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A comparison of hoki acoustic biomass estimates west coast South Island 1985 and 1988, Cook Strait 1987 and 1988

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1. INTRODUCTION

This paper briefly summarises the results of the 1985 and 1988 West Coast South Island (WCSI) hoki acoustic surveys, and examines the comparability of the two biomass estimates obtained. The biomass estimates for the 1987 and 1988 Cook Strait hoki surveys are also briefly discussed.

2. WEST COAST SOUTH ISLAND

2.1 Survey design

The 1985 and 1988 surveys were both designed to cope with a perceived problem of turnover of hoki within the survey area. It was thought a possibility that at no point during the spawning season was the vast majority of the spawning biomass actually present in the survey area. The designs of the two surveys used to cope with this problem were quite different and are briefly detailed below.

2.2 WCSI 1985

The original hypothesis behind the 1985 design was that there were a number of distinct spawning areas along the west coast, each being fed by their own "sub-population" of hoki (with minimal intermixing between spawning areas). The plan was to determine the spawning areas (from prior knowledge, fleet movements, and searching) and periodically survey them through the season, and also (to enable biomass estimation of each sub-population) estimate the mean residence time of a hoki within each spawning area.

The length of the west coast (from 41°S to 43°20'S) was searched several times, and high concentrations of hoki were located and surveyed. The data can reasonably be grouped to represent eight separate snapshots of biomass throughout the spawning season (see Table 1 and Figure 1) of which the last four relate to the height of the season. Figures 2a to 2d show the locations and estimated biomass of the surveyed aggregations which were used for the last four snapshots.

2.3 WCSI 1988

The 1985 hypothesis of distinct spawning areas and limited intermixing on the west coast was not held in 1988. The whole of the west coast was viewed as one spawning area with a constant intermixing of fish throughout the area.

There was still a possibility that turnover throughout the spawning season was occurring, but estimation of mean residence time was not considered feasible. Therefore, a different approach was developed in 1988. The objective was to do an initial survey of the west coast early in the season to determine the hoki biomass present, and to follow that with a second survey to measure the flow of hoki biomass into and out of the survey area (through a "tollgate"). A final cruise was also planned, which would either continue measuring the hoki flow through the tollgate (if the flow was continuing), or re-survey the whole area to check and improve the biomass estimate obtained from the first two surveys.

Bad weather and an inability to detect the flow of hoki into or out of the survey area meant that the 1988 surveys were reduced to obtaining three snapshot estimates of biomass. For the purposes of estimating a biomass index for 1988 (which is comparable to 1985), only a portion of the second cruise is relevant (see Figure 3a). (The first and third surveys were not conducted at the height of the season, and the first portion of the second cruise covered an area south of the survey area of immediate interest).

2.4 A biomass index

Absolute biomass estimates of spawning hoki are not possible without knowledge of the mean residence time of hoki within a survey area and precise knowledge of the mean intensity ratio of such hoki. However, a relative measure of hoki biomass can be obtained with the data we have available. Full details of the construction of a biomass index are given in Appendix 1. The general principles are as follows.

It is assumed that the expected hoki biomass in the survey area varies overs time in the manner shown in Appendix 1, Figure 1. The integral under this curve, divided by the mean residence time of hoki in the survey area, is equal to the total hoki spawning biomass. No information is available on residence time, but if the mean residence time is assumed to be constant (from year to year) then an estimate of the above integral can be used as an index of hoki spawning biomass. To estimate the integral, the season length, plateau height and plateau length must be estimated.

The biomass indices for the 1985 and 1988 west coast South Island surveys are given in Table 3, and the details of their estimation are as follows.

The plateau height for 1985 was estimated from the four snapshot estimates obtained during the height of the season (corrected for "background densities" — see table 2a and the discussion of hoki aggregations below). The 1988 plateau height was estimated by the single snapshot estimate obtained in cruise J0988 (see Table 2b and Figures 3a and 3b).

The season lengths were estimated from Fisheries Statistics Unit catch data for the given years. The apparently longer season in 1988 may be a reflection of the increased fishing activity in that year compared to 1985.

The plateau length for 1985 was estimated from the 1985 snapshots (see Figure 1) and is assumed to be the same for 1988. The plateau length is probably longer in both cases, and better estimates may be obtained from analysis of catch data. (For 1988, the plateau length is bounded by the finish date of the first cruise (30 June) and the start date of the third cruise (12 August), but this is a period of 44 days, so it does not usefully limit the length of the plateau.)

The plateau heights are derived from acoustic biomass estimates of hoki. Each acoustic biomass estimate for a given area is obtained from M, the mean areal backscattering of hoki recorded in the survey area; A, the size of the area; and W and T, estimates of, respectively, the mean weight and mean intensity ratio of the hoki surveyed.

The relationship is

$$\text{biomass estimate} = M.A.W/T$$

where W and T are derived from length frequency data collected during the acoustic survey, and from existing length–weight, and length–intensity ratio relationships. The length distribution is transformed according to the given relationship, to give a weight or intensity ratio distribution and hence an estimate of mean weight or mean intensity ratio.

The length–weight relationship used for deriving the WCSI biomass indices was derived from the J0988 cruise (Livingston in prep.) as it was felt to be the most appropriate for spawning hoki. The relationship by sex is:

male: $w = (13.7 \times 10^{-6}).L^{2.65}$

female: $w = (7.1 \times 10^{-6}).L^{2.81}$

where L is the length of a hoki in cm. and w its weight in kg.

The length–intensity ratio relationship used was

$$t = 10^{(0.0133L - 4.83)}$$

where t is the intensity ratio. The relationship was derived from a linear regression of target strength on fish length, where the target strengths of the fish were estimated by applying a mathematical model (Foote and Traynor 1988).

The large difference between the length distributions in 1985 and 1988 (see Table 3) is interesting. The drop in mean lengths does not indicate that there has been a dramatic decline in the mean lengths of the spawning hoki populations as a whole. The differences probably reflect the different sampling designs (in 1985 trawling was done only on aggregations, whereas in 1988 some trawling was done on the background densities), the different fish distribution (the huge Hokitika canyon aggregation of 1985 did not occur in 1988), and differences between the two vessels' trawling gear. The fact that the two surveys were carried out by different vessels may mean that the trawl sampling was biased in different ways. However, estimation of length distribution parameters is not critical to relative biomass estimation, as the ratio W/T is insensitive to even quite large changes in mean fish lengths (see Figure 7).

2.5 A comparison of the 1985 and 1988 WCSI biomass indices

2.5.1 Hoki aggregations

In 1985 it was believed that well defined aggregations of hoki were formed on the west coast during the spawning season, and that during the peak of the season most of the hoki biomass was to be found in these aggregations (this is why the 1985 survey design involved locating and surveying such aggregations). In 1988 it was believed that a significant proportion of the spawning hoki biomass may have been sparsely distributed over a large area (while still involved in spawning, they did not necessarily spend a large proportion of their time in the aggregations).

An examination of the 1988 results tends to support the belief held in 1985. Figure 4a shows the mean areal backscattering (a measure of fish density) of hoki measured over ½ n. m. legs during the middle survey of 1988. Fish densities were low on all but a small portion of the survey track. In fact 10% of the survey track was responsible for more than 60% of the biomass estimate (Figure 4b).

In 1985 no background densities were surveyed. In an attempt to correct the 1985 snapshots for the dispersed biomass which was not surveyed, a mean background density was estimated and applied to the 1988 survey area less the area covered by each 1985 snapshot (see Table 2a). The mean background density was taken to be the average of the lowest 60% of the hoki areal densities recorded in 1988. The value of 60% was derived from the model of hoki density distribution which has been implicit in this discussion, i.e. aggregations of hoki against a background scattering of hoki. The long tailed density distribution (Figure 4a) can be viewed as a composition of two distributions. There are the densities recorded in aggregations (which make up the tail of the overall distribution) and the remaining densities drawn from the background distribution. Figures 4c — 4g demonstrate that this view is supported by the data. They show the density distributions for increasingly larger percentages of the ordered data set. The distribution only becomes negatively skewed when the percentage reaches approximately 60%.

2.5.2 Precision

An idea of the precision of the 1985 and 1988 estimates can be obtained from Table 4. For each survey the coefficient of variation (c.v.) given can be viewed as a conservative estimate of the estimators true c.v. For 1985 individual biomass estimates are for aggregations, and the c.v. relates to the mean density calculated from an average weighted by transect length. (Tentative results from simulations suggest that the estimates of c.v. given are over–estimates).

To obtain a c.v. estimate for 1988 the cruise track (shown in Figure 3a) was divided into consecutive ½ n.m. legs, and a mean hoki density derived for each leg. Consecutive ½ n.m. legs can be combined to form 1 n.m. legs, and sets of legs of larger length can be similarly constructed. Clearly, a statistical correlation between consecutive legs (whatever their length) is to be expected. The nature of the dependence is complicated as it depends on the cruise track and the spatial distribution of the hoki. To obtain a preliminary estimate of the c.v., the variation in the "apparent c.v." with leg length was examined. (The "apparent c.v." is the estimate of the sample means c.v. when the density readings of the legs of a given length are taken to be a random sample.)

Figure 5a shows a typical example of how the apparent c.v. varies with leg length (for a particular stratum). If there was no correlation between legs, the plot would aproximate a horizontal line. When the legs are serially correlated, but identically distributed, the plot would be expected to climb to a plateau (the height reached being the true c.v.) as in Figure 5b. On the basis of the plots done for each stratum (Figure 5a being typical), 5 n.m. legs were chosen to estimate the c.v.s for the 1988 data.

2.5.3 Bias

In order to compare the 1985 and 1988 results, areas of bias involved in the estimates need to be considered.

The first area to be considered is the general acoustic method used. Layer identification, species composition of layers, and separation of bottom and fish echoes can all cause bias. The main concern with bias in comparing the 1985 and 1988 estimates is if the estimators are biased to significantly different degrees. As the two data sets have been analysed in the same manner and with the same software, separation of bottom and fish echoes is not a concern. Also, as the primary contribution to the biomass estimates came from densities recorded from highly aggregated hoki (easily identified as such from trawls) where bycatch is minimal, neither layer identification or species composition should be responsible for significantly different biases between estimators.

Second, the actual survey designs used must be considered. The 1985 snapshots have been corrected for the background densities of hoki which were not recorded. However, no attempt has been made to correct them for the aggregations of hoki which were not located (and hence not surveyed) during the periods concerned. The extent of this bias is difficult to estimate, as it depends on the effectiveness of the search techniques used. Certainly some credit must be given to the methods used, as hoki were located in previously unfished areas (Hokitika and Cook canyons).

Third, the relative levels of fishing activity in 1985 and 1988 must be taken into account (see Sullivan and Coombs, in prep.). A much larger quantity of fish (approx. 89,000 t) was removed from the west coast during 1988 before and during the period of the survey than in 1985, so that the estimate in 1988 is a underestimate relative to 1985. The extent of this bias is also very hard to estimate, so no correction has been attempted.

2.5.4 Confidence intervals

The primary purpose in comparing the estimates of spawning biomass on the west coast was to determine whether or not there has been a signifcant decline in stock size. The estimation of the biomass index for each year requires estimates of plateau height, plateau length, and season length. Unfortunately, the estimates of plateau length and season length are based on very little data, and there is no sensible way to estimate the variability associated with their estimation. However, the variance of the estimators of plateau height for each year can be estimated, and plateau height used as a biomass index. In doing so, it is assumed that the season lengths and plateau lengths are constant. This is not unreasonable, as the only data presently available (Table 3) suggest that the 1988 season was at least as long as the 1985 season, and also that the plateau length is considerably shorter than the season length (so that the biomass index is principally determined by the plateau height and season length — see Appendix 1).

The standard deviations of the plateau height estimators for 1985 and 1988 are given in Tables 2a and 2b, respectively. Their derivation assumes that no variability is associated with the size of the survey area, or the ratio of mean hoki weight to mean hoki intensity ratio. That is, for a given stratum (as in 1988), or a given aggregation (as in 1985), if the survey area is of size A, the mean areal backscattering in the area is M, the estimated mean hoki weight is W, the estimated mean hoki intensity ratio is T, and the biomass estimator for the area is B, then

$$\mathrm{var}(B) = \mathrm{var}\,(M.A.W/T)$$

$$= (A.W/T)^2\ \mathrm{var}(M)$$

For the 1985 aggregations

$$M = \frac{1}{\Sigma d_i} \sum_{i=1}^{n} d_i\, x_i$$

where d_i is the distance of the ith transect, x_i is the mean areal backscattering of the ith transect, and var(M) is estimated by

$$\frac{1}{\Sigma d_i\,(\Sigma d_i - 1)} \sum_{i=1}^{n} d_i^2 (M - x_i)^2$$

For a 1988 stratum

$$M = \frac{1}{n} \sum_{i=1}^{n} x_i$$

where x_i is the mean areal backscattering for the ith ½ n.m. leg, and var(M) is estimated by

$$\frac{S^2}{m} = \frac{1}{m(m-1)} \sum_{i=1}^{m} (\bar{y} - y_i)^2$$

where $m = n/10$, and $y_i = \frac{1}{10} \sum_{j=10(i-1)+1}^{10i} x_j$

(i.e. the variance is estimated from 5 n.m. legs)

Assuming a normal distribution for each estimator, the two sided 95% confidence intervals for the plateau heights in each year are:

1985: 174,000 to 244,000 t

1988: 133,000 to 269,000 t

It is more useful to consider a confidence interval on the difference of the two plateau heights. Under the above assumptions, a two sided 95% confidence interval for the difference (1988–1985) is:

-85,000 to 69,000 t.

2.5.5 Conclusion

In this paper an attempt has been made to make the best use of the data available to compare the relative sizes of the 1985 and 1988 WCSI hoki spawning stocks. The confidence interval derived for the difference of the two plateau heights depends on numerous assumptions. Nevertheless, it gives a fair indication of the probable relative changes in spawning biomass. It is reasonable to assume that as a worst case the stock has not declined more than 40% since 1985. (40% is derived by taking the lower bound of the confidence interval on the difference of plateau heights and dividing by the estimate of plateau height in 1985, i.e. 40% = 85,000/209,000.)

3. COOK STRAIT

In 1987 an acoustic survey was carried out on a large hoki aggregation found in Cook Strait Canyon. A similar survey was carried out in 1988, when fish were found in Cook Strait Canyon and the Narrows Basin (see Figures 6 a and b). Biomass indices were calculated for these two surveys on the same basis as for the WCSI surveys (see Table 5). In terms of comparability, the main concern is whether the single snapshots in each year were taken at the "height of the Cook Strait season". There is probably insufficient data to answer this question.

Almost no data is presently available for the estimation of season length and plateau length for the Cook Strait Canyon hoki season. The values given in Table 5 are simply round figures comparable to the estimates used for the WCSI.

The length–weight relationship used in deriving the biomass indices was obtained from data collected from Cook Strait during the 1988 survey (Livingston, in prep.). The relationship by sex is:

male: $w = (3.6 \times 10^{-6}) \cdot L^{2.94}$

female: $w = (3.7 \times 10^{-6}) \cdot L^{2.95}$

The length–intensity ratio relationship used for the WCSI was also used for the Cook Strait estimates.

The 1987 hoki biomass estimate for Cook Strait Canyon given in Do and Ball (1988) differs from the estimate of plateau height given in Table 5. This is because different methods were used for the estimation of the mean weight and mean intensity ratio of the hoki.

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5. APPENDIX 1

5.1 A biomass index for transient populations

It is assumed that over a given time period, each member of a population of fish visits a predefined survey area, stays within the area for a period of time, and then leaves. The aim is to estimate the biomass of the population.

Let the given time interval be (A,B), and assume the population of fish consists of n members, the ith member of which has fixed weight w_i, and stays within the area an unknown time T_i.

Let M(t) = the total biomass within the area at time t.

M(t) = 0 for t<A and t>B, but for A<t<B, M(t) is unknown and depends on which fish are within the area.

However,

$$\int_{t=A}^{t=B} M(t)\,dt = \sum_{i \varepsilon n} w_i T_i$$

as both measure the total weight. time over the season, (A,B).

Taking expected values,

$$\int_{t=A}^{t=B} E(M(t))\,dt = \sum_{i \varepsilon n} w_i E(T_i)$$

and assuming that the T_i are mutually independent and identically distributed, with mean α, then

$$\int_{t=A}^{t=B} E(M(t))\,dt = \alpha \sum_{i \varepsilon n} w_i$$

let $g(t) = E(M(t))$, $I(A,B) = \int_{t=A}^{t=B} g(t)dt$,

and $w = \sum_{i \varepsilon n} w_i$

then

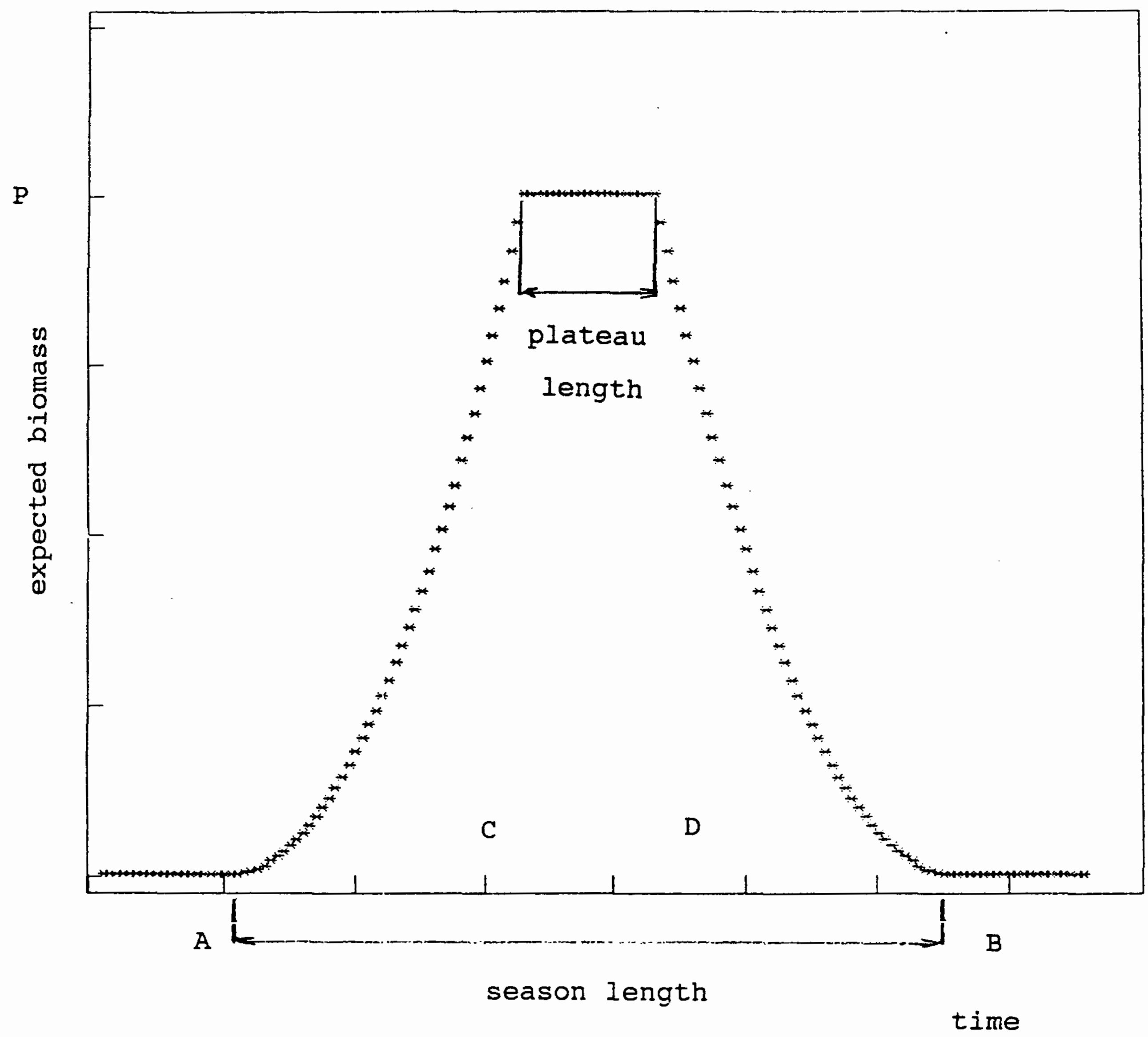
$$w = \frac{1}{\alpha} I(A,B)$$

Therefore, to estimate the absolute biomass of the populations, two quantities must be estimated; α, the mean residence time of a fish in the area, and I(A,B), the total biomass integral over the time period. If α can not be estimated, then an absolute biomass estimate is unattainable, even with good estimation of I(A,B). However, if α can be assumed to be stable from year to year, then relative estimates of biomass are achievable, even if only relative estimates of I(A,B) are available.

I(A,B) ideally should be estimated from a series of snapshot biomass estimates covering the whole time period (A,B). If a full series is not practical, then some assumptions about the general shape of g(t) must be made to allow an estimation. One possible general shape is shown in Figure 1. g(t) is assumed to climb from zero to some plateau value which is maintained for a period before its value again drops to zero. If the rise and decline are assumed to be quadratic, then

$$I(A,B) = P\left(\frac{1}{3}(B-A) + \frac{2}{3}(D-C)\right)$$

The parameters which then need to be estimated are B–A, the season length, D–C the plateau length, and P the plateau height.



Appendix 1 Figure 1.

Simple model for g(t), the expected hoki biomass in the survey area at time t.

Table 1. Acoustic estimates of hoki biomass during the 1985 WCSI spawning season (uncorrected for fish outside of the surveyed aggregations).

snapshot	1	2	3	4	5	6	7	8
period of season	13-7 18-7	19-7 21-7	22-7 24-7	25-7 27-7	30-7 1-8	2-8 5-8	11-8 13-8	14-8 15-8
estimate (1000's t)	26	28	43	91	232	169	175	165

Table 2a. Acoustic estimates of plateau height for the hoki spawning season WCSI 1985 (corrected for background densities by applying the mean of the lowest 60% of hoki areal densities recorded in 1988, to the survey area in 1988 less the area covered by each 1985 snapshot).

snapshot	area sq. km	snapshot (1000's t)	correction (1000's t)	est. plus correct.	est. s.d. of estimate
5	1096	232	23.4	255	30.2
6	1154	169	23.2	192	23.1
7	936	175	23.7	199	35.3
8	701	165	24.4	189	49.6
mean	971	185	23.7	209	17.9

Table 2b. Acoustic estimate of plateau height for the hoki spawning season WCSI 1988, by stratum.

stratum	1 & 2	4	5	6	7	total
area (sq. km.)	3415	4081	738	1777	332	10343
total dist. surveyed (n.m.)	135	118	93	134	21	501
biomass estimate (1000's t)	32	47	28	92	2	201
est. s.d. of estimate (1000's t)	9.4	7.5	10.7	30.9	1.1	34.8

Table 3. Fish and model parameters used to estimate biomass indices for the hoki spawning population WCSI 1985 and 1988.

Fish parameters

year	mean fish length male (cm)	female	prop. male/fem.	mean intensity ratio (e-4)	mean weight (kg)
1985	78.8	87.7	1.23	1.98	1.79
1988	74.5	82.1	1.23	1.73	1.54

Model parameters

year	season length (days)	plateau length (days)	plateau height (1000 t)	biomass index (million t.days)
1985	93	14	209	8.43
1988	103	14	201	8.78

Table 4. Estimates of c.v. for the acoustic estimates of hoki biomass on the WCSI.

stratum 1988	1 & 2	4	5	6	7
c.v. %	29	16	38	34	48

snapshot 1985	5	6	7	8
c.v. %	13	14	20	30

Table 5. Fish and model parameters used to estimate biomass indices for the hoki spawning population Cook Strait 1987 and 1988.

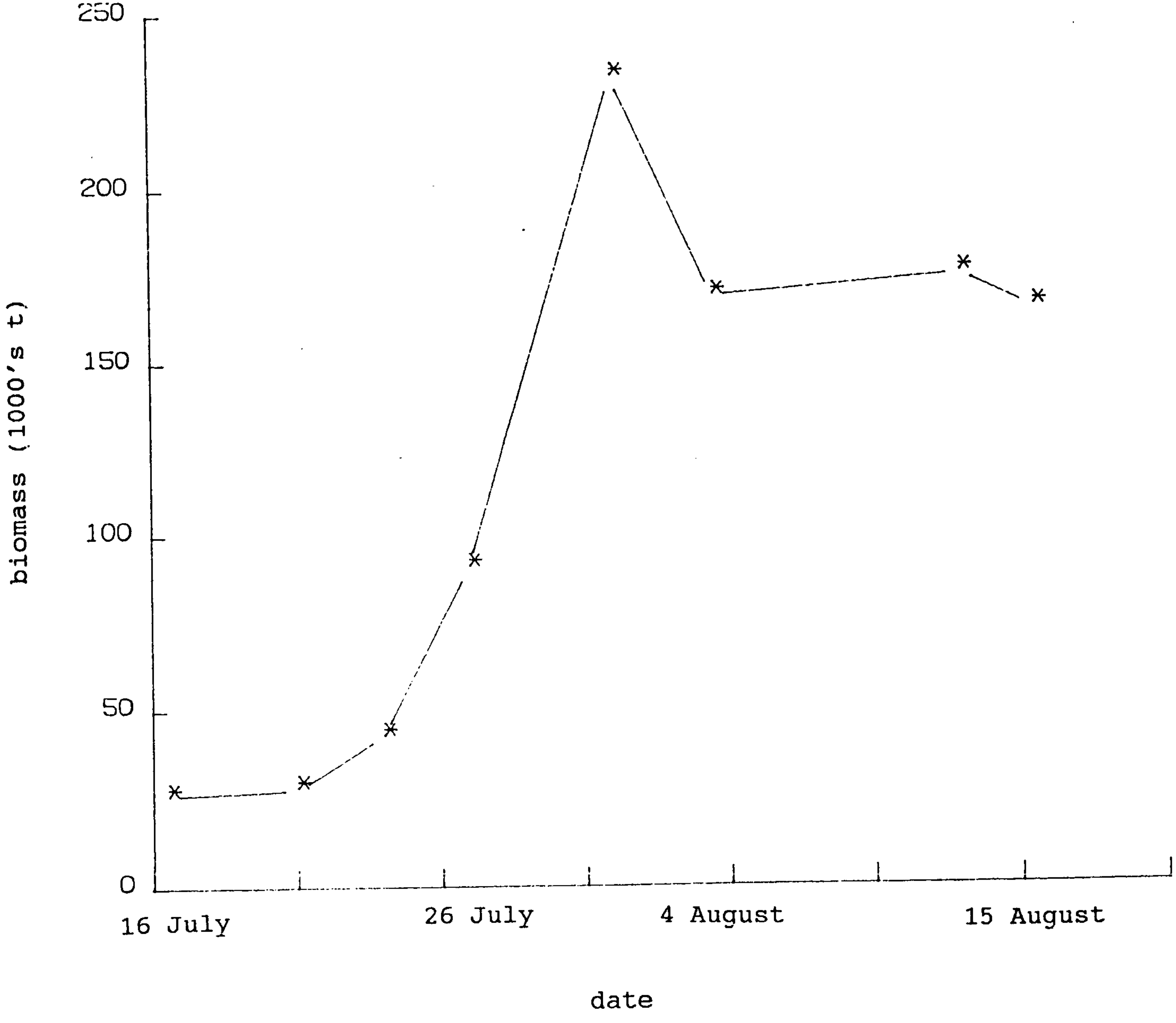
Fish parameters

year	mean fish length male (cm)	female	prop. male/fem.	mean intensity ratio (e-4)	mean weight (kg)
1987	77.2	83.6	0.67	1.89	1.63
1988	78.4	83.5	0.19	1.95	1.79

Model parameters

year	season length (days)	plateau length (days)	plateau height (1000 t)	biomass index (million t.days)
1987	100	15	72	3.13
1988	100	15	50	2.15

Figure 1. Acoustic estimates of hoki biomass during the 1985 WCSI spawning season.



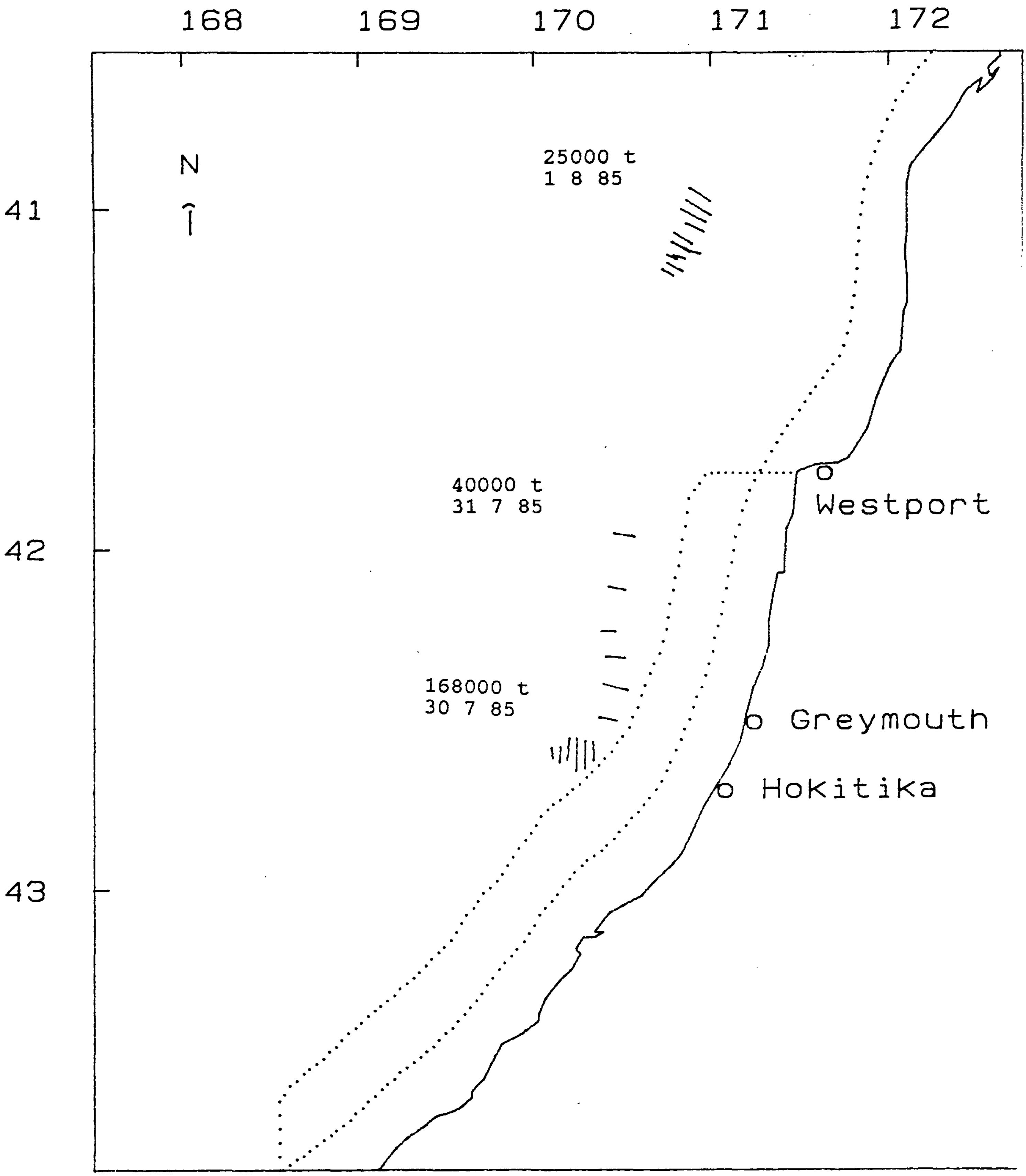


Figure 2a. The location and estimated magnitude of the hoki aggregations in 1985 on the WCSI for snapshot 5. The line segments show the position of the acoustic transects. The dotted lines mark the 12 n.m. and 25 n.m. closed areas.

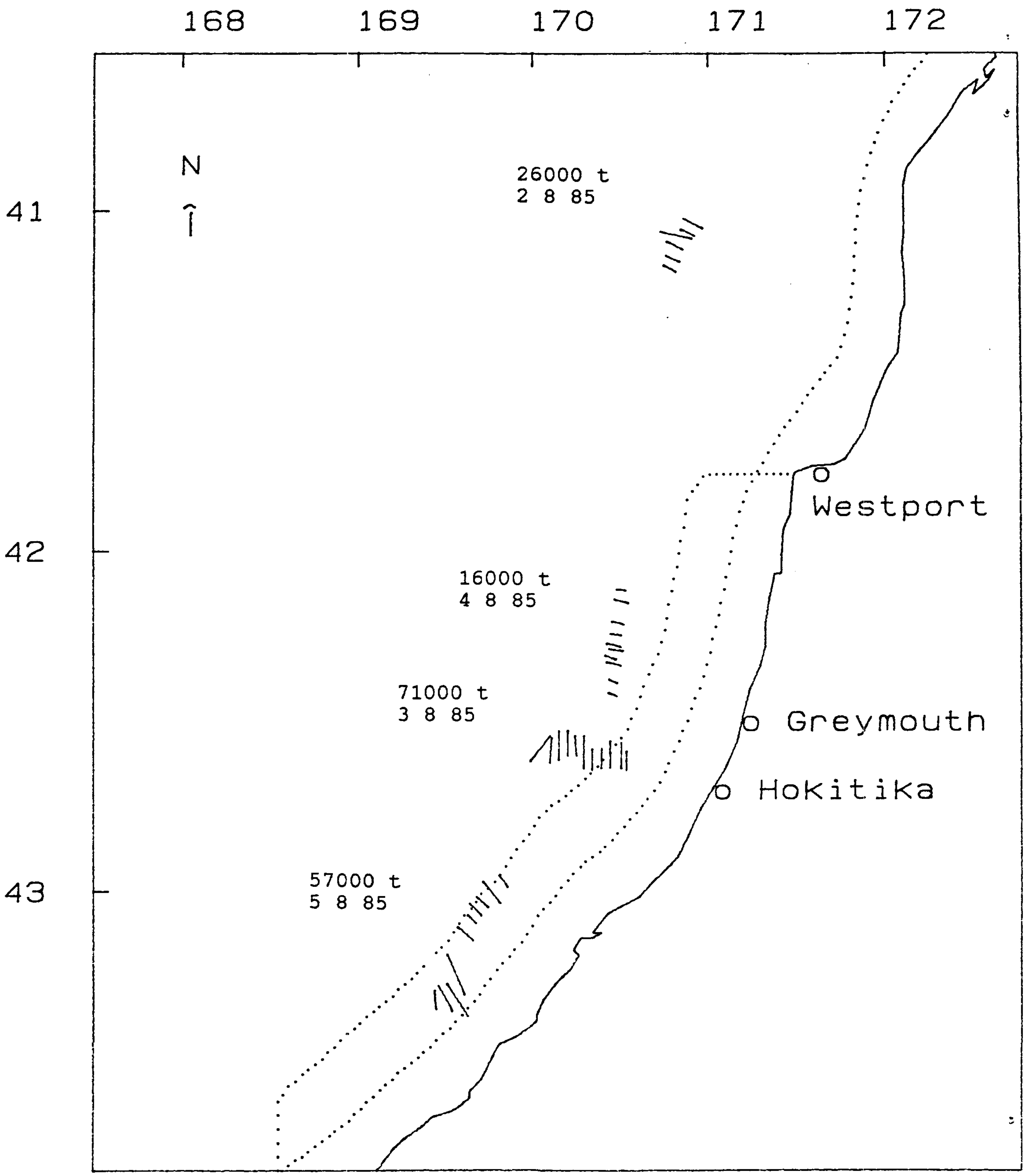


Figure 2b. The location and estimated magnitude of the hoki aggregations in 1985 on the WCSI for snapshot 6. The line segments show the position of the acoustic transects. The dotted lines mark the 12 n.m. and 25 n.m. closed areas.

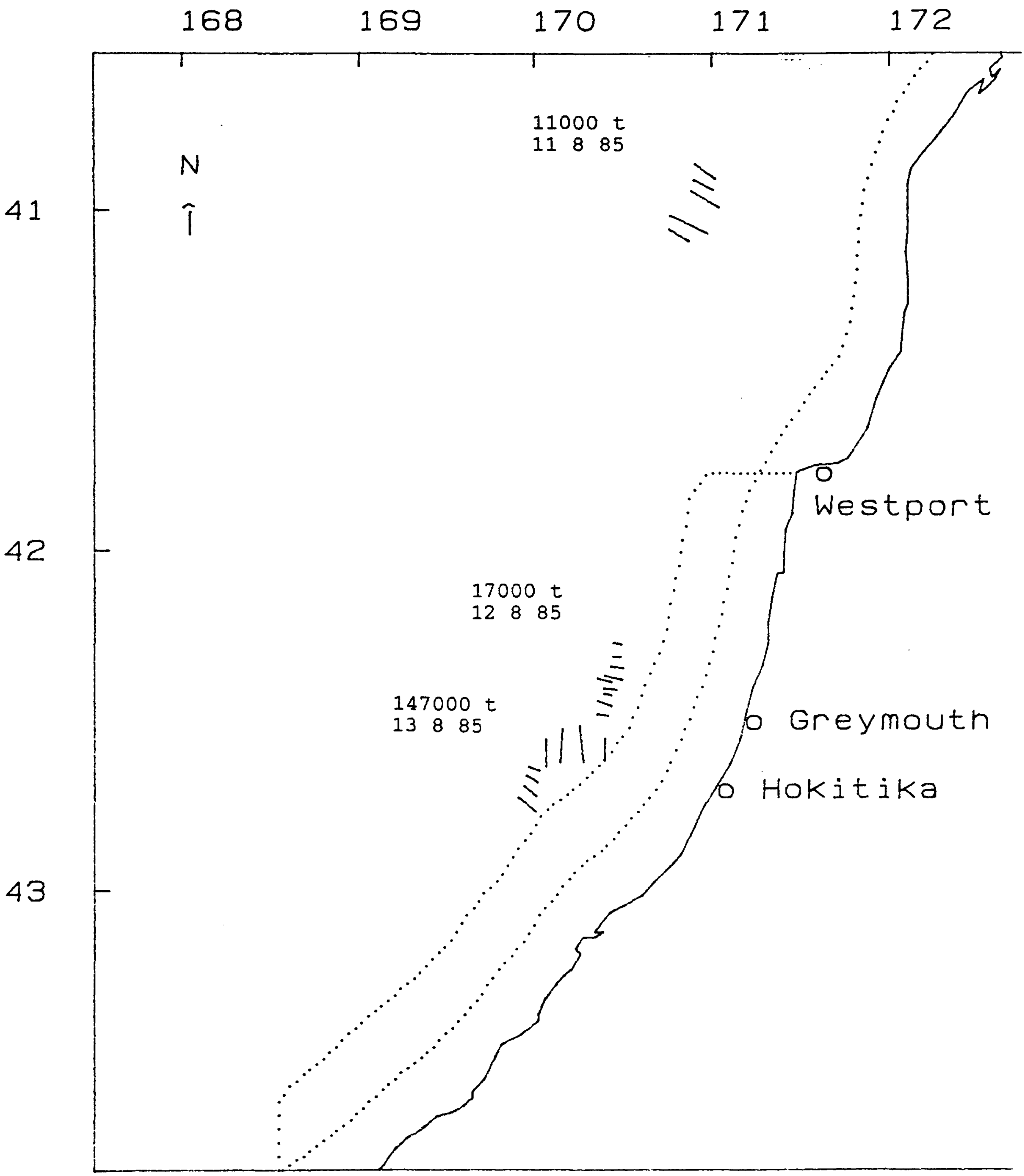


Figure 2c. The location and estimated magnitude of the hoki aggregations in 1985 on the WCSI for snapshot 7. The line segments show the position of the acoustic transects. The dotted lines mark the 12 n.m. and 25 n.m. closed areas.

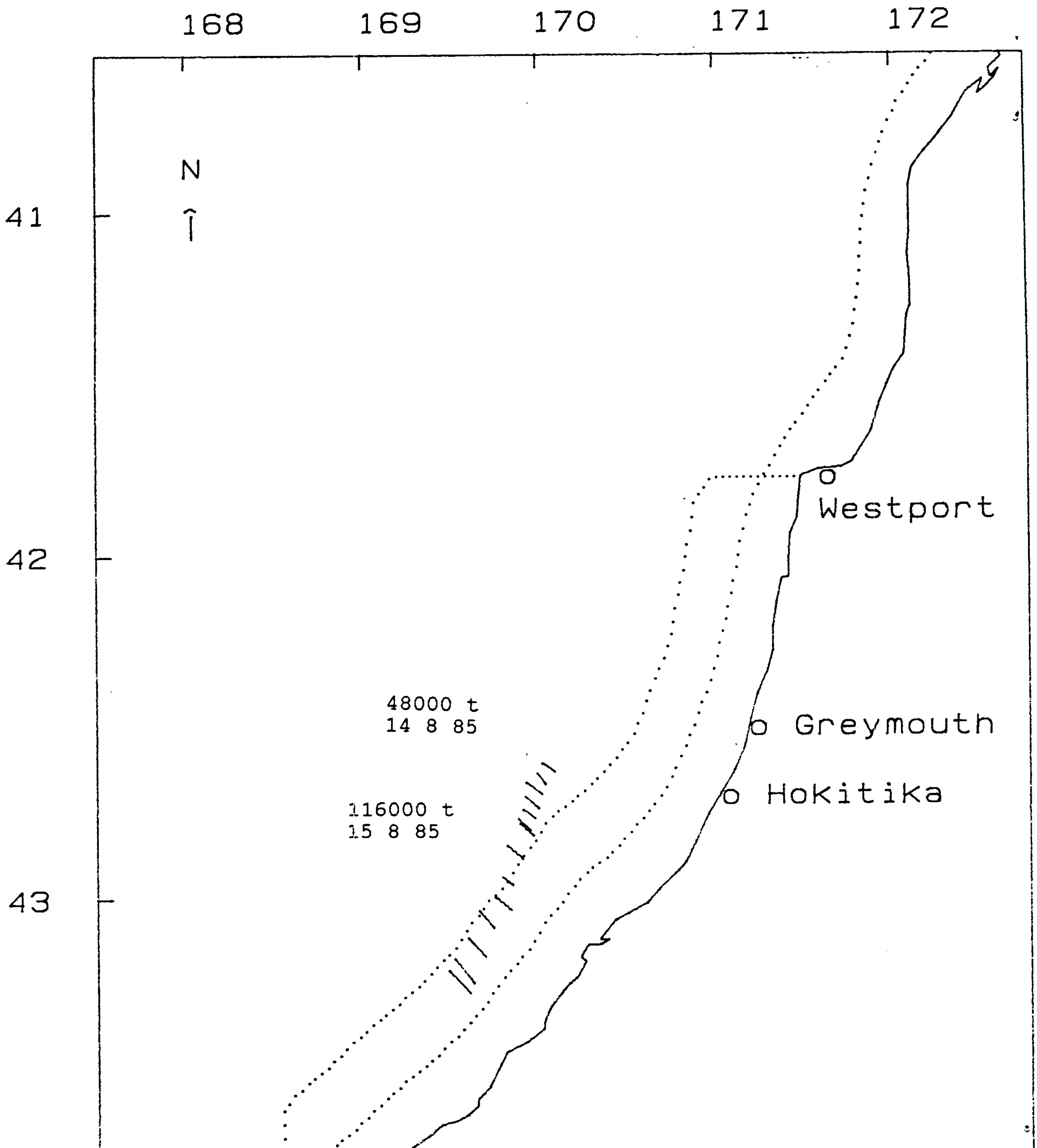


Figure 2d. The location and estimated magnitude of the hoki aggregations in 1985 on the WCSI for snapshot 8. The line segments show the position of the acoustic transects. The dotted lines mark the 12 n.m. and 25 n.m. closed areas.

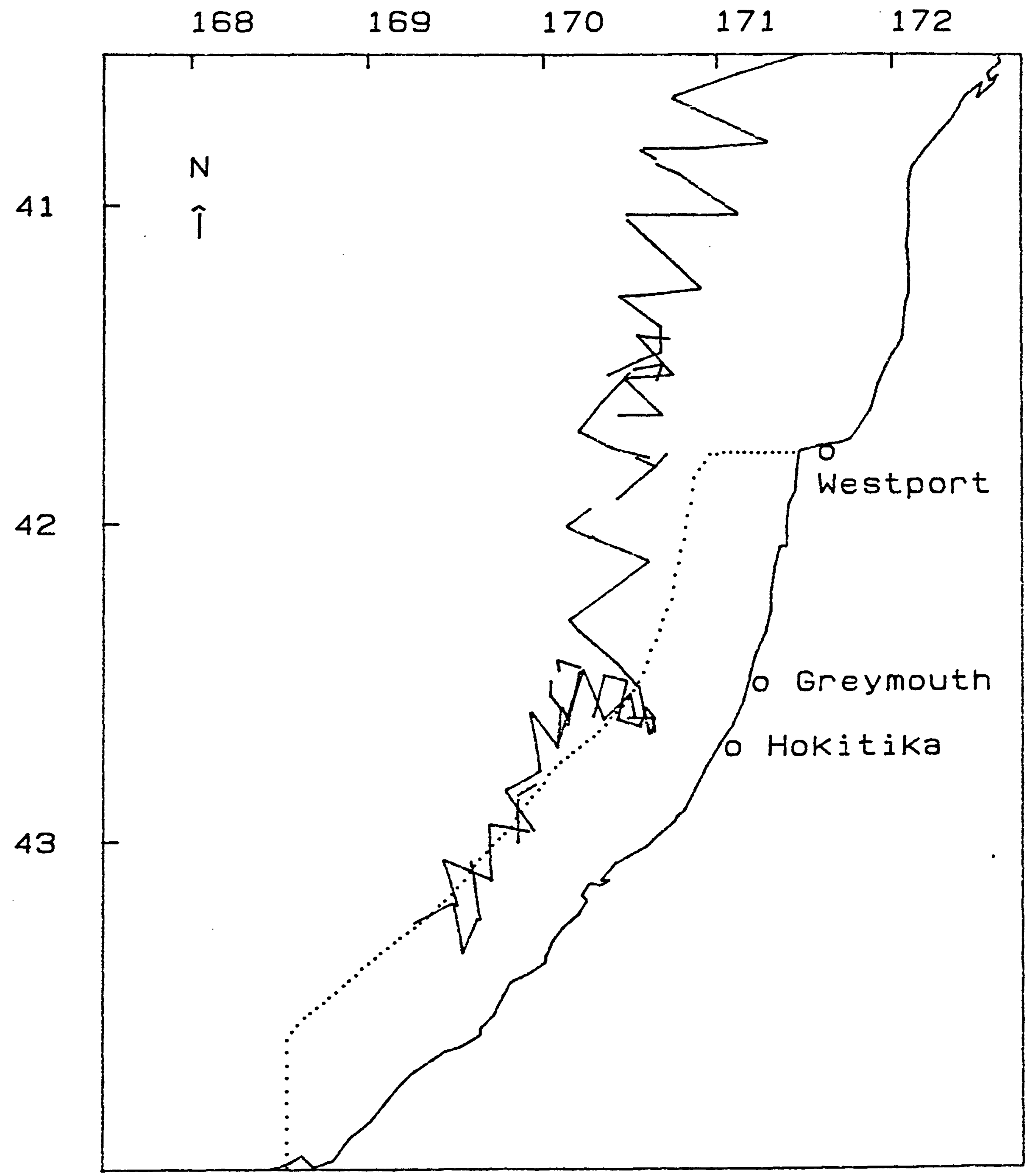


Figure 3a. The acoustic transects used for hoki biomass estimation in 1988. Data was recorded on the transects during cruise J09/88 from 29 July to 5 August 1988 on the WCSI. The dotted line marks the 25 n.m. closed area.

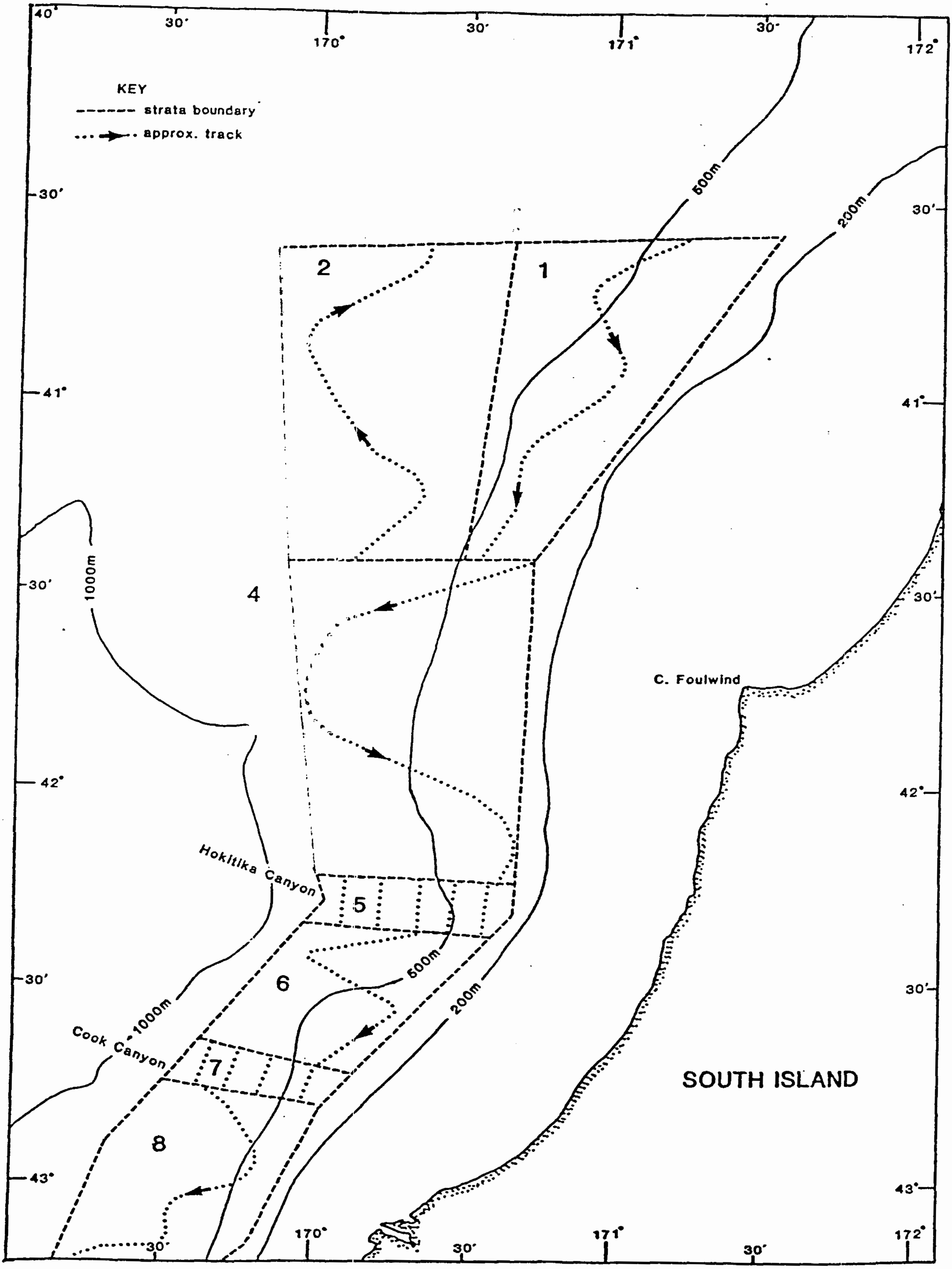


Figure 3b. The strata (and an idealized survey track) for the 1988 WCSI surveys. For J09/88 strata 1 and 2 were combined into a single stratum.

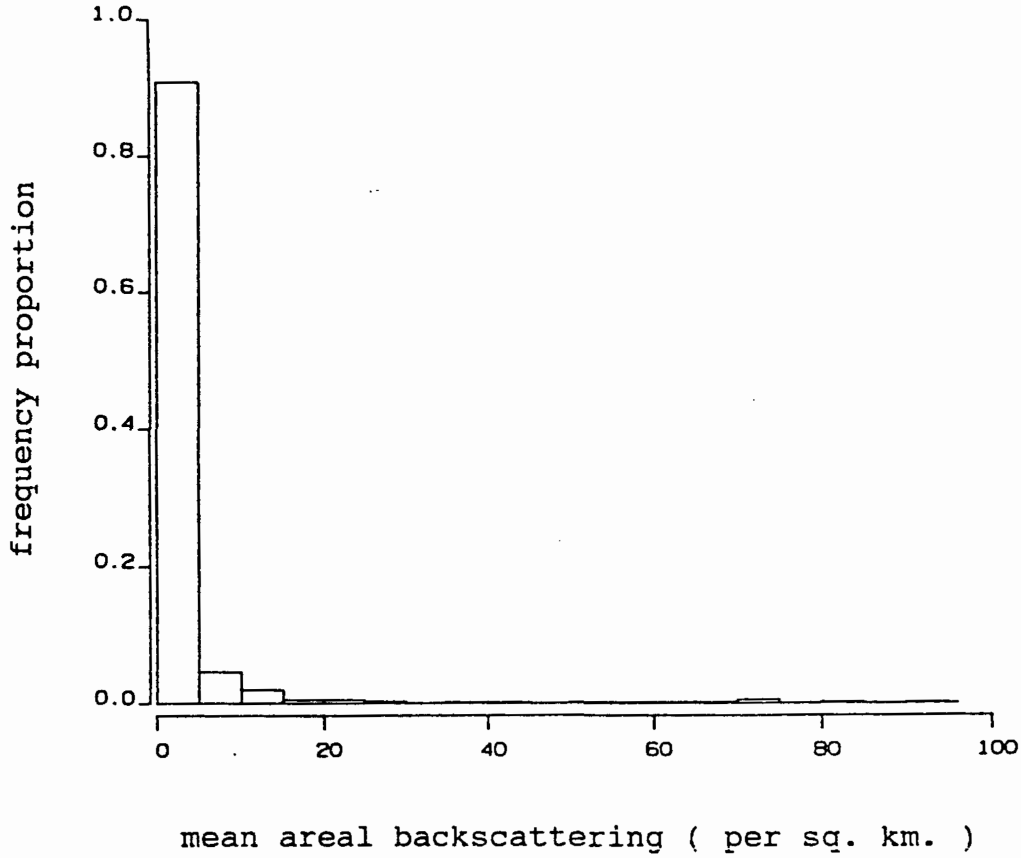


Figure 4a. The distribution of the mean areal backscattering of 1/2 n.m. legs recorded during cruise J09/88 29 July to 5 August 1988 on the WCSI.

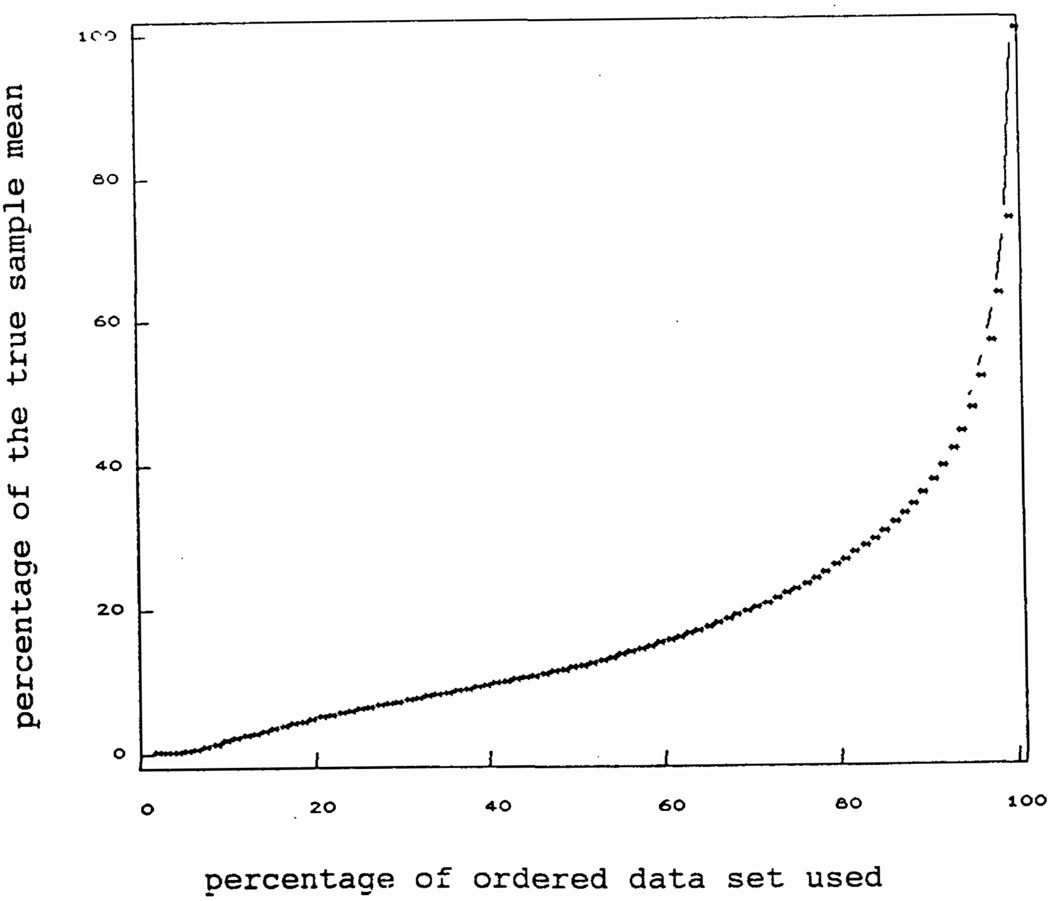


Figure 4b. The variation of the mean of an increasing percentage of the set of ordered mean areal backscattering of 1/2 n.m. legs recorded in cruise J09/88 29 July to 5 August 1988 WCSI.

Figures 4c - 4g.

The distributions of the lowest 30%, 40%, 50%, 60% and 70% of mean areal backscattering of 1/2 n.m. legs recorded during cruise J09/88 29 July to 5 August 1988 on the WCSI.

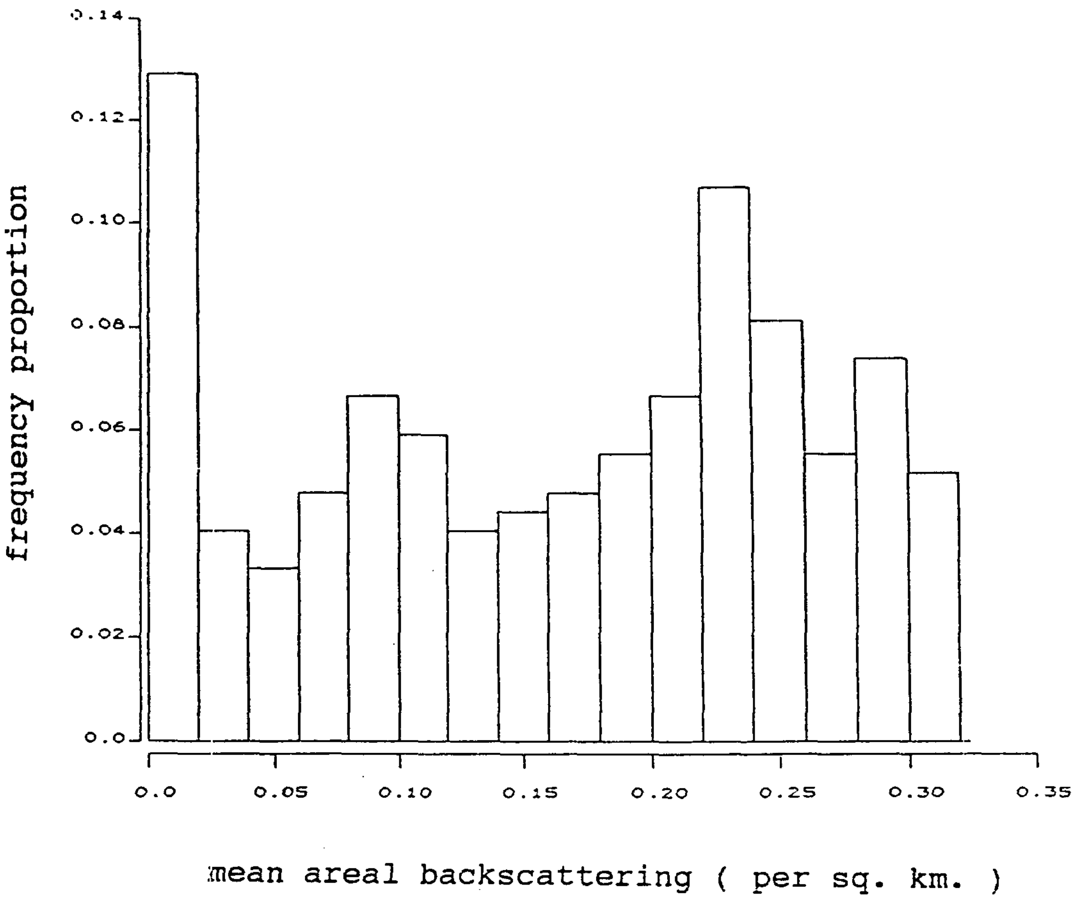
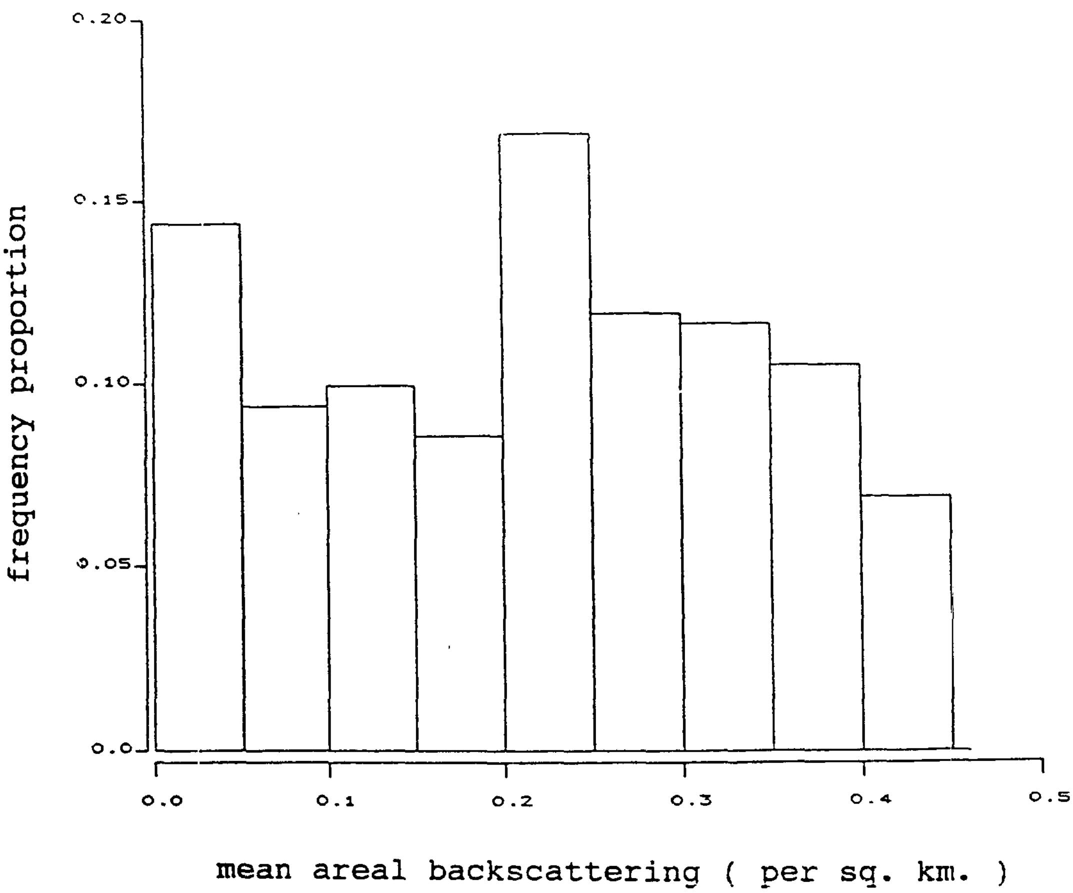


figure 4c.



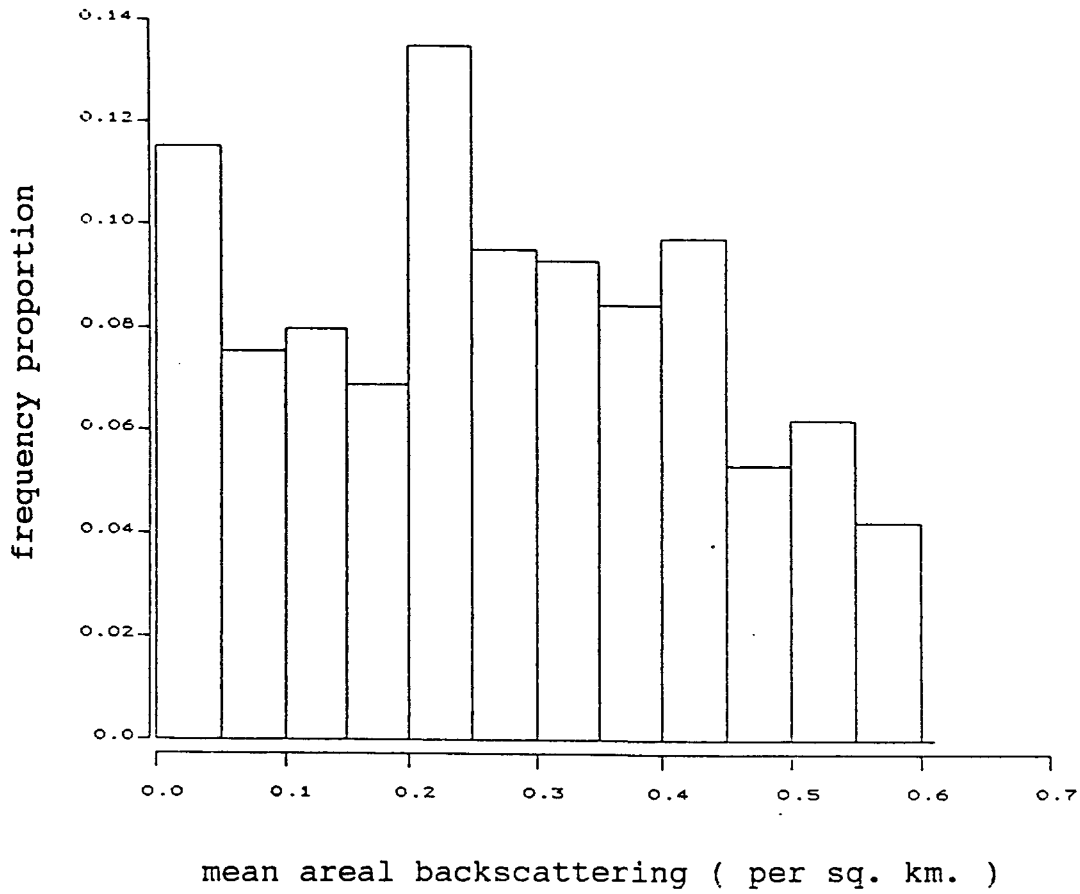


figure 4e.

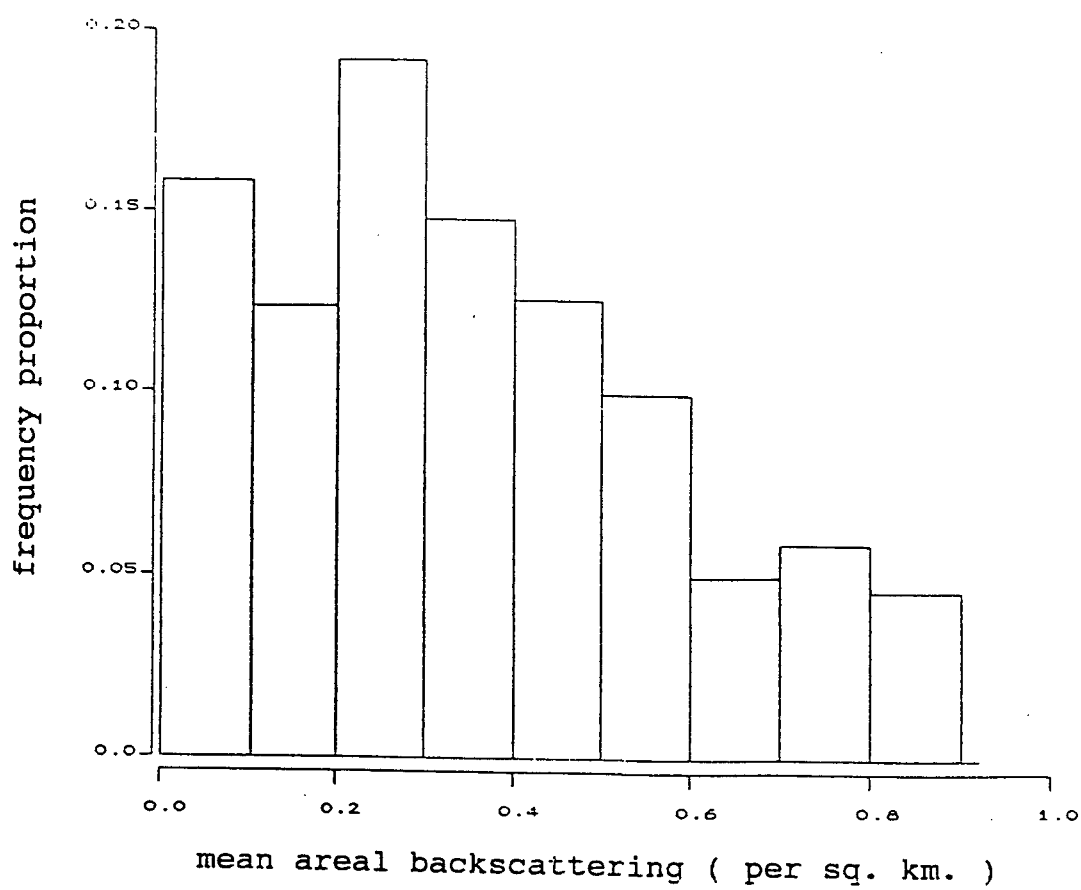


figure 4f.

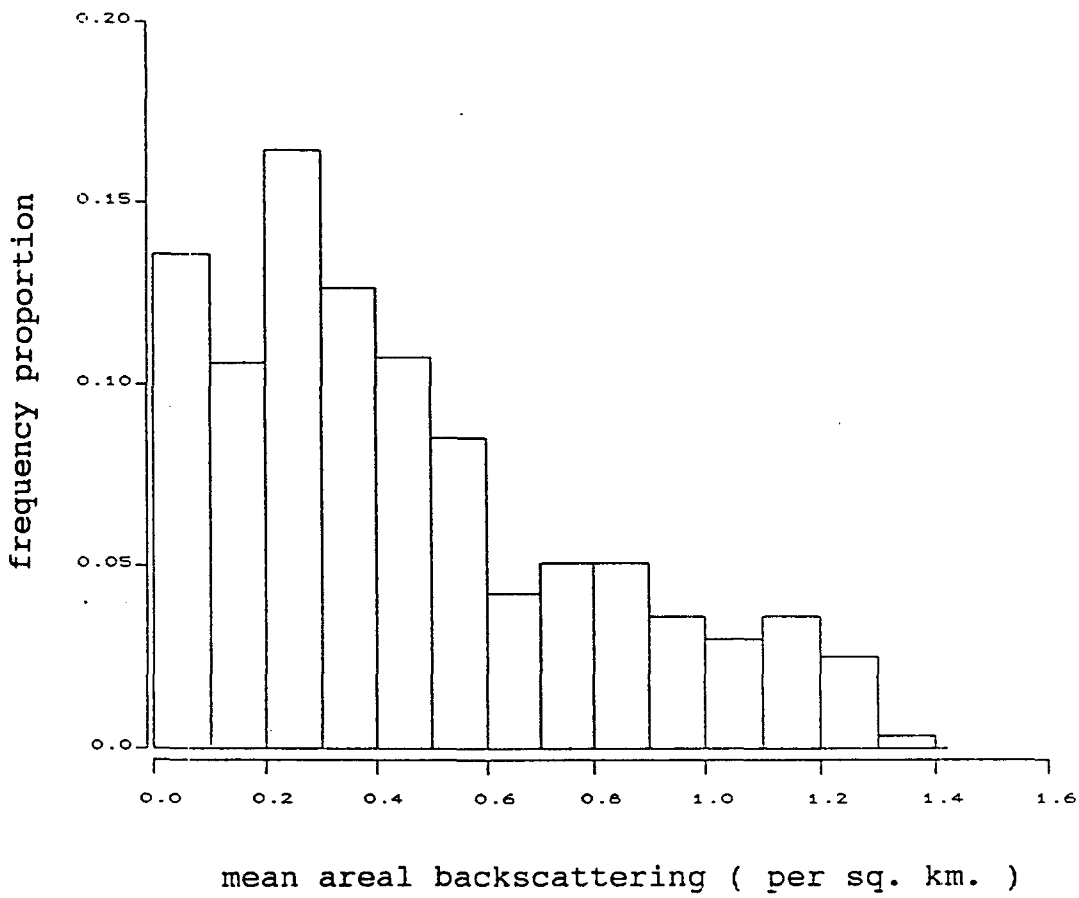

0.20
0.15
0.10
0.05
0.0
frequency proportion
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
mean areal backscattering (per sq. km.)

figure 4g.

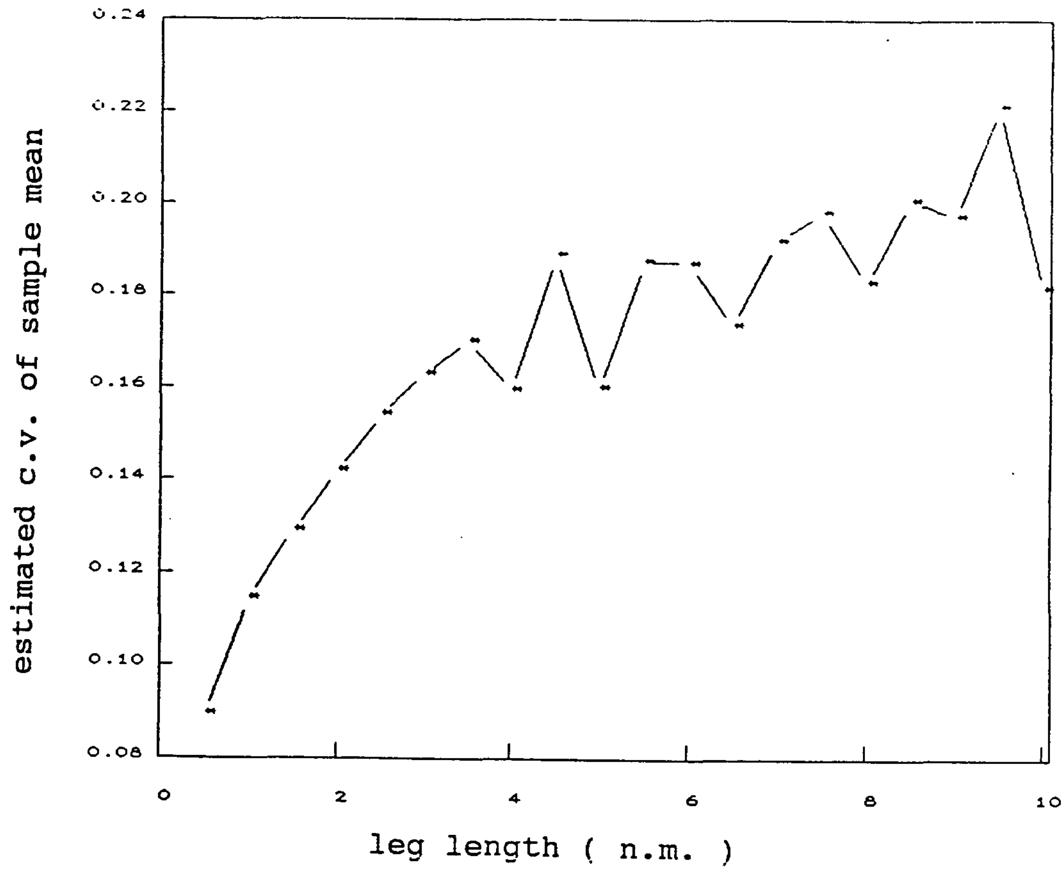


Figure 5a.

The variation of the apparent c.v. of the sample mean, with leg length for mean areal backscatterings recorded in strata 4 during cruise J09/88 on the WCSI.

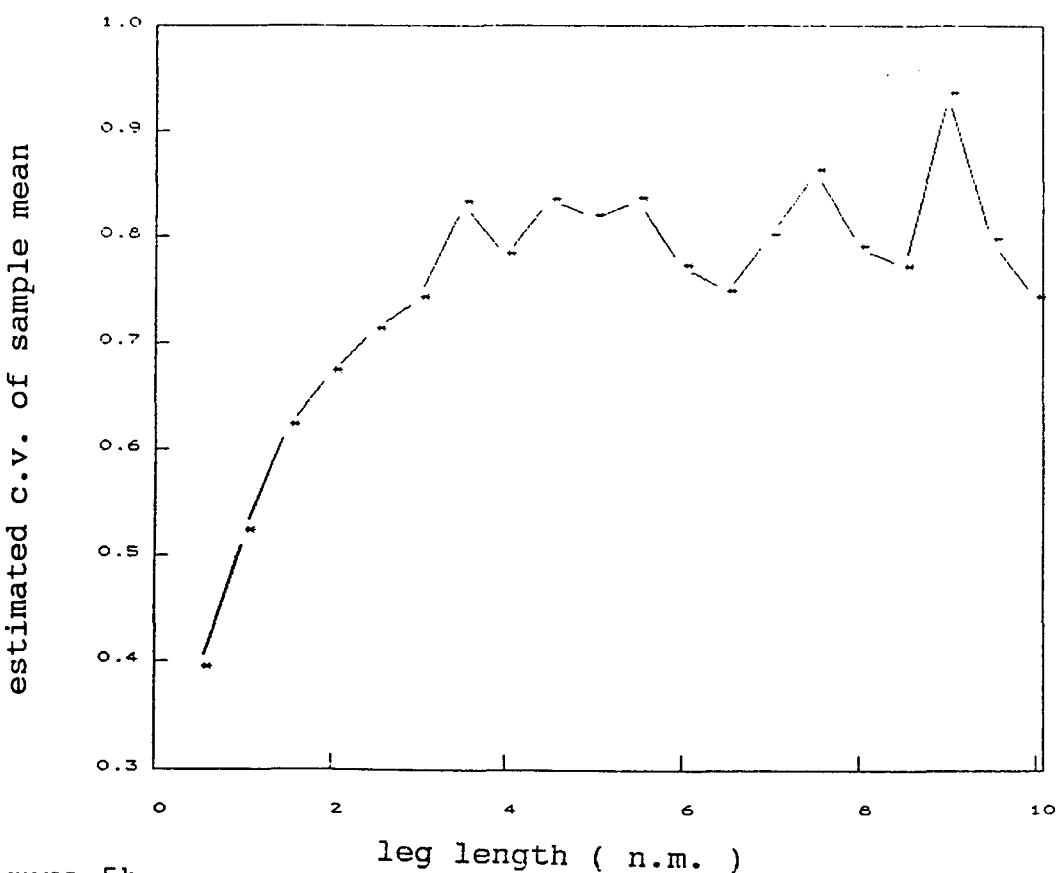


Figure 5b.

The variation of the apparent c.v. of the sample mean, with leg length for simulated mean areal backscatterings (constructed by using a moving average of a random sample from a Normal distribution).

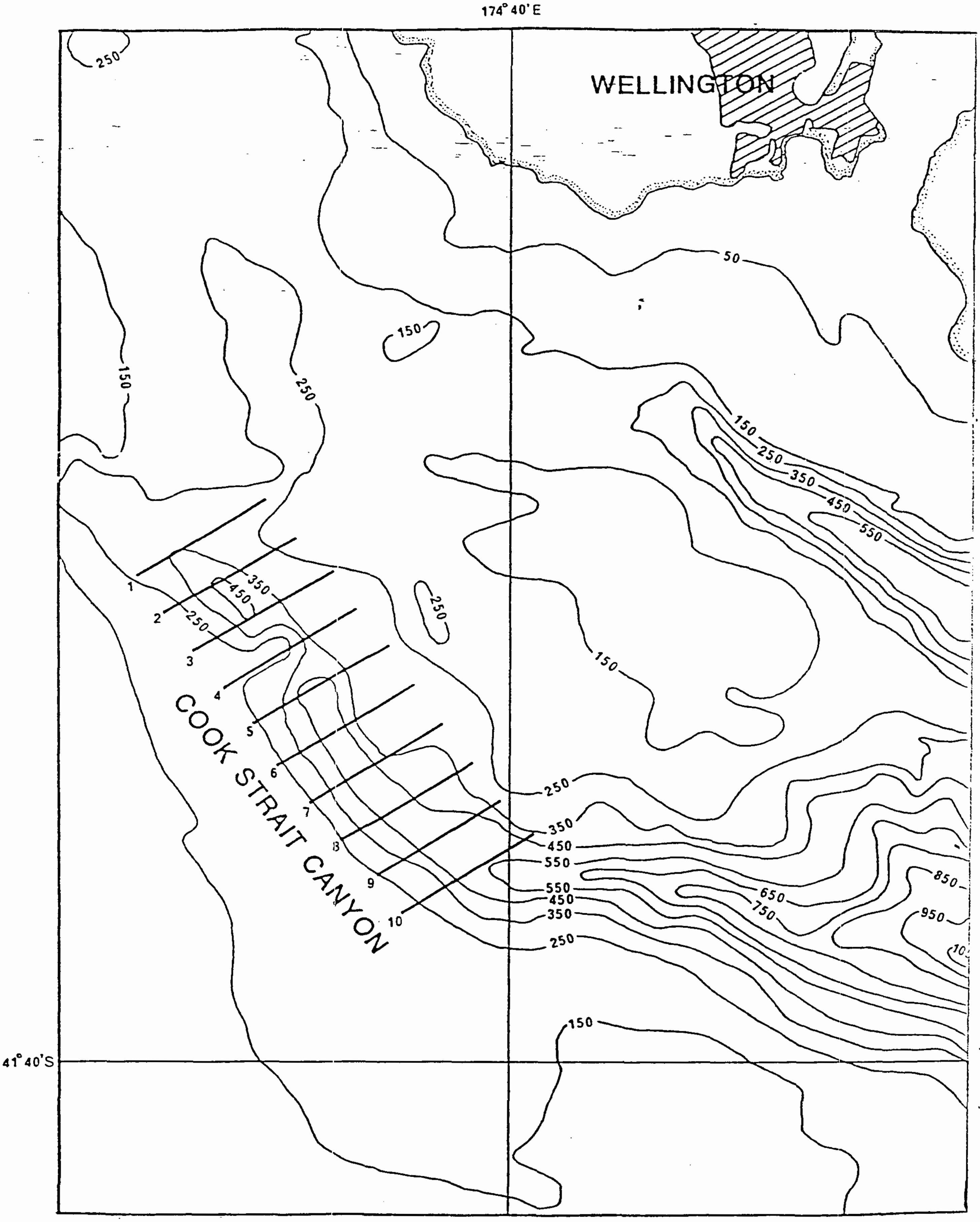


Figure 6a. Survey area and transects in Cook Strait canyon 1987.

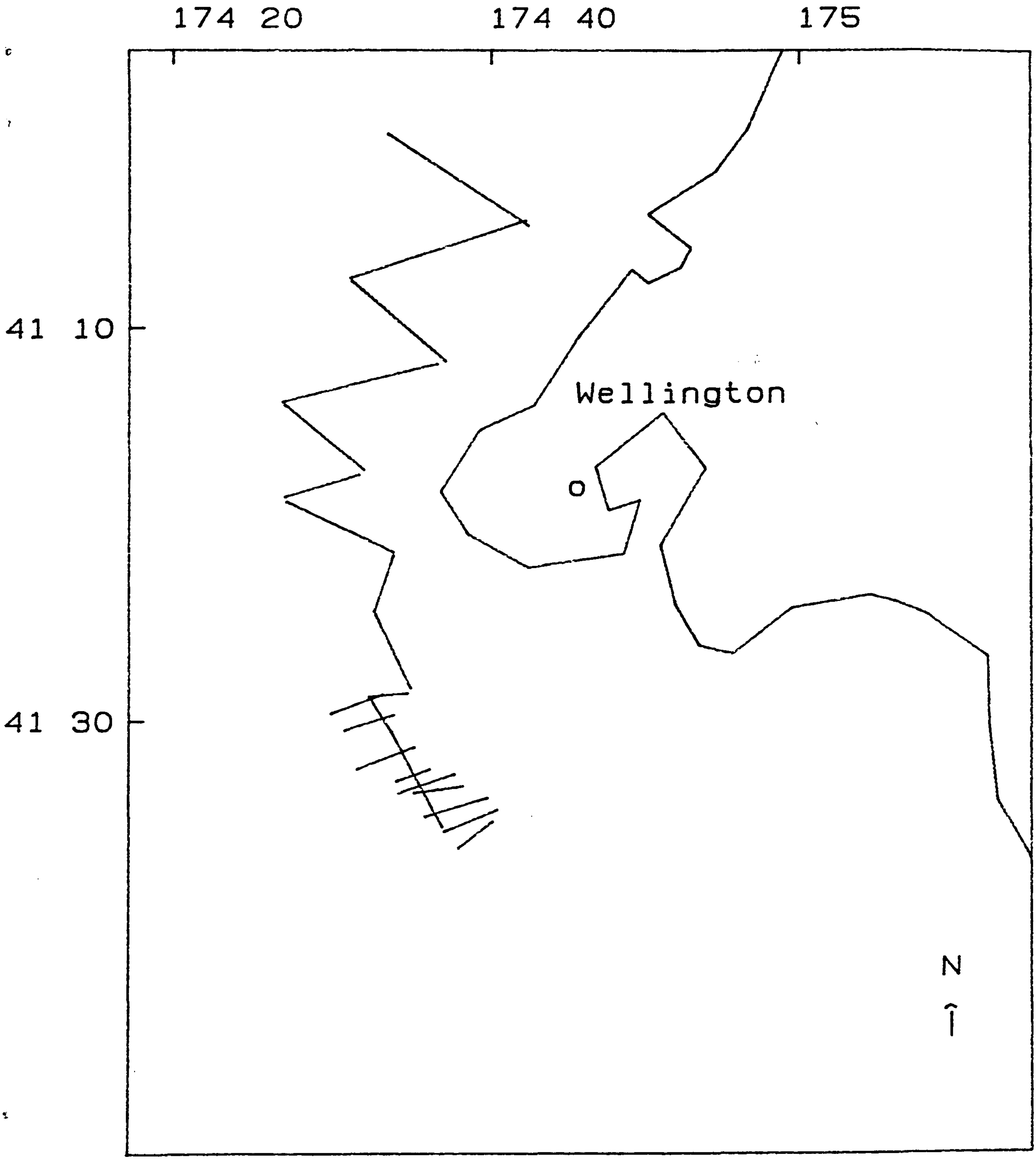


Figure 6b. Survey area and transects in Cook Strait canyon and Narrows basin 1988.

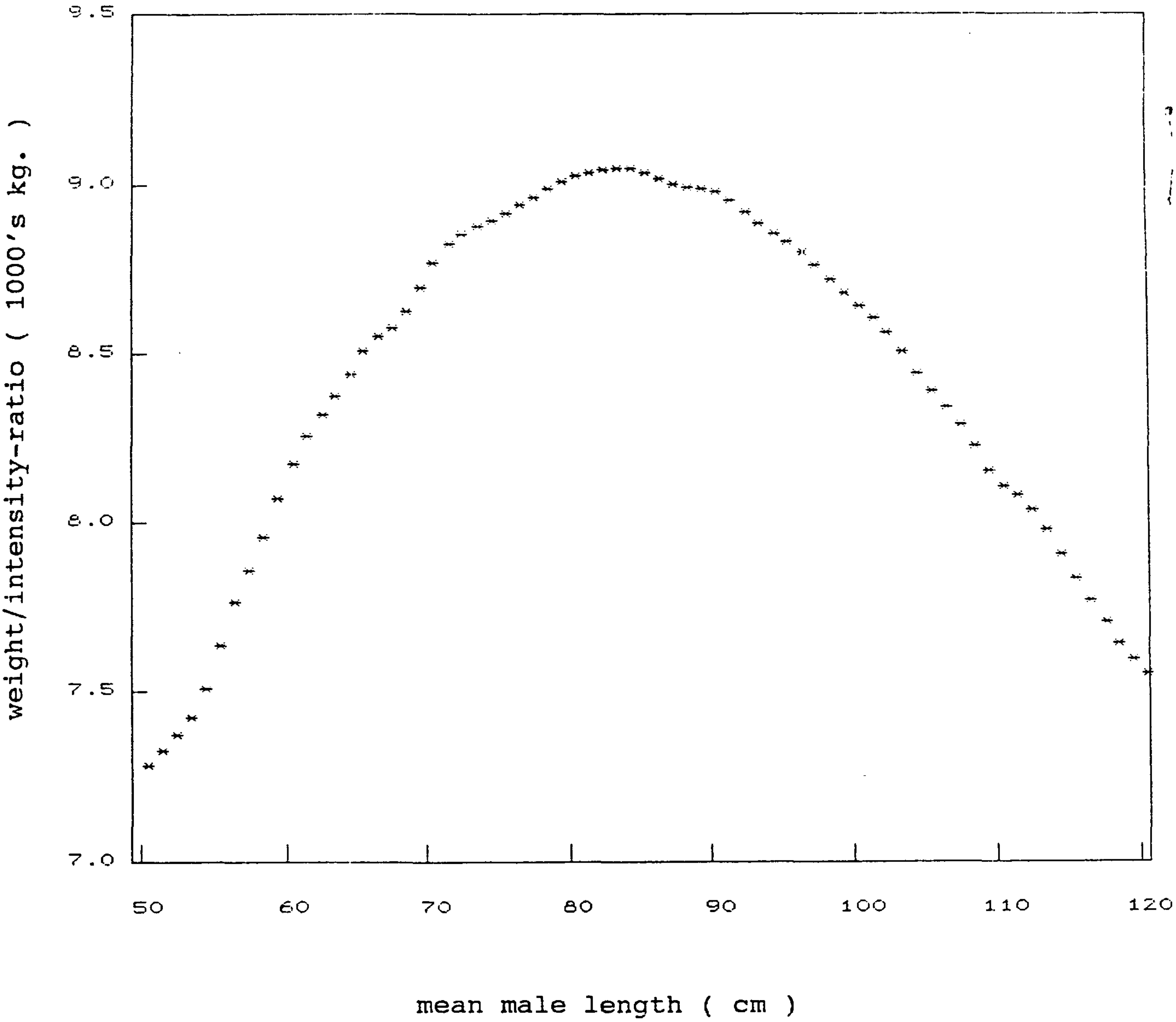


Figure 7.

Variation of the ratio of estimated mean hoki weight to estimated mean hoki intensity ratio, with changes in mean hoki length. The results were obtained by using the length-weight relationship for the WCSI, taking the male-female ratio to be 1.23 (as on the WCSI 1985), and for given mean male length x cm, taking the mean female length to be x+9 cm.