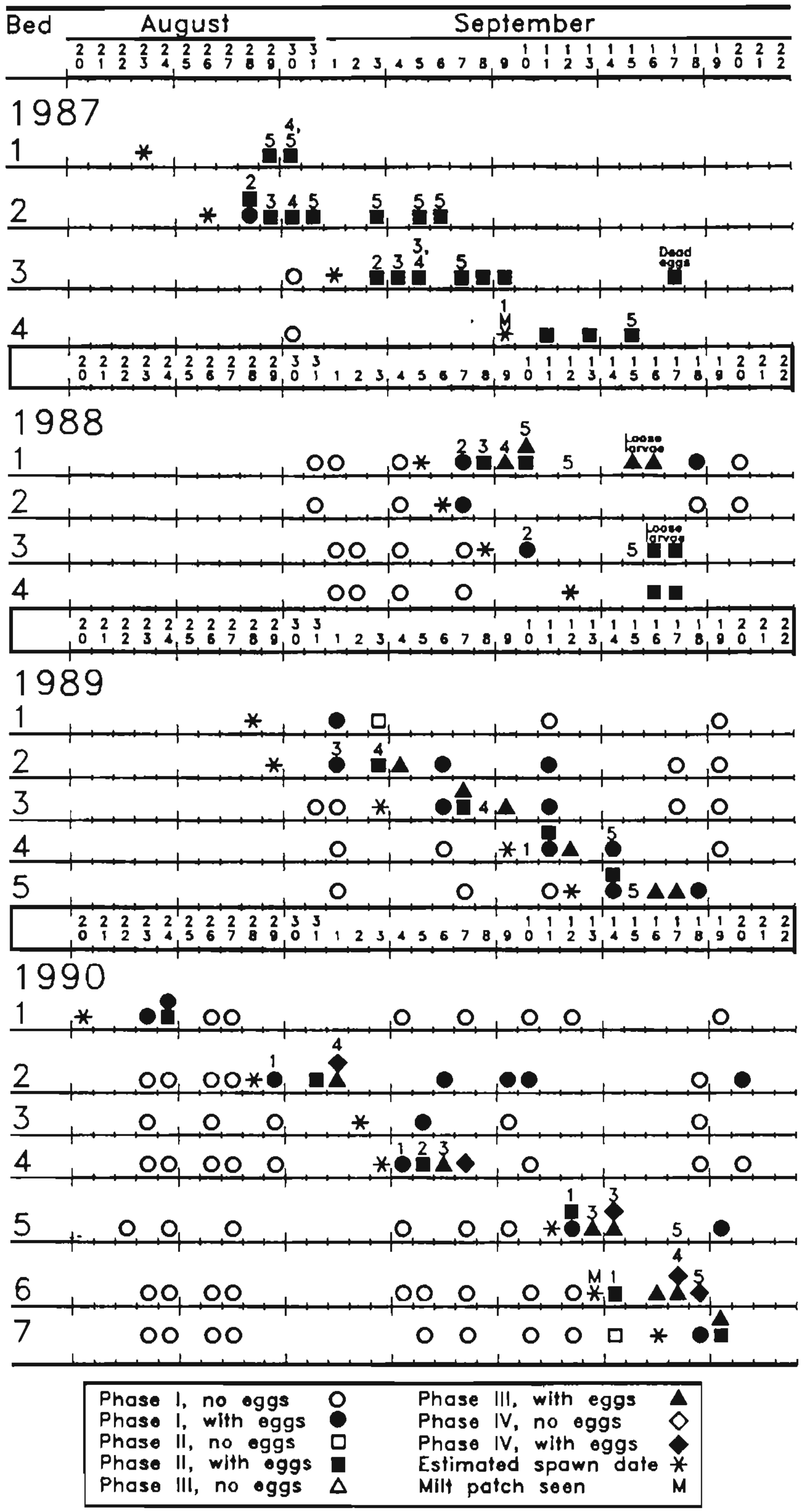



Fig. 11
Relation between the density of herring eggs and the thickness of the egg bed. The regression is forced through the origin. 1986 data (squares) are from Messieh et al. (1987). 1987 data (triangles) are from the present study.

Fig. 12
Timing of herring spawning at Fisherman's Bank, 1987–1990. Numbers indicate maturity stages (Baxter 1971) of sampled eggs. Not all sampling inspections in 1987 are shown.



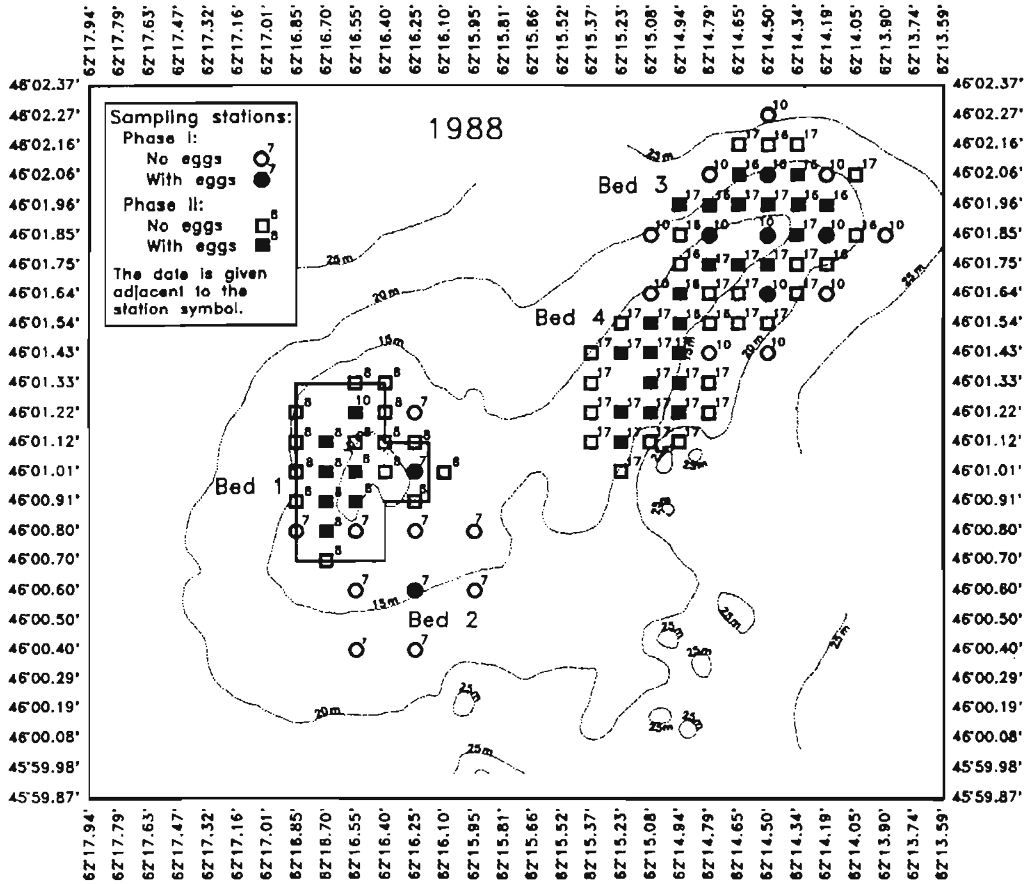



Fig. 13. Fisherman's Bank, showing stations used to define boundaries of spawning beds, from surveys conducted 7 -17 September 1988. The box indicates the area within which a randomized grid was established for Phase III sampling.

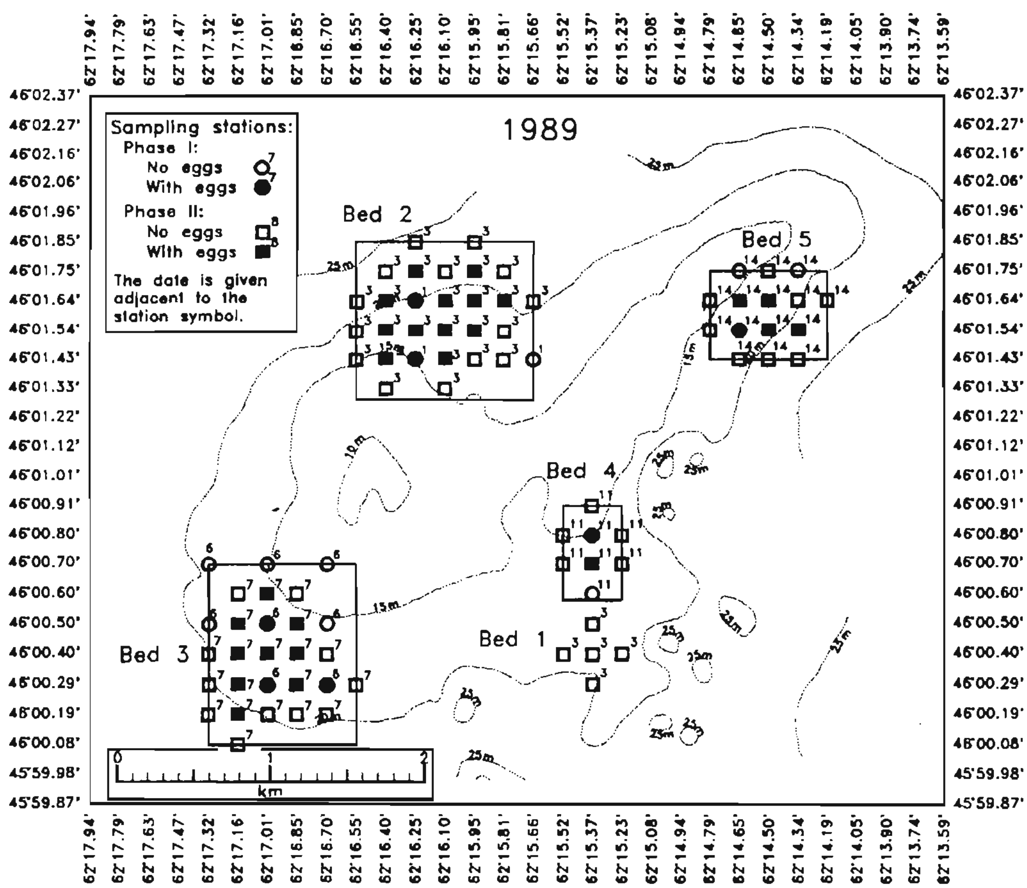



Fig. 14. Fisherman's Bank, showing stations used to define boundaries of spawning beds, from surveys conducted 1-14 September 1989. The boxes indicate the areas within which randomized grids were established for Phase III sampling.

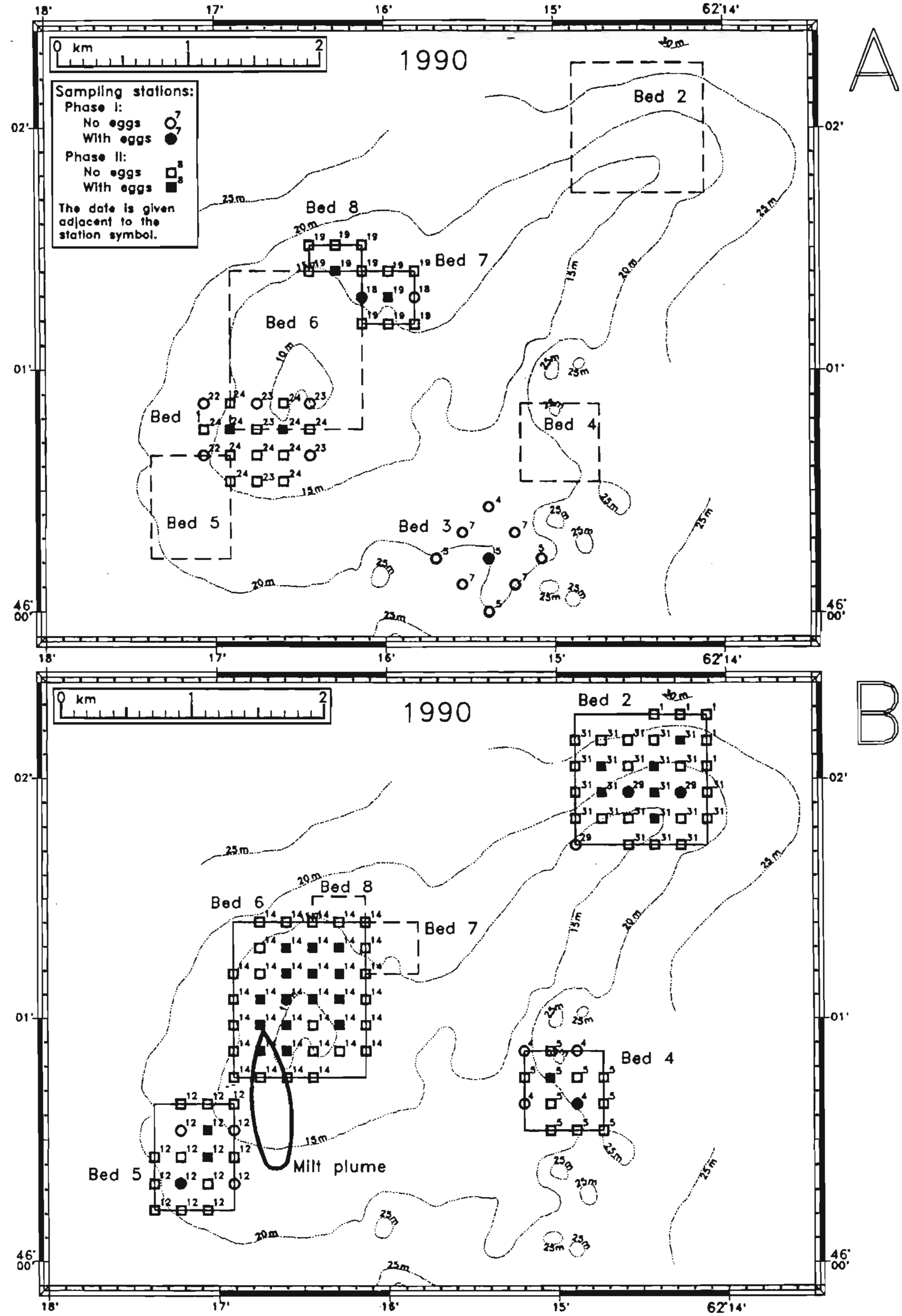



Fig. 15
Fisherman's Bank, showing stations used to define boundaries of spawning beds, from surveys conducted 22 August – 20 September 1990. Boxes indicate areas within which stations were randomly chosen for Phase III sampling. Stations for Beds 1, 3, 7, and 8 are shown in A and stations for Beds 2, 4, 5, and 6 are shown in B. The milt plume observed on 13 September is also shown in B.

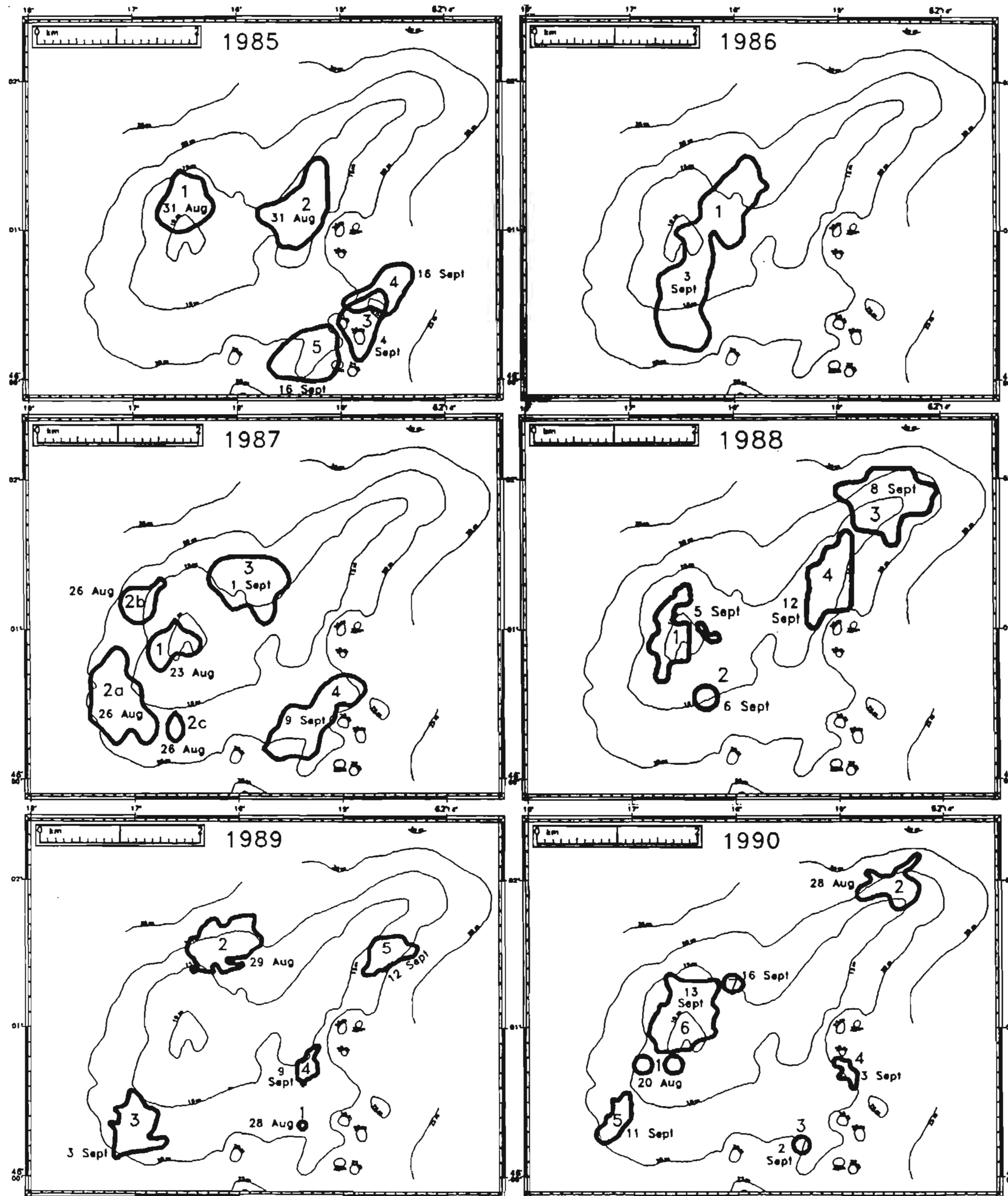



Fig. 16
Locations of spawning beds at Fisherman's Bank, 1985-1990. 1985 data from Messieh (1986), 1986 data from Messieh et al. 1987.

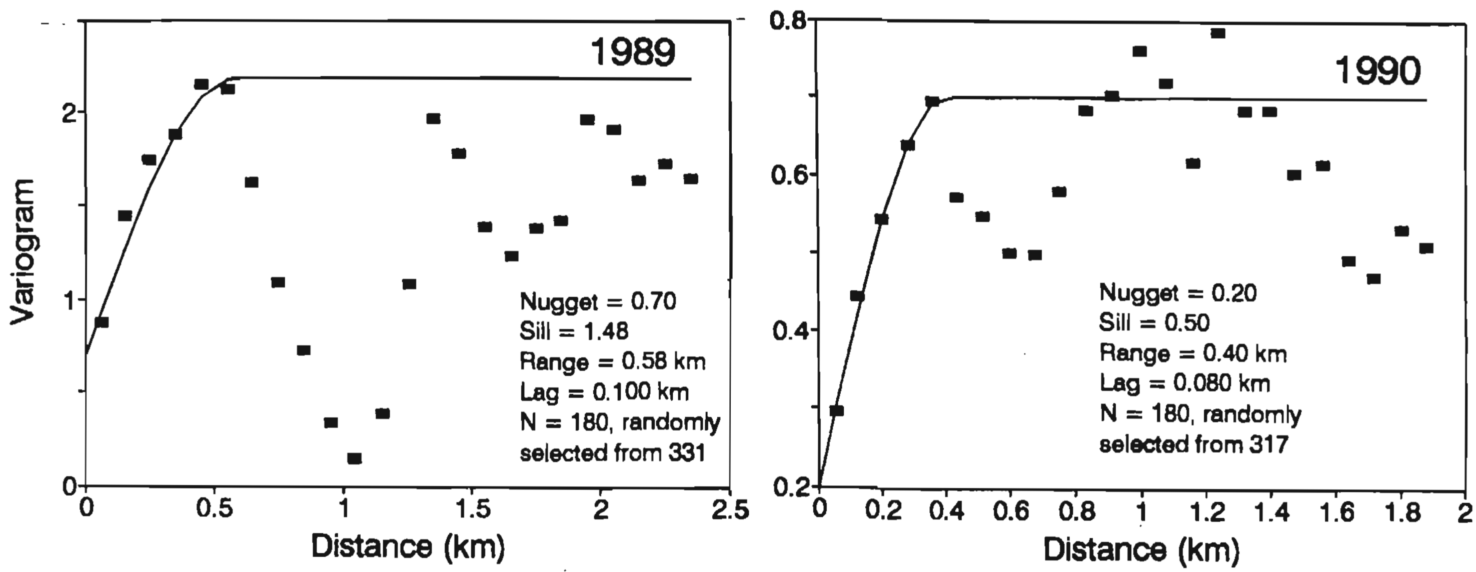



Fig. 17.
Variograms of herring egg thickness at Fisherman's Bank, all beds, 1989 and 1990.

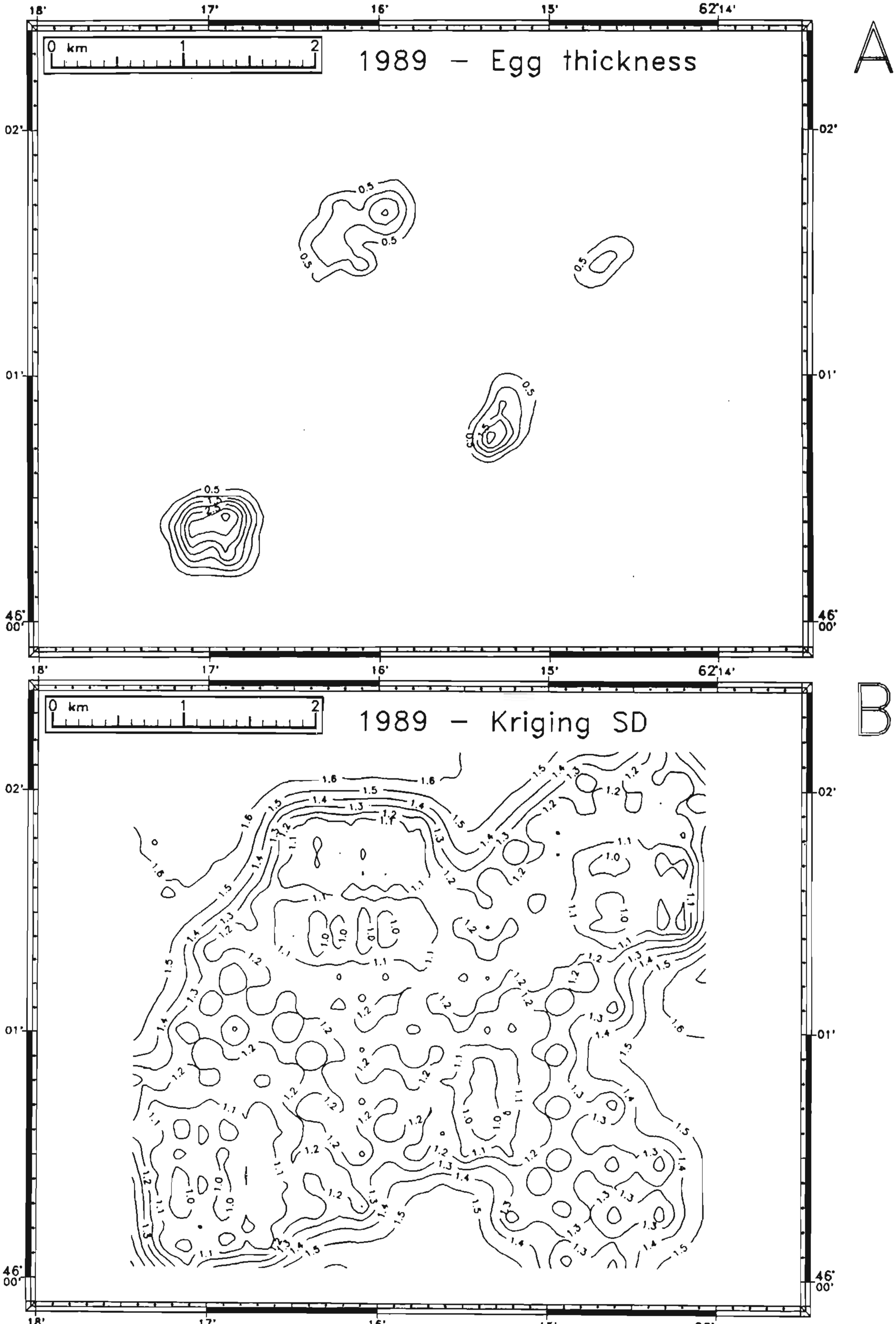



Fig. **18.**
Herring egg contours at Fisherman's Bank in 1989, derived from point kriging. (A) Contours of egg thickness (cm). (B) Contours of kriged standard deviation.

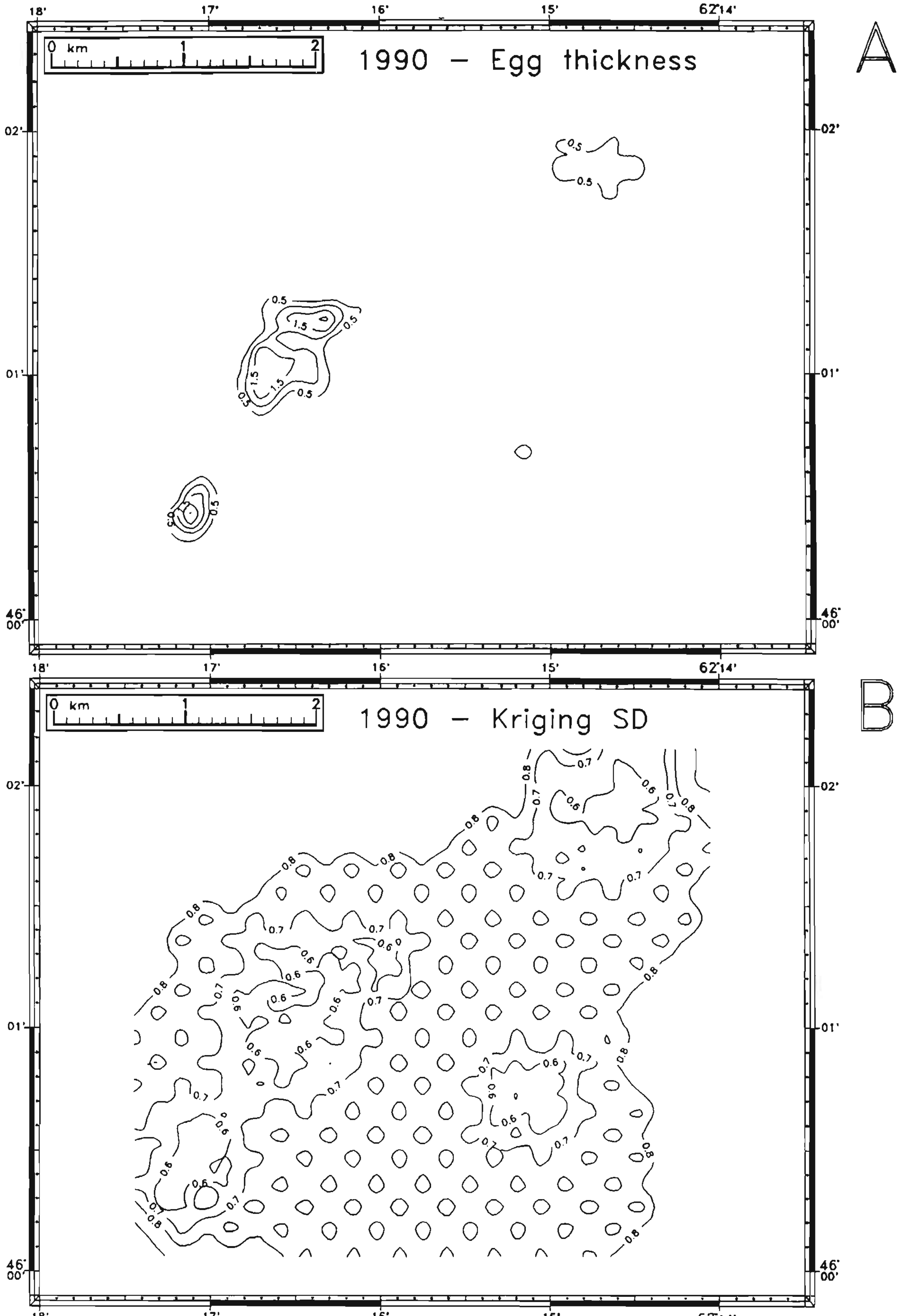



Fig. 19.
Herring egg contours at Fisherman's Bank in 1990, derived from point kriging. (A) Contours of egg thickness (cm). (B) Contours of kriged standard deviation.

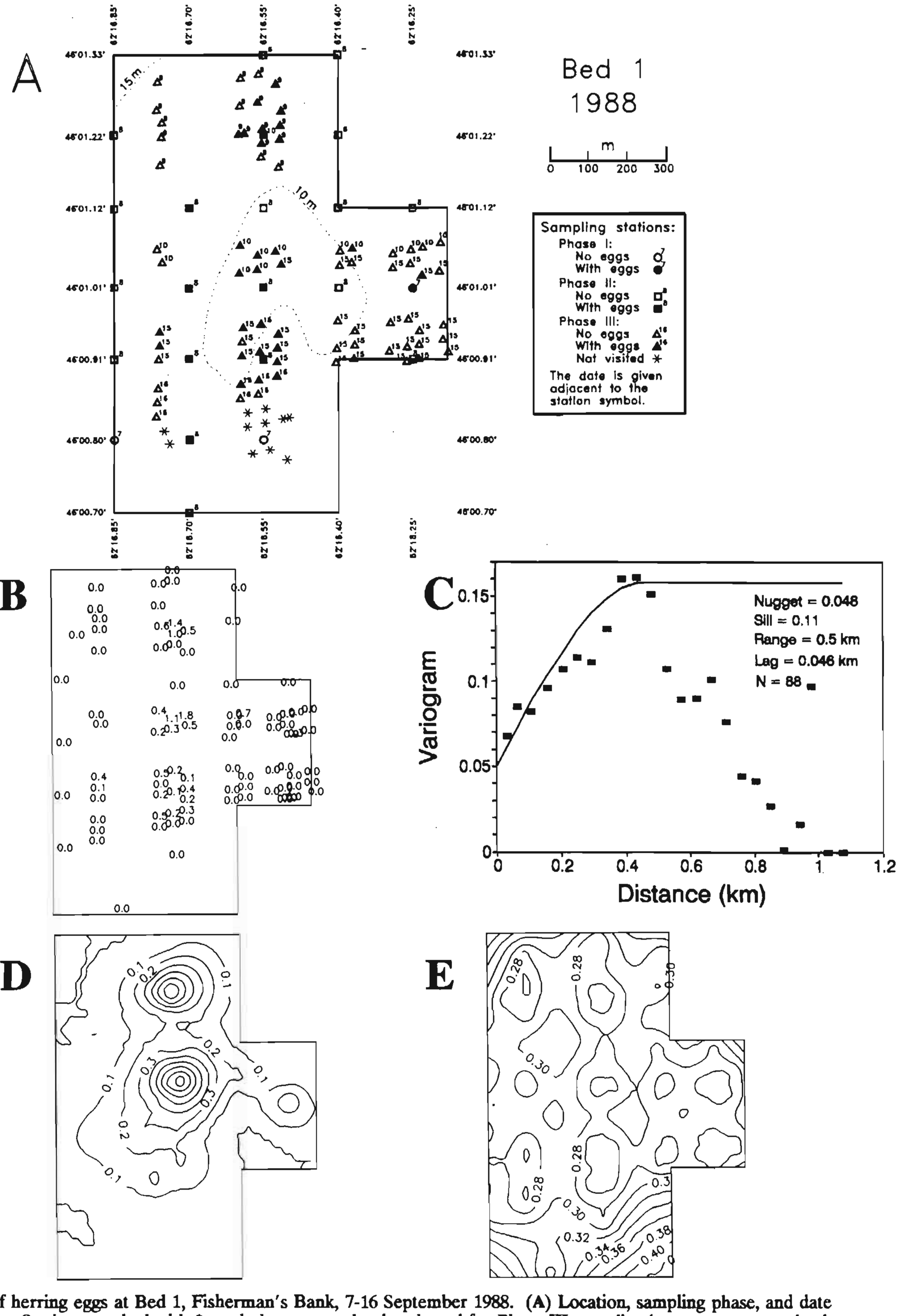



Fig. 20.
Distribution of herring eggs at Bed 1, Fisherman's Bank, 7-16 September 1988. **(A)** Location, sampling phase, and date of sample sites. Stations marked with * symbols were randomly selected for Phase III sampling but were not examined. **(B)** Egg thickness (cm) at sample sites. **(C)** Variogram of egg thickness. **(D)** Contour map of egg thickness derived from point kriging. **(E)** Contour map of kriging standard deviation of egg thickness.

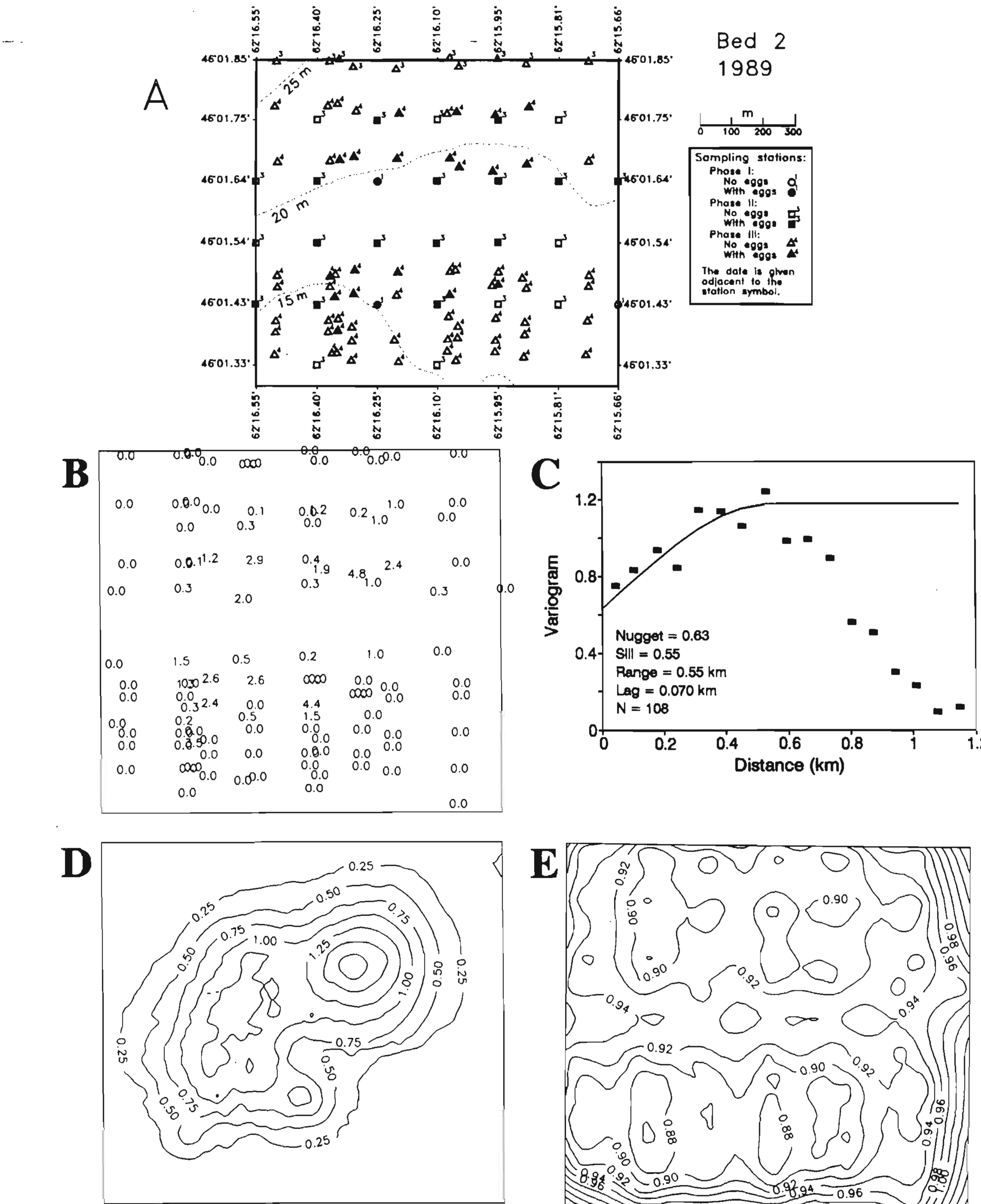
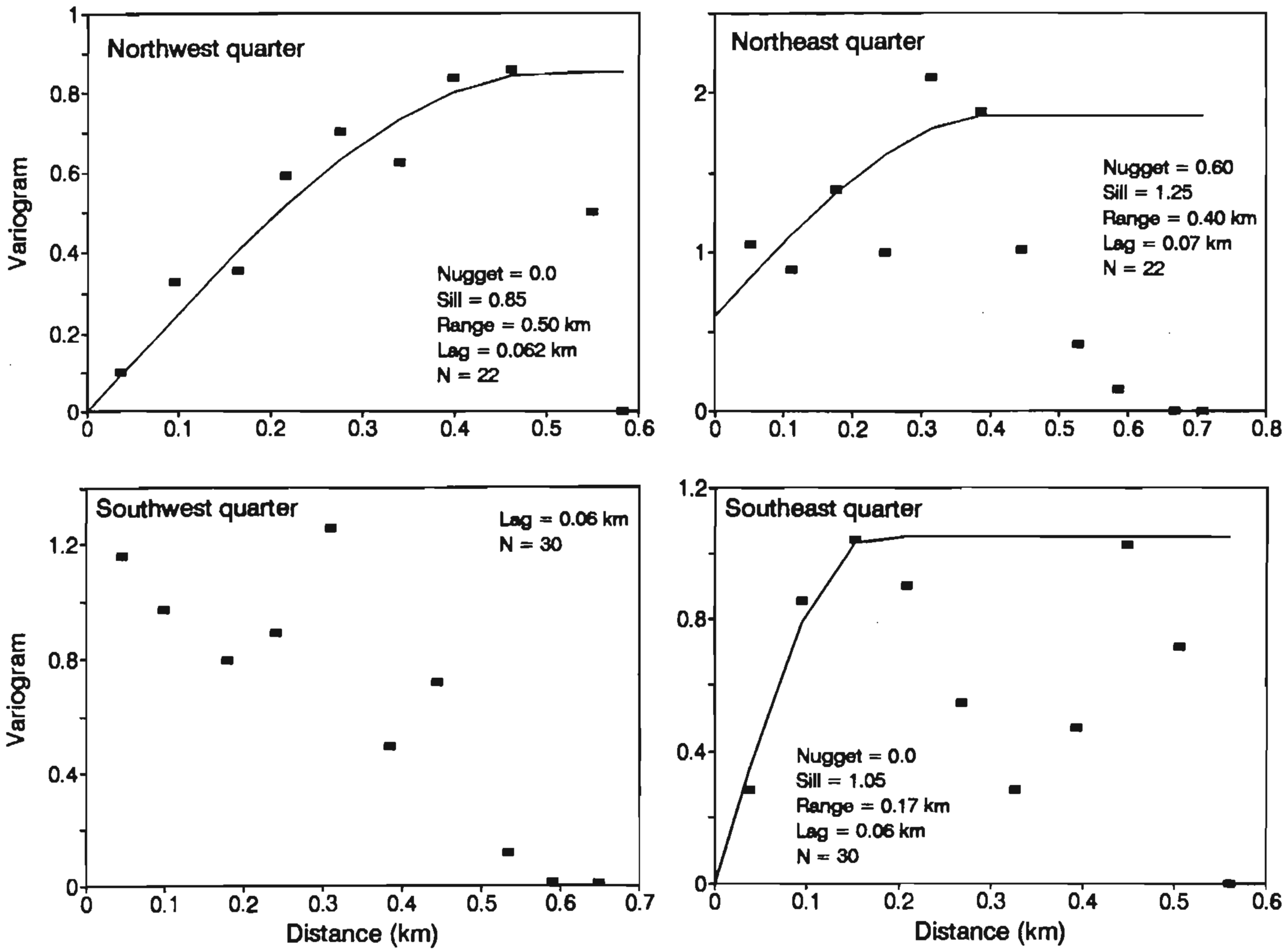



Fig. 21.
Distribution of herring eggs at Bed 2, Fisherman's Bank, 1-4 September 1989. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness. (F) Variograms of egg thickness by quarter.

Fig. 21 (continued)

**F**



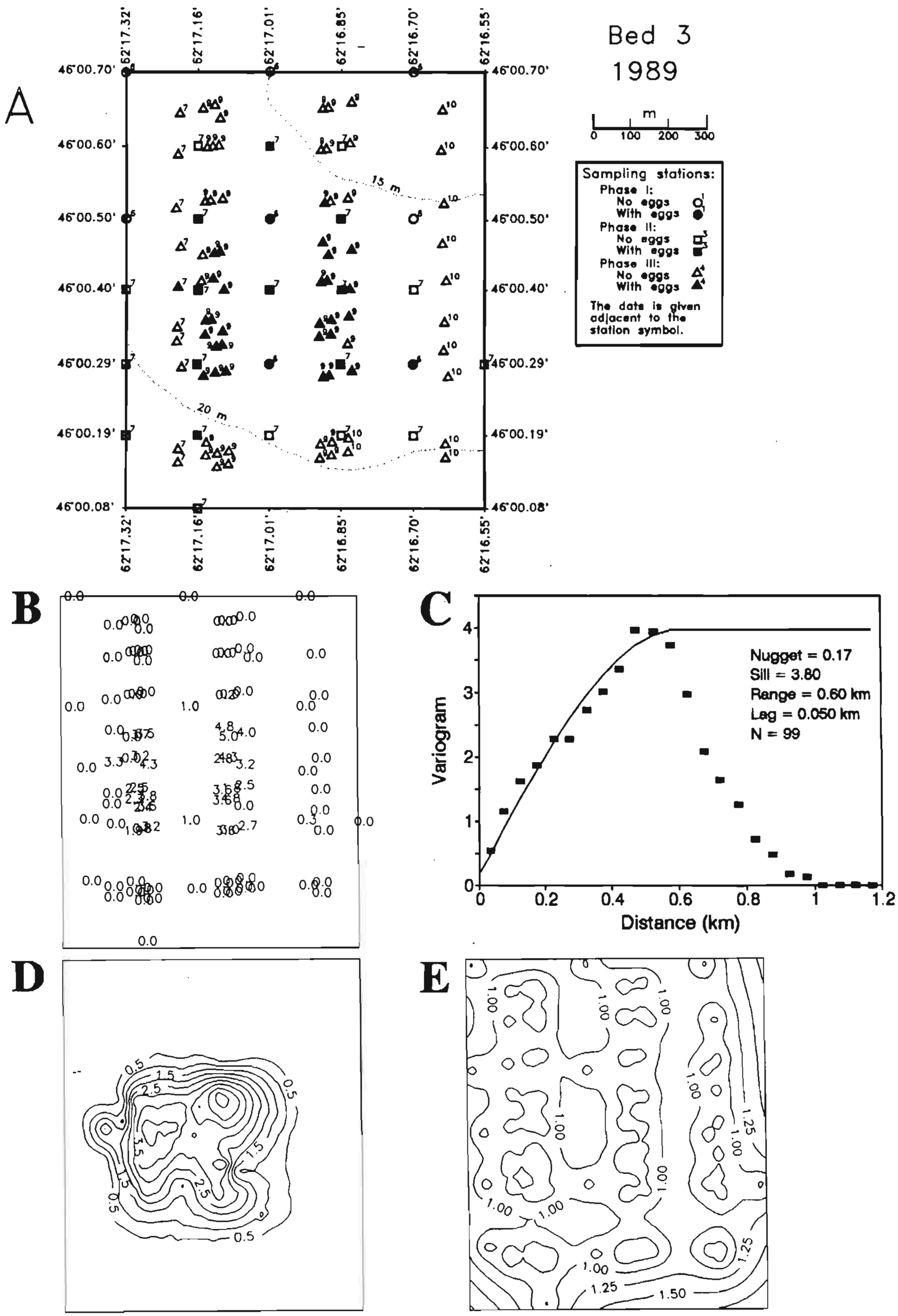
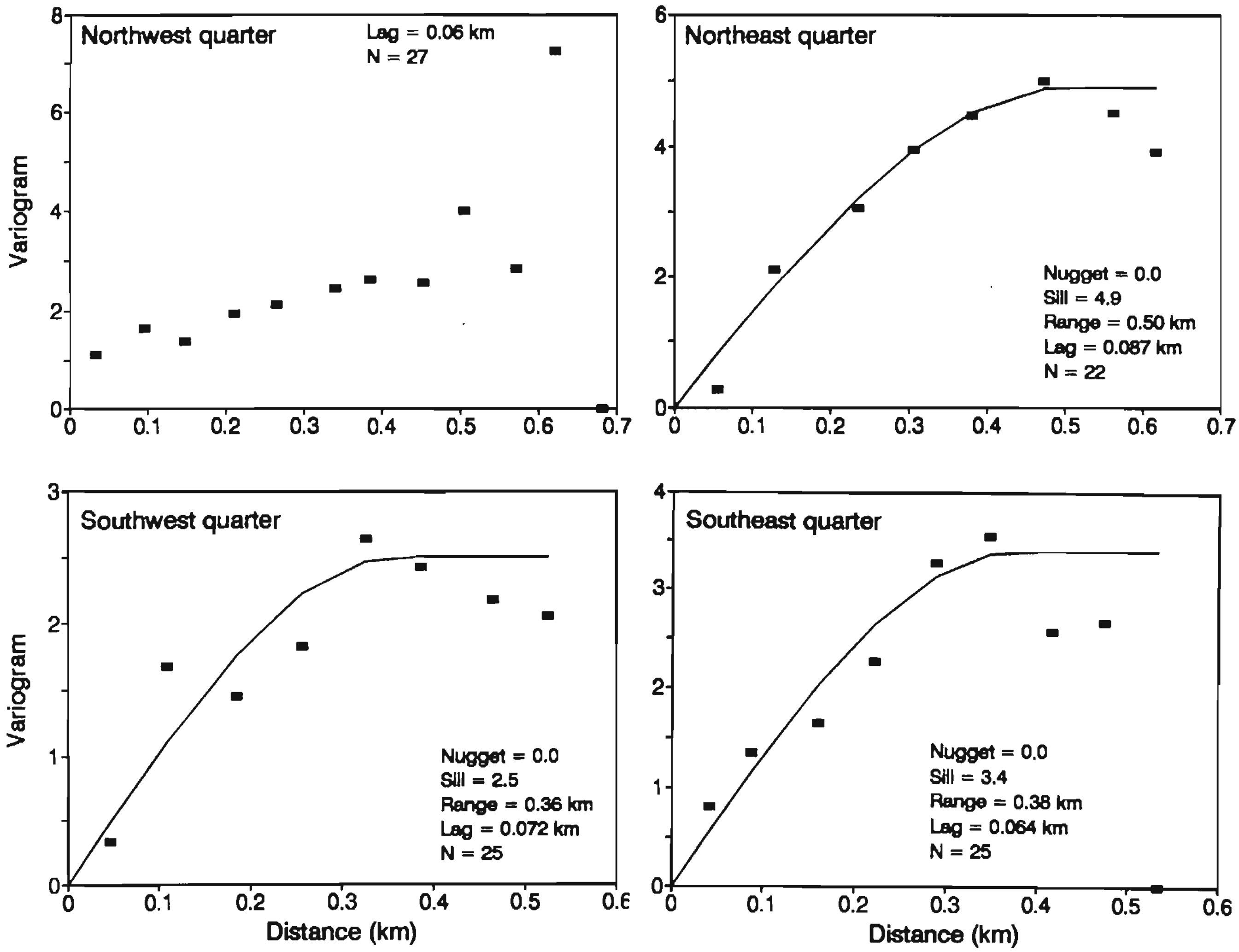



Fig. 22.
Distribution of herring eggs at Bed 3, Fisherman's Bank, 6-10 September 1989. (A) Location, sampling phase, and date 10of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness. (F) Variograms of egg thickness by quarter of sampling area.

Fig. 22 (continued)

**F**



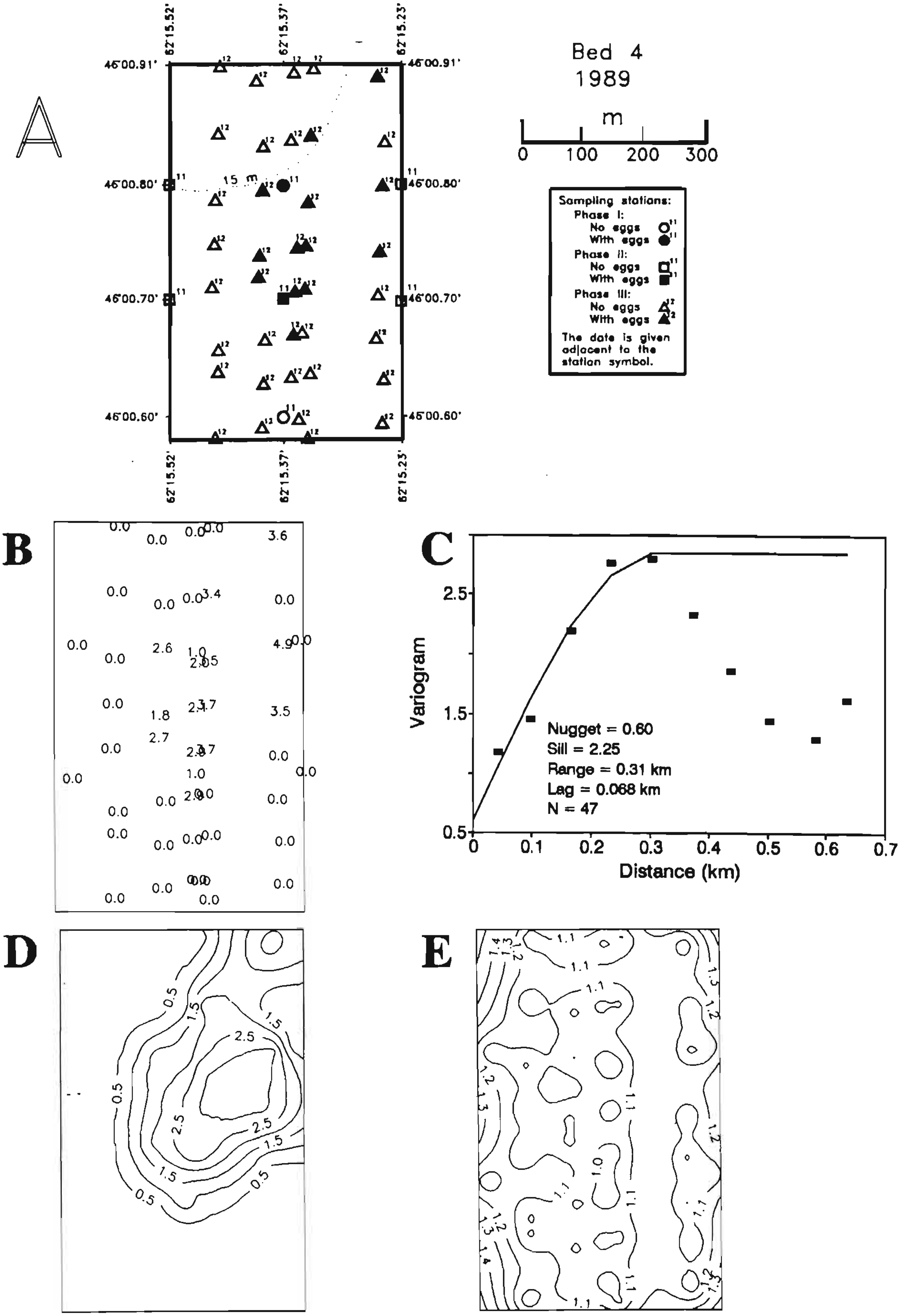



Fig. 23.
Distribution of herring eggs at Bed 4, Fisherman's Bank, 6-10 September 1989. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness.

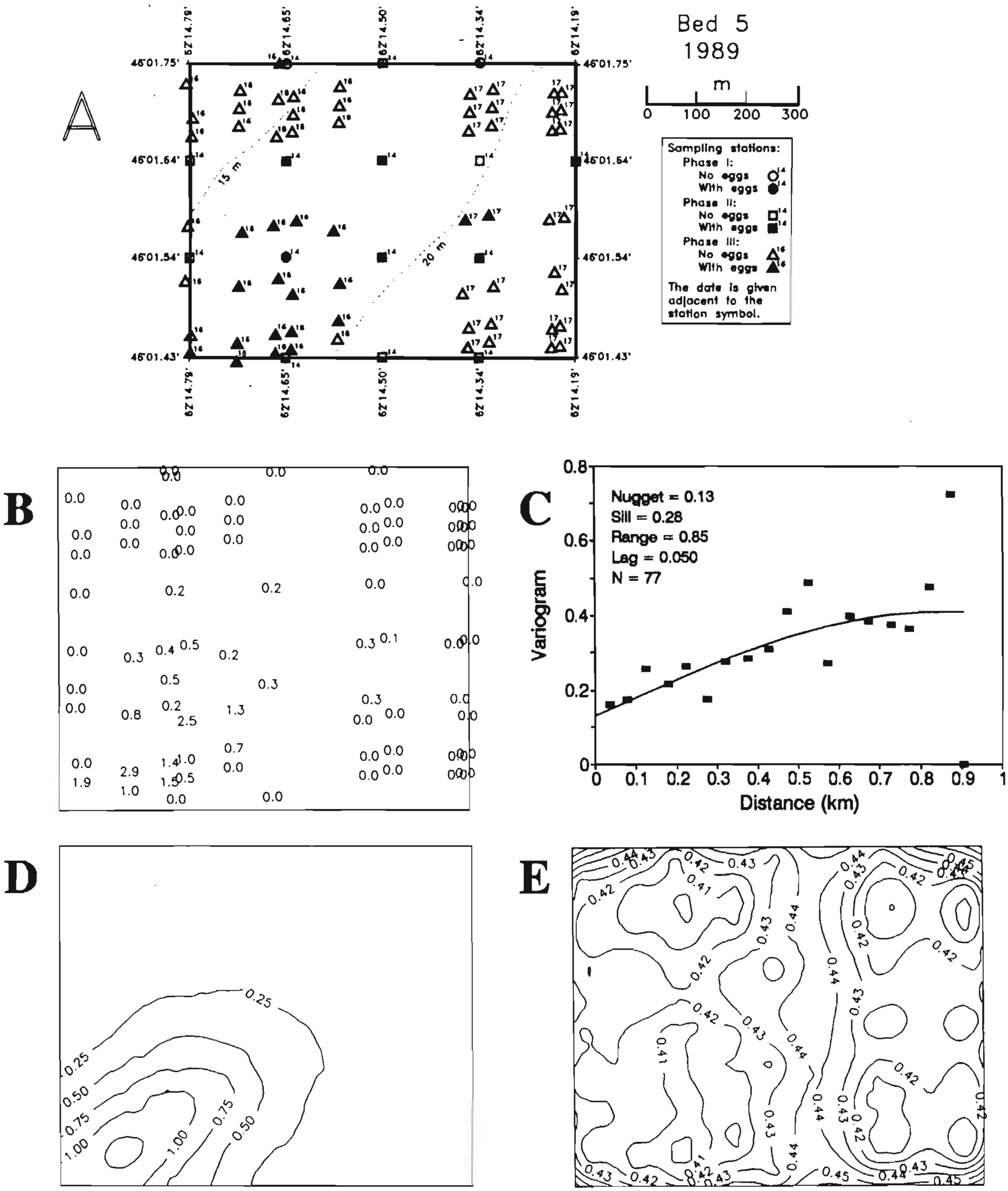



Fig. 24.
Distribution of herring eggs at Bed 5, Fisherman's Bank, 14-17 September 1989. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness.

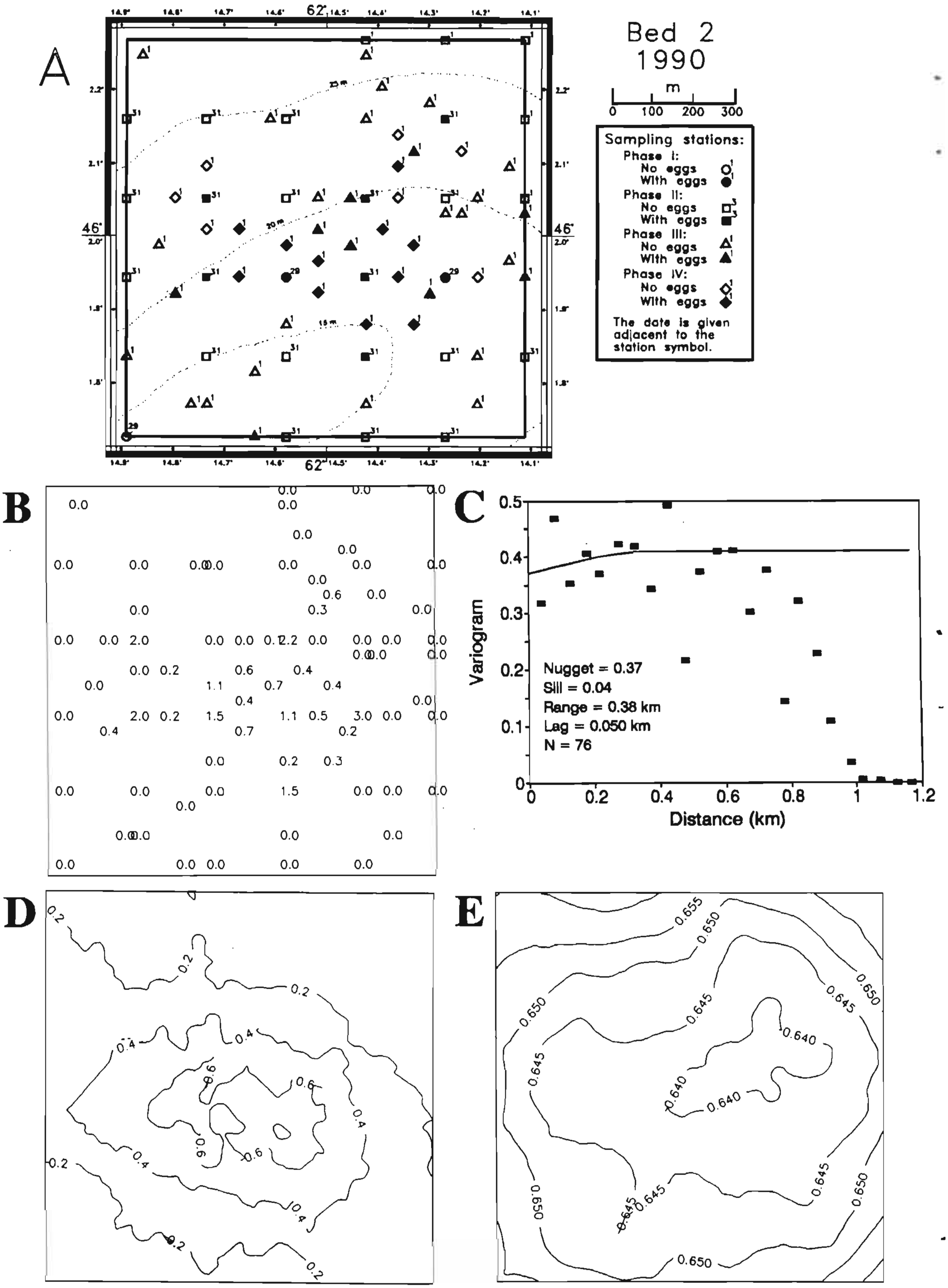



Fig. 25.
Distribution of herring eggs at Bed 2, Fisherman's Bank, 29 August - 1 September 1990. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness.

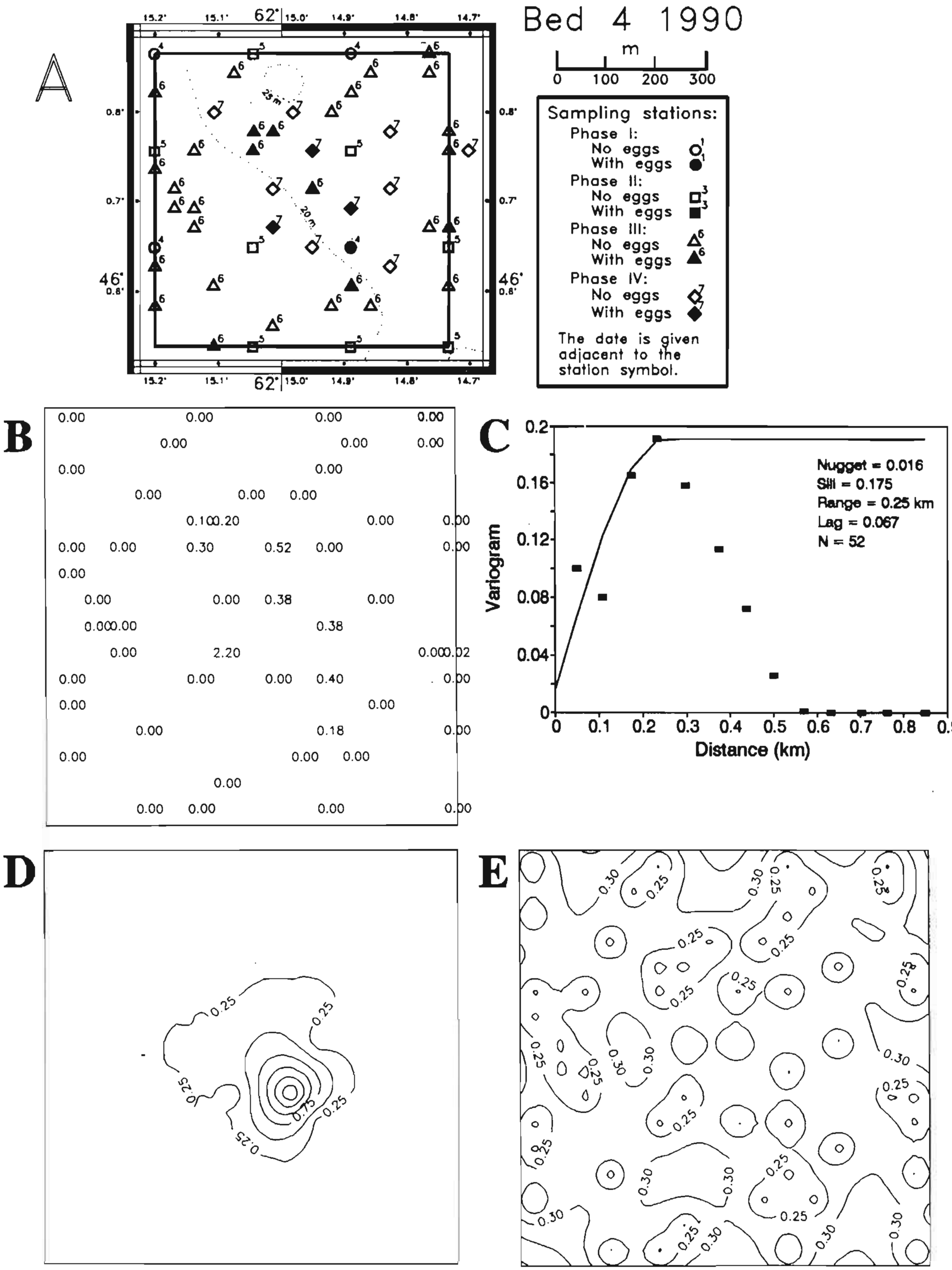



Fig. 26.
Distribution of herring eggs at Bed 4, Fisherman's Bank, 4-7 September 1990. **(A)** Location, sampling phase, and date of sample sites. **(B)** Egg thickness (cm) at sample sites. **(C)** Variogram of egg thickness. **(D)** Contour map of egg thickness derived from point kriging. **(E)** Contour map of kriging standard deviation of egg thickness.

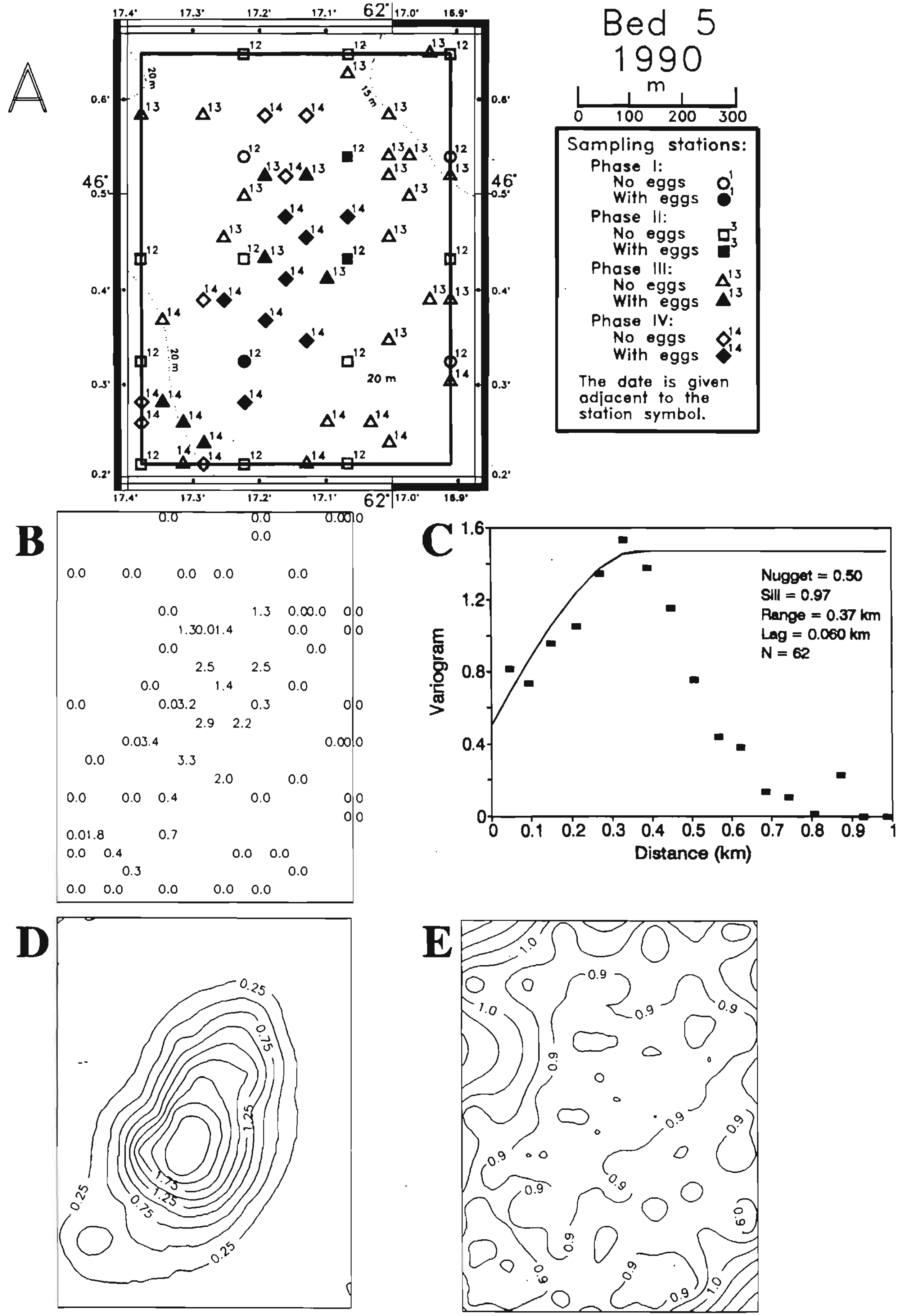



Fig. 27.
Distribution of herring eggs at Bed 5, Fisherman's Bank, 12-14 September 1990. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness.

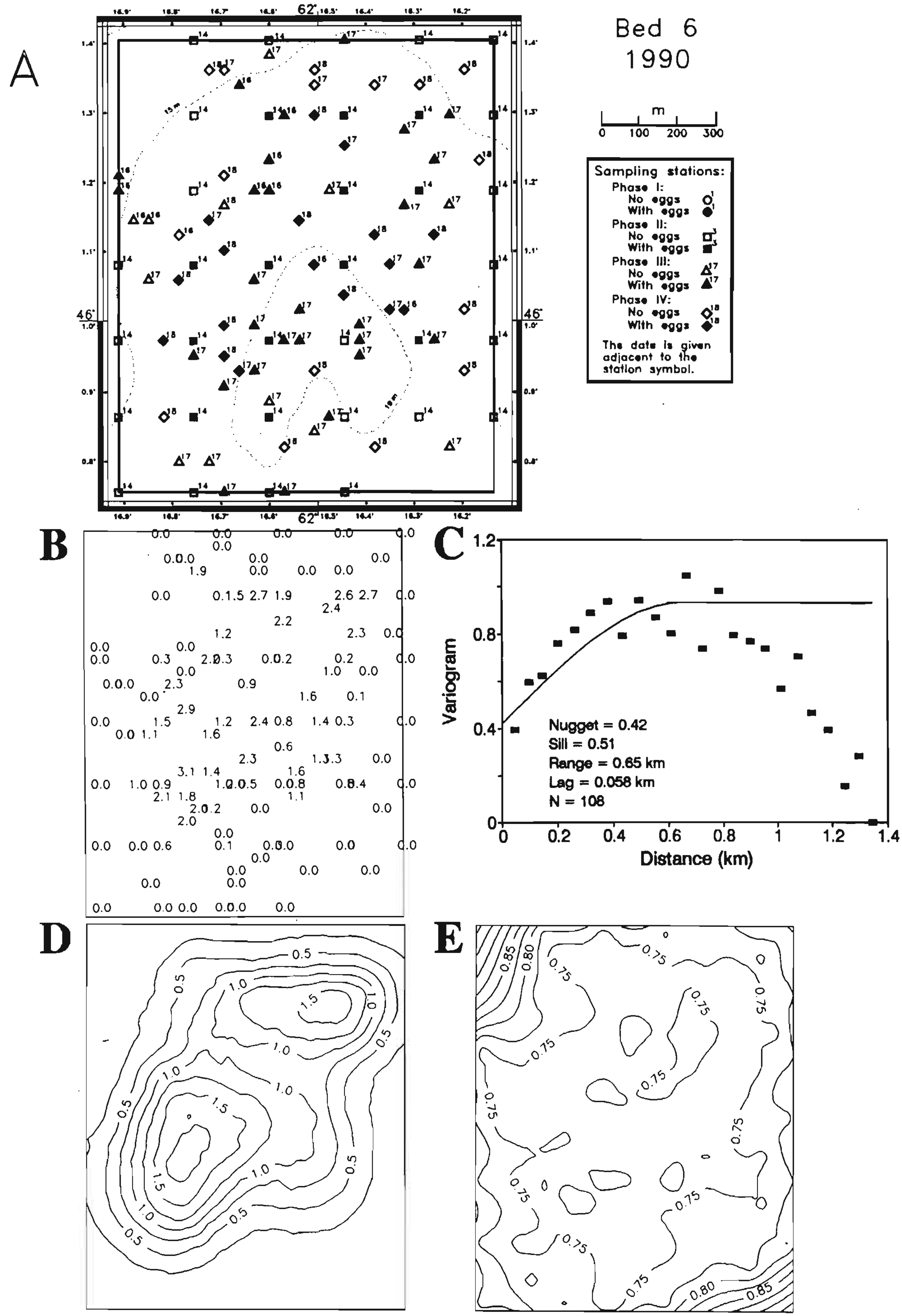
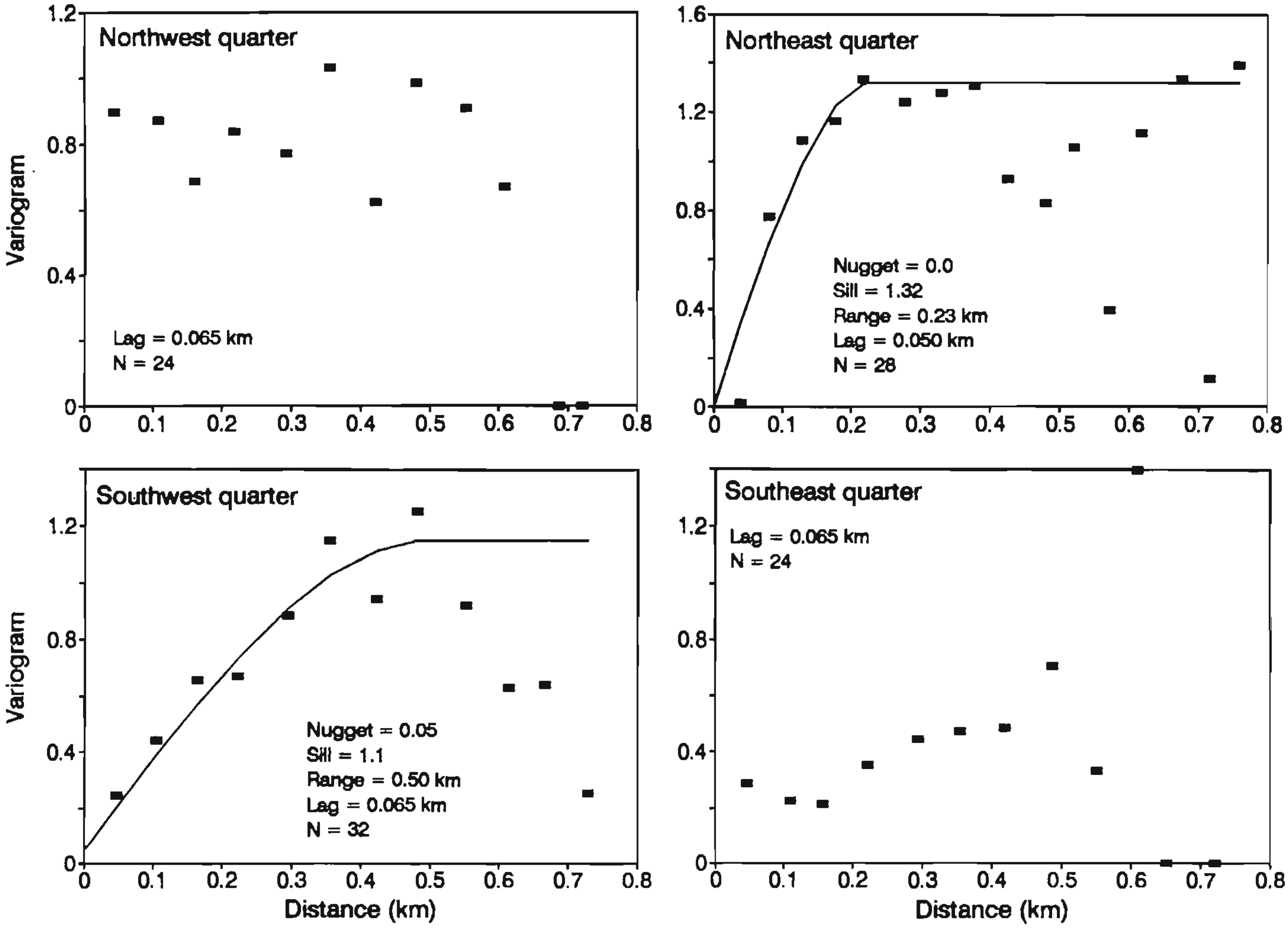



Fig. 28.
Distribution of herring eggs at Bed 6, Fisherman's Bank, 14 - 18 September 1990. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites. (C) Variogram of egg thickness. (D) Contour map of egg thickness derived from point kriging. (E) Contour map of kriging standard deviation of egg thickness. (F) Variograms of egg thickness by quarter of sampling area.

Fig. 28 (continued)

# F



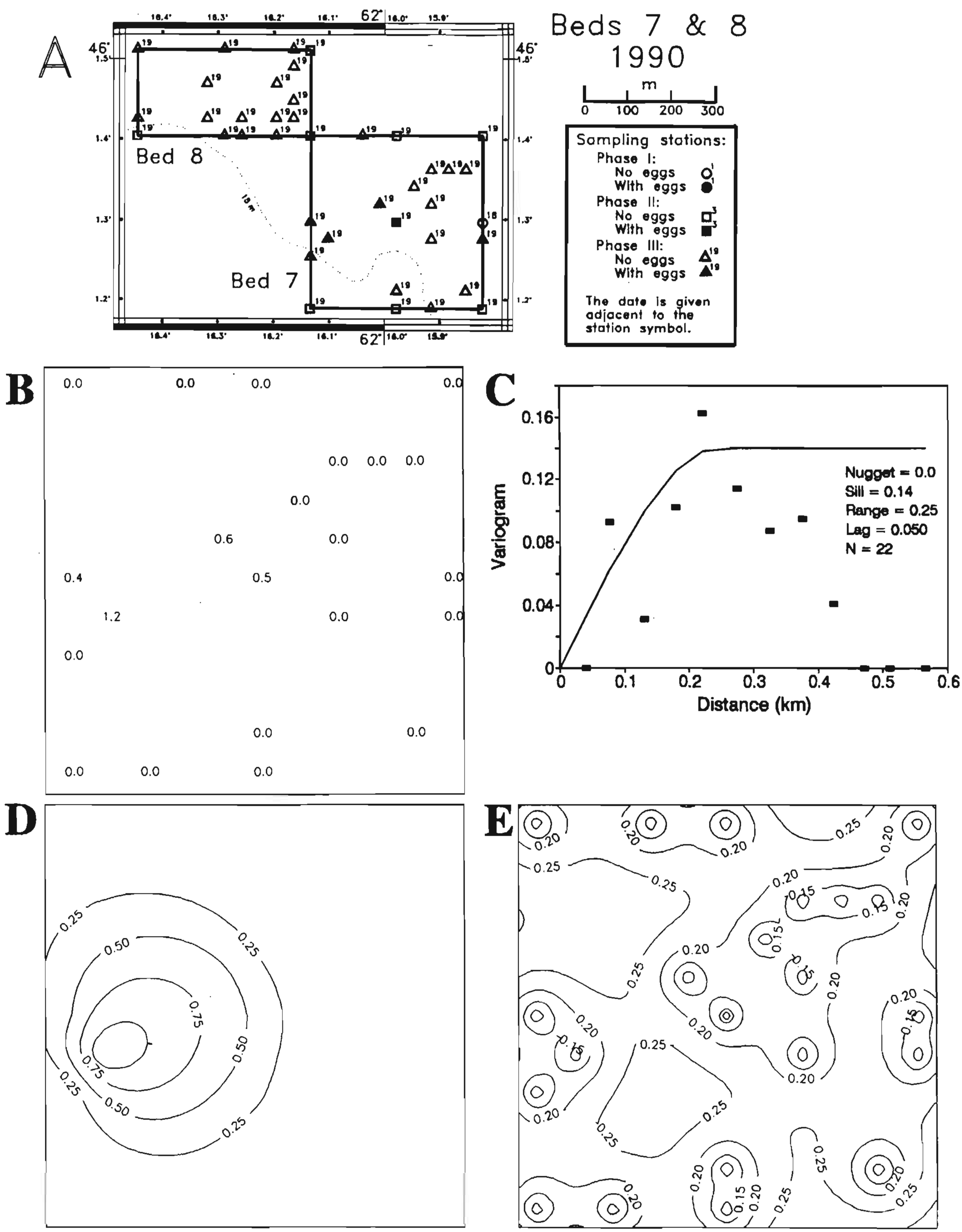



Fig. 29.
Distribution of herring eggs at Beds 7 and 8, Fisherman's Bank, 18 - 19 September 1990. (A) Location, sampling phase, and date of sample sites. (B) Egg thickness (cm) at sample sites in Bed 7. (C) Variogram of egg thickness, Bed 7. (D) Contour map of egg thickness derived from point kriging, Bed 7. (E) Contour map of kriging standard deviation of egg thickness, Bed 7.

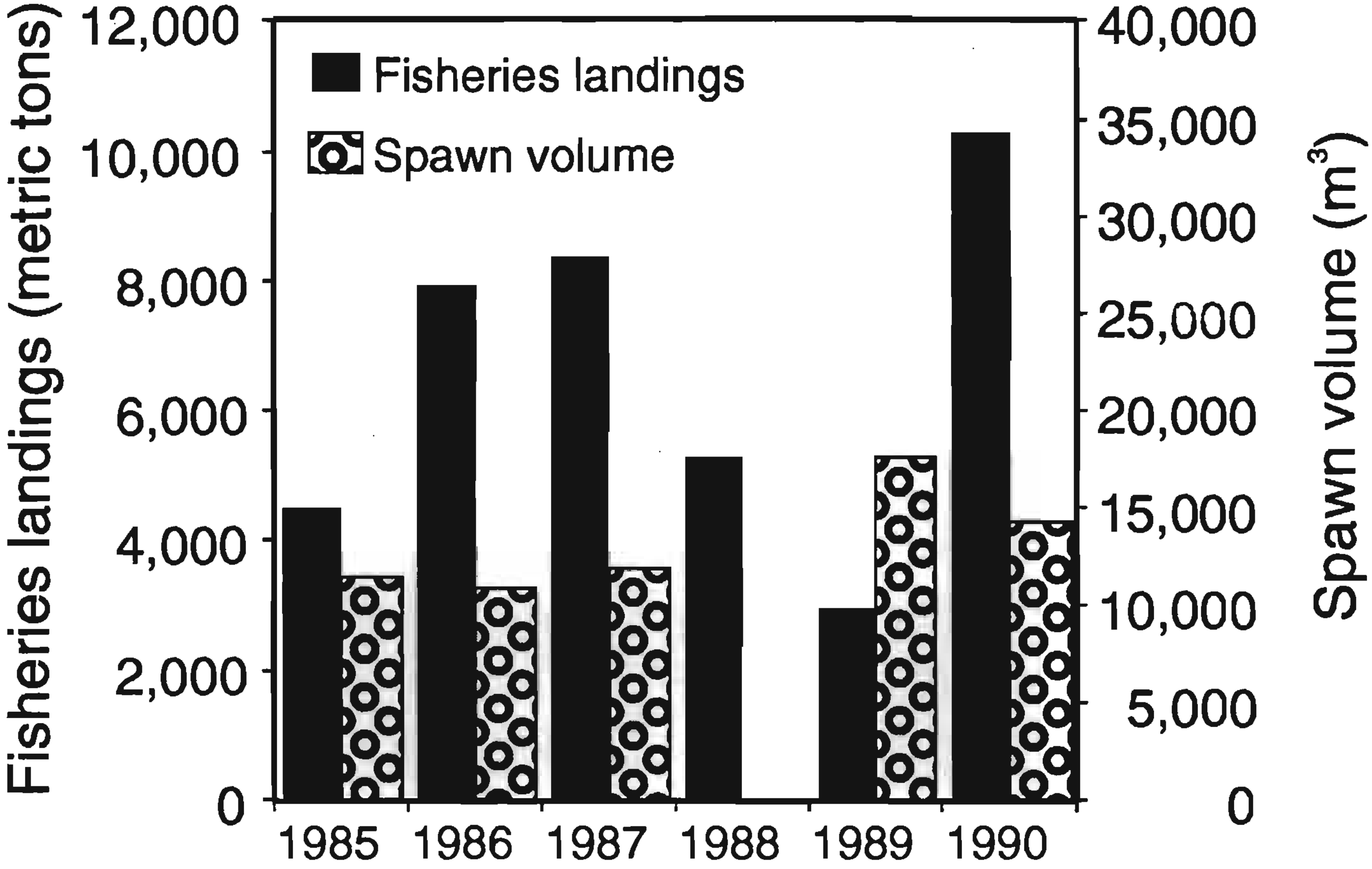



Fig. 30
Herring landings and spawn volume at Fisherman's Bank, 1985-1990. No data on spawn volume in 1988.

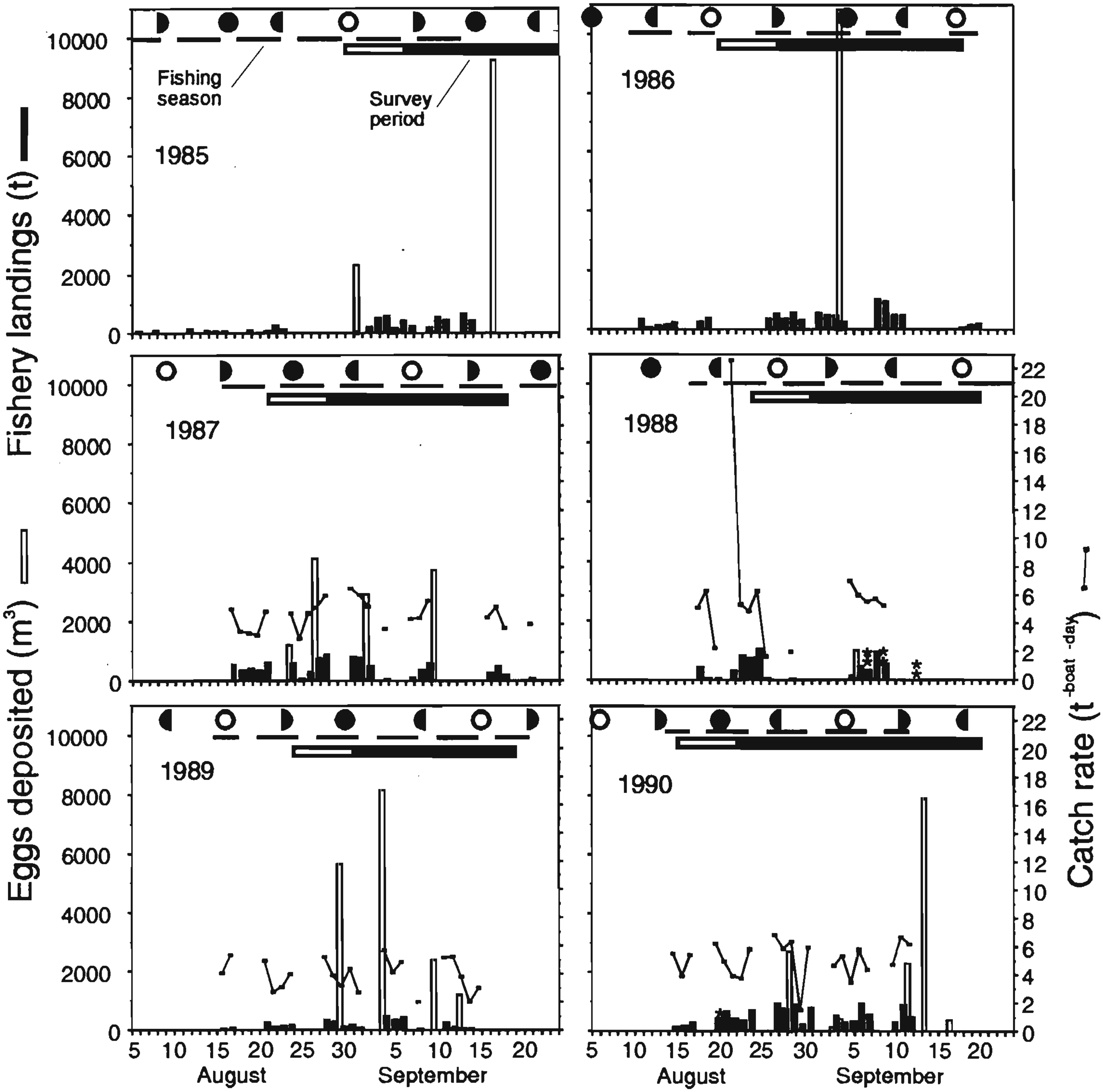



Fig. 31
Herring spawn volumes, landings, catch rates, lunar phases, fishing seasons, and survey periods at Fisherman's Bank, 1985-1990. 1985 and 1986 egg data are derived from Messieh (1986) and Messieh et al. (1987) respectively. Egg estimates for 1988-1990 are based on kriging. Open rectangles before survey period bars indicate periods for which spawn deposition would likely be subsequently detected by surveys. Asterisks indicate spawn depositions whose volume was not estimated.

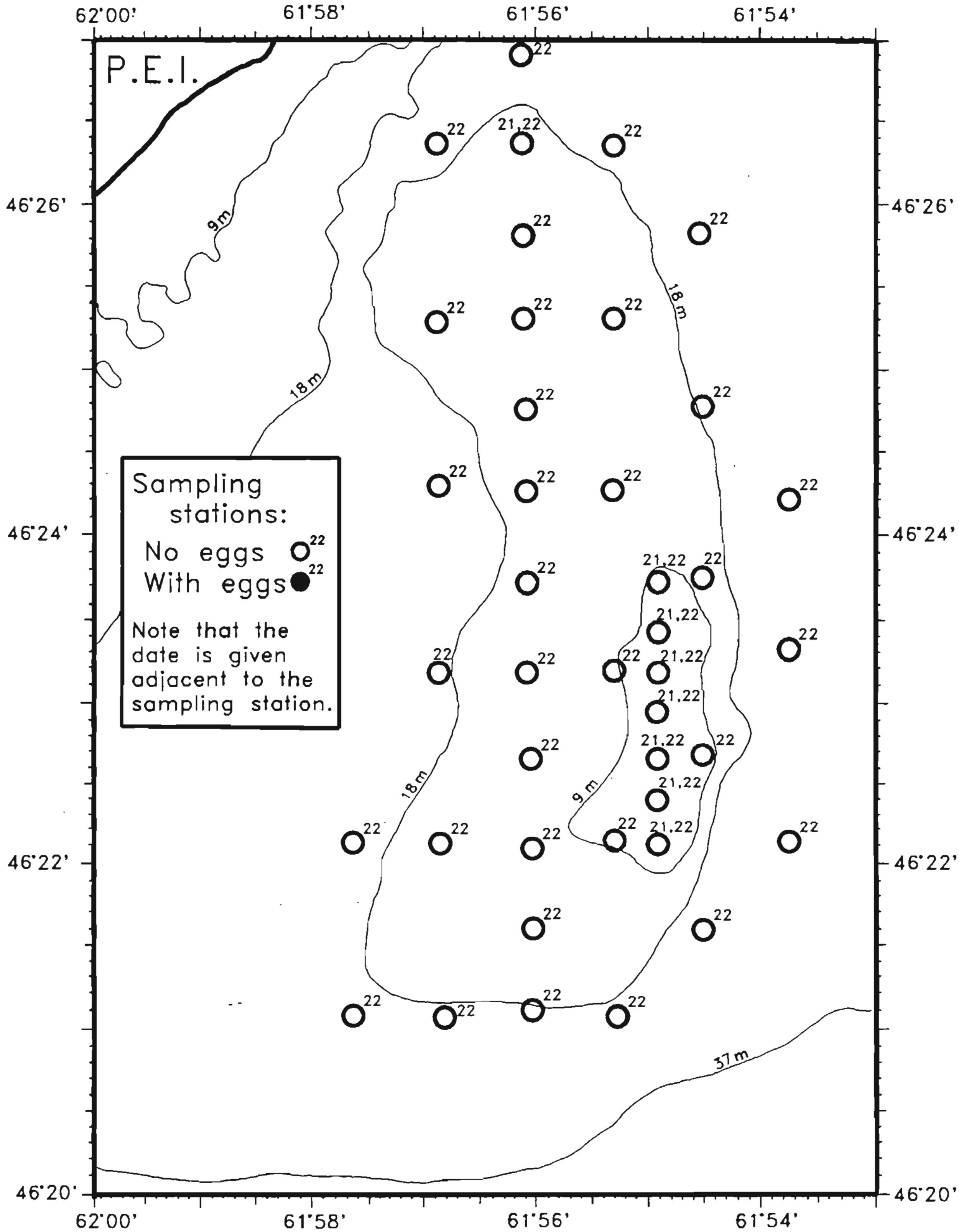



Fig. 32
Sampling stations on Milne Bank examined in September 1988. Stations on 21 September were examined by dredge; stations on 22 September were examined by video camera.

**Appendix A.**

Navigation

Navigation to sampling points was by Loran C receivers set on Time Delay (TD) display, using 5930-X (purple) and 5930-Y (grey) lines of position. All TD readings were to 0.1 microsecond. An initial conversion between Loran TD and Latitude/Longitude (LL) was derived from a Si-tex Koden Model 787c Loran unit (Koden Electronics Ltd., Tokyo), which has an internal processor that estimates LL from Loran TDs. Multiple linear regressions were calculated from 129 stations on and near Fisherman's Bank where both LLs and TDs were recorded. Results were:

LAT = 4540.30301+(0.19121 LORANpurple)+(-0.0175947 LORANgrey)

LONG = 6144.47786+(-0.007882 LORANpurple)+(0.119487 LORANgrey)

LORANpurple = -28629.140+(5.25750 LAT)+(0.77449 LONG)

LORANgrey = -53319.229+(0.34766 LAT)+(8.42070 LONG),

where latitude (LAT) and longitude LONG) are expressed as DDMM.XX (DD, degrees; MM, minutes; XX, hundredths of minutes) and Loran TDs are expressed without 1,000s and 10,000s; i.e. 14,332.6 microseconds is given as 332.6. Regression $r^2$s were greater than 0.999.

Internal conversion algorithms in Loran C units assume a spherical earth, but in reality signals are delayed by irregularities on the earth's surface. This means that site-specific landpath corrections must be applied to LLs derived from Loran readings. We calculated correction factors by obtaining LLs from a Loran unit at seven points around the Beach Point-Murray Harbour-Gaspereau area, which is the nearest land to Fisherman's Bank. These LLs were then compared to those obtained from charts. Canadian Hydrographic Service nautical chart 4420, scale 1:18,233, was used to determine all locations except one, which was derived from chart 4403, scale 1:75,000.

LL readings from charts were numerically greater than those given by the Loran unit at the same point. For latitude the difference ($\pm$SD) was 0.156 ($\pm$0.023) minutes or 288 m. For longitude, the difference was 0.174 ($\pm$0.11) minutes or 224 m. The mean distance between a point and the LL coordinates given by the Loran unit for that point was 365 m.

Revised LL - TD conversion equations, corrected for these landpath errors, were:

LAT = 4540.45901+(0.19121 LORANpurple)+(-0.017593 LORANgrey)

LONG = 6144.65186+(-0.007882 LORANpurple)+(0.11947 LORANgrey)

LORANpurple = -28629.14+(5.25750 (LAT-0.156))+(.77449 (LONG-0.174))

LORANgrey = -53319.229+(0.34766 (LAT-0.156))+(8.42070 (LONG-0.174))

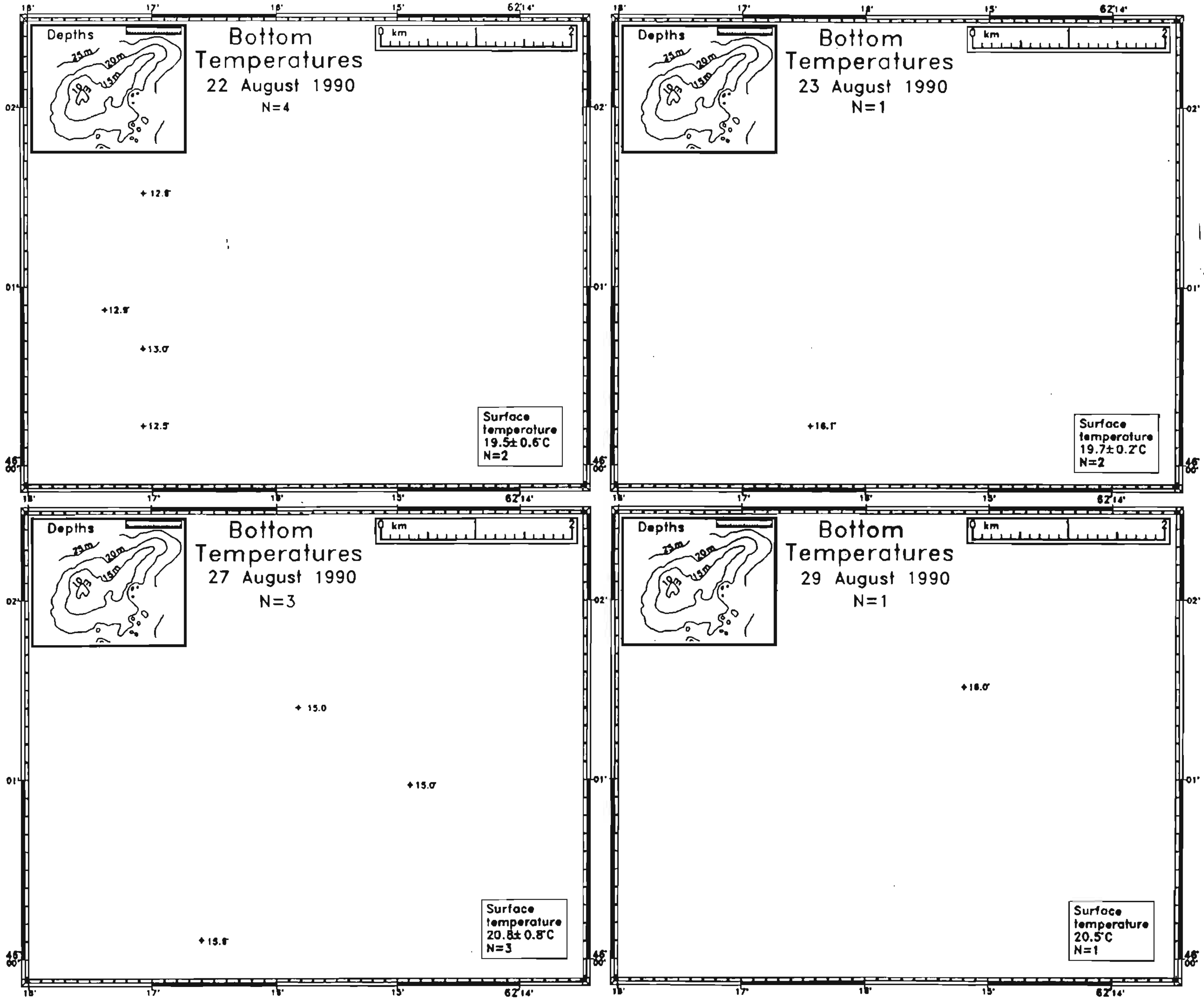
Maximum resolution of the Loran system, as represented by distances equivalent to 0.1 microsecond TDs, was 35.2 m in the north-south axis and 15.3 m in the east-west axis.

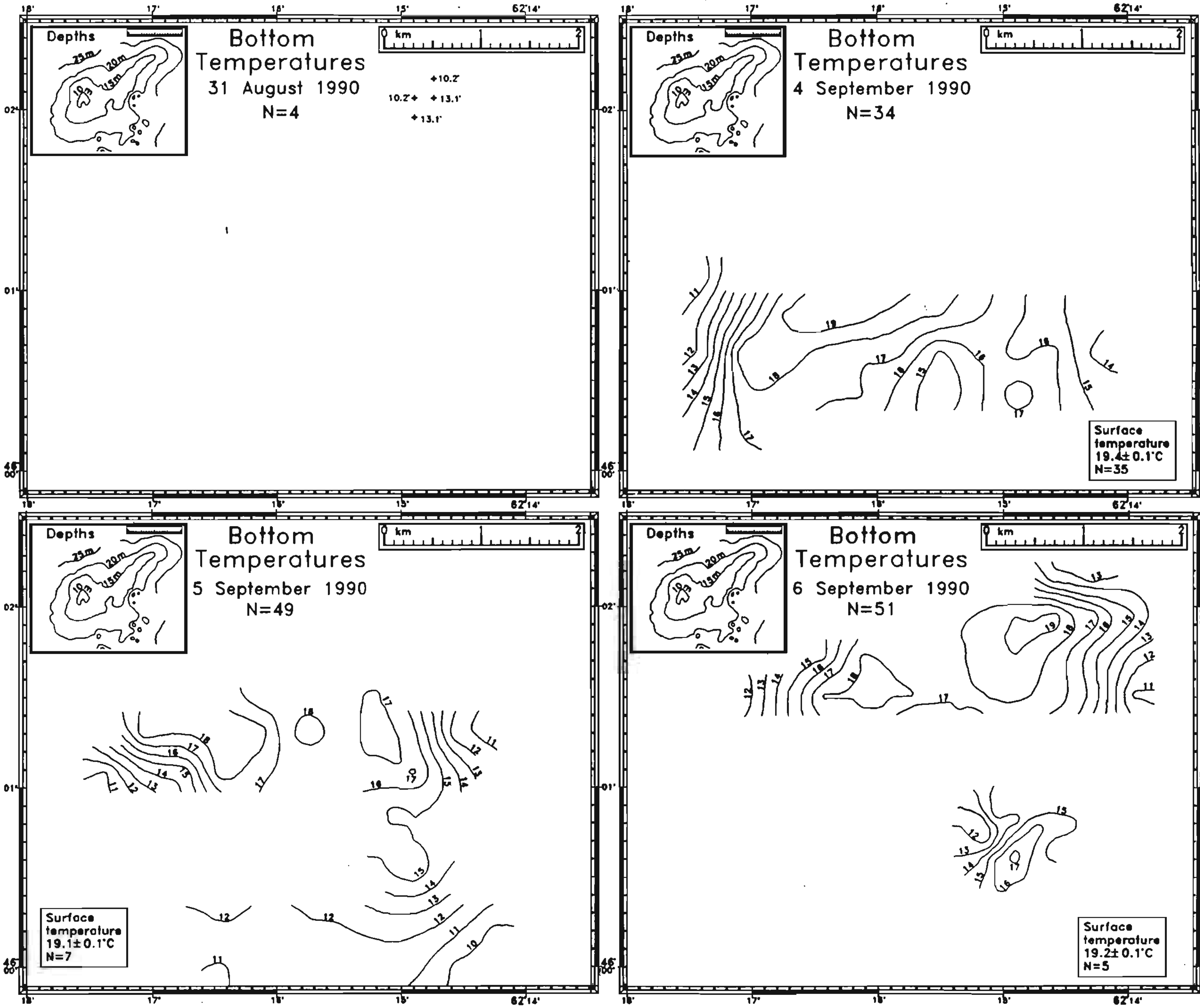
Longitude was converted into distance (km) by the formula:

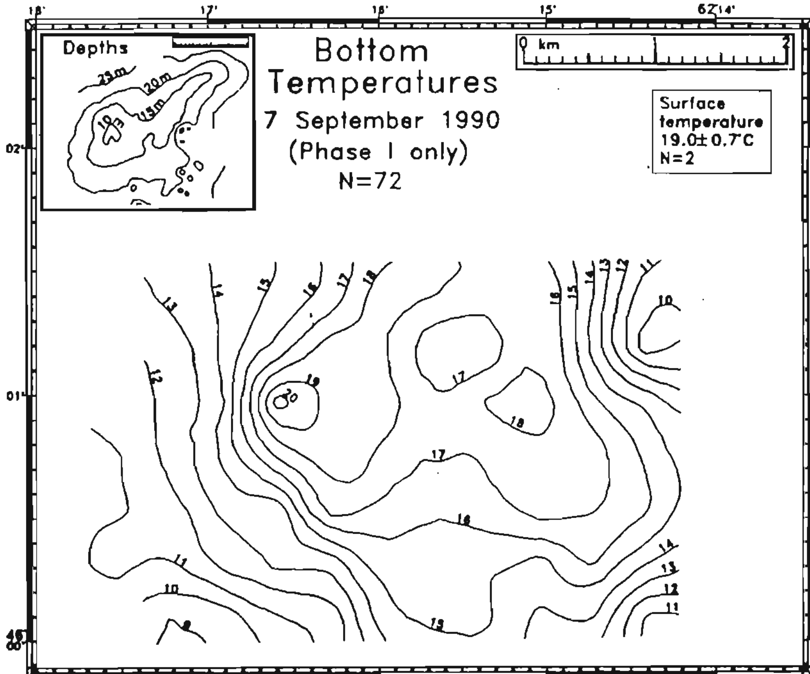
1' longitude = 0.5895099 $\pi$ cos (latitude).

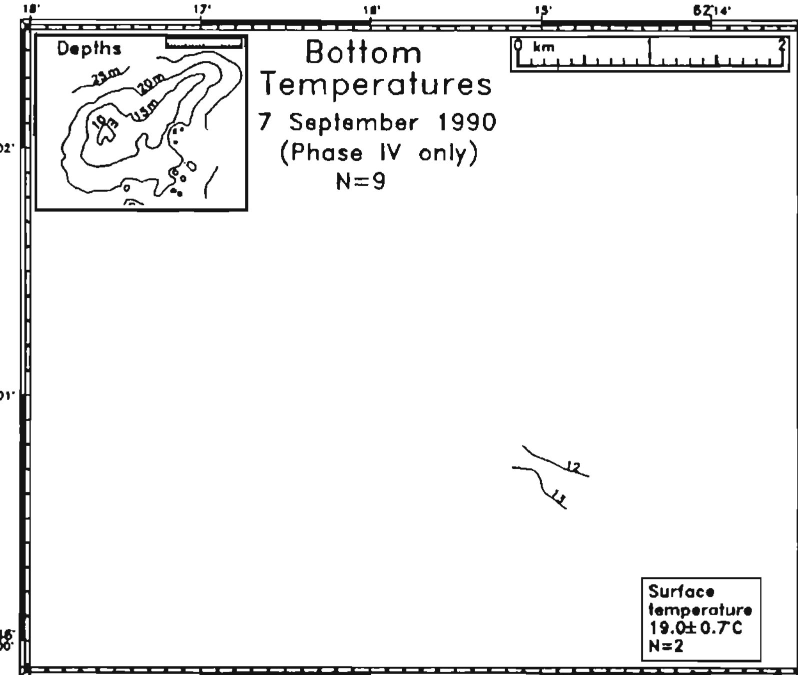
This indicates that a minute of longitude at Fisherman's Bank (46°01'N) is equivalent to 1.28611 km.

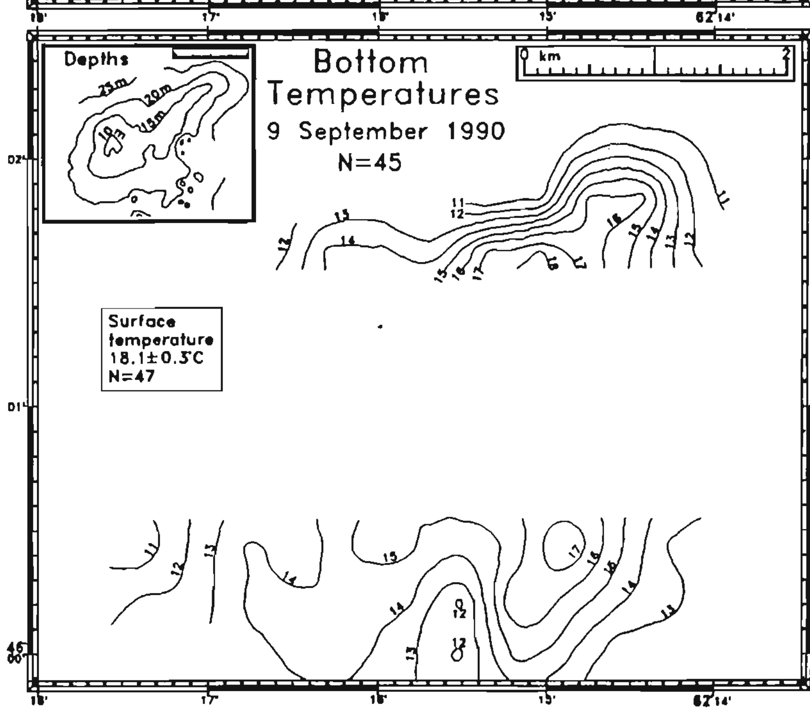
**Appendix B**
Surface and bottom temperatures at Fisherman's Bank, 1990.

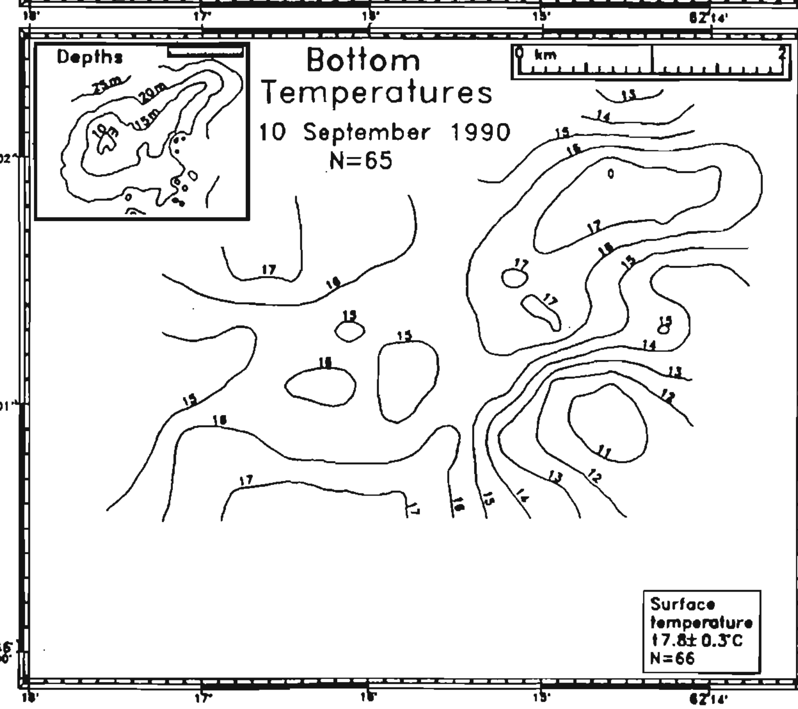


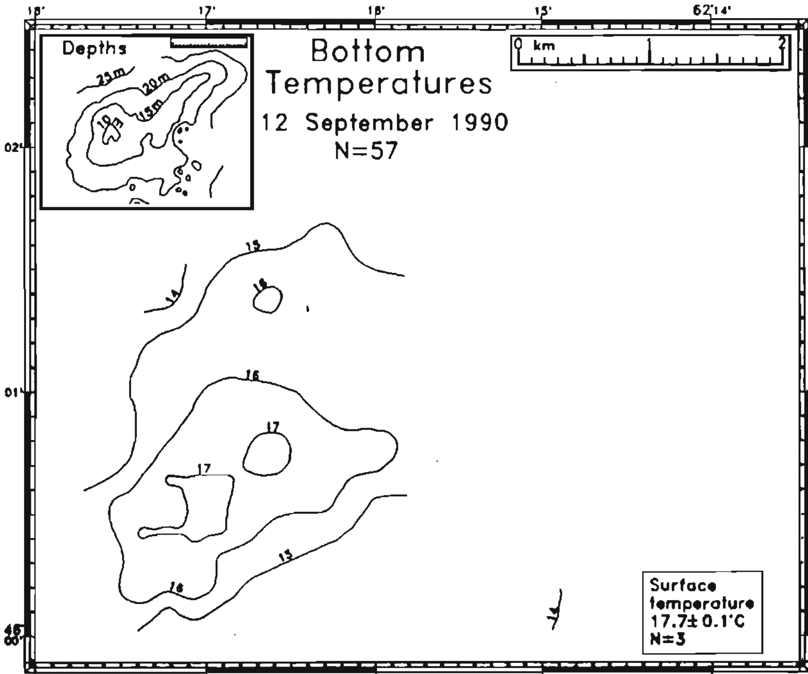

Bottom Temperatures
31 August 1990
N=4
Depths
25m
20m
15m
10m
0 km 1 2
+10.2'
10.2'+
+13.1'
+13.1'
Bottom Temperatures
4 September 1990
N=34
Surface temperature
19.4± 0.1°C
N=35
Bottom Temperatures
5 September 1990
N=49
Surface temperature
19.1± 0.1°C
N=7
Bottom Temperatures
6 September 1990
N=51
Surface temperature
19.2± 0.1°C
N=5
18'
17'
16'
15'
62°14'
02'
01'
45°00'

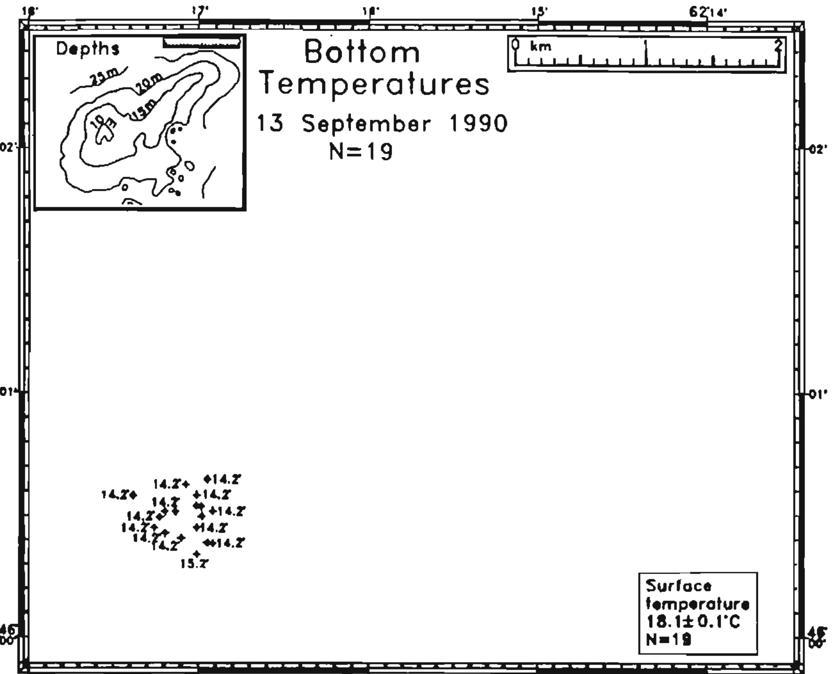

Depths
Bottom Temperatures
7 September 1990
(Phase I only)
N=72
km
Surface temperature
19.0±0.7°C
N=2

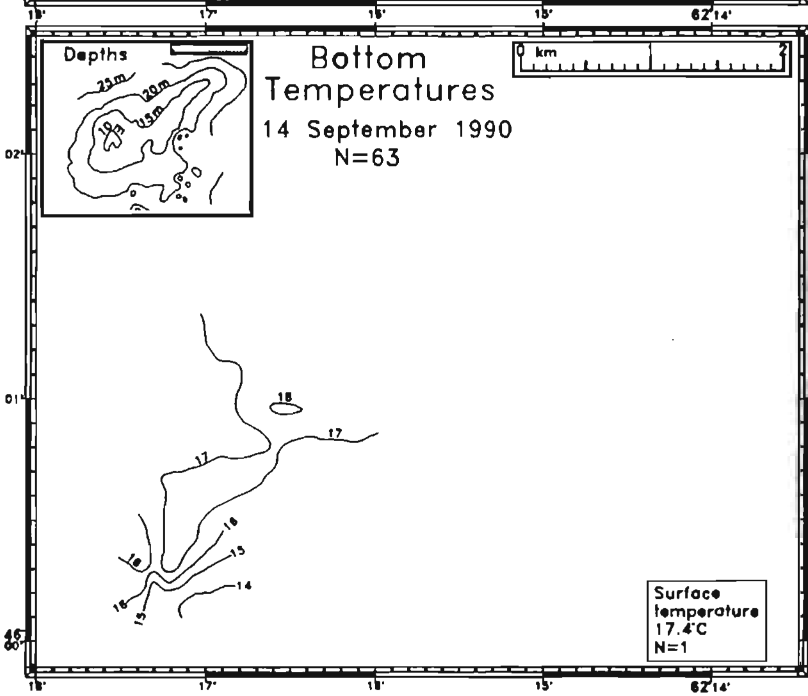

Depths
Bottom Temperatures
7 September 1990
(Phase IV only)
N=9
km
Surface temperature
19.0±0.7°C
N=2

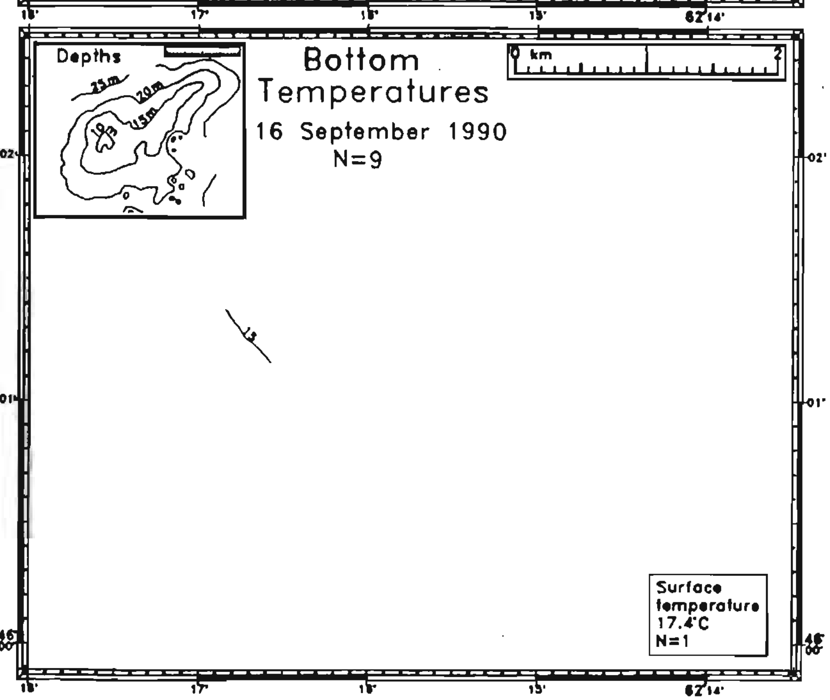

Depths
Bottom Temperatures
9 September 1990
N=45
km
Surface temperature
18.1±0.3°C
N=47

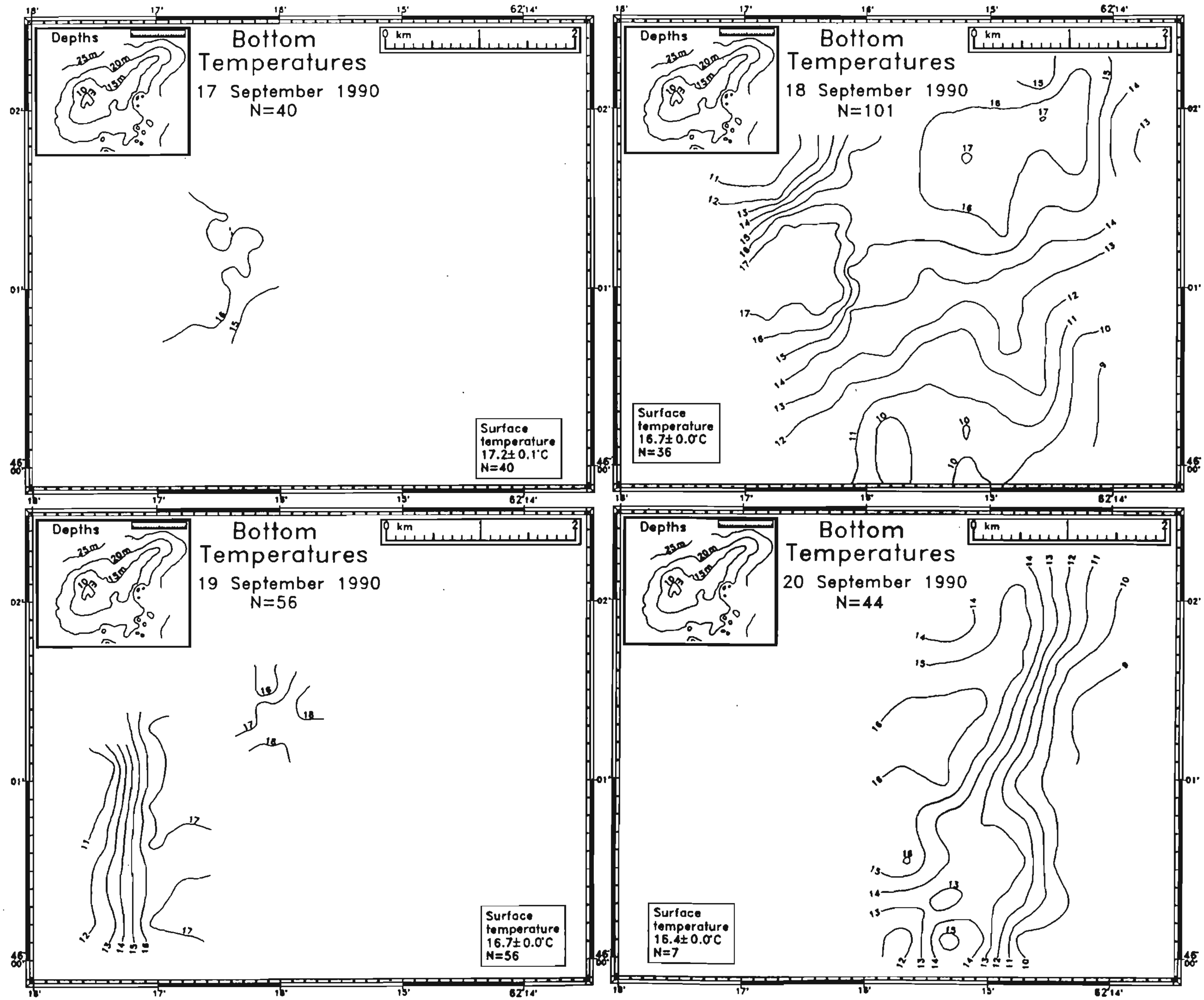

Depths
Bottom Temperatures
10 September 1990
N=65
km
Surface temperature
17.8±0.3°C
N=66


Depths
25m
20m
15m
10m
km
0
2
Bottom Temperatures
12 September 1990
N=57
Surface temperature
17.7± 0.1°C
N=3

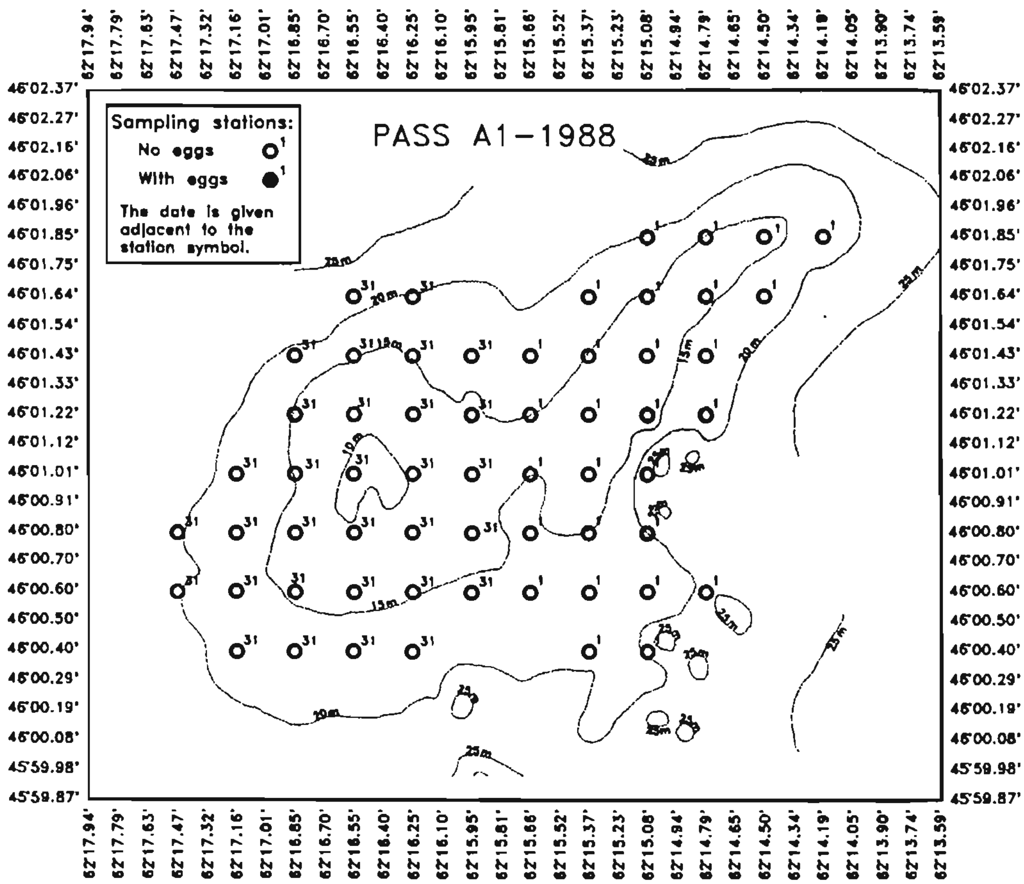

Depths
25m
20m
15m
10m
km
0
2
Bottom Temperatures
13 September 1990
N=19
Surface temperature
18.1± 0.1°C
N=19


Depths
25m
20m
15m
10m
km
0
2
Bottom Temperatures
14 September 1990
N=63
Surface temperature
17.4°C
N=1

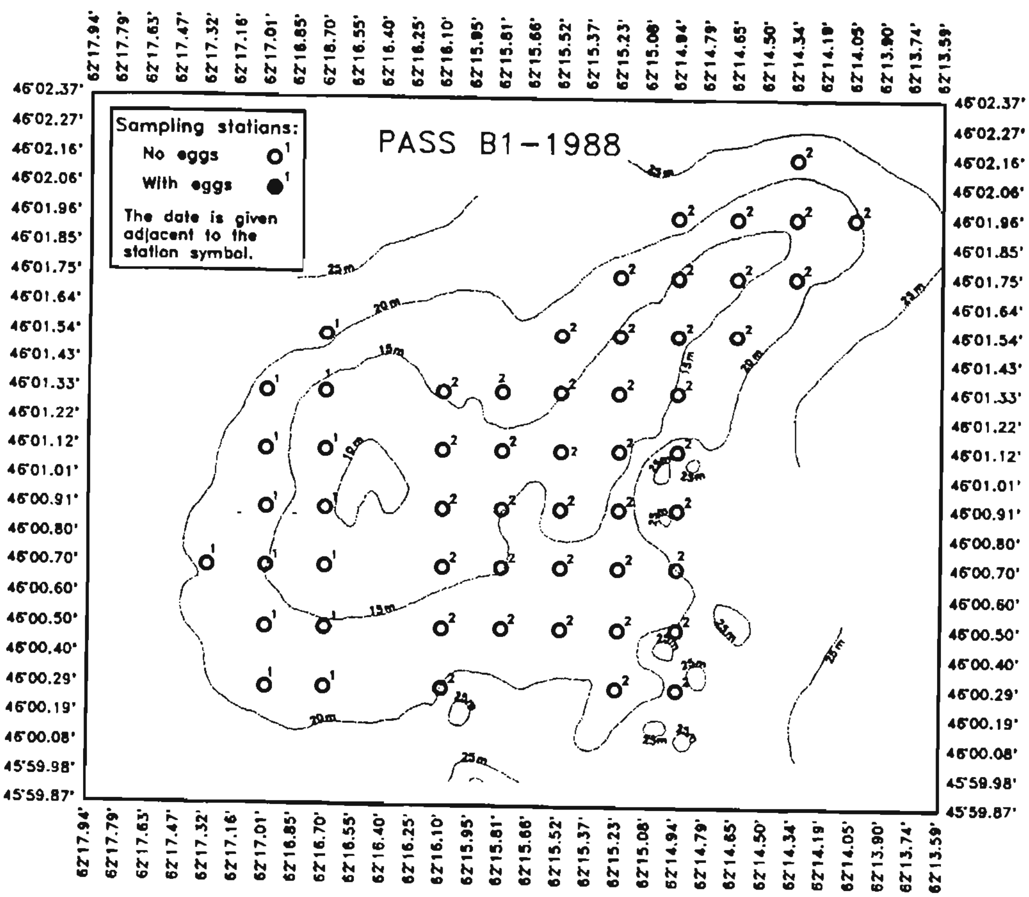

Depths
25m
20m
15m
10m
km
0
2
Bottom Temperatures
16 September 1990
N=9
Surface temperature
17.4°C
N=1


Depths
25m
20m
15m
10
Bottom Temperatures
17 September 1990
N=40
0 km 1 2
Surface temperature 17.2± 0.1°C N=40
Bottom Temperatures
18 September 1990
N=101
Surface temperature 16.7± 0.0°C N=36
Bottom Temperatures
19 September 1990
N=56
Surface temperature 16.7± 0.0°C N=56
Bottom Temperatures
20 September 1990
N=44
Surface temperature 16.4± 0.0°C N=7
62°14'
15'
16'
17'
18'
02'
01'
46° 00'

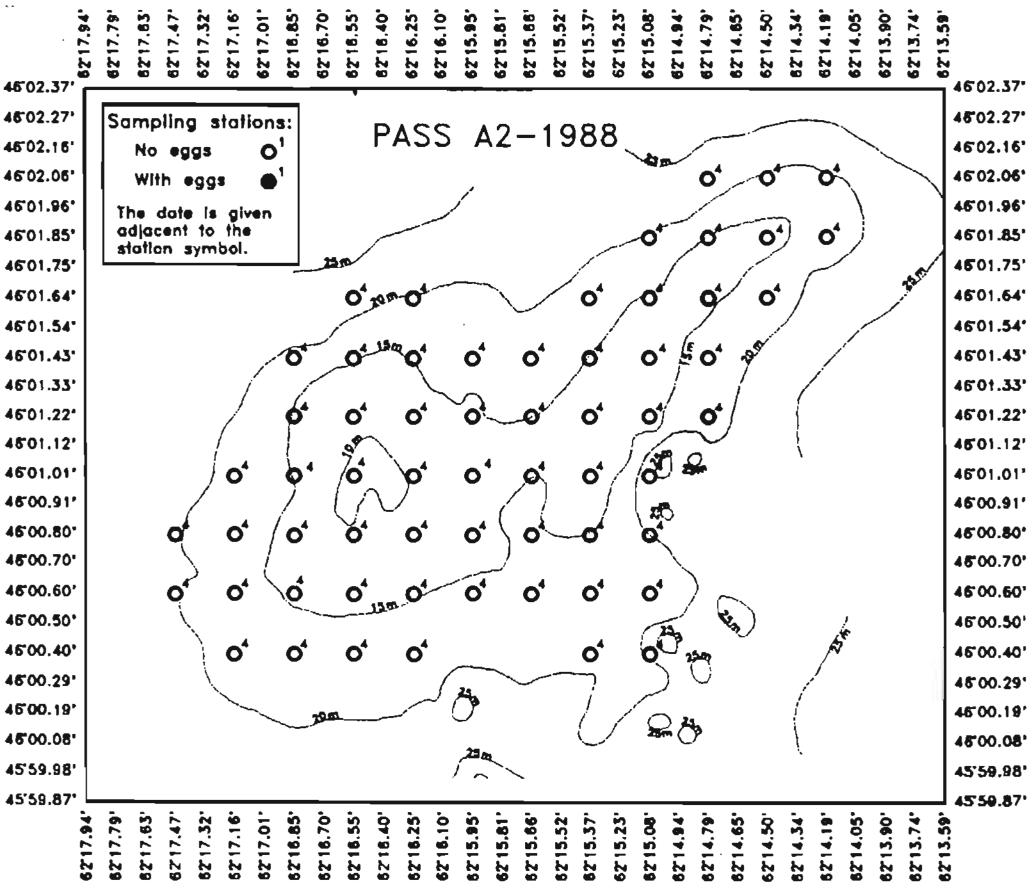
**Appendix C**
**Stations examined on Fisherman's Bank during Phase I sampling, 1988-1990.**



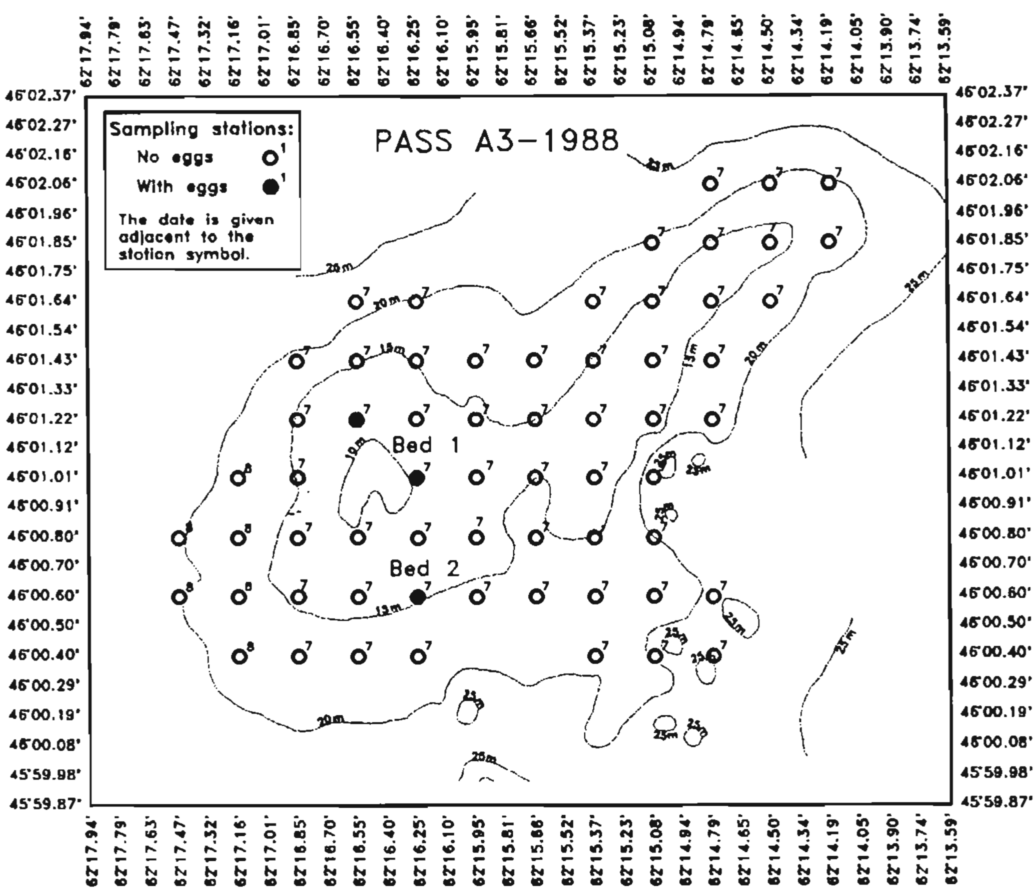

Appendix **C1** Stations on Fisherman's Bank examined during Pass A1, Phase I sampling, 31 August and 1 September 1988.



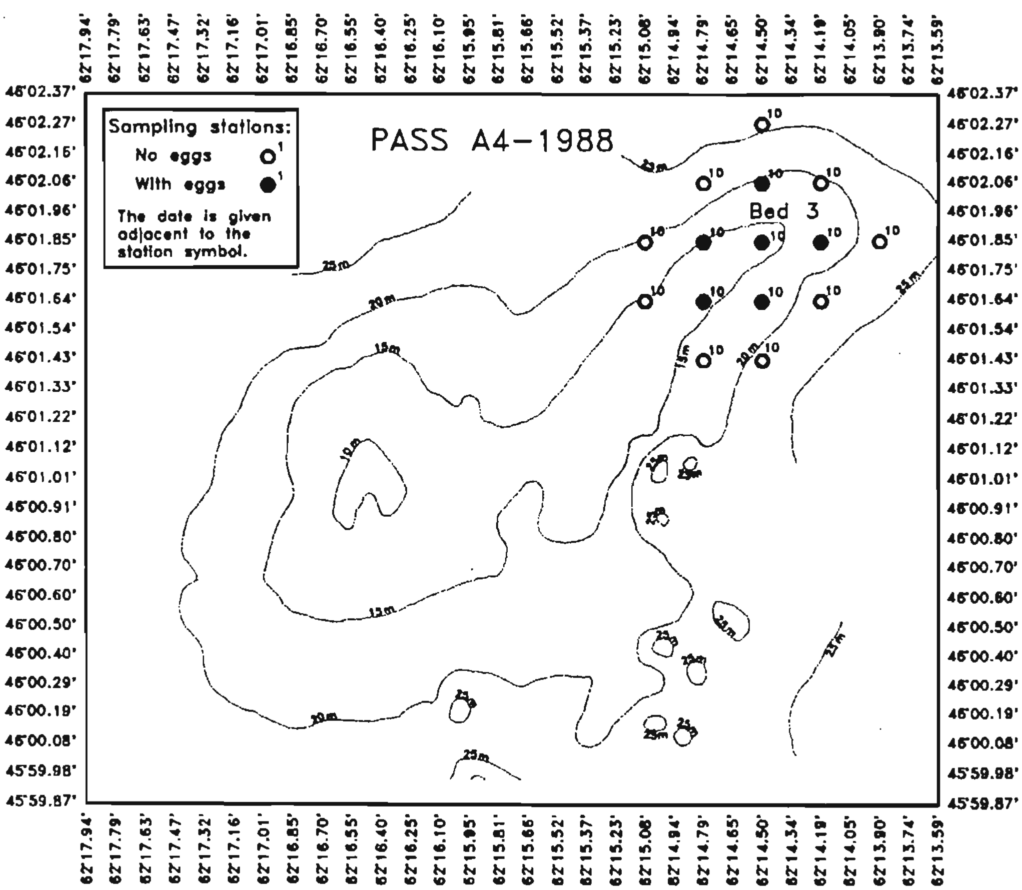

Appendix **C2** Stations on Fisherman's Bank examined during Pass B1, Phase I sampling, 1 and 2 September 1988.



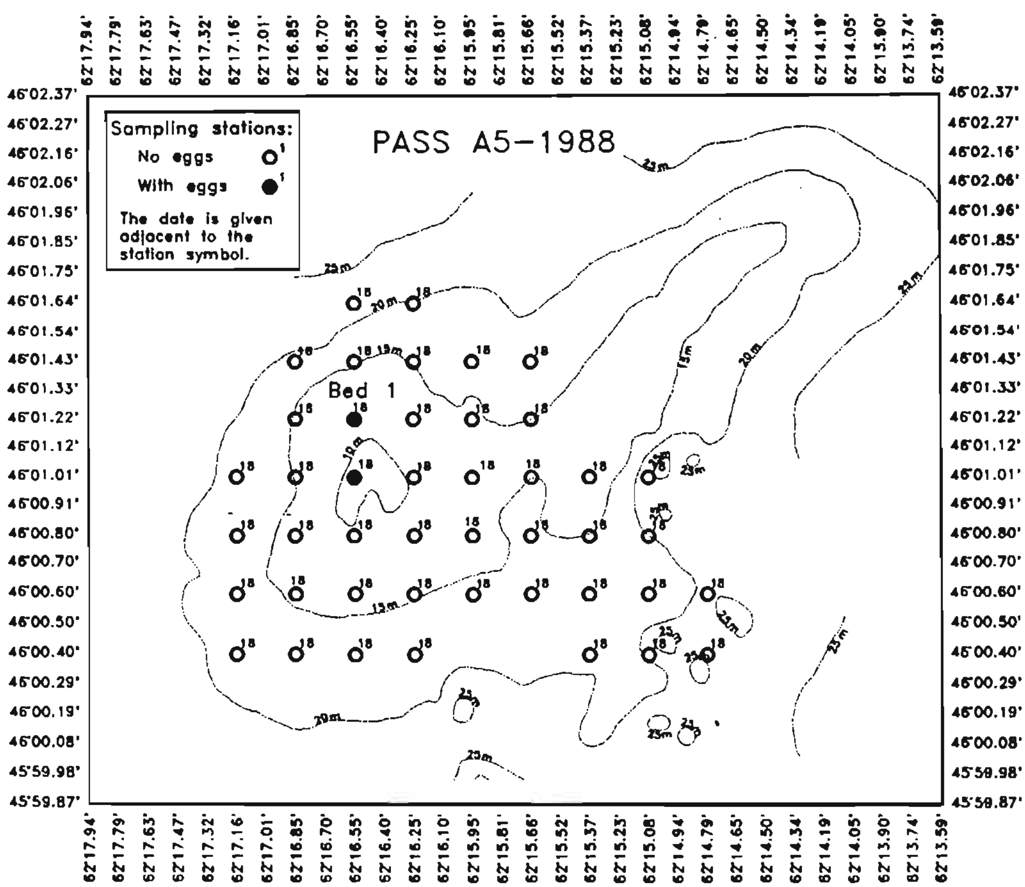

Appendix C3 Stations on Fisherman's Bank examined during Pass A2, Phase I sampling, 4 September 1988.



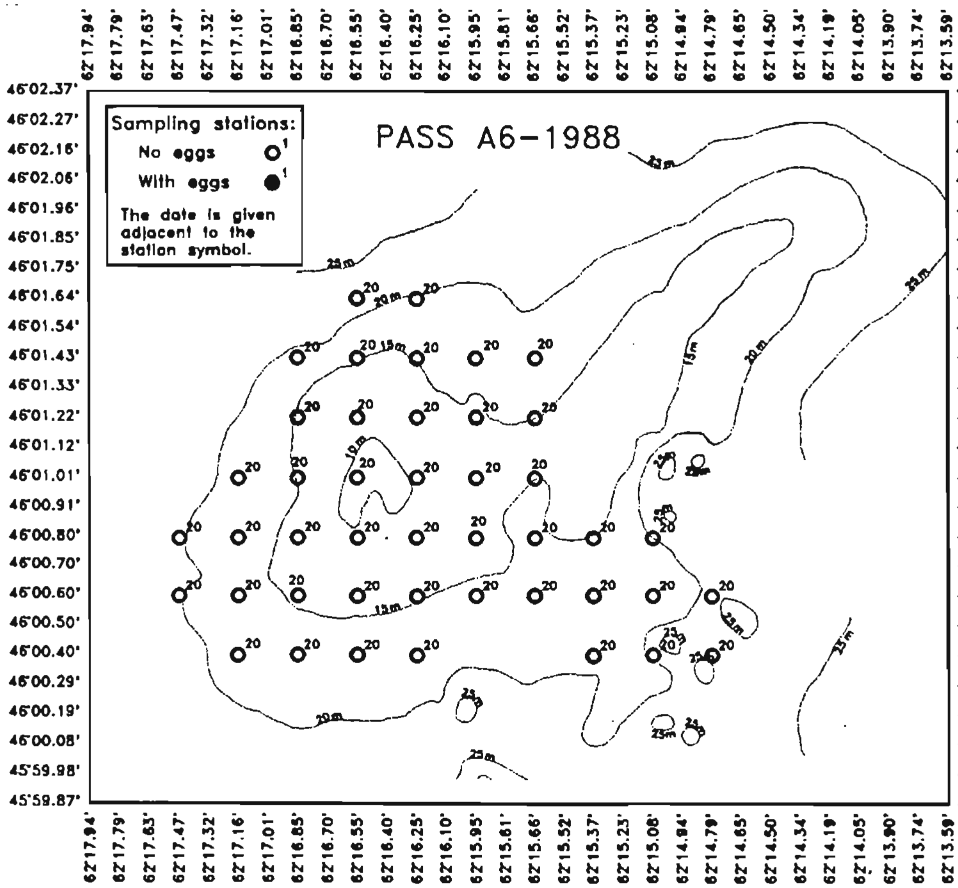

Appendix C4 Stations on Fisherman's Bank examined during Pass A3, Phase I sampling, 7 and 8 September 1988.



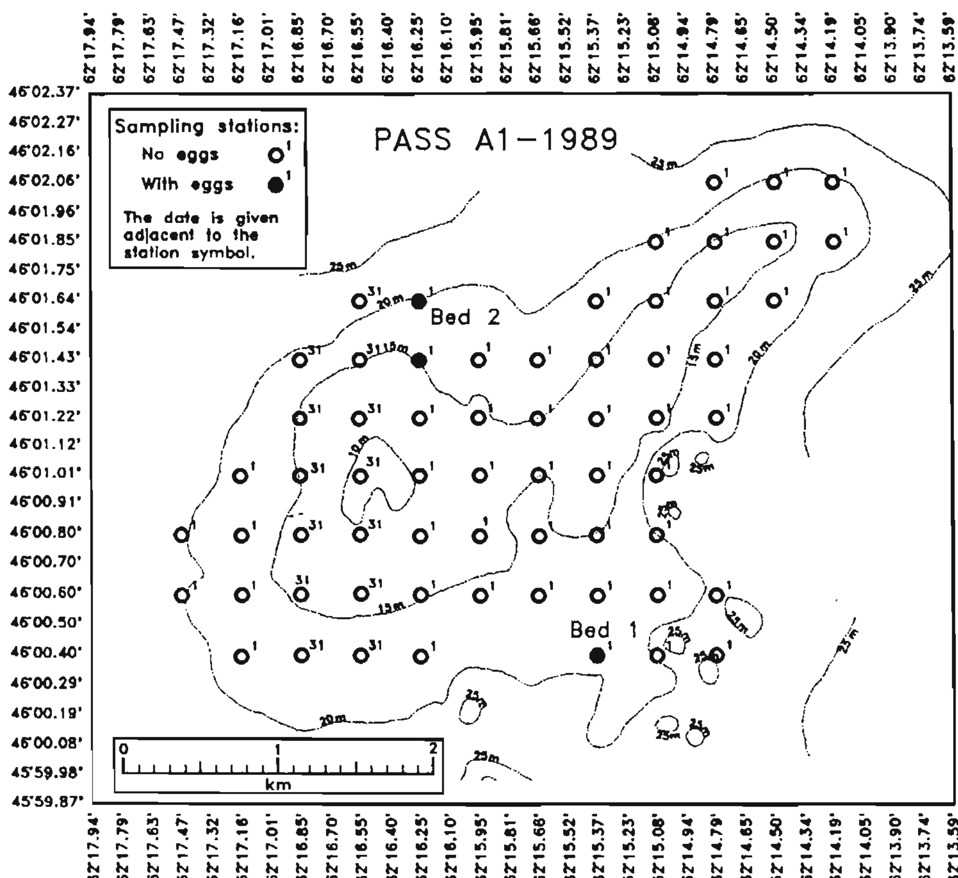

Appendix C5 Stations on Fisherman's Bank examined during Pass A4, Phase I sampling, 10 September 1988.



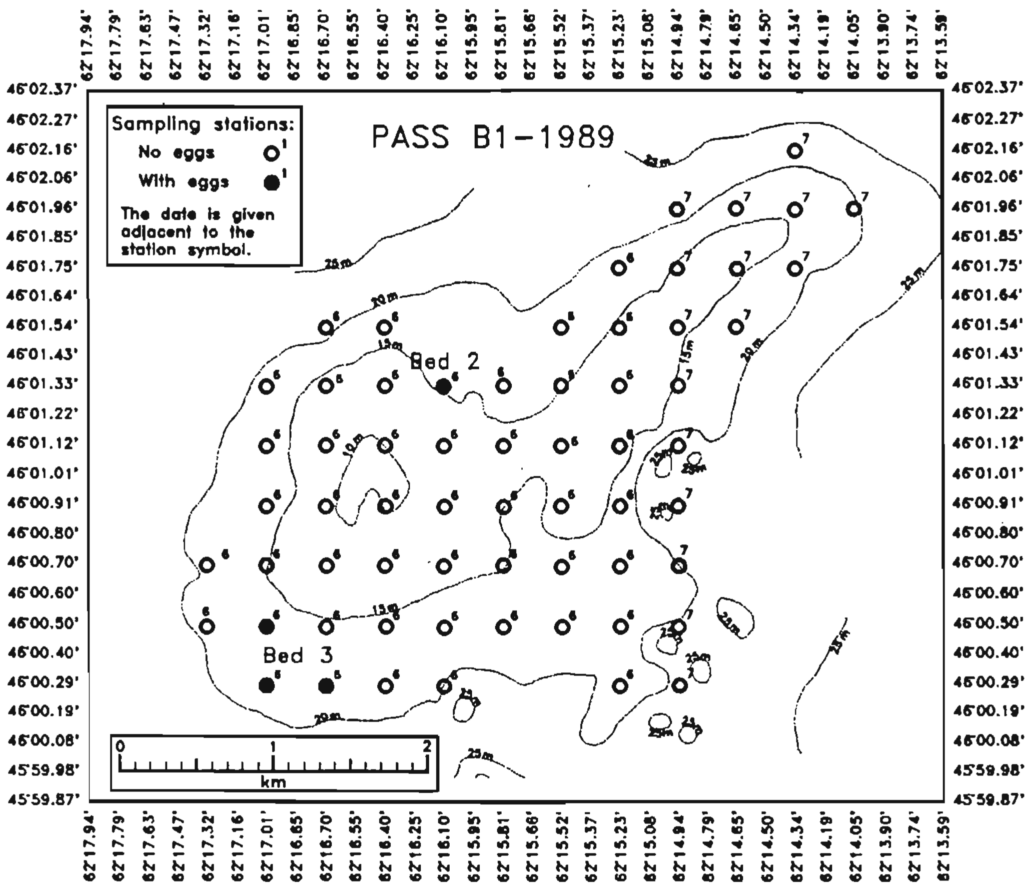

Appendix C6 Stations on Fisherman's Bank examined during Pass A5, Phase I sampling, 18 September 1988.



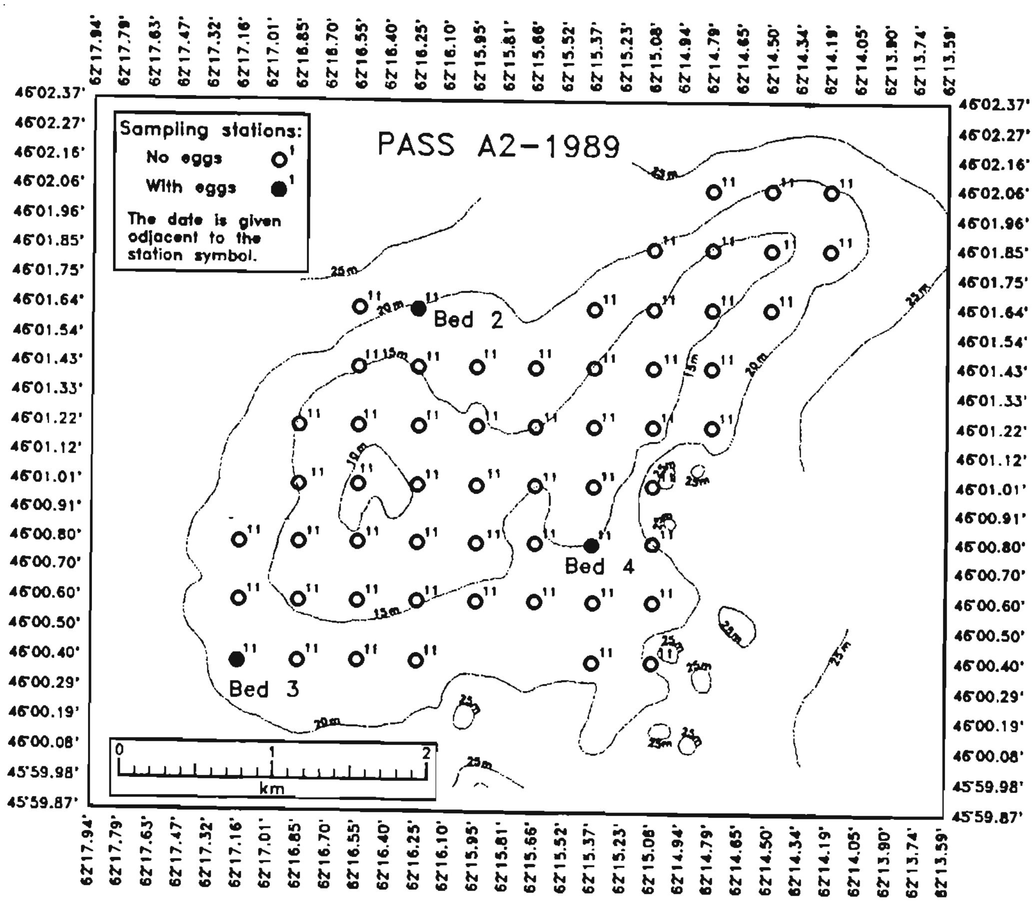

Appendix C7 Stations on Fisherman's Bank examined during Pass A6, Phase I sampling, 20 September 1988.



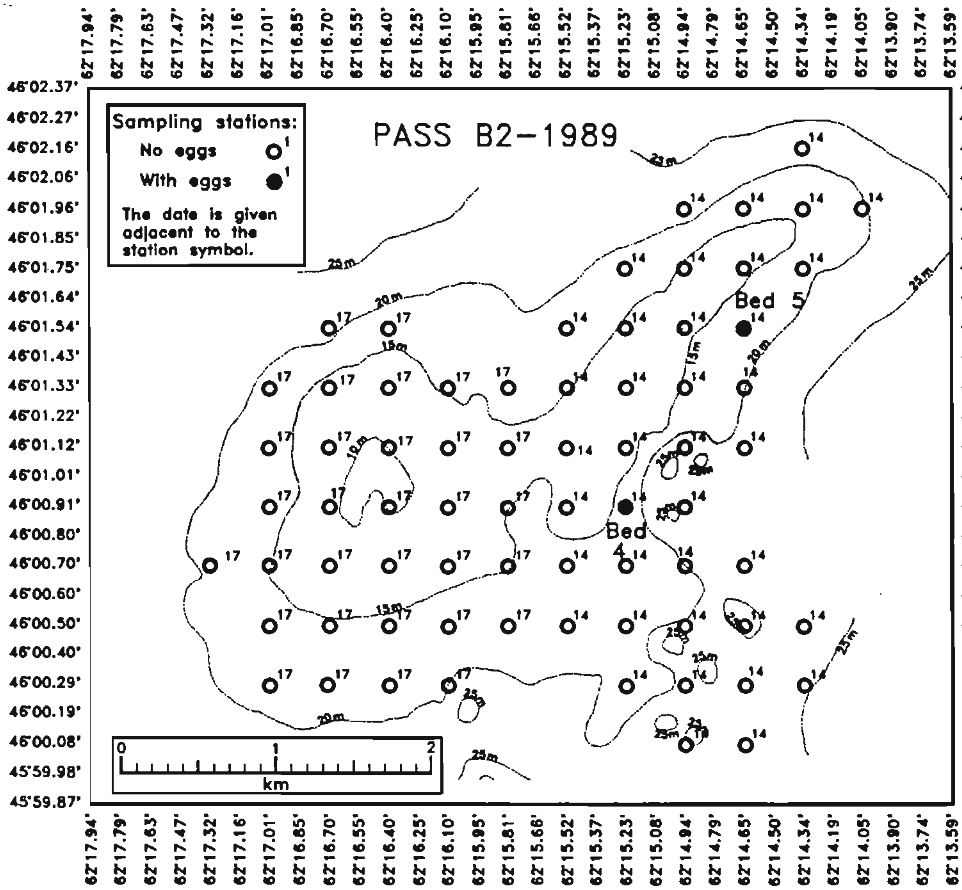

Appendix C8 Stations on Fisherman's Bank examined during Pass A1, Phase I sampling, 31 August and 1 September 1989.



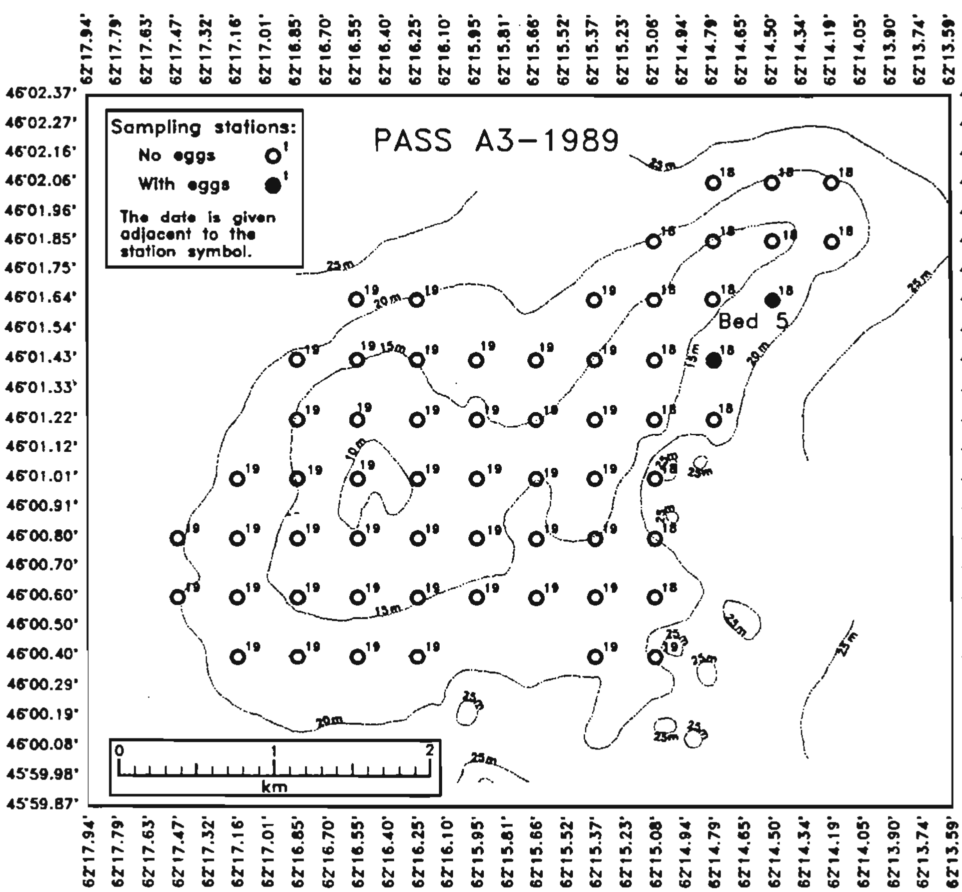

Appendix C9 Stations on Fisherman's Bank examined during Pass B1, Phase I sampling, 6 and 7 September 1989.



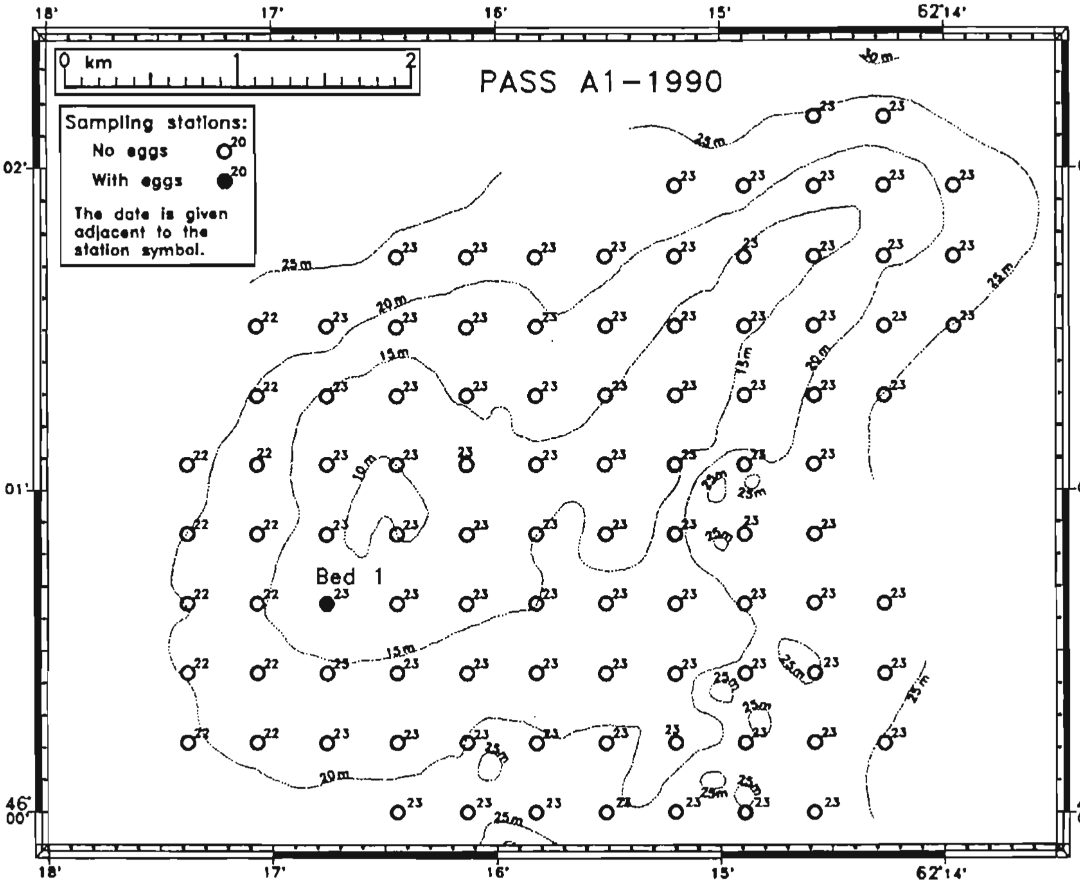

Appendix C10 Stations on Fisherman's Bank examined during Pass A2, Phase I sampling, 11 September 1989.



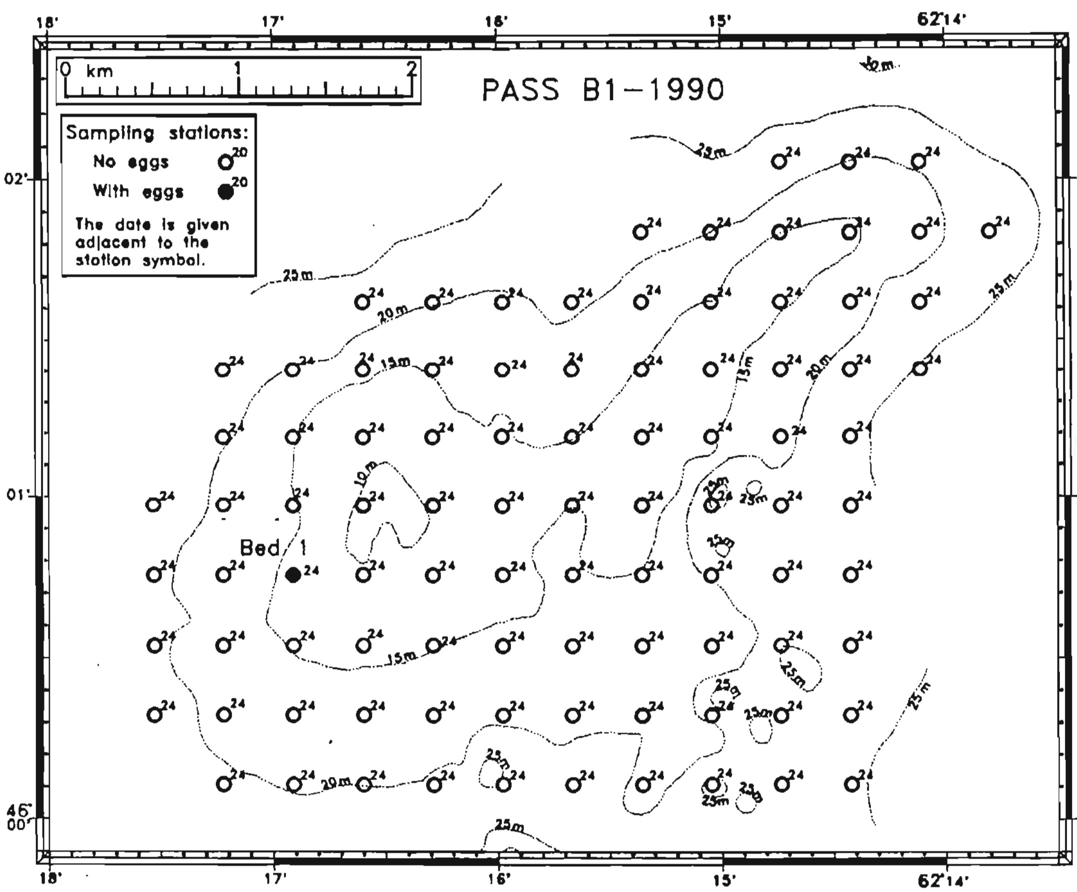

Appendix C11 Stations on Fisherman's Bank examined during Pass B2, Phase I sampling, 14 and 17 September 1989.



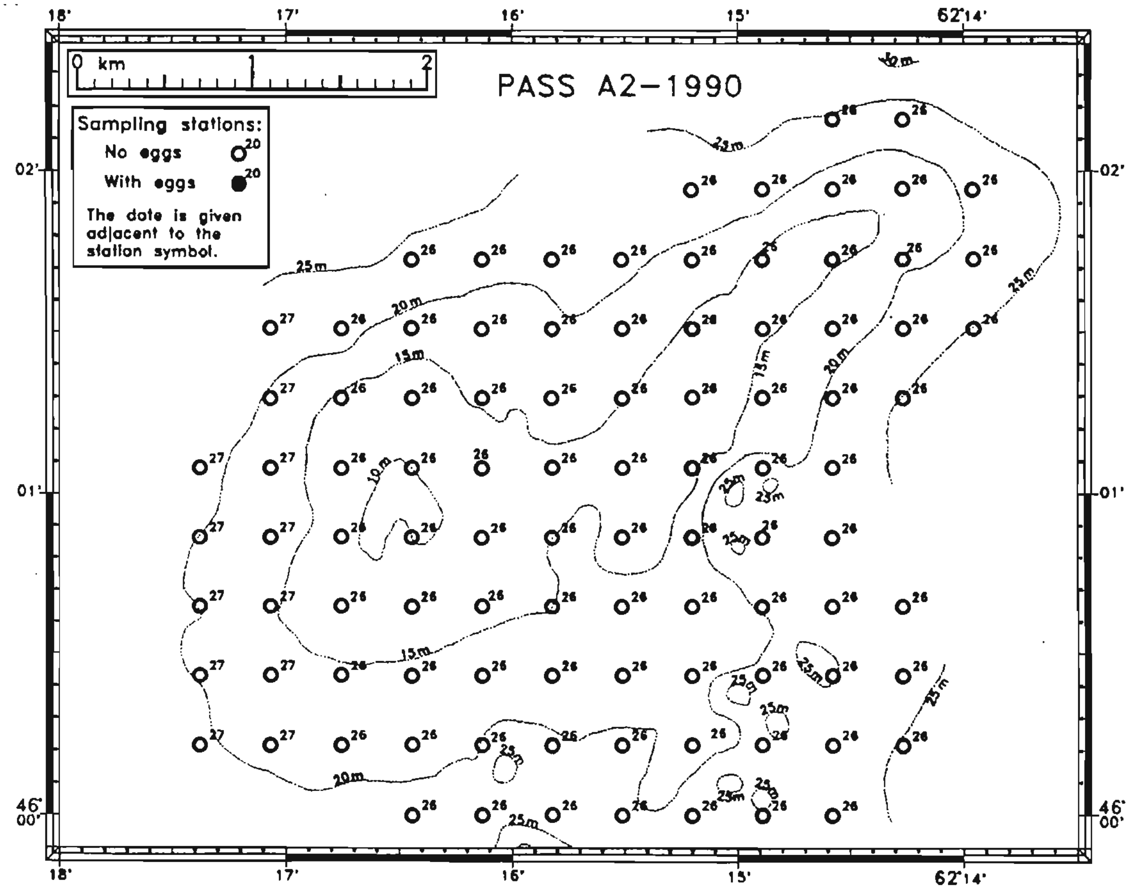

Appendix C12 Stations on Fisherman's Bank examined during Pass A3, Phase I sampling, 18 and 19 September 1989.



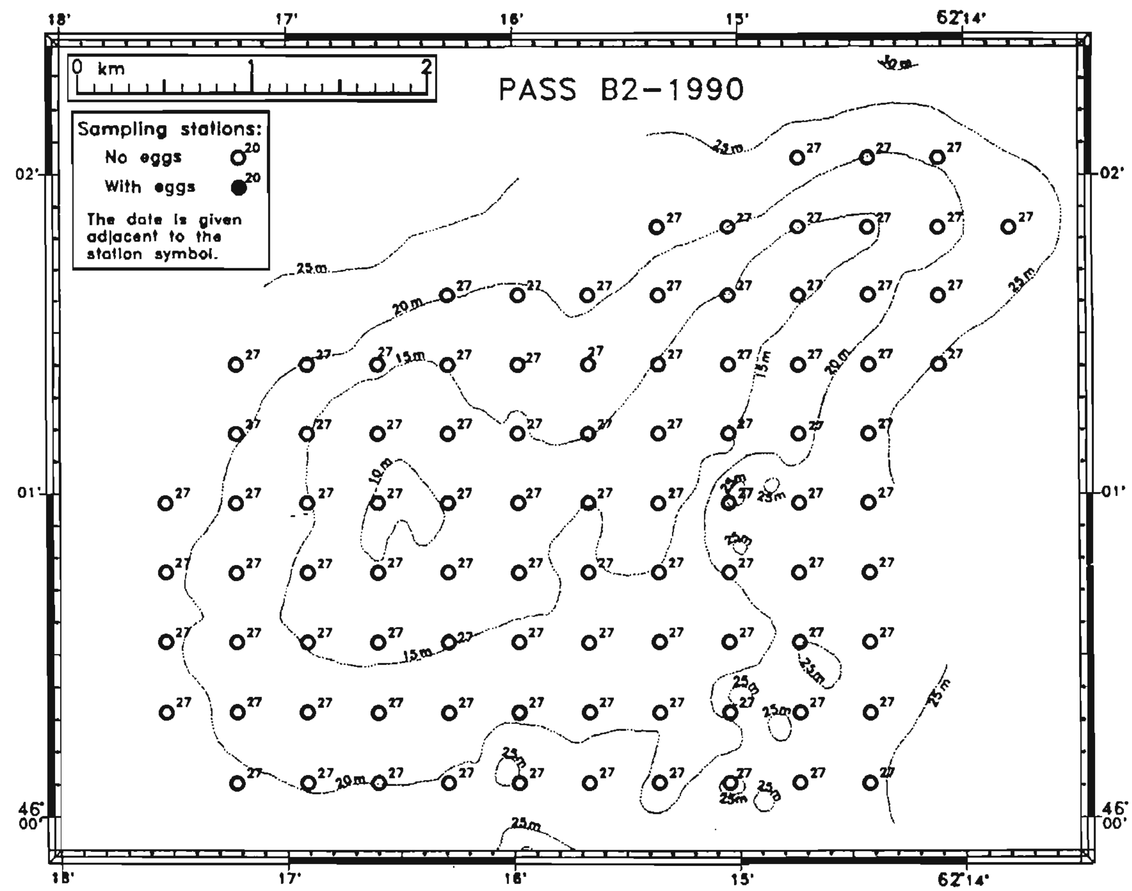

Appendix C13 Stations on Fisherman's Bank examined during Pass A1, Phase I sampling, 22-23 August 1990.



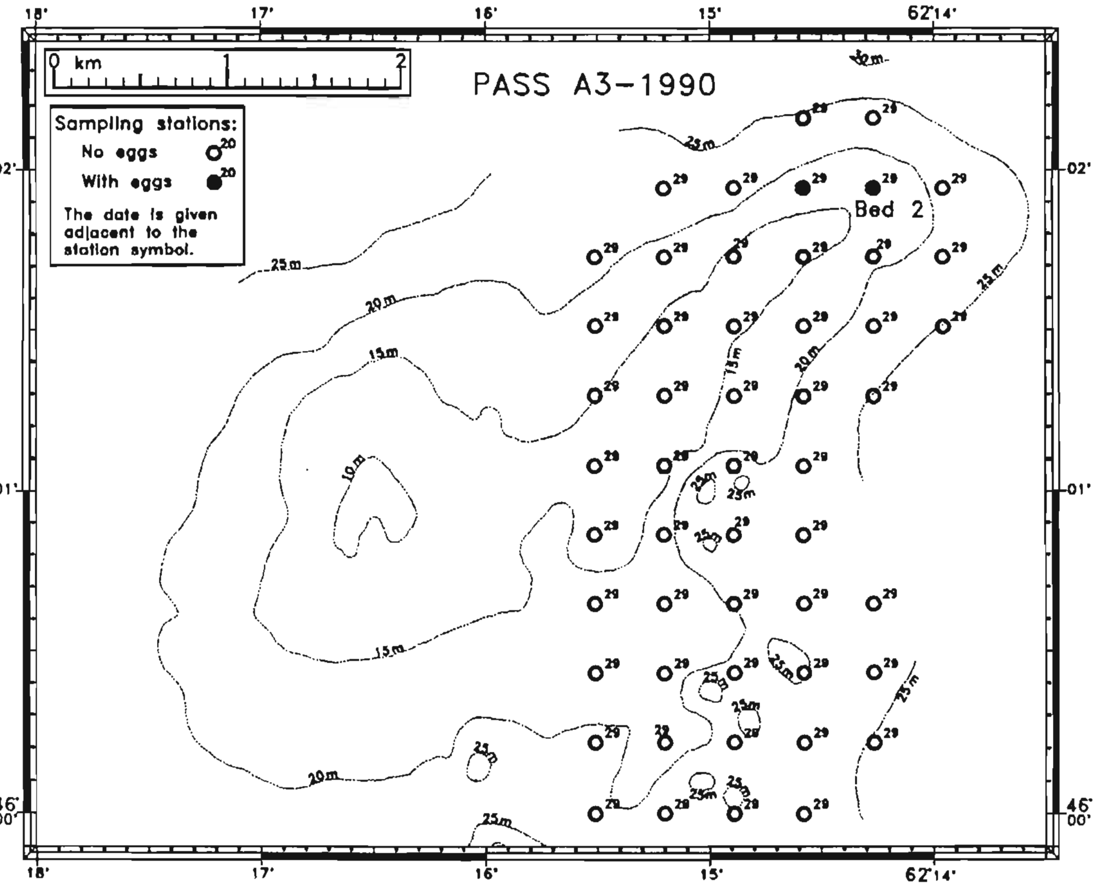

Appendix C14 Stations on Fisherman's Bank examined during Pass B1, Phase I sampling, 24 August 1990.



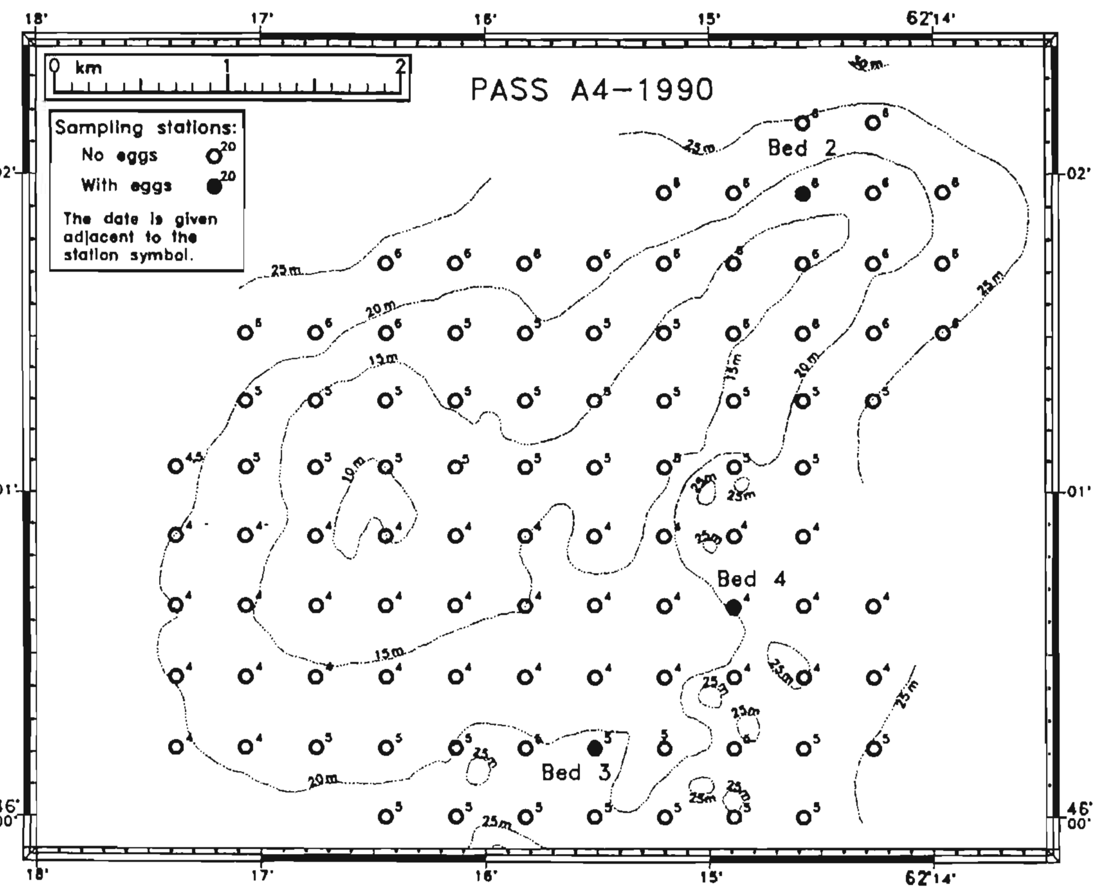

Appendix C15 Stations on Fisherman's Bank examined during Pass A2, Phase I sampling, 26-27 August 1990.



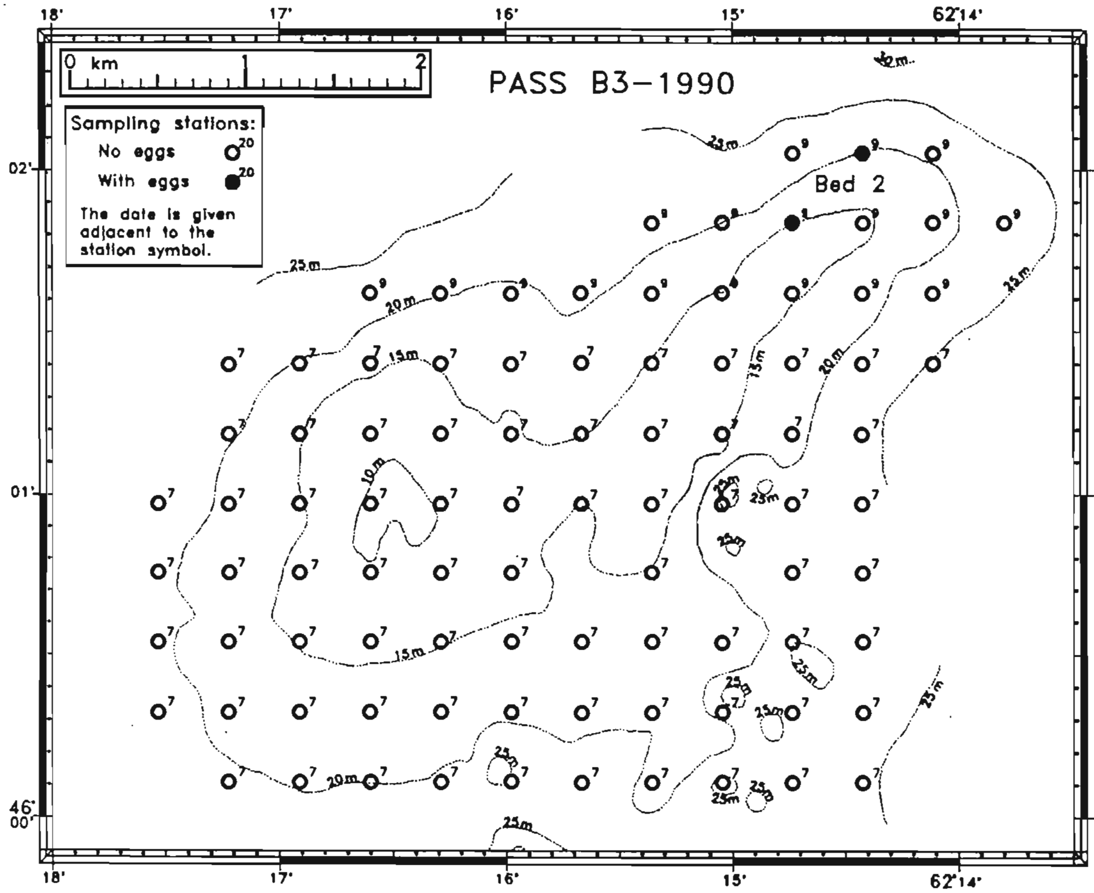

Appendix C16 Stations on Fisherman's Bank examined during Pass B2, Phase I sampling, 27 August 1990.



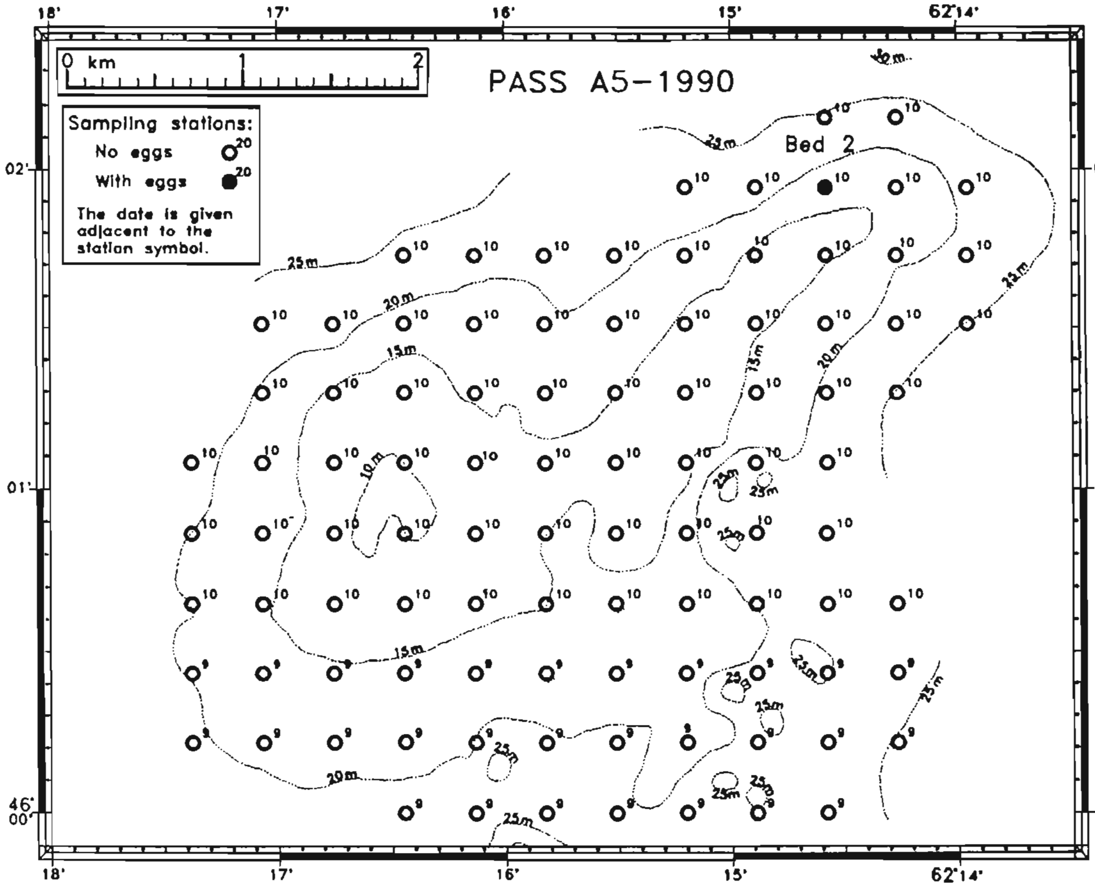

Appendix C17 Stations on Fisherman's Bank examined during Pass A3, Phase I sampling, 29 August 1990.



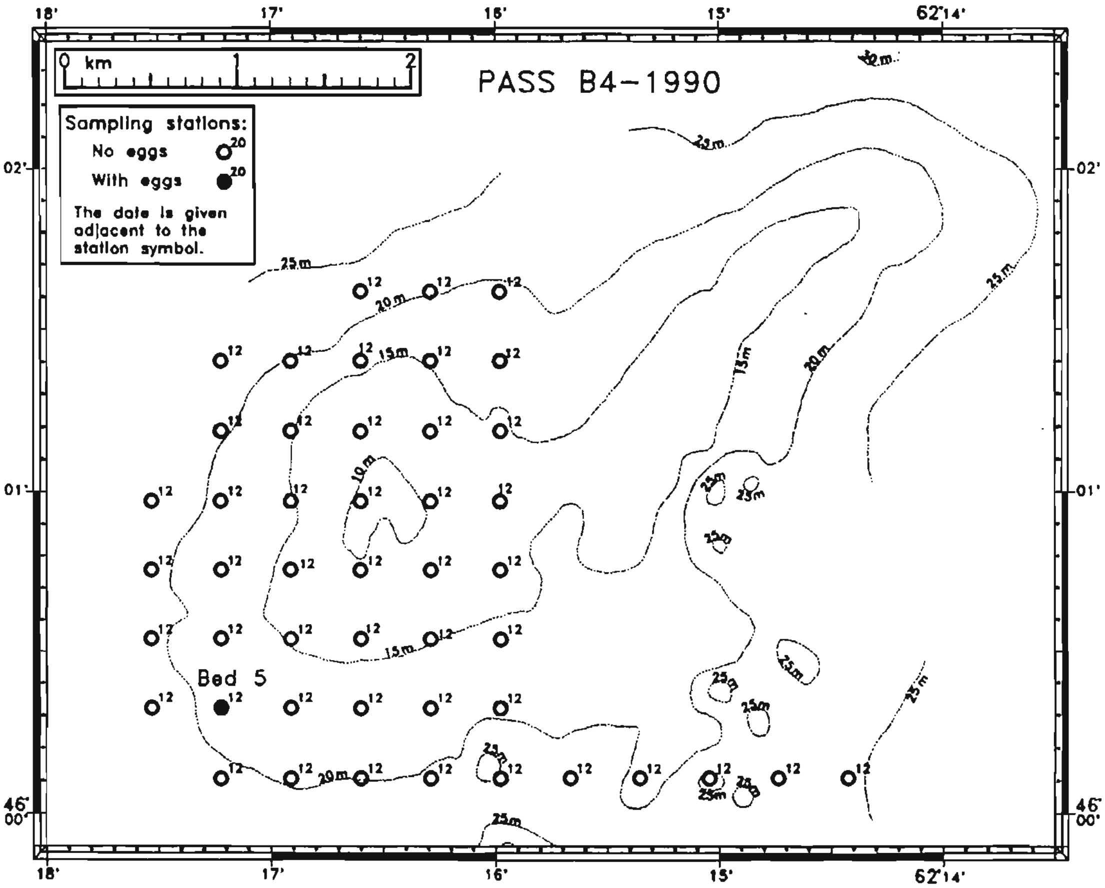

Appendix C18 Stations on Fisherman's Bank examined during Pass A4, Phase I sampling, 4-6 September 1990.



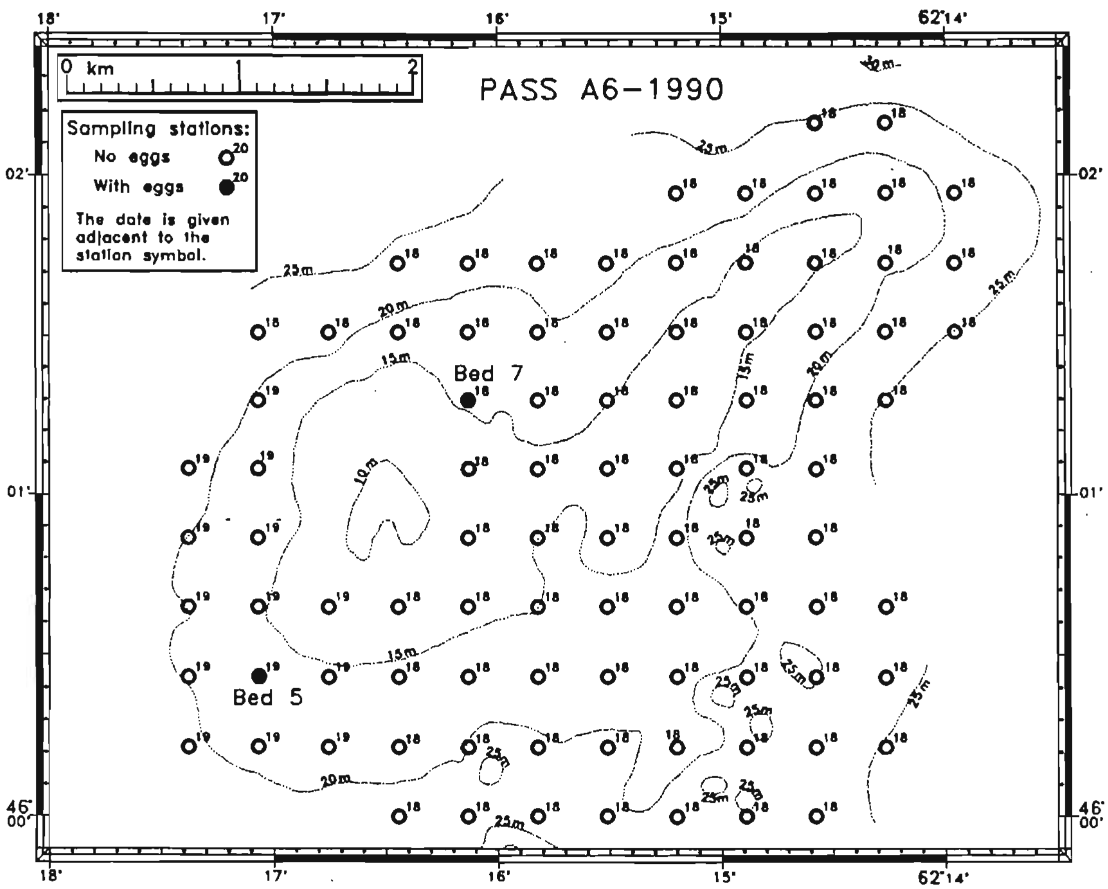

Appendix C19 Stations on Fisherman's Bank examined during Pass B3, Phase I sampling, 7–9 September 1990.



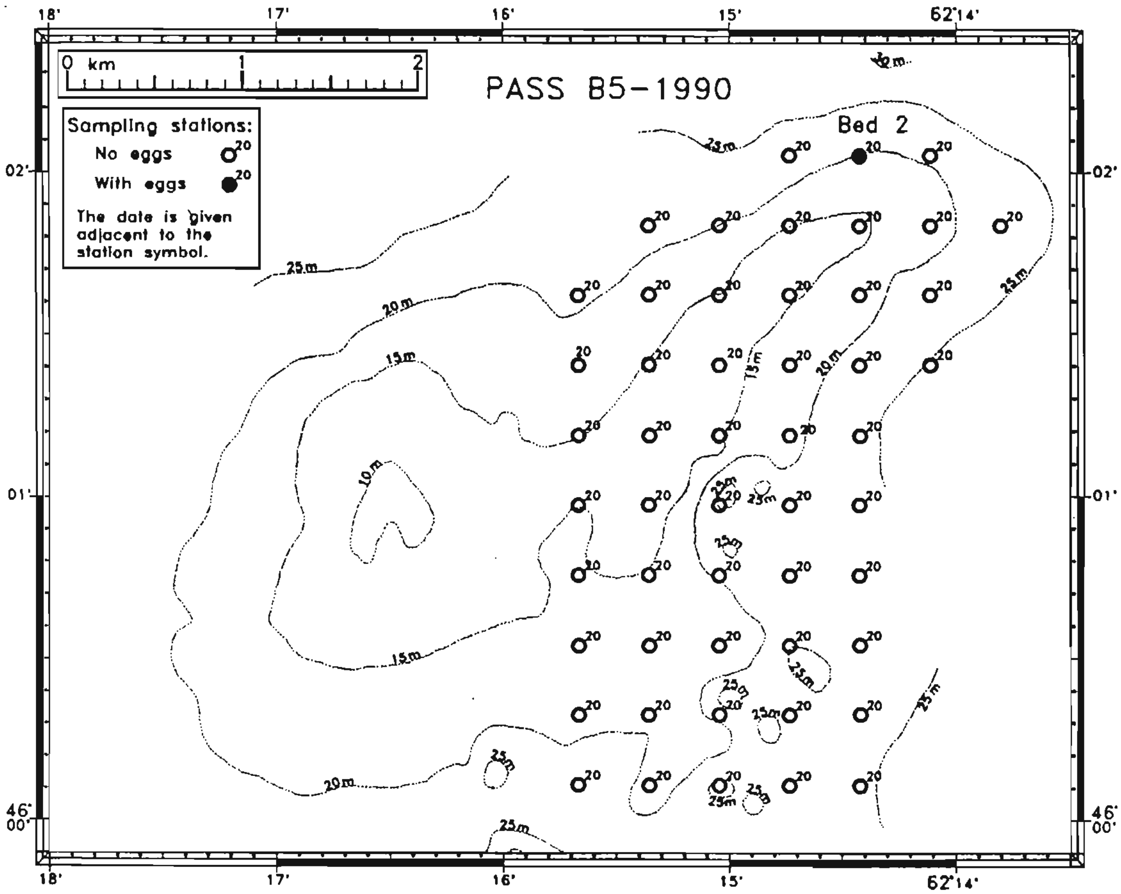

Appendix C20 Stations on Fisherman's Bank examined during Pass A5, Phase I sampling, 9–10 September 1990.



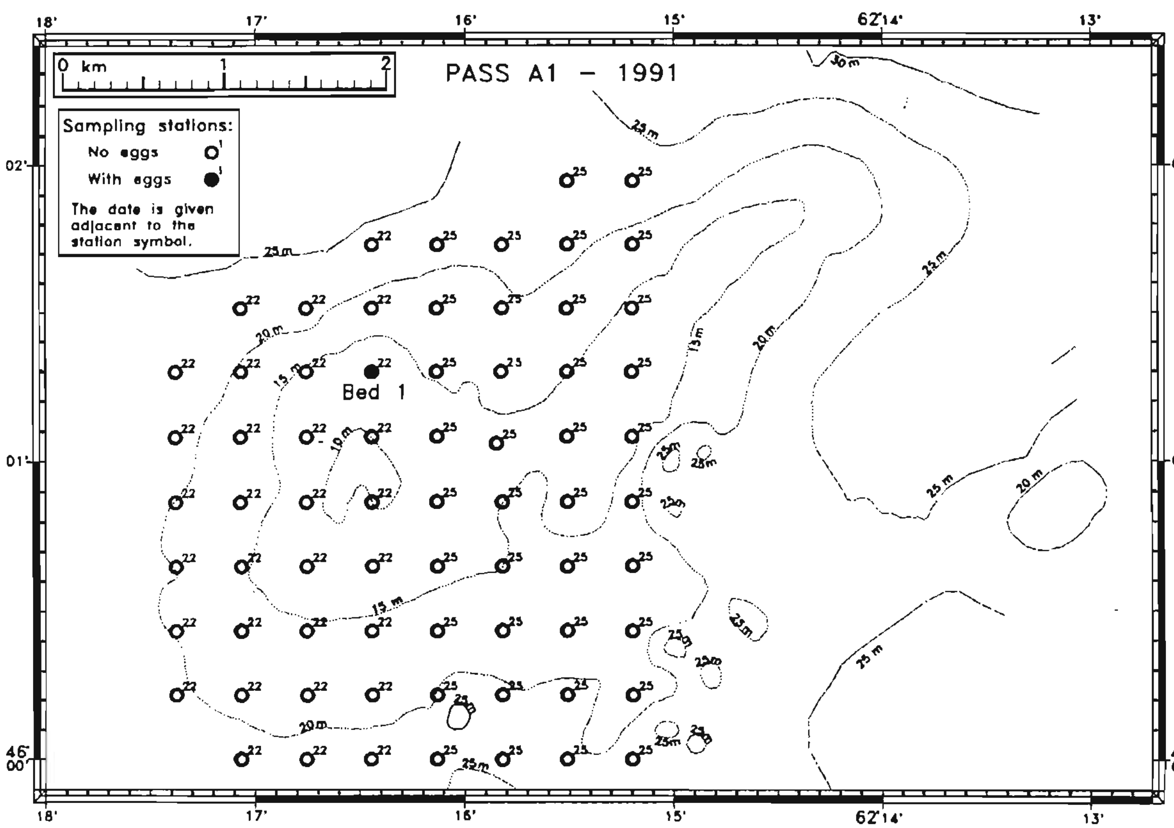

Appendix C21 Stations on Fisherman's Bank examined during Pass B4, Phase I sampling, 12 September 1990.




Appendix C22 Stations on Fisherman's Bank examined during Pass A6, Phase I sampling, 18-19 September 1990.




Appendix **C23** Stations on Fisherman's Bank examined during Pass B5, Phase I sampling, 20 September 1990.




Appendix **C24** Stations on Fisherman's Bank examined during Pass A1, Phase I sampling, 22–25 August 1991.