Incorporating Fixed and Repeat Sets in the Stratified Random Survey for Groundfish in the Southern Gulf of St. Lawrence

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ABSTRACT

Research vessel data collected in the southern Gulf of St. Lawrence from 1971 to 1988 were analyzed to assess the effect of including non-randomly allocated fishing stations in abundance indices for Atlantic cod, American plaice, and white hake. Five methods were used. The biggest changes from the established abundance indices occurred for the period from 1985 to 1988, with all methods of adding stations resulting in a lower mean number of cod caught per tow for 1985 and 1986, lower mean number of plaice caught per tow for 1985, and substantial differences in the number of white hake caught per tow from 1985 to 1988. Although the alternative methods violate statistical properties, it is recommended that fishing sets at all locations be included in the calculation of research vessel abundance indices, treating fixed stations as random, and averaging repeat sets for cod and plaice, but including only the first of repeated sets for white hake.

INTRODUCTION

The abundance index for groundfish stocks in the southern Gulf of St Lawrence consists of a 24-year time series of surveys conducted in autumn in NAFO Division 4T (Figure 1). The *E.E.Prince* was used from 1971 to 1985, the *Lady Hammond* from 1986 to 1991, and the *Alfred Needler* from 1992 onwards. In 1985, the *Lady Hammond* fished alongside the *E.E.Prince* for a comparison between the two vessels; in 1992, a comparison between the *Lady Hammond* and the *Alfred Needler* was made one month prior to the groundfish survey.

Stratified random surveys were conducted from 1971 to 1983. Starting with the 1984 survey, a fixed design was used with stations chosen from those fished in the previous three years (Hurlbut and Clay, 1990). The stations chosen in 1984 were fished until 1987, and starting in 1988 the survey design reverted to the stratified random scheme used earlier. In 1984, 3 strata (401-403) were added to the design. From 1984 to 1987, several stations were fished more than once in a survey - some as many as 8 or more times.

During the comparative fishing experiment between the *E.E.Prince* and the *Lady Hammond* in 1985, stations were fished at night as well as during the day, with the *E.E.Prince* being limited to daytime fishing only. In 1985, additional fixed fishing locations were chosen because of the increase in available fishing time, and, since 1985, fishing sets have been made in both the day and the night. In 1988, a comparison of daytime and nighttime fishing was made by fishing many stations once in each time period.

Beginning in the mid-1950s, seasonal surveys using 26 fixed stations were conducted annually in the southwestern Gulf of St Lawrence (Halliday and Koeller, 1981). By the 1960s, the number of fixed fishing stations had been reduced to 13 of the original stations. These 13 stations in northwestern 4T continued to be fished until 1988, along with the annual groundfish survey stations.

The abundance indices for groundfish stocks in 4T use only the stratified random stations fished from 1971 to 1983, only the 61 stations fished in each year from 1984 to 1987, and only the daytime sets fished in 1988 (Table 1). Since 1989, the survey design has been consistent, with all sets allocated randomly within strata. The question is whether all the fishing sets over the entire time period can be used in the calculation of abundance indices and their variance. Results of various methods of including more sets are summarized here. These initial analyses focus on results for 4T Atlantic cod, white hake, and American plaice.

METHODS

The stratified mean number of fish caught per standard tow (1.75 nm), calculated from the annual groundfish surveys, is assumed to be directly proportional to abundance, and is used as an abundance index. To date, the strata added in 1984 have not been included in the indices for cod or plaice, and were not used in these analyses for any of the three species. Calculations follow those described in Cochran (1977), and are summarized here.

The stratified mean catch/tow (in numbers of fish of a species of interest) is calculated:

$$\bar{y}_{st} = \sum_{h=1}^{H} \frac{N_h \bar{y}_h}{N} \qquad (1)$$

where N_h = number of trawlable units (i.e. possible sample units) in stratum h
$\Sigma N_h = N$ = number of trawlable units in the survey area, and

$\bar{y}_h$ = mean number/tow in stratum *h*, calculated from:

$$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h} \qquad (2)$$

where y_{hi} = number of fish caught in tow *i* in stratum *h*

n_h = number of fishing tows (sets) made in stratum *h*

The estimated variance of the stratified mean is:

$$v(\bar{y}_{st}) = \frac{1}{N^2} \sum_{h=1}^{H} N_h(N_h - n_h)\frac{s_h^2}{n_h} \qquad (3)$$

where s_h^2 = estimate of the variance of the mean in stratum *h*, from:

$$s_h^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2 \qquad (4)$$

The stratified mean number/tow thus calculated is referred to here as the assessment index, and the fishing sets included are as described earlier, and referred to as the assessment sets. There are two classes of fishing sets to consider including in the abundance index - repeat sets and sets at fixed stations. The fixed stations fall into two categories: the 13 stations fished in addition to the random stations from 1971 to 1988; and the fixed stations from 1984 to 1987 that were not fished in each year.

Five alternative calculations for an abundance index are condsidered:

Modifications to the current stratified random design:
1) Treat all fixed stations as random; include only the first set at repeated stations (i.e. all fishing stations are included but a weight of zero is given to catches of repeat fishing sets).
2) Treat all fixed stations as random; average all repeat catches before including in a stratum average (i.e. catches are weighted by the number of sets at each station).
3) Treat all fixed stations as random; even repeat sets are considered random (i.e. catches from all fishing sets are weighted equally).

Mixed design with partial replacement of fishing sets:
4) Assume a mixed random and fixed station survey design with partial replacement of stations; stations fished in consecutive years are assumed fixed, all others are assumed random; catches at stations repeated within a year are averaged before inclusion.
5) Assume a mixed random and fixed station survey design with partial replacement of stations; stations fished in consecutive years are assumed fixed, all others are assumed random; only the catch from the first set at a station repeated within a year is included.

The most recent cod and white hake abundance indices have not adjusted catches for differences between the *E.E.Prince* and the *Lady Hammond*, although cod catches have been adjusted for the difference between the *Lady Hammond* and the *Alfred Needler*. American plaice catches have been adjusted for differences between the *E.E.Prince* and the *Lady Hammond*, but not between the *Lady Hammond* and the *Alfred Needler*. In determining the effect of additional fishing sets and locations on the

established abundance indices, adjustments were made to *Lady Hammond* plaice catches to make them comparable to *E.E.Prince* catches, but no other adjustments were made. Because 1988 was the last year for sampling fixed stations and for repeating sets, it was considered unnecessary to include data from the *Alfred Needler* in the present analyses.

Repeat Sets

Stations that were fished more than once during a survey were examined for trends in the catches from the first to last fishing set at that location. The number of days between sets, the time of day (sets fished between 7:00 am and 7:00 pm were considered daytime sets, the remaining sets were nighttime sets), and whether catches decreased or increased, were examined to see if adding these sets would bias estimates.

Calculations for the first and third alternative abundance indices are as previously described; the difference being which sets are included. For the second alternative, repeat sets were included in the mean number/tow by calculating weighted averages and variances for the estimated strata means and variances - weighted by the number of sets at each station. Thus, the following calculations for strata means and variances replace equations 2 and 4:

$$\bar{y}_h = \frac{\sum_{i=1}^{n_h} w_i y_{hi}}{\sum_{i=1}^{n_h} w_i}$$

$$s_h^2 = \frac{1}{\sum w_i - 1} \sum_{i=1}^{n_h} w_i \left(y_{hi} - \bar{y}_h\right)^2$$

where w_i = 1÷(number of fishing sets at the location of set *I*)

Mixed Design - random and fixed fishing stations

If, in conducting the groundfish survey in a given year, *m* fishing stations are retained from the previous year and *u* new stations are allocated, both the matched and unmatched portions of the survey can be used to provide estimates of the mean number/tow. The calculations described in Cochran (1977) can easily be modified for a stratified sampling design. In this case, the matched and unmatched samples are divided into their separate strata, and the means and variances found for each strata are used to find the stratified mean and variance using equations 1 and 3. The assumption is that there is information in the fixed stations that can be used from one year to the next to provide more accurate and precise esimates (Cochran, 1977). These calculations can be extended to include several years of matched locations.

The survey design from 1971 to 1983, with 13 fixed stations as well as randomly allocated stations falls within the scope of repeat sampling with partial replacement; the fact that the surveys were not designed to benefit from a mixture of fixed and random stations is not a problem, but may affect the gain in precision obtained. During 1984 to 1987, however, all stations were fixed, but in some years were not fished. In analyzing these surveys as mixed designs, the unmatched stations are treated as random.

From Cochran:
If $\bar{y}_{ku}$, $\bar{y}_{km}$, and $\bar{y}_k$ = means of the unmatched portion, the matched portion, and the entire sample on occasion *k*, then $\bar{y}_{2u}$ and $\bar{y}_{2m}$ provide independent estimates $\bar{y}_{2u}'$ and $\bar{y}_{2m}'$ of $\bar{y}_2'$, the mean

number/tow on occasion 2.

So: mean: variance:

$$\bar{y}_{2u}' = \bar{y}_{2u} \quad , \quad \frac{s_2^2}{u} = \frac{1}{w_{2u}}$$

$$\bar{y}_{2m}' = \bar{y}_{2m} + b(\bar{y}_1 - \bar{y}_{1m}) \quad , \quad \frac{s_2^2(1-\rho)}{m} + \rho^2 \frac{s_2^2}{n} = \frac{1}{w_{2m}}$$

where b is found from a regression of catches in the matched fishing stations in year 2 on catches in the matched stations in year 1

ρ is the correlation coefficient of catches in the matched fishing stations in the 2 years.

Then the best estimate of the mean number/tow in year 2 is :

$$\bar{y}_2' = \phi_2 \bar{y}_{2u}' + (1-\phi_2)\bar{y}_{2m}'$$

where:

$$\phi_2 = \frac{w_{2u}}{w_{2u} + w_{2m}}$$

And the variance of $\bar{y}_2'$ is: $$v(\bar{y}_2') = \frac{1}{w_{2u} + w_{2m}}$$

If the fishing locations in a stratum are either all matched or all unmatched, the stratum variance for the second year is calculated as usual (i.e. using equation 4). If there is only one matched location in a stratum between two years, the regression parameter and correlation coefficient can be calculated for all matched stations between the two surveys, or for several strata combined.

RESULTS

Repeated stations 1984-1988:

There are 146 repeat fishing sets in the 5 year time period 1984-1988. These include 102 stations that were fished twice in the the same survey, 10 stations that were fished three times, 1 station that was fished 8 times, 1 fished 9 times, and 1 station that was fished 10 times.

The following table summarizes the number of days between successive fishing sets at a single station, by year:

Year	0-1 days	2-7 days	8-14 days	15-21 days	22-28 days	Total Repeat Sets
1984	0	2	0	2	2	6
1985	1	3	11	2	0	17
1986	22	1	9	1	0	33
1987	10	0	6	6	1	23
1988	64	2	1	0	0	67

Repeat sets in 1985 include those for both survey vessels; the 8-10 fishing sets at each of 3 stations occurred in 1986; 1988 was the comparison of day and night fishing. The summary by time of day (day or

night) of first and repeat fishing sets is (e.g. in 1987, 5 sets were fished first in the day and then repeated at night):

Year	Day and then day	Day and then night	Night and then day	Night and then night
1984	6	0	0	0
1985	14	3	0	0
1986	7	9	7	10
1987	0	5	8	10
1988	0	45	22	0

The mean difference in catches (first catch minus second catch) at a single station for cod was not significantly different from zero (mean=16.3 P=0.56). Sixty-one of the repeat catches were larger than the first catch and 78 catches were smaller; catches at 6 stations were zero in both the first and second set.

The mean difference in plaice catches was not significantly different from zero (mean=15.4 P=0.50). Sixty repeat catches were larger, 77 were smaller, and at 9 stations, both catches were zero.

For hake, the mean difference in catches at a repeated station was not significantly different from zero (mean=-22.3, P=0.12), but only 28 stations showed a decrease from first to second catch, while 62 stations showed an increase. In addition, at the 3 three stations that were sampled multiple times, repeat catches showed increases before levelling off and then declining. If only the first 2 fishing sets at all repeated stations are used, the mean difference in first and second catch is -29.8. P=0.05; nineteen stations show a decrease from first to second catch while forty-seven stations show an increase.

Fixed stations - 1970-1988

The original 13 fixed stations are identified in the data files by their experiment type; experiment type 1 indicates randomly allocated stations and experiment type 2 indicates one of the 13 fixed stations. In examining the data, it was discovered that some stations have been mis-identified in the past. The following table lists the fishing sets that had been given incorrect experiment type:

Year	Set Number	Experiment Type	Should be
1972	46	2	1
1974	67	2	1
1979	30	1	2
1982	46	2	1
	50	1	2
	64	1	2
1983	47	1	2
	61	1	2
	62	1	2
	66	1	2
1988	83	2	1
	142	2	1

In addition, fixed stations in the region of the borders between strata 417, 418, and 420 were not consistently allocated to the same strata from 1971 to 1988, and it was discovered that the location of some fixed stations has drifted over the years, sometimes several miles from their original co-ordinates (Figures 2-7).

Because the abundance indices used to date in assessing the status of 4T stocks have used only randomly allocated stations from 1971 to 1983, they would be affected by mis-identification of experiment

types, but not by drifting of locations or mis-allocation of strata for fixed stations. Before examining the effects of including more fishing sets, however, the indices were recalculated using corrected experiment type designation (changes were minimal) and the 13 fixed stations were given consistent strata allocation for use in the alternative calculations.

The correlations of catches at fixed stations in consecutive years vary greatly and are often very small or negative (Figure 8). In addition, from 1983 to 1987, the correlations are often inconsistent within a stratum (i.e. the correlation of catches at several stations in two consecutive years may be high and positive, while correlations of catches at other stations within the same stratum may be negative). In the entire time period, but especially from 1971 to 1983, there is often only 1 matched station within a stratum between two years. Therefore, although for the mixed design analysis it is best to use estimators calculated within strata (distributional changes may be obscured in survey-wide estimates), strata were combined to calculate correlations. In many cases, the number of matched sets was still only 2 or 3, and the resulting estimates sometimes gave rise to unreasonable mean numbers/tow. For example, for cod in 1978, stratum 422, b was calculated to be 6.06 on the basis of 2 matched locations, and the mean number/tow for that stratum was then -1245. In cases where combining 2 or 3 strata gave results that seemed reasonable, they gave results similar to those resulting from survey-wide estimates. Thus, for consistency, b and ρ were calculated using all the matched stations in two consecutive surveys.

The mixed design approach can be extended to use fixed stations fished several years apart. Correlations were therefore calculated for matched stations for the period from 1983 to 1987 between all possible pairs of surveys (numbers in brackets refer to the number of stations matched in the pair of years (e.g. 26 stations fished in 1983 were fished again in 1985):

COD:

	1984	1985	1986	1987
1983	.83 (22)	.67 (26)	.71 (26)	.68 (25)
1984		.27 (94)	.35 (94)	.50 (96)
1985			.16 (130)	.29 (131)
1986				.45 (135)

PLAICE:

	1984	1985	1986	1987
1983	.53	.60	.54	.58
1984		.82	.58	.61
1985			.73	.54
1986				.49

HAKE:

	1984	1985	1986	1987
1983	.83	.78	.19	.76
1984		.73	.71	.75
1985			.85	.41
1986				.31

For these analyses, repeat sets were averaged, and both the *E.E.Prince* and the *Lady Hammond* surveys were included for 1985, but the results do not change if repeat sets are not used or only the *E.E.Prince* data are used in 1985. Cod catches in all surveys are most highly correlated with the 1983 survey catches regardless of the passage of time, and it appears that correlations between fixed locations increased with time (e.g. the correlation between catches in 1984 and 1986 is higher than between 1984 and 1985). Plaice catches in 1983, 1984, and 1986 are most highly correlated with catches in 1985, and

white hake catches in 1984 are highly correlated with catches in all other years. Correlations between surveys more than one year apart are in general not high, and it was decided to limit analyses to catches in consecutive years.

Comparison of Trends

COD

The view of the 4T cod stock abundance is the same using any of the 6 indices: the stock was at low abundance in the early 1970's, increasing to the 1980's and then rapidly decreasing from 1988 (Table 2, Figure 9). The assessment index is higher than the alternative indices throughout most of the early to mid-1980's, but lower for 1978 and 1979. The biggest differences are decreases for 1985 and 1986 for all alternative methods. For all except 1979, 1980, 1982, and 1984, there is no difference between the stratified random and the mixed design alternative methods.

The coefficients of variation of the mean follow similar trends regardless of calculation method, with the assessment sets resulting in lower cv's for only 1974, 1977, 1978. In addition, the 1988 assessment cv is lower than all except the stratified random method with equal weighting of all sets. The 1985 cv's are high for all 6 methods, but the 1986 cv's are much smaller for all 5 alternative methods than for the assessment sets.

Including both surveys in calculations for 1985 results in decreasing both the mean number/tow and its cv for all alternative methods (Table 3, Figure 10).

PLAICE

There are almost no differences between the mean number of 4T plaice/tow calculated by any of the 6 methods (Table 4, Figure 11). The stock appears low in the early 1970's, increases to a maximum in 1977 and then declines in the 1980's, remaining quite stable through the mid- to late 1980's. The largest difference occurs for 1979, with the mixed design methods resulting in the smallest mean number/tow. The coefficients of variation are a little more variable; the largest differences are for 1984 to 1988 where the assessment sets result in the largest cv's, while the stratified random method with equal weighting of all sets results in the smallest.

Using both surveys for 1985 decreases the coefficients of variation for all alternative methods for that year, and brings the alternative estimates of mean number/tow even closer together (Table 5, Figure 12).

WHITE HAKE

The abundance of white hake in the Gulf of St. Lawrence appears much more stable than that of the other two species examined; all 6 methods show variablity but no major swings in abundance throughout the time period (Table 6, Figure 13). The mean number of white hake caught per tow is quite variable for 1986 to 1988 depending on which method of analysis is used, with the biggest difference occurring for 1986, where the stratified random method with equal weighting of sets results in a very large mean number/tow, and averaging all repeat sets, both in the mixed design and stratified random method, results in larger estimates than using only the first occurrence at each station. 1986 was the year in which each of 3 stations was fished from 8 to 10 times. The mean number/tow estimated for 1987 is highest if only the assessment sets are used, resulting in a somewhat smoother trend than if repeated stations are included in the analysis. The cv's resulting from the different methods are similar, except for the period 1984 to 1988.

of 3 stations was fished from 8 to 10 times. The mean number/tow estimated for 1987 is highest if only the assessment sets are used, resulting in a somewhat smoother trend than if repeated stations are included in the analysis. The cv's resulting from the different methods are similar, except for the period 1984 to 1988.

Including data from both surveys in 1985 decreases the the mean number/tow and corresponding cv for that year for all alternative methods (Table 7, Figure 14).

DISCUSSION

The purpose of adding fishing sets to the assessment abundance index is to include as much information as possible in the estimation procedure. We want to be sure that in adding sets, we are not also adding bias or creating an illusion of having more information than we actually have. The assumption of a completely random allocation of fishing sets within strata, even for repeat sets, would seem to give the impression of more information than exists, as well as giving too much weight to certain fishing stations within a stratum. The assumption of completely random fishing stations whether fixed or not may bias the mean. The mixed design calculations, while statistically correct for most of the time series, may not be entirely appropriate even for those data because of the problems with the number of matched stations between consecutive years; alternative combinations of strata for calculation of the regression parameter and correlation coefficient can make some difference in the results. In any case, the gain in precision is expected to be modest unless the correlation is high and the proportion of matched stations is optimum (Cochran 1977).

Whichever way additional sets are handled, the overall abundance picture does not change for the three species examined here. For cod, in all cases, the mean number/tow and coefficient of variation for 1985 and 1986 are smaller than if only the assessment sets are used, and the trend from 1971-1990 is basically the same (Figures 9 and 10). For plaice, the mean number/tow doesn't change, but there is a decrease in the coefficient of variation for alternative methods from 1984 to 1988 (Figures 11 and 12). All methods of using repeat sets (either averaged, or with equal weighting) result in larger mean number of white hake per tow in 1985 and 1986 (Figures 13 and 14). The groundfish survey in strata 415 to 439 is thought not to adequately reflect the abundance of white hake in the Gulf of St. Lawrence (Clay et al, 1985), particularly before the mid-1980's, and it may be that locations chosen for resampling within a survey were based in part on expectation of good hake catches.

The fixed stations fished from 1970 to 1988 were chosen to address several needs, one of which was determination of cod and plaice recruitment (Halliday and Koeller, 1981). This may be part of the reason for an increase in mean number of cod per tow in 1977 and 1978 if the fixed stations are included. Otherwise, inclusion of these fixed stations has no major impact on our perception of cod, plaice or white hake abundance, but does decrease the cv's for cod and plaice for several years from 1970 to 1983.

In using only the 61 fixed stations that were fished in each year from 1984-1987, 1 stratum (comprising 4.7% of the survey area) is omitted from the estimation of stratified mean number/tow, only one fishing set is included in each of 3 strata (comprising in total 9.7% of the survey area), and only 2 sets are included in the stratum that comprises 15.7% of the survey (Table 1, Figure 1). This would seem to present a serious problem in representation.

The mean number/tow at age and the length frequency of the population are other indices that are used in assessing a stock. The 3 alternative stratified random methods can be easily adapted for these indices. The survey protocol specifies subsampling for age, based on length of fish. It is difficult to see how to modify the mixed design calculations to average numbers at length betweeen consecutive years, given the growth experienced by the fish.

The current survey design is stratified random and presents no statistical problems. The difficulty here is with the historical data, and once they are satisfactorily analysed, there will be no need to modify the estimates produced. The recommendation is to treat fixed stations as random and average catches at repeated stations before including them in the strata means and variances for cod and plaice, but to

include only the first of repeated sets for white hake. For other species, fixed stations should be treated as random, but catches at repeated stations should be examined for trends before a decision is made whether to average the catches, or use only the first fishing set in the abundance index.

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Table 1. Number of stations fished from 1971 to 1988 in the southern Gulf of St Lawrence groundfish surveys.

Stratum	Area (percent of 4T)	Stations (1971-1983) fixed	Stations (1971-1983) random	Stations Used (84-87)	Stations Fished 1984	1985	1986	1987	1988
415	3.75	1	1-2	3	3	6	6	6	4
416	5.23	4	1-3	5	7	9	9	9	7
417	2.57	4	1-3	4	5	6	6	7	5
418	1.93	1	1-2	4	5	6	6	6	5
419	2.17		2	2	2	3	4	4	3
420	3.79	1	1-3	3	4	5	6	6	3
421	1.61		0-2	2	3	2	3	3	0
422	6.10	2	2-4	6	9	11	11	11	6
423	15.74		3-4	2	3	8	9	8	4
424	5.15		0-3	2	4	6	6	6	3
425	3.09		2	2	3	3	3	3	3
426	1.90		2	2	3	3	3	3	3
427	4.66		2-3	0	1	5	3	5	2
428	0.99		0-2	1	1	3	3	3	2
429	8.31		3-4	3	5	6	6	6	3
431	6.96		1-3	1	4	5	7	5	3
432	1.48		2	2	4	2	2	2	3
433	5.82		2-3	3	7	9	9	9	4
434	5.94		2-3	3	5	6	7	7	5
435	3.13		1-3	2	4	5	5	5	2
436	4.70		2	3	5	5	6	6	3
437	2.43		2-3	3	4	5	5	5	4
438	0.82		2	2	2	3	3	3	2
439	1.73		2	1	2	3	2	3	2

Table 2. Mean catch/tow of cod and corresponding coefficient of variation using various methods of calculations. Includes only the *E.E.Prince* survey in 1985

a) assessment abundance index
b) stratified random design, assuming all stations are random; uses 1st of each repeated set
c) stratified random design, assuming all stations are random; averages repeated sets
d) stratified random design, assuming all stations are random; equal weighting of all sets
e) mixed fixed and random design; averages repeated sets
f) mixed fixed and random design; uses 1st of each repeated set

Mean No/Tow:

year	a	b	c	d	e	f
1971	32.414	30.02	30.02	30.02	29.19	29.19
1972	33.56	39.06	39.06	39.06	39.18	39.18
1973	36.568	34.75	34.75	34.75	33.23	33.23
1974	30.19	34.2	34.2	34.2	34.18	34.18
1975	26.577	29.21	29.21	29.21	29.01	29.01
1976	59.816	58.56	58.56	58.56	53.36	53.36
1977	50.402	70.28	70.28	70.28	78.32	78.32
1978	77.828	104.99	104.99	104.99	97.43	97.43
1979	139.54	146.95	146.95	146.95	130.57	130.57
1980	134.31	132.98	132.98	132.98	123.5	123.5
1981	226.65	204.71	204.71	204.71	198.55	198.55
1982	160.66	168.37	168.37	168.37	148.97	148.97
1983	165.04	164.02	164.02	164.02	157.99	157.99
1984	134.31	126.51	126.33	126.23	114.82	115.00
1985	297.32	240.01	238.16	243.63	233.18	234.94
1986	275.17	201.46	195.77	200.79	191.25	197.7
1987	138.06	132.2	135.43	135.51	135.53	132.52
1988	216.47	210.71	232.36	220.27	228.3	209.88
1989	159.48	159.48	159.48	159.48	159.48	159.48
1990	102.403	102.403	102.403	102.403	102.403	102.403

CV

1971	0.13	0.13	0.13	0.13	0.14	0.14
1972	0.15	0.11	0.11	0.11	0.11	0.11
1973	0.18	0.15	0.15	0.15	0.16	0.16
1974	0.08	0.12	0.12	0.12	0.11	0.11
1975	0.24	0.19	0.19	0.19	0.19	0.19
1976	0.17	0.12	0.12	0.12	0.12	0.12
1977	0.13	0.19	0.19	0.19	0.16	0.16
1978	0.24	0.25	0.25	0.25	0.27	0.27
1979	0.12	0.10	0.10	0.10	0.11	0.11
1980	0.19	0.15	0.15	0.15	0.16	0.16
1981	0.17	0.14	0.14	0.14	0.14	0.14
1982	0.18	0.17	0.17	0.17	0.18	0.18
1983	0.11	0.10	0.10	0.10	0.10	0.10
1984	0.12	0.12	0.12	0.12	0.10	0.10
1985	0.38	0.32	0.32	0.31	0.32	0.32
1986	0.33	0.14	0.13	0.13	0.13	0.14
1987	0.12	0.10	0.10	0.09	0.10	0.10
1988	0.17	0.22	0.21	0.15	0.22	0.22
1989	0.12	0.12	0.12	0.12	0.12	0.12
1990	0.10	0.10	0.10	0.10	0.10	0.10

Table 3. Mean catch/tow of cod and corresponding coefficient of variation using various methods of calculations. Includes both surveys in 1985

a) assessment abundance index
b) stratified random design, assuming all stations are random; uses 1st of each repeated set
c) stratified random design, assuming all stations are random; averages repeated sets
d) stratified random design, assuming all stations are random; equal weighting of all sets
e) mixed fixed and random design; averages repeated sets
f) mixed fixed and random design; uses 1st of each repeated set

Mean No/Tow:

year	a	b	c	d	e	f
1971	32.414	30.02	30.02	30.02	29.19	29.19
1972	33.56	39.06	39.06	39.06	39.18	39.18
1973	36.568	34.75	34.75	34.75	33.23	33.23
1974	30.19	34.2	34.2	34.2	34.18	34.18
1975	26.577	29.21	29.21	29.21	29.01	29.01
1976	59.816	58.56	58.56	58.56	53.36	53.36
1977	50.402	70.28	70.28	70.28	78.32	78.32
1978	77.828	104.99	104.99	104.99	97.43	97.43
1979	139.54	146.95	146.95	146.95	130.57	130.57
1980	134.31	132.98	132.98	132.98	123.5	123.5
1981	226.65	204.71	204.71	204.71	198.55	198.55
1982	160.66	168.37	168.37	168.37	148.97	148.97
1983	165.04	164.02	164.02	164.02	157.99	157.99
1984	134.31	126.51	126.33	126.23	114.82	115.00
1985	297.32	217.07	226.91	242.7	223.85	214.03
1986	275.17	201.46	195.77	200.79	191.13	197.60
1987	138.06	132.2	135.43	135.51	135.53	132.52
1988	216.47	210.71	232.36	220.27	228.3	209.88
1989	159.48	159.48	159.48	159.48	159.48	159.48
1990	102.403	102.403	102.403	102.403	102.403	102.403

CV

1971	0.13	0.13	0.13	0.13	0.14	0.14
1972	0.15	0.11	0.11	0.11	0.11	0.11
1973	0.18	0.15	0.15	0.15	0.16	0.16
1974	0.08	0.12	0.12	0.12	0.11	0.11
1975	0.24	0.19	0.19	0.19	0.19	0.19
1976	0.17	0.12	0.12	0.12	0.12	0.12
1977	0.13	0.19	0.19	0.19	0.16	0.16
1978	0.24	0.25	0.25	0.25	0.27	0.27
1979	0.12	0.10	0.10	0.10	0.11	0.11
1980	0.19	0.15	0.15	0.15	0.16	0.16
1981	0.17	0.14	0.14	0.14	0.14	0.14
1982	0.18	0.17	0.17	0.17	0.18	0.18
1983	0.11	0.10	0.10	0.10	0.10	0.10
1984	0.12	0.12	0.12	0.12	0.10	0.10
1985	0.38	0.19	0.20	0.15	0.20	0.19
1986	0.33	0.14	0.13	0.13	0.13	0.14
1987	0.12	0.10	0.10	0.09	0.10	0.10
1988	0.17	0.22	0.21	0.15	0.22	0.22
1989	0.12	0.12	0.12	0.12	0.12	0.12
1990	0.10	0.10	0.10	0.10	0.10	0.10

Table 4. Mean catch/tow of plaice and corresponding coefficient of variation using various methods of calculations. Includes only the *E.E.Prince* survey in 1985

a) assessment abundance index
b) stratified random design, assuming all stations are random; uses 1st of each repeated set
c) stratified random design, assuming all stations are random; averages repeated sets
d) stratified random design, assuming all stations are random; equal weighting of all sets
e) mixed fixed and random design; averages repeated sets
f) mixed fixed and random design; uses 1st of each repeated set

Mean Number/tow

year	a	b	c	d	e	f
1971	152.31	140.61	140.61	140.61	134.08	134.08
1972	130.34	139.46	139.46	139.46	141.22	141.22
1973	135.48	133.45	133.45	133.45	126.43	126.43
1974	278.59	301.95	301.95	301.95	254.07	254.07
1975	301.88	284.48	284.48	284.48	283.7	283.7
1976	524.75	501.45	501.45	501.45	509.03	509.03
1977	606.21	640.19	640.19	640.19	631.03	631.03
1978	323.58	325.29	325.29	325.29	325.45	325.45
1979	494.12	487.66	487.66	487.66	422.07	422.07
1980	306.52	306.59	306.59	306.59	302.84	302.84
1981	354.59	336.82	336.82	336.82	329.71	329.71
1982	166.34	183.50	183.50	183.50	167.57	167.57
1983	211.15	201.21	201.21	201.21	198.08	198.08
1984	119.35	114.11	116.72	115.89	116.85	115.68
1985	152.78	130.59	133.47	131.17	133.42	136.32
1986	143.74	132.73	134.98	134.42	132.48	131.97
1987	145.26	144.31	141.63	139.37	145.18	145.1
1988	154.00	148.12	145.24	141.70	149.78	153.07
1989	116.89	116.89	116.89	116.89	116.89	116.89
1990	197.67	197.67	197.67	197.67	197.67	197.67

CV

1971	0.30	0.24	0.24	0.24	0.24	0.24
1972	0.29	0.25	0.25	0.25	0.25	0.25
1973	0.21	0.17	0.17	0.17	0.15	0.15
1974	0.13	0.12	0.12	0.12	0.16	0.16
1975	0.17	0.16	0.16	0.16	0.17	0.17
1976	0.20	0.15	0.15	0.15	0.15	0.15
1977	0.24	0.22	0.22	0.22	0.19	0.19
1978	0.37	0.36	0.36	0.36	0.36	0.36
1979	0.14	0.14	0.14	0.14	0.15	0.15
1980	0.15	0.13	0.13	0.13	0.13	0.13
1981	0.26	0.28	0.28	0.28	0.28	0.28
1982	0.24	0.22	0.22	0.22	0.18	0.18
1983	0.15	0.16	0.16	0.16	0.16	0.16
1984	0.15	0.13	0.13	0.13	0.12	0.12
1985	0.19	0.16	0.15	0.14	0.14	0.15
1986	0.26	0.15	0.15	0.13	0.15	0.14
1987	0.22	0.17	0.15	0.12	0.17	0.17
1988	0.24	0.21	0.20	0.14	0.19	0.20
1989	0.11	0.11	0.11	0.11	0.11	0.11
1990	0.12	0.12	0.12	0.12	0.12	0.12

Table 5. Mean catch/tow of plaice and corresponding coefficient of variation using various methods of calculations. Includes both surveys in 1985

a) assessment abundance index
b) stratified random design, assuming all stations are random; uses 1st of each repeated set
c) stratified random design, assuming all stations are random; averages repeated sets
d) stratified random design, assuming all stations are random; equal weighting of all sets
e) mixed fixed and random design; averages repeated sets
f) mixed fixed and random design; uses 1st of each repeated set

Mean Number/tow

1971	152.31	140.61	140.61	140.61	134.08	134.08
1972	130.34	139.46	139.46	139.46	141.22	141.22
1973	135.48	133.45	133.45	133.45	126.43	126.43
1974	278.59	301.95	301.95	301.95	254.07	254.07
1975	301.88	284.48	284.48	284.48	283.7	283.7
1976	524.75	501.45	501.45	501.45	509.03	509.03
1977	606.21	640.19	640.19	640.19	631.03	631.03
1978	323.58	325.29	325.29	325.29	325.45	325.45
1979	494.12	487.66	487.66	487.66	422.07	422.07
1980	306.52	306.59	306.59	306.59	302.84	302.84
1981	354.59	336.82	336.82	336.82	329.71	329.71
1982	166.34	183.5	183.5	183.5	167.57	167.57
1983	211.15	201.21	201.21	201.21	198.08	198.08
1984	119.35	114.11	116.72	115.89	116.85	115.68
1985	152.78	121.93	119.26	121.16	122.50	126.32
1986	143.74	132.73	134.98	134.42	132.64	132.09
1987	145.26	144.31	141.63	139.37	145.18	145.1
1988	154	148.12	145.24	141.7	149.78	153.07
1989	116.89	116.89	116.89	116.89	116.89	116.89
1990	197.67	197.67	197.67	197.67	197.67	197.67

CV

1971	0.30	0.24	0.24	0.24	0.24	0.24
1972	0.29	0.25	0.25	0.25	0.25	0.25
1973	0.21	0.17	0.17	0.17	0.15	0.15
1974	0.13	0.12	0.12	0.12	0.16	0.16
1975	0.17	0.16	0.16	0.16	0.17	0.17
1976	0.20	0.15	0.15	0.15	0.15	0.15
1977	0.24	0.22	0.22	0.22	0.19	0.19
1978	0.37	0.36	0.36	0.36	0.36	0.36
1979	0.14	0.14	0.14	0.14	0.15	0.15
1980	0.15	0.13	0.13	0.13	0.13	0.13
1981	0.26	0.28	0.28	0.28	0.28	0.28
1982	0.24	0.22	0.22	0.22	0.18	0.18
1983	0.15	0.16	0.16	0.16	0.16	0.16
1984	0.15	0.13	0.13	0.13	0.12	0.12
1985	0.19	0.11	0.11	0.08	0.10	0.10
1986	0.26	0.15	0.15	0.13	0.15	0.15
1987	0.22	0.17	0.15	0.12	0.17	0.17
1988	0.24	0.21	0.20	0.14	0.19	0.20
1989	0.11	0.11	0.11	0.11	0.11	0.11
1990	0.12	0.12	0.12	0.12	0.12	0.12

Table 6. Mean catch/tow of white hake and corresponding coefficient of variation using various methods of calculations. Includes only the *E.E.Prince* survey in 1985

a) assessment abundance index
b) stratified random design, assuming all stations are random; uses 1st of each repeated set
c) stratified random design, assuming all stations are random; averages repeated sets
d) stratified random design, assuming all stations are random; equal weighting of all sets
e) mixed fixed and random design; averages repeated sets
f) mixed fixed and random design; uses 1st of each repeated set

Mean Number/tow

year	a	b	c	d	e	f
1971	2.68	2.8	2.8	2.8	2.8	2.8
1972	1.53	1.73	1.73	1.73	1.69	1.69
1973	5.94	5.83	5.83	5.83	5.83	5.83
1974	10.46	10.68	10.68	10.68	10.66	10.66
1975	8.43	8.26	8.26	8.26	8.19	8.19
1976	7.1	7.27	7.27	7.27	7.55	7.55
1977	3.51	4.47	4.47	4.47	4.35	4.35
1978	10.17	9.68	9.68	9.68	10.17	10.17
1979	7.5	8.28	8.28	8.28	8.17	8.17
1980	7.02	7.37	7.37	7.37	7.18	7.18
1981	12.43	11.88	11.88	11.88	11.71	11.71
1982	3.76	3.86	3.86	3.86	4.2	4.2
1983	3.37	3.58	3.58	3.58	3.51	3.51
1984	6.95	5.6	5.26	5.66	5.12	5.46
1985	7.54	6.87	9.01	9.01	7.32	5.22
1986	16.62	13.13	20.26	28.82	20.1	13.05
1987	10.36	6.91	6.96	6.04	6.94	6.92
1988	12.2	10.5	13.38	12.55	12.88	12.96
1989	9.9	9.9	9.9	9.9	9.9	9.9
1990	9.24	9.24	9.24	9.24	9.24	9.24

CV

1971	0.41	0.39	0.39	0.39	0.39	0.39
1972	0.29	0.28	0.28	0.28	0.28	0.28
1973	0.71	0.72	0.72	0.72	0.72	0.72
1974	0.44	0.43	0.43	0.43	0.44	0.44
1975	0.48	0.48	0.48	0.48	0.48	0.48
1976	0.42	0.41	0.41	0.41	0.39	0.39
1977	0.29	0.28	0.28	0.28	0.27	0.27
1978	0.34	0.34	0.34	0.34	0.33	0.33
1979	0.34	0.32	0.32	0.32	0.32	0.32
1980	0.17	0.15	0.15	0.15	0.15	0.15
1981	0.32	0.31	0.31	0.31	0.31	0.31
1982	0.34	0.33	0.33	0.33	0.30	0.30
1983	0.17	0.17	0.17	0.17	0.18	0.18
1984	0.35	0.21	0.20	0.17	0.20	0.21
1985	0.34	0.35	0.37	0.26	0.45	0.47
1986	0.31	0.20	0.38	0.23	0.37	0.20
1987	0.28	0.21	0.24	0.20	0.21	0.21
1988	0.18	0.23	0.28	0.20	0.29	0.35
1989	0.27	0.27	0.27	0.27	0.27	0.27
1990	0.23	0.23	0.23	0.23	0.23	0.23

Table 7. Mean catch/tow of white hake and corresponding coefficient of variation using various methods of calculations. Includes both surveys in 1985

a) assessment abundance index
b) stratified random design, assuming all stations are random; uses 1st of each repeated set
c) stratified random design, assuming all stations are random; averages repeated sets
d) stratified random design, assuming all stations are random; equal weighting of all sets
e) mixed fixed and random design; averages repeated sets
f) mixed fixed and random design; uses 1st of each repeated set

Mean number/tow

year	a	b	c	d	e	f
1971	2.68	2.8	2.8	2.8	2.8	2.8
1972	1.53	1.73	1.73	1.73	1.69	1.69
1973	5.94	5.83	5.83	5.83	5.83	5.83
1974	10.46	10.68	10.68	10.68	10.66	10.66
1975	8.43	8.26	8.26	8.26	8.19	8.19
1976	7.1	7.27	7.27	7.27	7.55	7.55
1977	3.51	4.47	4.47	4.47	4.35	4.35
1978	10.17	9.68	9.68	9.68	10.17	10.17
1979	7.5	8.28	8.28	8.28	8.17	8.17
1980	7.02	7.37	7.37	7.37	7.18	7.18
1981	12.43	11.88	11.88	11.88	11.71	11.71
1982	3.76	3.86	3.86	3.86	4.2	4.2
1983	3.37	3.58	3.58	3.58	3.51	3.51
1984	6.95	5.6	5.26	5.66	5.12	5.46
1985	7.54	8.86	11.23	11.94	11.13	8.9
1986	16.62	13.13	20.26	28.82	19.89	13.07
1987	10.36	6.91	6.96	6.04	6.94	6.92
1988	12.2	10.5	13.38	12.55	12.88	12.96
1989	9.9	9.9	9.9	9.9	9.9	9.9
1990	9.24	9.24	9.24	9.24	9.24	9.24

CV

1971	0.41	0.39	0.39	0.39	0.39	0.39
1972	0.29	0.28	0.28	0.28	0.28	0.28
1973	0.71	0.72	0.72	0.72	0.72	0.72
1974	0.44	0.43	0.43	0.43	0.44	0.44
1975	0.48	0.48	0.48	0.48	0.48	0.48
1976	0.42	0.41	0.41	0.41	0.39	0.39
1977	0.29	0.28	0.28	0.28	0.27	0.27
1978	0.34	0.34	0.34	0.34	0.33	0.33
1979	0.34	0.32	0.32	0.32	0.32	0.32
1980	0.17	0.15	0.15	0.15	0.15	0.15
1981	0.32	0.31	0.31	0.31	0.31	0.31
1982	0.34	0.33	0.33	0.33	0.30	0.30
1983	0.17	0.17	0.17	0.17	0.18	0.18
1984	0.35	0.21	0.20	0.17	0.20	0.21
1985	0.34	0.32	0.23	0.21	0.29	0.30
1986	0.31	0.20	0.38	0.23	0.38	0.20
1987	0.28	0.21	0.24	0.20	0.21	0.21
1988	0.18	0.23	0.28	0.20	0.29	0.35
1989	0.27	0.27	0.27	0.27	0.27	0.27
1990	0.23	0.23	0.23	0.23	0.23	0.23

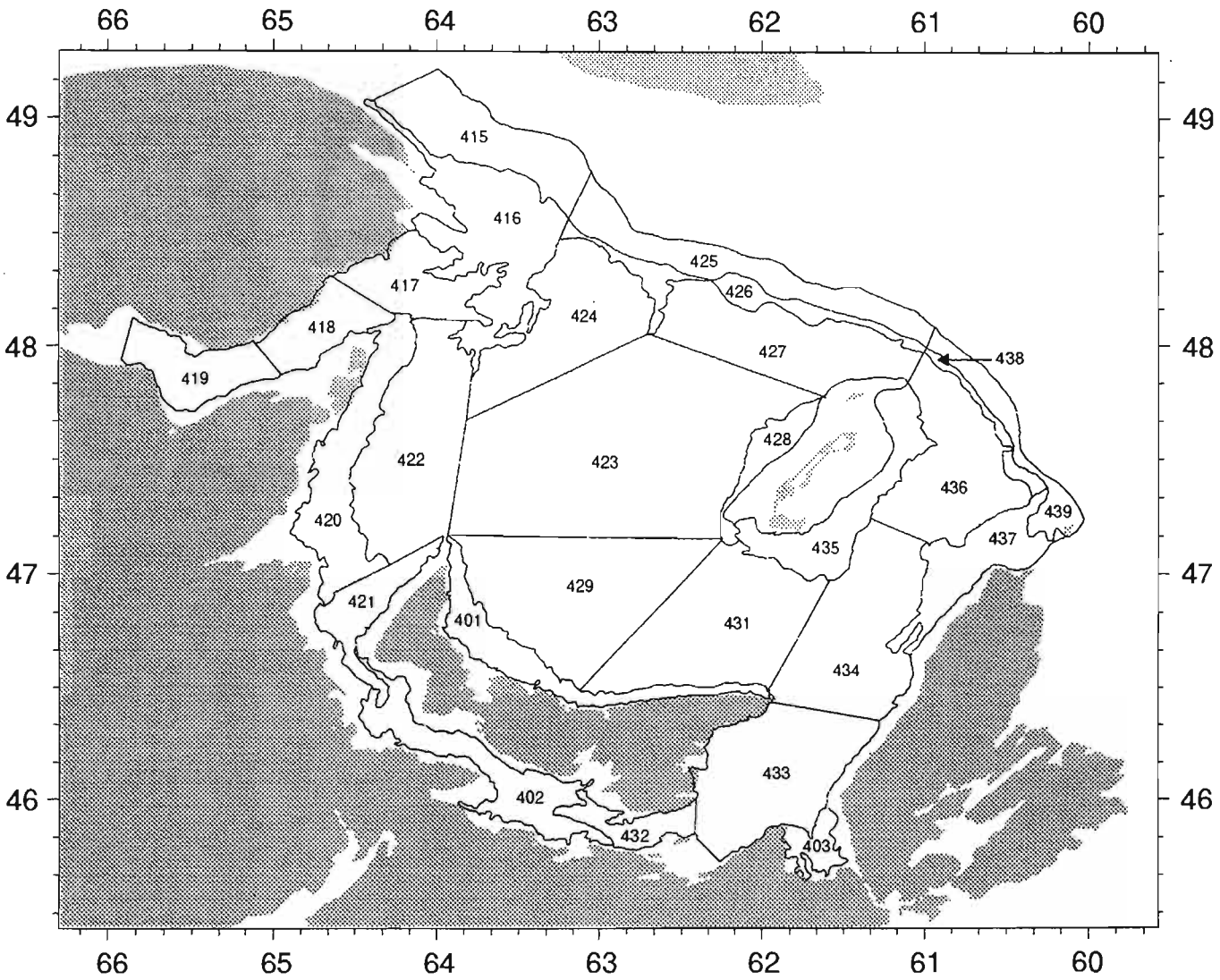


Figure 1. Survey area and strata boundaries used in southern Gulf of St. Lawrence research surveys

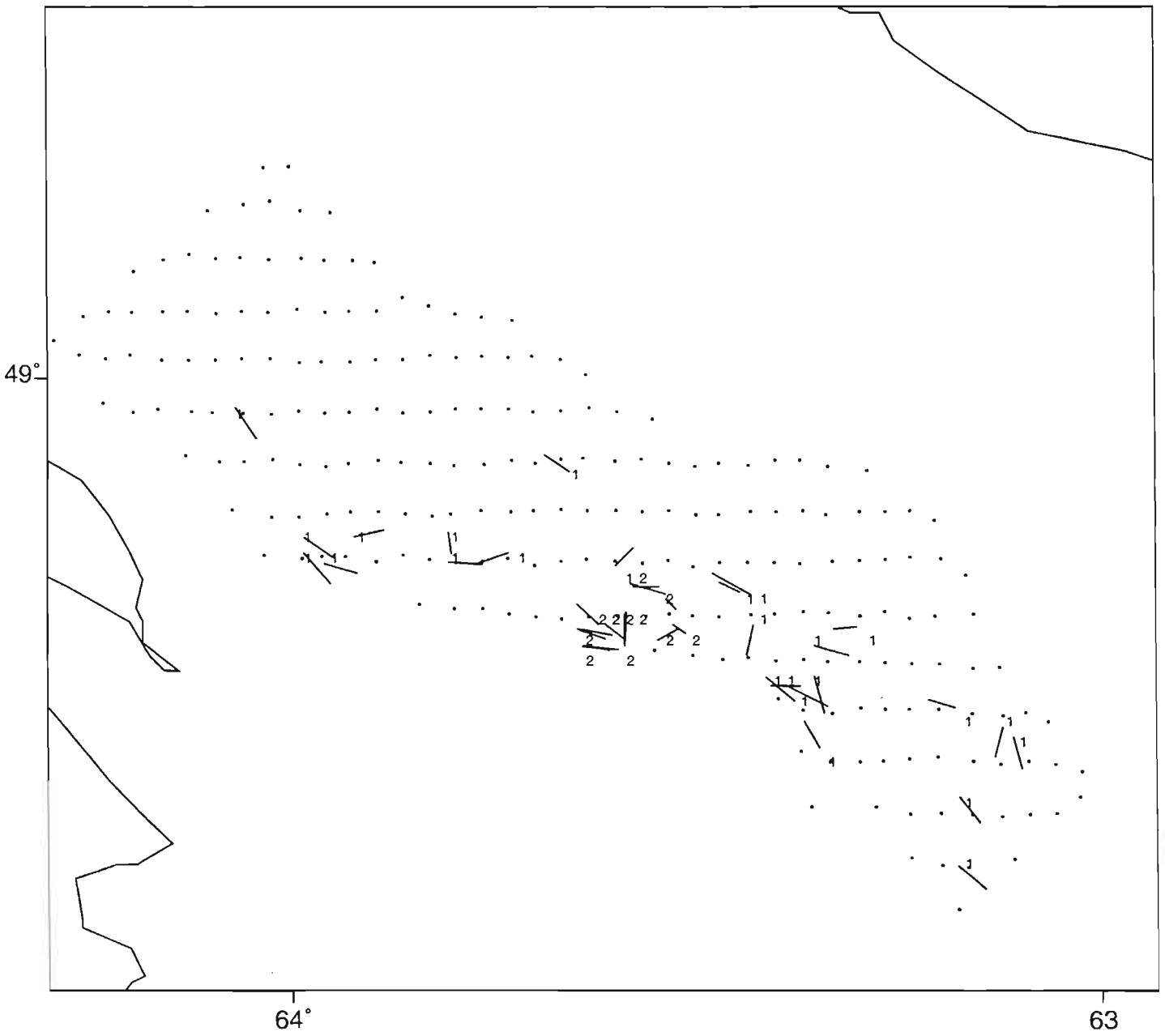


Figure 2. Set tracks of stations fished in stratum 415 from 1970 to 1983. Dots represent starting locations of possible fishing sets. Numbers next to the tracks indicate allocation of set - 1 = random - 2 = fixed

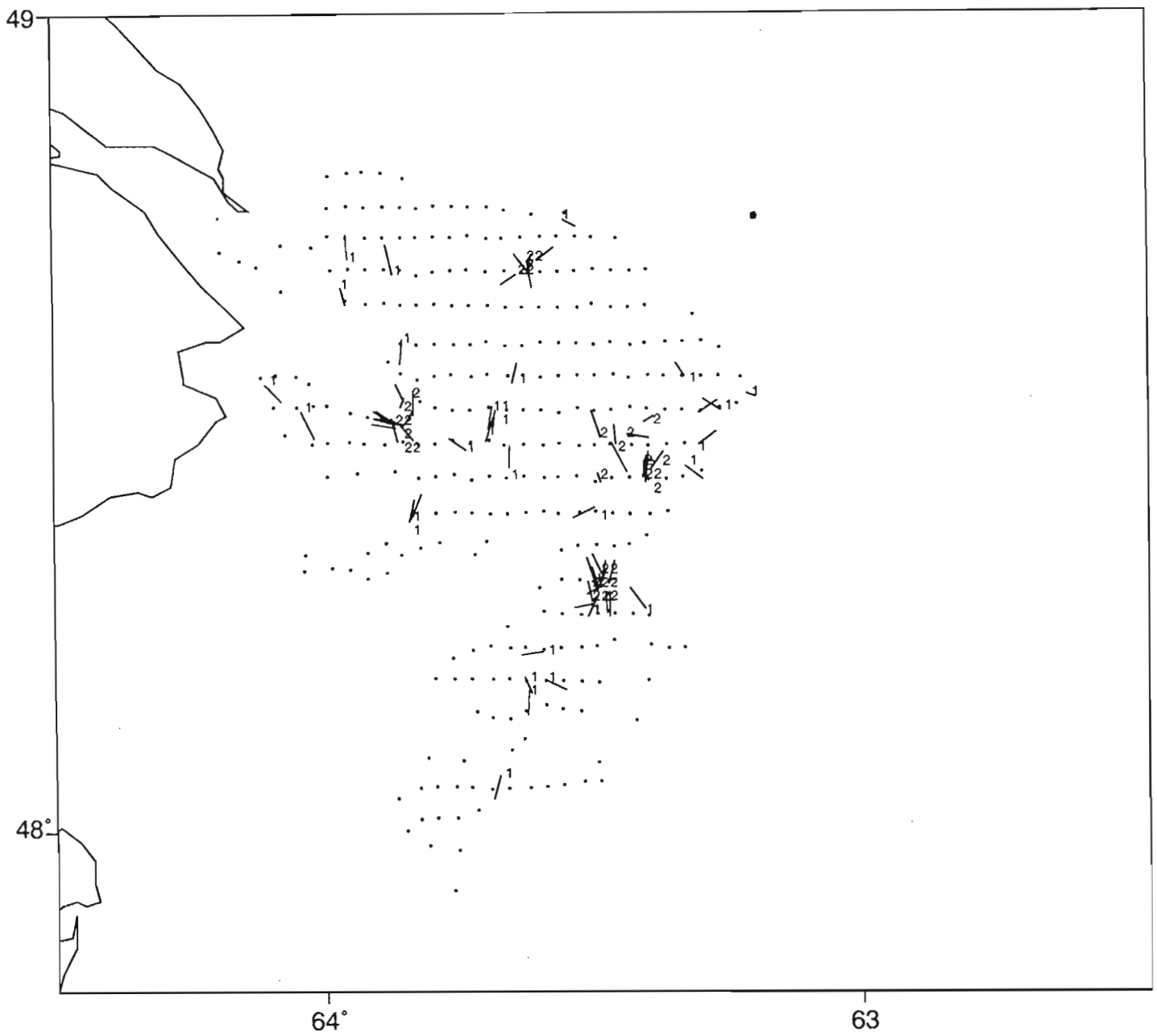


Figure 3. Set tracks of stations fished in stratum 416 from 1970 to 1983. Dots represent starting locations of possible fishing sets. Numbers next to the tracks indicate allocation of set - 1 = random - 2 = fixed

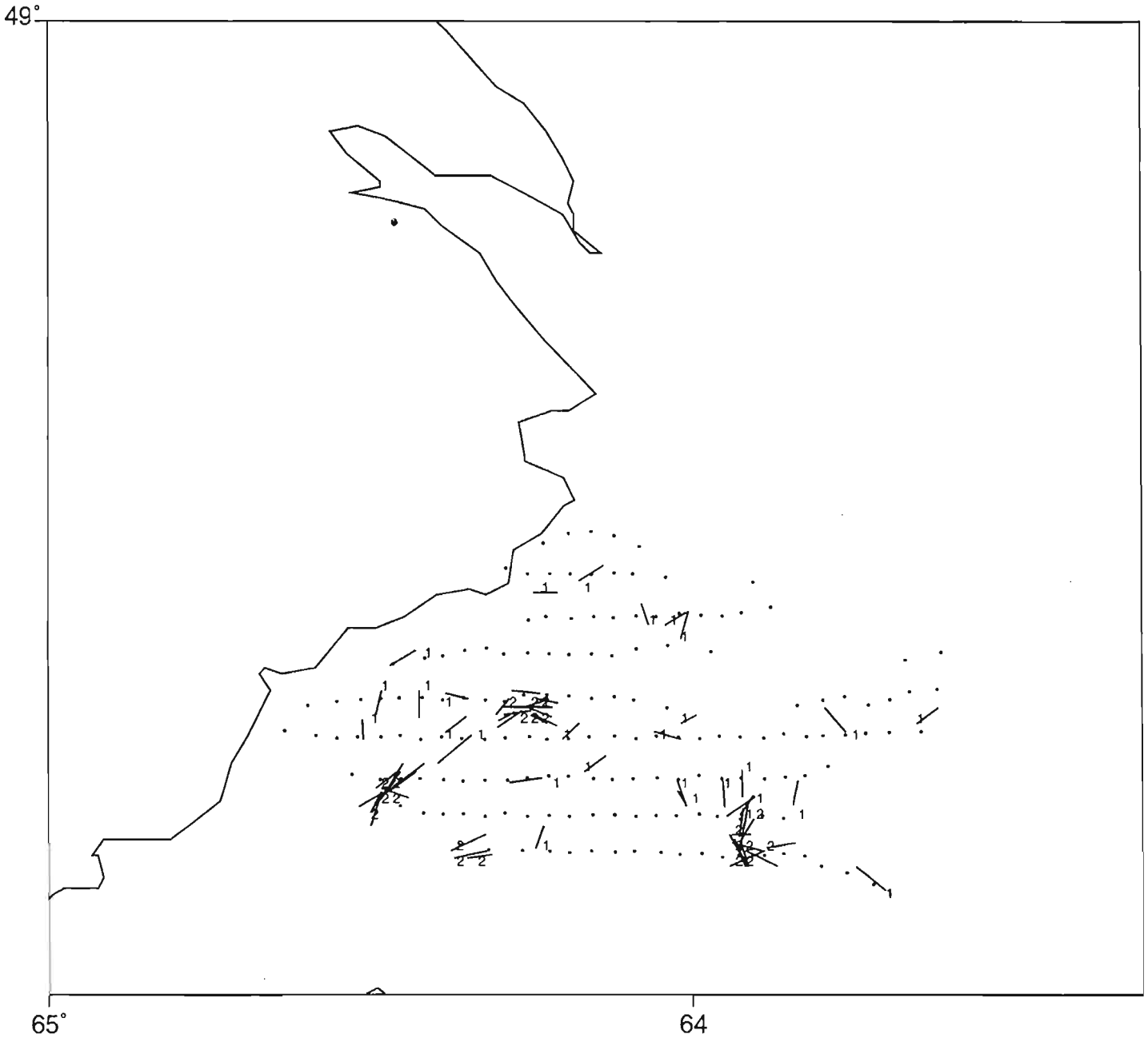


Figure 4. Set tracks of stations fished in stratum 417 from 1970 to 1983. Dots represent starting locations of possible fishing sets. Numbers next to the tracks indicate allocation of set - 1 = random - 2 = fixed

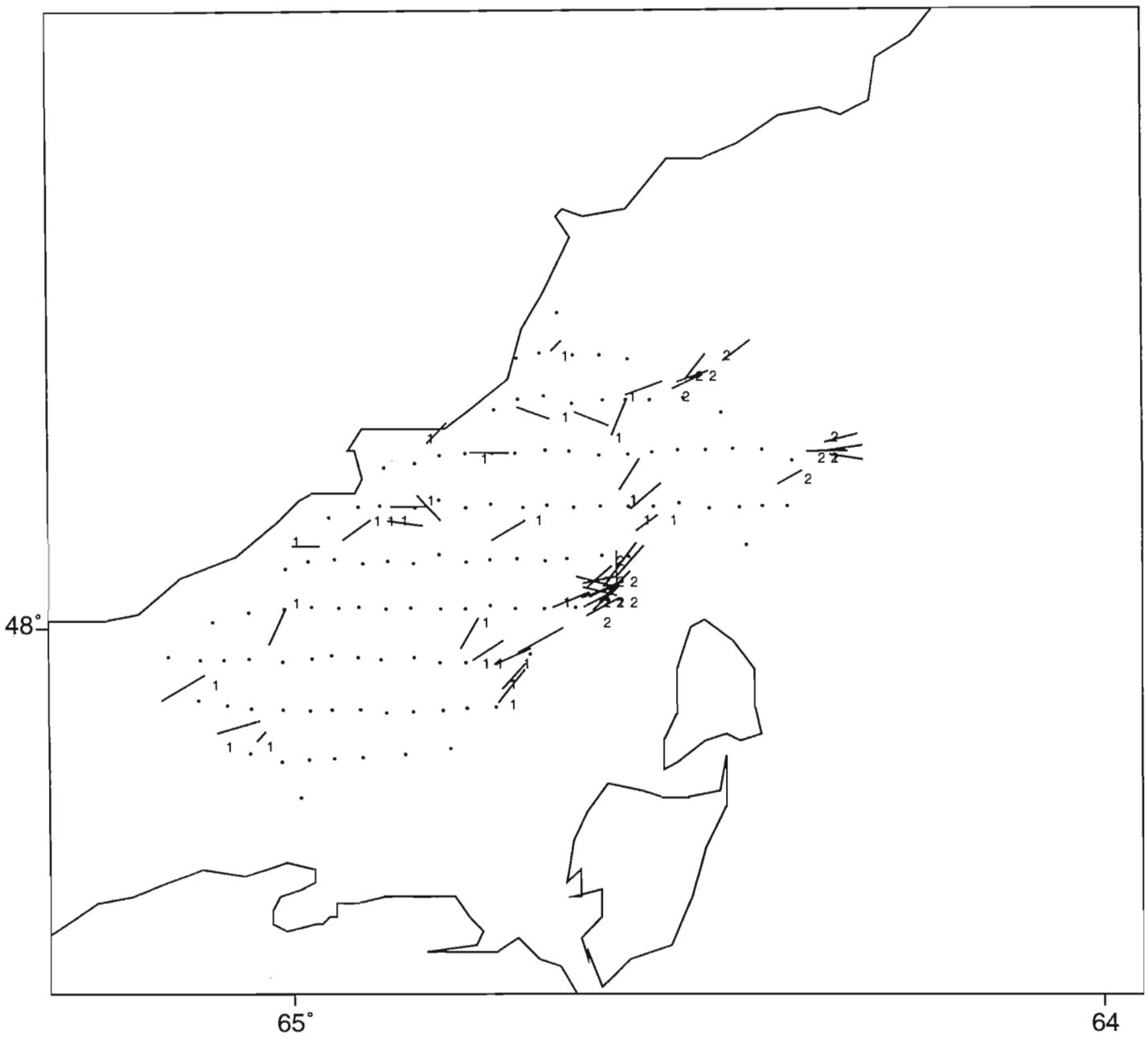


Figure 5. Set tracks of stations fished in stratum 418 from 1970 to 1983. Dots represent starting locations of possible fishing sets. Numbers next to the tracks indicate allocation of set - 1 = random - 2 = fixed

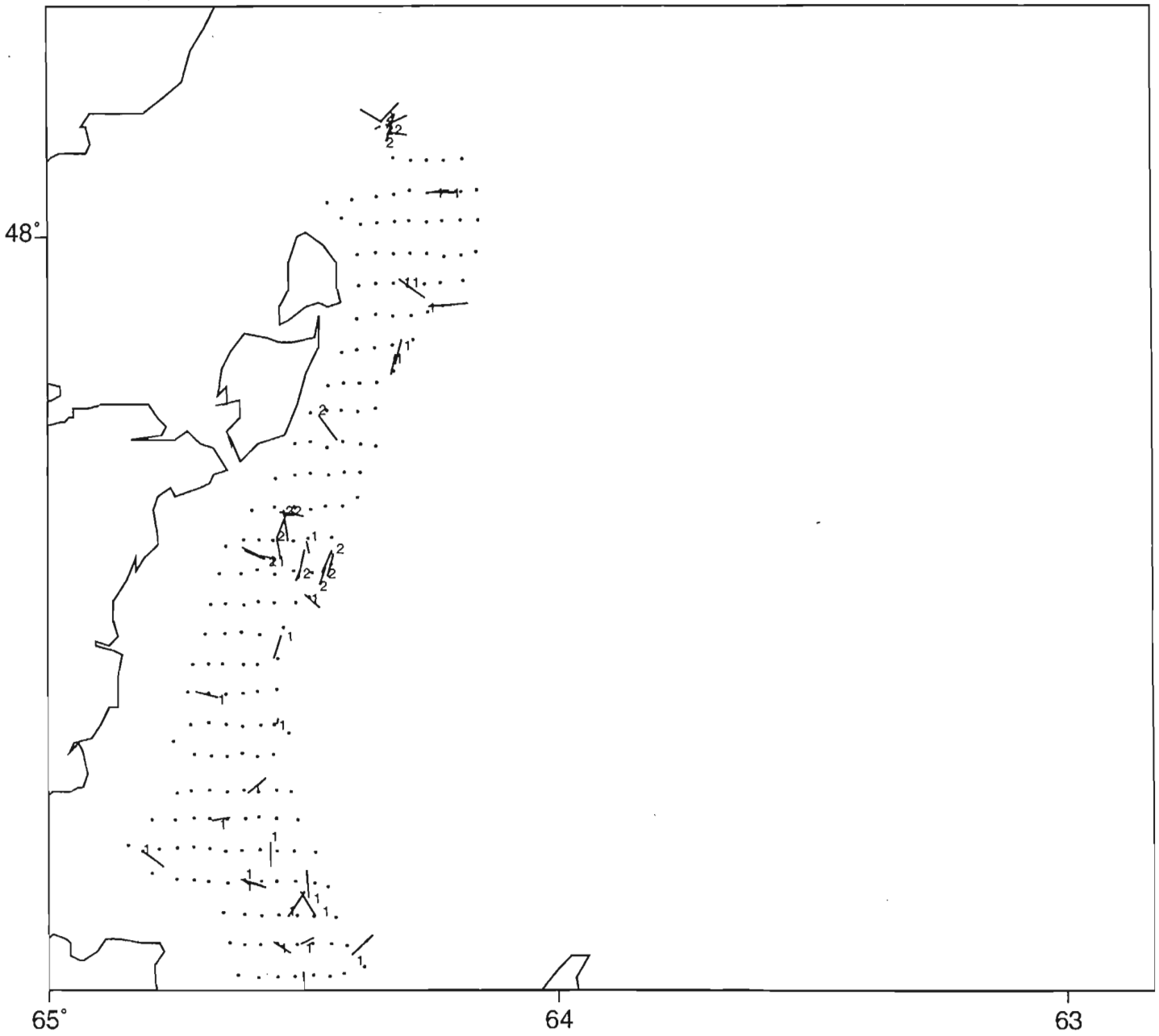


Figure 6. Set tracks of stations fished in stratum 420 from 1970 to 1983. Dots represent starting locations of possible fishing sets. Numbers next to the tracks indicate allocation of set - 1 = random - 2 = fixed

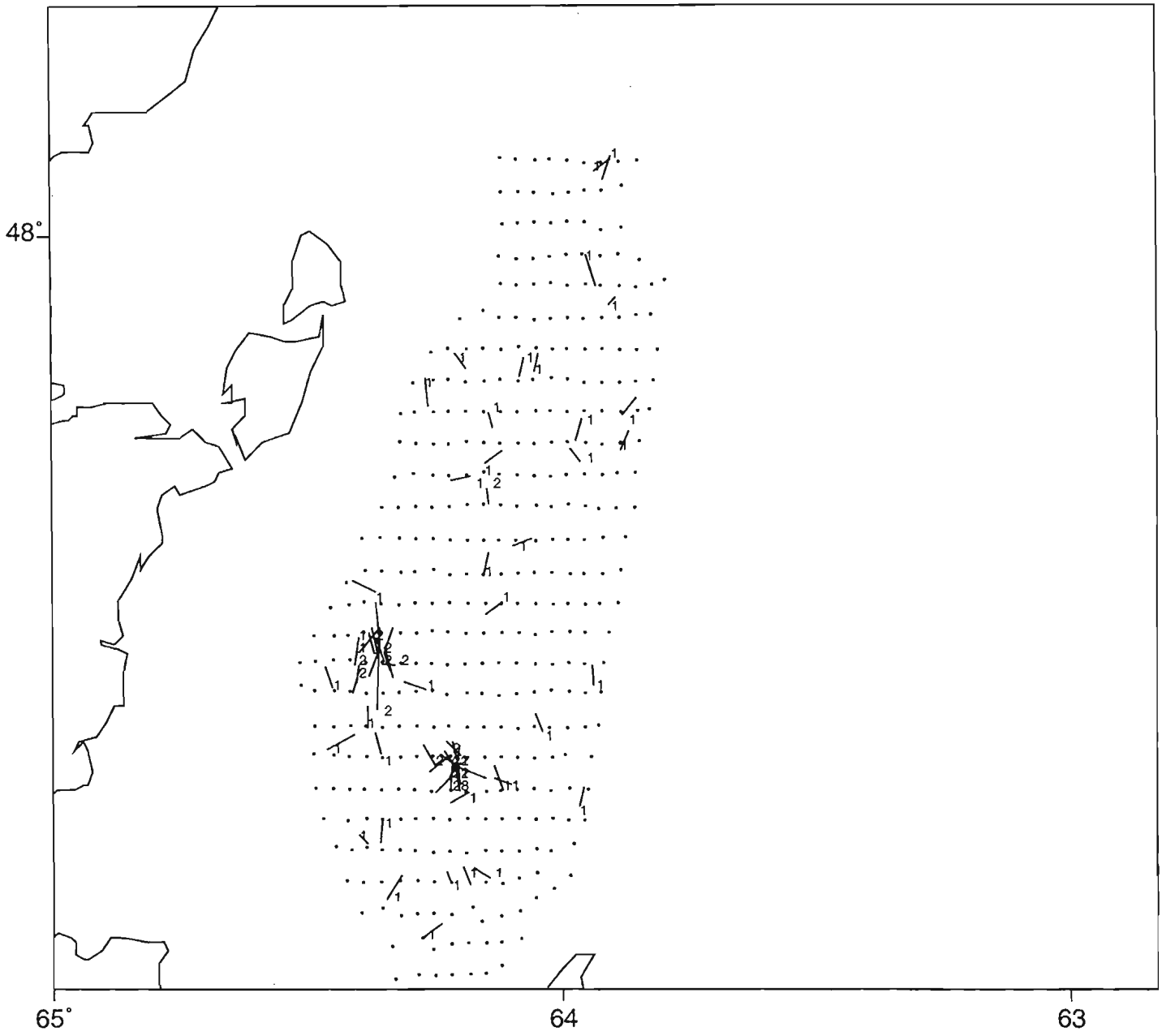


Figure 7. Set tracks of stations fished in stratum 422 from 1970 to 1983. Dots represent starting locations of possible fishing sets. Numbers next to the tracks indicate allocation of set - 1 = random - 2 = fixed

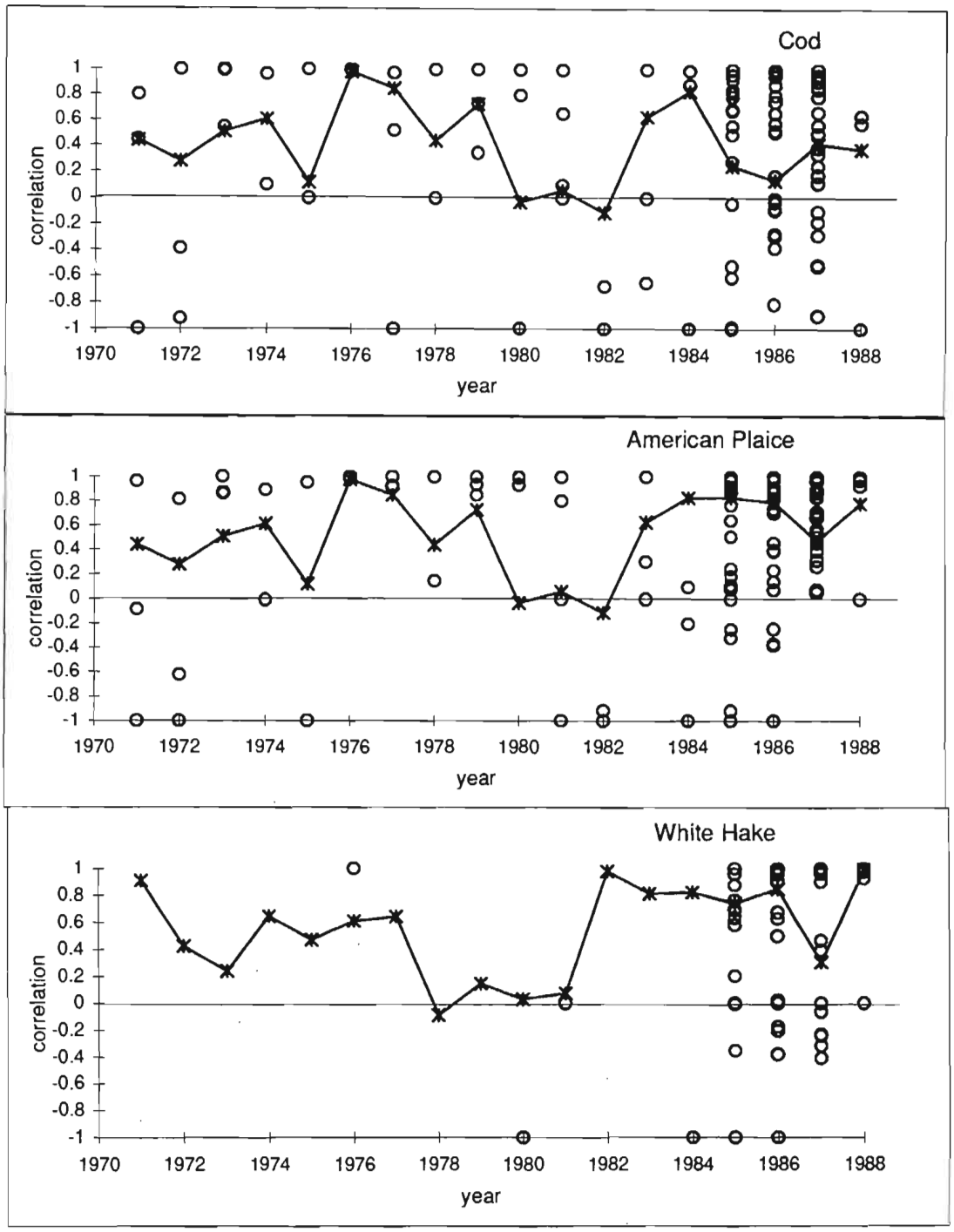
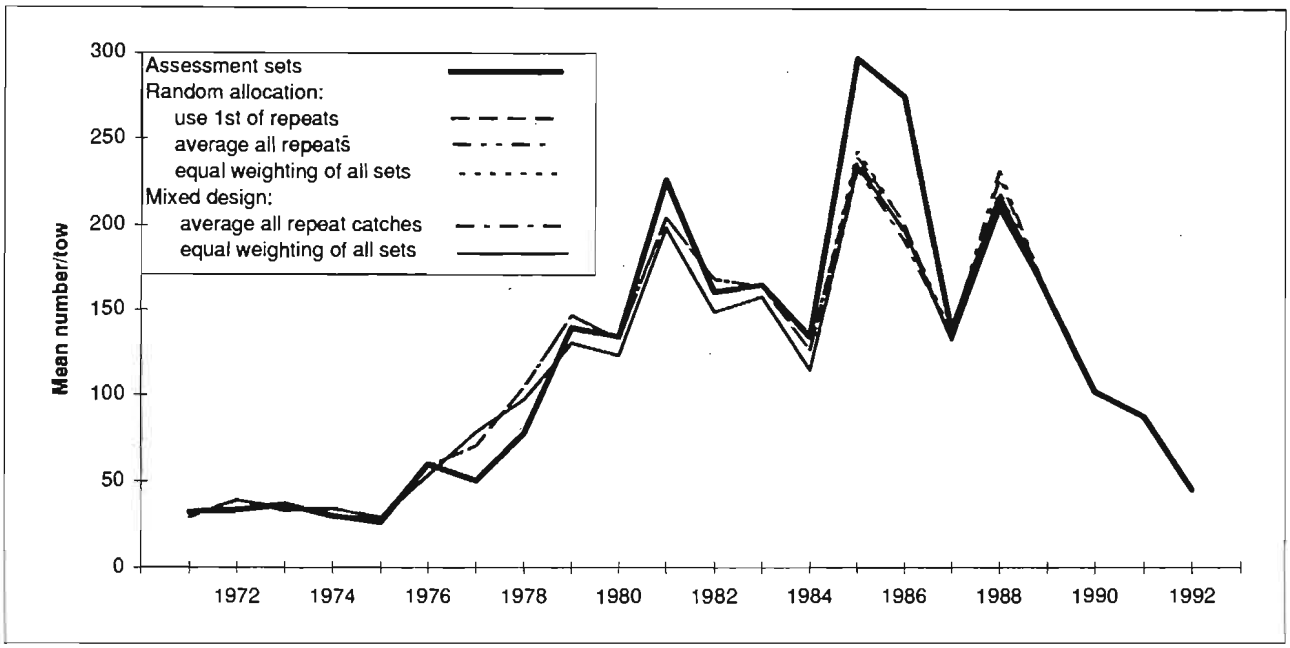


Figure 8. Correlation of cod, plaice, and white hake catches in matched fishing locations between consecutive years in 4T research surveys. Circles denote within-stratum correlations; asterisks denote survey-wide correlations.



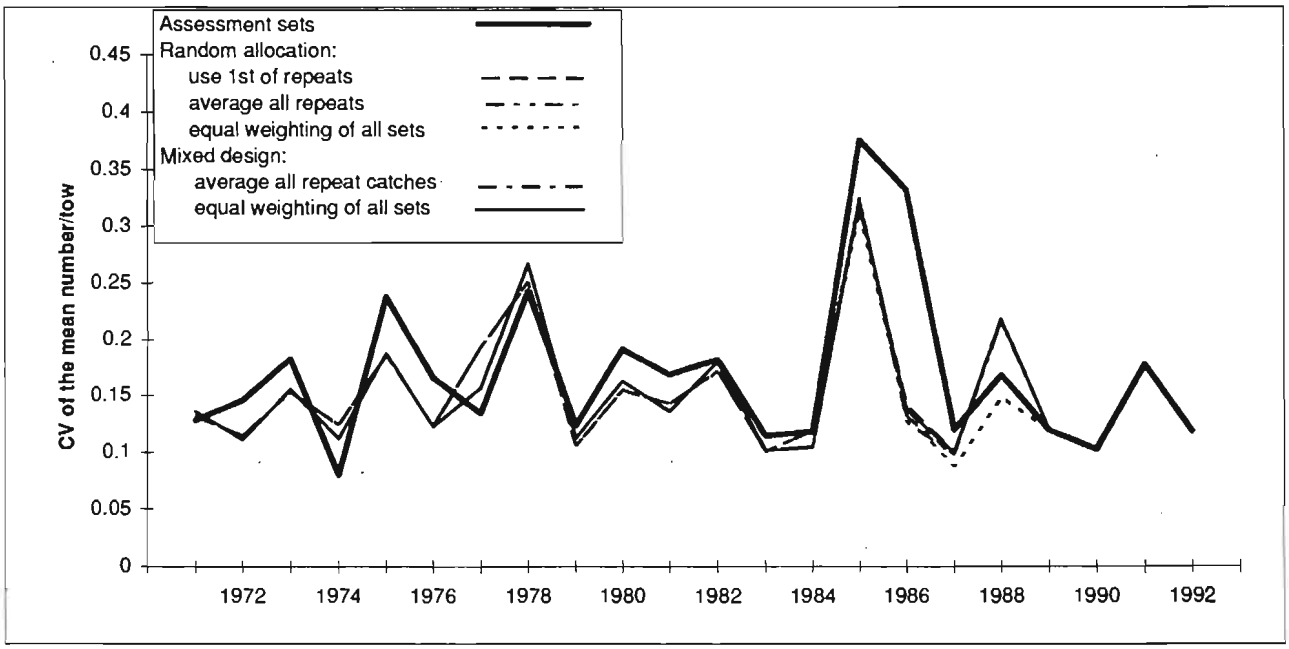


Figure 9. Mean number of cod/tow and coefficient of variation for the various methods of including repeat and fixed sets in the 4T research vessel data; only P327 is included for 1985

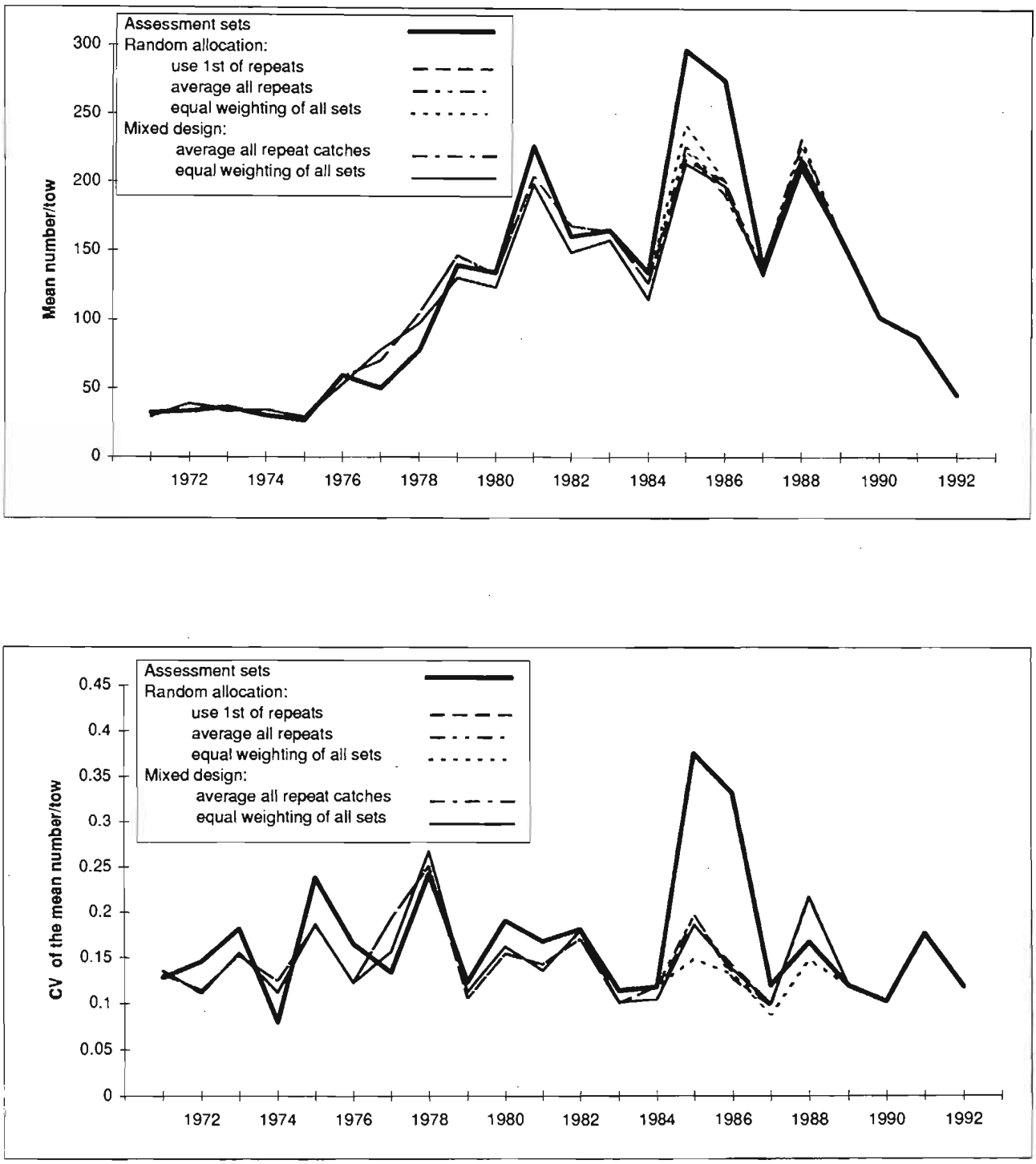
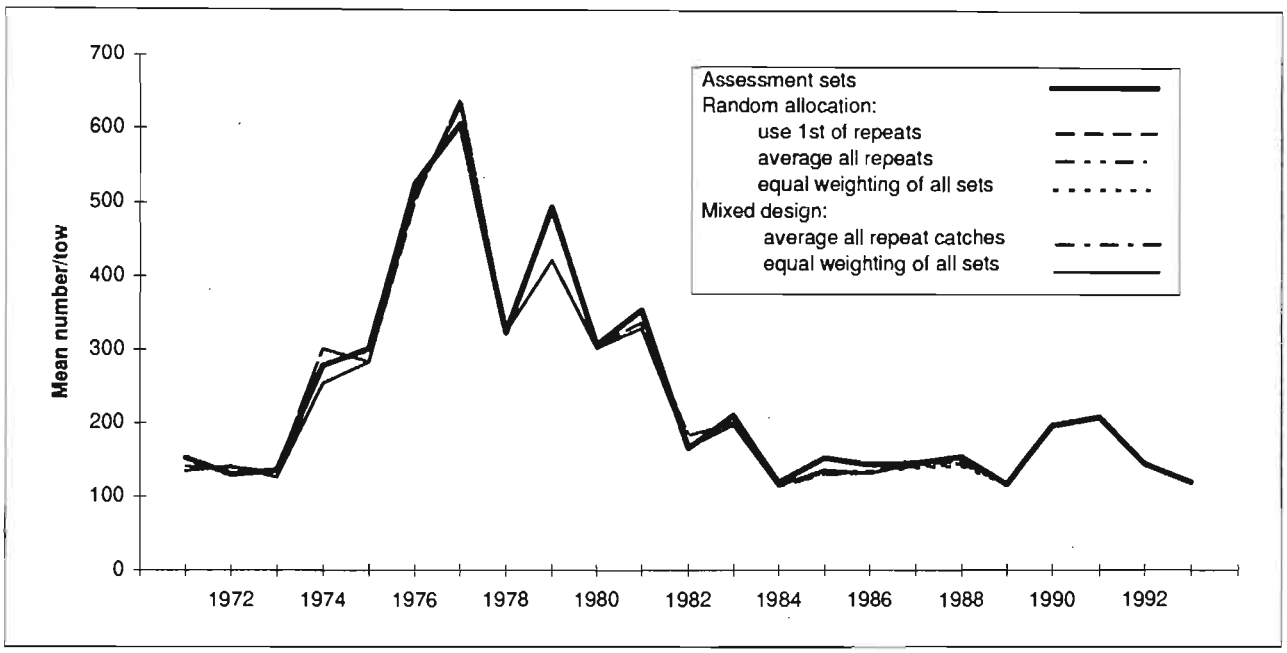


Figure 10. Mean number of cod/tow and coefficient of variation for the various methods of including repeat and fixed sets in the 4T research vessel data; both P327 and H141 are included for 1985



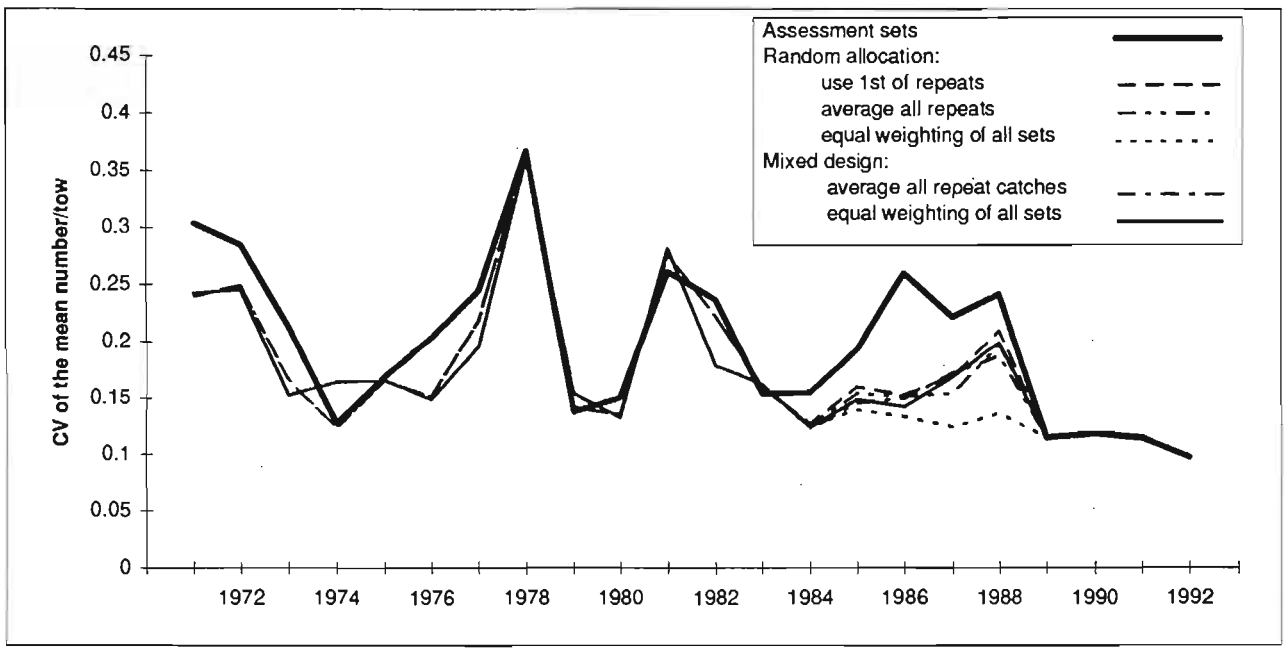
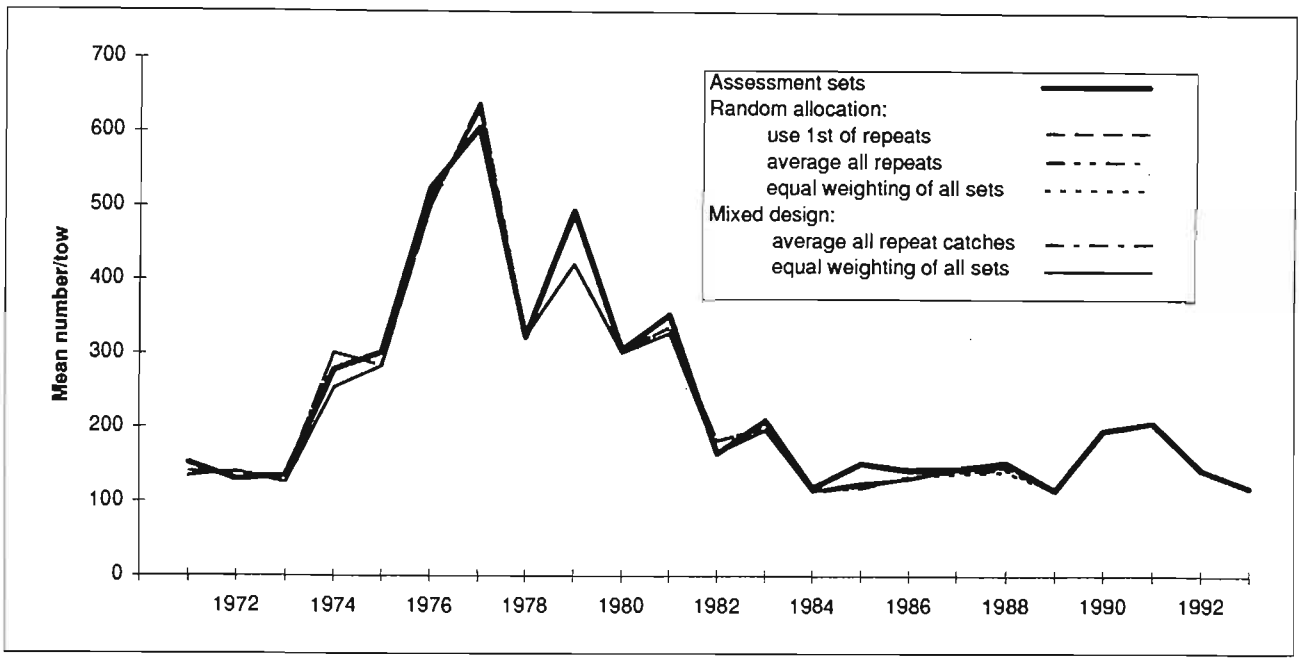


Figure 11. Mean number of plaice/tow and coefficient of variation for the various methods of including repeat and fixed sets in the 4T research vessel data; only P327 is included for 1985



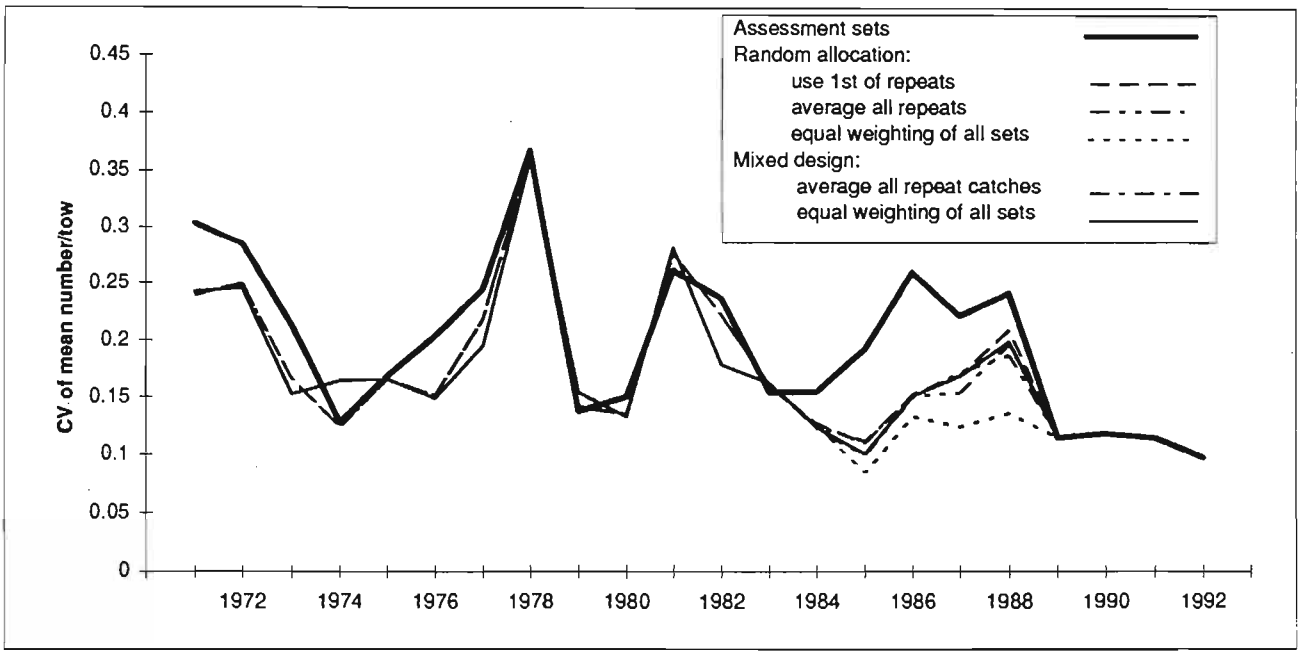
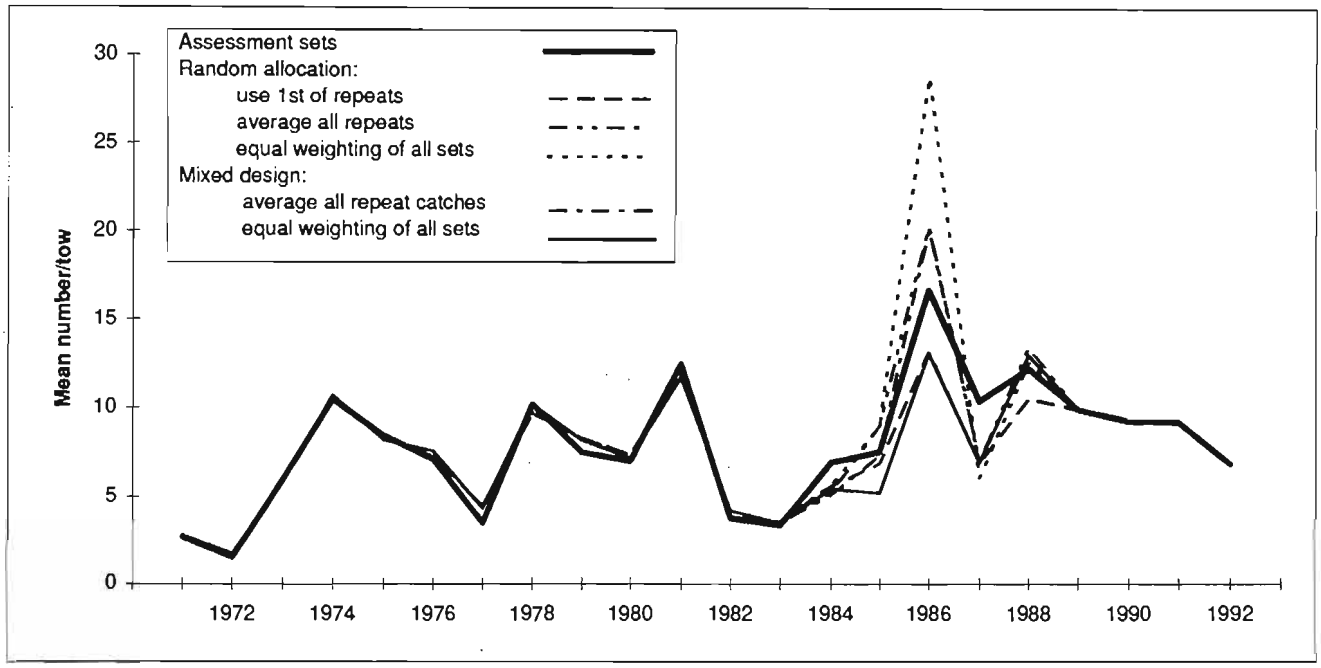


Figure 12. Mean number of plaice/tow and coefficient of variation for the various methods of including repeat and fixed sets in the 4T research vessel data; both P327 and H141 are included for 1985



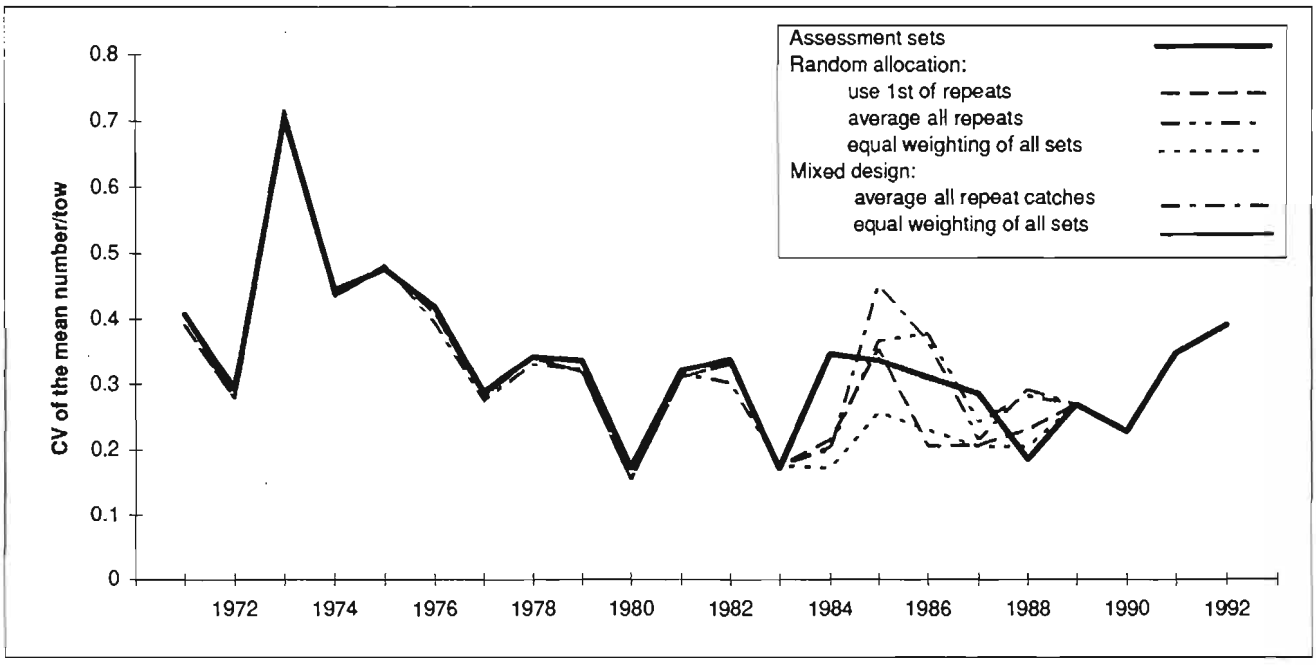
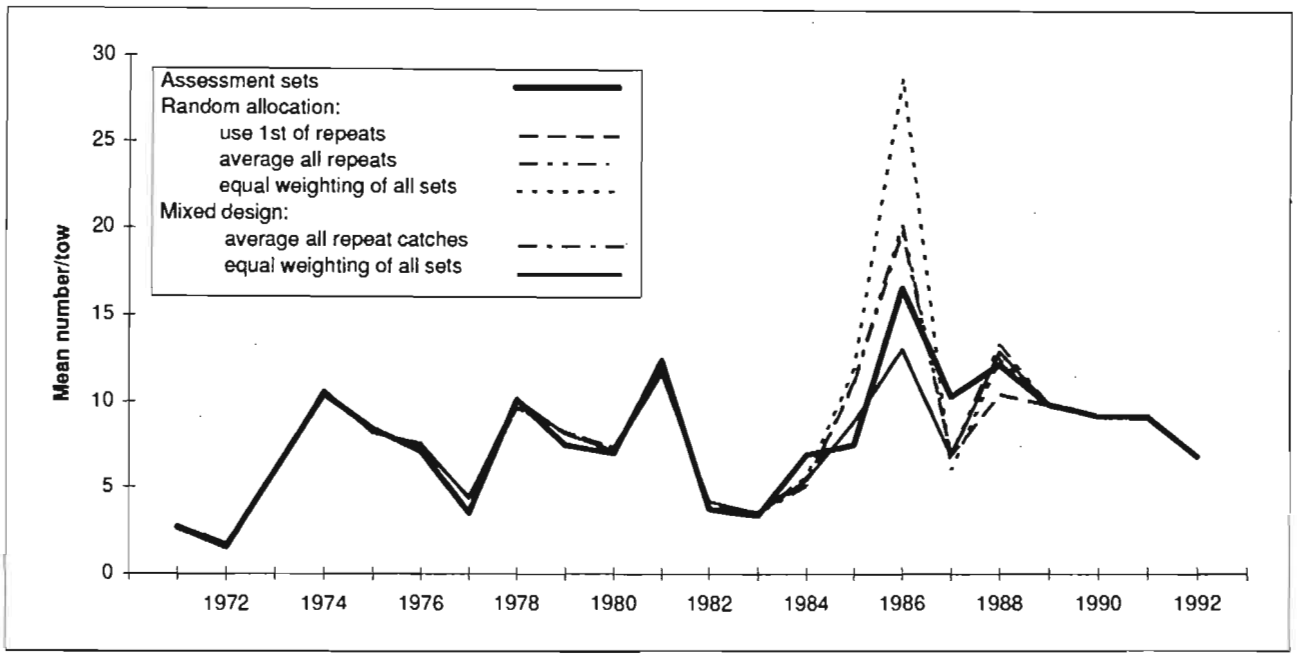


Figure 13. Mean number of white hake/tow and coefficient of variation for the various methods of including repeat and fixed sets in the 4T research vessel data; only P327 is included for 1985



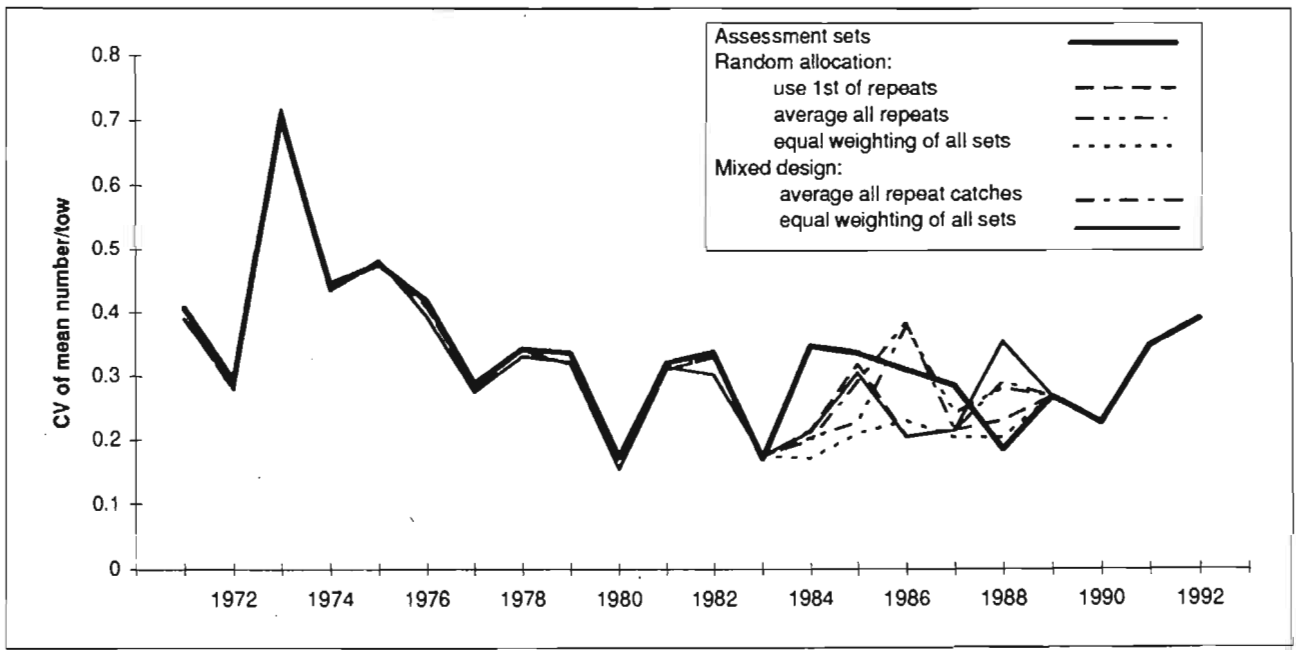


Figure 14. Mean number of white hake/tow and coefficient of variation for the various methods of including repeat and fixed sets in the 4T research vessel data; both P327 and H141 are included for 1985