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EXECUTIVE SUMMARY

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An acoustic survey of spawning hoki abundance on the west coast South Island (WCSI) was carried out from *Tangaroa* from 26 June to 31 August 2000. Five acoustic snapshots were completed from 25 July to 31 August. The survey also had an extensive random trawling component to estimate the proportion of hoki biomass in mixed layers north of Hokitika Canyon. A total of 169 trawls were carried out, including 134 random bottom trawls, 11 bottom trawls for mark identification, and 20 midwater trawls.

This report expands on the original survey analysis of Cordue (*New Zealand Fisheries Assessment Report 2002/26*), which was concerned primarily with biomass estimation. Further analyses of trawl and acoustic data are presented including detailed descriptive data on the spatial and temporal distribution of hoki, bottom trawl estimates of biomass for hoki and other major species, and correlations between acoustic density estimates and commercial catch rates. This work was part of a project to further develop the acoustic technique and to evaluate survey design for a proposed 2004 WCSI survey.

Relatively precise (c.v. less than 25%) trawl estimates of abundance were obtained for hoki, ling, hake, silver warehou, javelinfish, bigeyed rattail, lookdown dory, sea perch, ribaldo, and giant stargazer. However, the survey area, north of Hokitika Canyon, did not encompass the full depth range of some of these species. Trawl catches during the day were higher than at night for 11 of the 13 most common species. Daytime trawl biomass estimates of hoki in the northern area (Strata 1&2 and 4) ranged between 3000 and 7500 t.

The hoki acoustic abundance index of 427 000 t derived from a complete re-analysis of raw data was within 5% of the existing estimate, derived from Cordue (2002). There was a general association between acoustic estimates of hoki density and commercial CPUE at the scale of the acoustic strata. Acoustic densities and CPUE were highest in Hokitika Canyon (Strata 5A and 5B) and south (Stratum 6) and lower in northern areas (Strata 1&2 and 4). Over 95% of the commercial catch from the WCSI in 2000 was taken within the acoustic survey area.

Hoki mix marks occurred throughout the survey area, accounting for over 70% of the biomass. The proportion of hoki in mixed species marks is the major source of uncertainty in acoustic estimates of hoki on the WCSI. Future surveys require more trawling with new gear types (e.g., finer mesh trawls), away from the bottom, and south of Hokitika Canyon, to further investigate species composition in mixed species marks.

1. INTRODUCTION

Hoki is New Zealand's largest fishery with a current TACC of 200 000 t. The main fishery occurs on the west coast South Island (WCSI), where hoki spawn during June to September. The WCSI fishery accounted for 47% of the hoki catch in 2001–02 (Ballara et al. 2003).

Acoustic surveys have provided relative abundance indices for spawning hoki on the WCSI since 1988, with annual surveys from 1988 to 1993, and then in 1997, and 2000 (review by O'Driscoll 2002). The next WCSI survey is scheduled for winter 2004. Another survey of the WCSI spawning ground is required because of continuing uncertainty about the status of the western hoki stock, with some model runs during the 2003 assessment indicating current biomass below 30% B_0 (Annala et al. 2003).

There was much uncertainty associated with abundance indices from the acoustic surveys of the WCSI in 1997 (Cordue & Ballara 1998) and 2000 (Cordue 2002) because of species mix in the northern strata. Acoustic methods work best where fish occur in readily identifiable single-species aggregations. Hoki do form such aggregations during spawning on the WCSI, particularly in Hokitika Canyon. However, away from the main spawning areas hoki typically occur in a bottom-oriented, low-density layer which also contains other species. Because these mixed species layers occur over relatively wide areas, they can account for a significant portion of the total hoki biomass (O'Driscoll 2002).

The design of the 2000 WCSI survey was modified substantially to investigate species composition in mixed species layers (Cordue 2002). In addition to the acoustic snapshots and conventional mark identification trawls, there was a large, stratified, random trawling component in northern strata. These random trawls were used to partition acoustic backscatter from these areas (Cordue 2002).

This report describes background work carried out to further develop the acoustic technique and to evaluate survey design for a proposed 2004 WCSI survey (Objective 4 of Ministry of Fisheries research project HOK2002/03). This involved further analysis of trawl and acoustic data from the 2000 survey to improve our knowledge of mark composition and the distribution of fish marks in relation to commercial catch. The report provides detailed descriptive data on the spatial and temporal distribution of hoki, trawl estimates of biomass for hoki and other major species, and correlations between acoustic density estimates and commercial catch rates. These data were not presented in the original analysis of Cordue (2002), which was concerned primarily with biomass estimation.

2. METHODS

2.1 Survey design

The survey design in 2000 was based on the approach used in previous WCSI surveys, and described in detail by Coombs & Cordue (1995), Cordue (2002), and O'Driscoll (2002). Briefly, this design follows the methods of Jolly & Hampton (1990), as adapted by Coombs & Cordue (1995) to produce an abundance index for transient fish populations. Estimates of the spawning biomass during the "main" spawning season are obtained from several subsurveys or "snapshots", each consisting of random parallel transects within strata defined by depth and/or position. These estimates are then averaged to obtain an estimate of the "mean plateau height" (the average abundance during the main spawning season). Under various model assumptions, annual estimates of mean plateau height form a valid relative abundance time series (Cordue et al. 1992).

As in previous WCSI surveys, there were six main strata (Strata 1&2, 4, 5A, 5B, 6, and 7 in Figure 1). In 2000, Strata 1&2, and 4 were substratified by depth to improve trawl estimates of species composition (Cordue 2002). Stratum boundaries were adjusted slightly in this report based on recorded depths to better reflect depth cut-offs (Table 1). Stratum areas were then calculated using MapInfo software. Stratum areas differ slightly from those used by Cordue (2002) and O'Driscoll (2002), which were based on less detailed boundaries (Table 1, Figure 1). The number of acoustic transects allocated to each stratum is given in Table 1.

The survey was carried out from 26 June to 5 July, and then from 24 July to 31 August. All acoustic snapshots were between 24 July and 31 August (Table 2). The aim of the first leg from 26 June to 5 July was to carry out bottom trawls in Stratum 1&2 to investigate species mix before the main hoki season started (see Section 2.3). All work was carried out from the 70-m research stern trawler *Tangaroa*.

2.2 Acoustic data collection

Hull and towed *CREST* systems with 38 kHz split-beam transducers were used for all acoustic data collection. Details of the acoustic systems were provided by Cordue (2002). Transects were run at 8–10 knots. When the towbody was used, this was deployed 30–50 m below the surface. Acoustic data were also collected on the hull system during all trawls.

Data were also collected for estimating the acoustic target strength (TS) of hoki and associated species, but are not described in this report (see Macaulay 2001).

2.3 Trawling

Trawls fell into three main categories: pre-season species mix trawls, random bottom trawls, and target identification trawls.

Species mix trawls were carried out to investigate the species composition of mixed species layers in Stratum 1&2 before the main hoki season. Subareas of about 5 n. mile by 10 n. mile containing a mixed layer were identified and a series of 4–10 bottom trawls was carried out. Trawl positions within the subareas were chosen randomly, with care taken to ensure that trawl paths did not cross.

Random bottom trawls were carried out to determine the proportion of hoki in mixed species layers during the main acoustic survey period (24 July to 31 August). The design (Cordue 2002) called for 22 bottom trawls in each snapshot: 3 in each of 1&2A, 1&2B, 4A, and 4B, and 5 in 1&2C and 4C. Trawls were at random depths within each substratum, but exact locations were chosen for "logistical convenience" (Cordue 2002), and so tended to be between acoustic transects.

All species mix trawls and random bottom trawls were carried out using an eight-seam hoki bottom trawl with 100 m sweeps, 50 m bridles, 58.8 m groundrope, 45 m headline, and 60 mm codend mesh. The trawl doors were Super Vee type with an area of 6.1 m^2. At each location the trawl was towed for 3 n. miles at a speed over the ground of 3.5 knots. This is the same trawl and procedure used in hoki trawl surveys (Hurst et al. 1992). Measurements of doorspread (from a Scanmar 400 system) and headline height (from a Furuno net monitor) were recorded during each tow. Tows were carried out both during the day and at night, but the periods around sunrise and sunset were avoided.

Target identification trawls were carried out opportunistically during the survey to aid interpretation of acoustic data. Usually these were targeted on relatively dense marks where it was not certain if the mark contained predominately hoki. Target identification trawls were also carried out in support of target strength work. Both the hoki bottom trawl and a NIWA 119 midwater trawl (about 40 m diameter opening, with 150 m bridles and 60 mm codend mesh) were used for target identification.

For each trawl all items in the catch were sorted into species and weighed on Seaway motion-compensating electronic scales accurate to about 0.3 kg. Where possible, finfish, squid, and crustaceans were identified to species and other benthic fauna to species or family. A random sample of up to 600 individuals of each species from every tow was measured. In most tows the sex and macroscopic gonad stage of all hoki in the length sample were also determined. More detailed biological data were collected on a subsample of fish per trawl, and included fish length, weight, sex, and occasional observations on stomach contents.

2.4 Acoustic data analysis

Cordue (2002) presented only acoustic data summarised by substrata, so much of the information on the fine-scale distribution of hoki in the survey area was not published. To obtain this fine-scale information it was necessary to re-integrate the acoustic data. An initial attempt was made to re-integrate acoustic data using the bottom and region definitions applied by Cordue (2002). This was problematic for two reasons. First, many of the integrated files using the original ESP bottom definitions required substantial post-processing because some sea-bed had been included. Post-processing involved manually editing out the 1 m bins which included bottom and was very time consuming. This type of post-processing and quality control was carried out following the original analysis (Sira Ballara, NIWA Wellington, pers. comm.), but because it was a manual process it would have taken just as long to replicate the post-processing in our reanalysis. Second, the original mark definition was often based on depth, so some regions contained several hoki mark types, while other hoki marks were split between two or more regions.

We decided it was more efficient to repeat the entire acoustic analysis, starting with the raw data. This provided a useful check on the original analysis, as well as allowing us to present acoustic data summarised by mark type and at spatial scales smaller than the substrata.

Re-analysis of acoustic data followed the general procedure described by O'Driscoll (2002). Data were analysed using standard echo integration methods (MacLennan & Simmonds 1992), as implemented in NIWA's Echo Sounder Package (ESP2) software (McNeill 2001). Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions corresponding to various acoustic mark types were then identified. Marks were classified subjectively, based on their appearance on the echogram (shape, structure, depth, strength, etc), and using information from mark identification trawls. Marks were divided into three main categories.

1. Hoki schools
Hoki form elongated schools in midwater, but sometimes making contact with the bottom. These are usually of moderate to high density (echo amplitude), in 200–750 m water depth. Trawls on hoki school marks typically produce clean catches (over 90% by weight) of hoki.

2. Hoki mix
Hoki mix consists of lower density marks consisting of hoki and a variety of other species. The most common mark type on the WCSI is a bottom-oriented, low density, "fuzzy" layer, which may extend up to 100 m above the bottom. Hoki mix can also occur in midwater.

3. Non-hoki

Non-hoki pelagic marks are usually layers rather than schools, often with a wavy, undulating appearance. These are typically shallower than hoki schools, and there is less "structure" in the mark, with no obvious single targets. The use of the vessel's hull-mounted 12 kHz echosounder during much of the survey helped mark identification as non-hoki pelagic layers tend to be much stronger on 12 kHz than on 38 kHz, possibly because the swimbladders of the small mesopelagic species involved resonate at these lower frequencies (Bull 2000). Other non-hoki marks include silver warehou, which can be recognised by their relatively low target strength and school structure.

Backscatter from regions identified as hoki were integrated to produce estimates of acoustic density (m^{-2}). All backscatter from hoki schools, and hoki mix in Strata 5A, 5B, 6, and 7, was assumed to be 100% hoki. Backscatter from hoki mix marks in the northern strata (1&2 and 4) was partitioned based on the species composition of the catch in random bottom trawls using the "standard" method (MacLennan & Simmonds 1992).

The standard method for partitioning acoustic backscatter from mixed species layers assumes that the proportion of backscatter contributed by hoki (P(hoki)) is proportional to the product of its catch rate (c_{hoki}) and its mean TS (σ_{hoki}), as a weighted average of the total catch:

$$P(\text{hoki}) = \frac{c_{hoki}\sigma_{hoki}}{\sum_{i=1}^{n} c_i \sigma_i} \qquad (1)$$

where n is the number of species caught by the trawl. Equation (1) assumes all species have an equal ratio of vulnerability to trawl and acoustic gears. This assumption is unlikely to be correct (Cordue 2002, O'Driscoll 2003), but in the absence of reliable estimates of acoustic:trawl vulnerability ratios, the Hoki Working Group in 2001 agreed to adopt this standard approach.

In this report, all catch rates (c_i) were expressed as kg km^{-2} (see Section 2.5) and mean target strengths (σ_i) were expressed per kilogram, instead of per fish. This was done for simplicity since fish in trawl catches were weighed rather than counted. The mean TS per kilogram of species in each trawl were estimated from the mean lengths of fish in the catch using estimated length-weight parameters (determined from the subsample of fish weighed during each survey) and best available target strength-length relationships (Table 3). P(hoki) was estimated for each snapshot and stratum as the average P(hoki) from all trawls (including both day and night trawls) on the mixed layer in that snapshot and stratum.

The species mix decomposition described above is analogous to the standard method used by Cordue (2002), but differed in some of the details. For example, Cordue (2002) based his estimates of P(hoki) on numbers rather than weights and considered only the 11 "most important" species. Some of the TS-length relationships in Table 3 (including the relationship for hoki) are also different from those used by Cordue (2002).

Following presentation of initial results to the Hoki Working Group on 25 June 2003, it was suggested that P(hoki) was likely related to depth and that it may be better to calculate P(hoki) for each (depth-defined) substratum of Strata 1&2 and 4. There were insufficient tows to calculate P(hoki) by snapshot and substrata, so a second set of values was calculated giving average P(hoki) in each substrata from all snapshots.

After species decomposition was carried out, acoustic density was output in two ways. First, average acoustic density over each transect was calculated. These values were used to estimate abundance. Second, acoustic backscatter was integrated over 10-ping bins (vertical slices) to produce a series of acoustic densities for each transect. These data had a high spatial resolution, with each value (10 pings) corresponding to about 100 m along a transect, and were used to produce plots showing the fine-scale spatial distribution of acoustic density.

Transect acoustic density estimates were converted to hoki biomass using the ratio, r, of mean weight to mean backscattering cross section (linear equivalent of TS) for hoki. For the 2000 WCSI survey, O'Driscoll (2002) estimated r = 14 763 kg m^{-2}. Biomass estimates and variances were then obtained for each stratum in each snapshot using the formulae of Jolly & Hampton (1990), as described by Coombs & Cordue (1995). Stratum estimates were combined to produce snapshot estimates, and the snapshots were averaged to obtain the overall abundance index for the survey.

Acoustic data collected during all random bottom trawls were also analysed. Data corresponding to the tow duration (i.e., corrected for the lag of the trawl behind the vessel based on warp length and water depth) were integrated to calculate the mean acoustic density during the trawl. Acoustic data were integrated in depth bins of 5 m so trawl catches could be compared to acoustic backscatter within varying distances from the bottom.

2.5 Trawl data analysis

Trawl catch rates (kg km^{-2}) were calculated by scaling trawl catches by the estimated swept area (measured doorspread multiplied by tow distance). Estimates of trawlable biomass with associated coefficients of variation (c.v.s) were then calculated from species mix and random bottom trawls for the 13 most abundant species using the formulae of Vignaux (1994). Biomass estimates by stratum were produced separately for day and night tows. Scaled length frequencies were also calculated for the major species with the Trawlsurvey Analysis Program, version 3.2 (Vignaux 1994), using length-weight data collected during the survey. Only trawls where the gear performance was satisfactory (codes 1 or 2) were used for estimating biomass and calculating length frequencies.

2.6 Comparison with commercial catch data

The distribution of hoki backscatter from the acoustic survey and research trawl catch rates were compared to catch rates from the commercial hoki fishery.

Commercial catch and effort data were from individual tow records recorded on trawl-catch-effort-processing-return (TCEPR) forms. TCEPR data are regularly extracted and groomed for catch-per-unit effort (CPUE) analyses and we used a groomed CPUE dataset. Individual tows within the acoustic survey area in 2000 were assigned to acoustic strata based on their start positions. Tows were also divided into categories corresponding to the timing of the five acoustic snapshots.

Unstandardised catch rates (t per km towed) were averaged by snapshot and strata and compared to trawl catch rates and acoustic density estimates.

3. RESULTS

3.1 Data collection

Four subareas of Stratum 1&2 were selected for species mix trawling in the first leg from 26 June to 5 July. A total of 32 bottom trawls (14 day tows and 18 night tows) were carried out, with 4–10 tows in each of these areas (Table 2, Figure 2). During this period there were also 3 mark identification trawls (1 midwater and 2 bottom) and 5 trawls (4 bottom and 1 midwater) in support of TS experimental work (Figure 3).

Five acoustic snapshots were successfully completed during the second leg from 24 July to 31 August: there were 18–22 random bottom trawls in Strata 1&2 and 4 during each snapshot (see Table 2), giving a total of 102 tows (47 day tows and 55 night tows) (Figure 4). Twenty-three targeted trawls (5 bottom and 18 midwater) were also carried out (see Figure 3).

In the following sections, trawl data are presented before acoustic data, because of the importance of trawls in decomposing the acoustic backscatter.

3.2 Trawl data

3.2.1 Catch

A total catch of 107.3 t was recorded from all successful trawl stations (Table 4). Over 130 species or species groups were caught. The main species in the catch (Table 4) were hoki (45.3%), ling (16.6%), silver warehou (9.8%), and hake (6.4%).

3.2.2 Gear parameters

Gear parameters by depth and for all observations are summarised in Table 5. Missing headline and doorspread values were calculated from data collected in the same depth range on the survey. Gear parameters from random bottom trawls were similar to those obtained from *Tangaroa* during trawl surveys in the Sub-Antarctic (O'Driscoll & Bagley 2001) and Chatham Rise (Livingston et al. 2002). Targeted tows tended to be shorter than random tows.

3.2.3 Trawl biomass estimates

Day and night biomass estimates for 13 most abundant (i.e., those with highest estimated biomass) species are presented by substrata for species mix trawls (26 June to 5 July) in Table 6, and for random bottom trawls (24 July to 31 August) in Table 7. There were too few tows in each snapshot to estimate biomass in all substrata, so substrata were combined to obtain estimates of hoki biomass in each snapshot (Table 8).

Estimates of biomass from trawls during the day were higher than night estimates for 11 of the 13 species (Table 7). Estimated hoki biomass was over 4 times greater during the day than at night in Stratum 1&2 during the acoustic survey period (Table 7), but only 1.8 times greater during species mix trawling before the main spawning season (Table 6). These results show that there is diurnal variation in catchability, and suggest that the magnitude of this variation may be seasonal. Quantitative analysis of trawl results as a relative estimate of abundance depends on the assumption of equal catchability. If trawl estimates are to be used for assessment purposes, we recommend including only random trawls carried out during the day, within a specified time period, as is currently done in random trawl surveys for hoki in other areas (O'Driscoll & Bagley 2001, Livingston et al. 2002).

Coefficients of variation show that relatively precise (c.v. less than 25%) estimates of abundance were obtained from day tows from 24 July to 31 August for hoki, ling, hake, silver warehou, javelinfish, big-eyed rattail, lookdown dory, sea perch, ribaldo, and giant stargazer (Table 7). However, the survey may not encompass the full depth range of some of these species. For example, giant stargazer had highest catch rates at 100–200 m in inshore trawl surveys of the WCSI (Stevenson & Hanchet 2000), much shallower than the depth range covered by this survey. Catch rate plots (Figure 5) show almost all giant stargazer were caught in the 2000 hoki survey were in the shallowest substrata (300–430 m). Of the four most abundant species, hoki, ling, and silver warehou were most abundant shallower than 500 m, while hake were more common in the deeper (500–650 m) substrata (Figure 5).

Day biomass estimates of hoki in Stratum 1&2 were higher in the second leg of the survey (2105 t, Table 7) than in species mix trawls before the main spawning season (1658 t, Table 6). This is consistent with the expected increase in hoki on the WCSI during the spawning season, although the difference between the estimates is not statistically significant. The biomass estimates from species mix trawls (see Table 6) may have been positively biased (i.e., too high) because only areas where a mixed layer was visible acoustically were selected for trawling.

Biomass estimates of hoki by snapshot ranged between 2968 t in Snapshot 3 and 7456 t in Snapshot 4 (Table 8). Estimated c.v.s for all snapshots were relatively high (26–66%) because of the small number of tows and changes in trawlable biomass between snapshots were not statistically significant. There were insufficient tows to calculate biomass by snapshot in each substratum, so biomass estimates are given by stratum in Table 8.

3.2.4 Length frequencies

Scaled length frequencies for hoki, ling, silver warehou, and hake are presented in Figures 6–9. Hoki showed some interesting temporal patterns, with smaller fish (less than 60 cm) being much more abundant in species mix trawls from 28 June to 4 July than in random bottom trawls from 25 July to 29 August (Figure 6). These small hoki were mostly caught during the day, suggesting that they migrated away from the zone sampled by the bottom trawl at night. Consequently, the mean length of fish caught at night (l = 71.1 cm) was greater than during the day (l = 64.5 cm) during the first leg of the survey (Figure 6). An opposite diurnal pattern was observed during the second survey period from 25 July to 29 August, when the mean length of fish in day trawls (l = 73.5 cm) was greater than in night trawls (l = 69.8 cm). This may have been due to larger fish ascending from the bottom at night to spawn. The complex temporal patterns in hoki length frequencies reinforce the need to carry out all tows within a similar time period if trawls are to be used quantitatively.

Hoki from daytime research bottom trawls in Strata 1&2 and 4 from 25 July to 29 August 2000 were smaller on average than hoki in the WCSI commercial catch (from all areas) in the 2000 spawning season (Ballara et al. 2002). The mean length of hoki in the commercial catch was 80.3 cm in 2000 (O'Driscoll 2002), compared to 73.5 cm for research tows. This size difference was likely related to differences in the distribution of commercial and research tows (see Section 3.4) and selection for larger fish by commercial vessels.

Length frequencies for ling, silver warehou, and hake were similar in both legs of the survey, and only data from 25 July to 29 August are shown in Figures 7–9. Length frequencies from day and night tows were also similar for these three species.

3.2.5 Species composition in northern strata

Hoki made up between 0 and 85% of the catch by weight in individual random bottom trawls. When averaged by snapshot and stratum between 14 and 53% of the catch by weight was hoki (Table 9). The average proportion of hoki in the catch (over both strata) was highest in Snapshot 1. There was also a relatively high proportion of hoki (42% by weight) in Stratum 1&2 during species mix trawls between 26 June and 5 July. This was surprising, because the aim of the first part of the survey was to obtain estimates of species composition before the spawning season when the proportion of hoki in the area was expected to be low (Cordue 2002).

When calculated by substratum for all snapshots combined, the average proportion of hoki in the catch was highest in Substratum 1&2B (40% hoki by weight) and Substratum 4B (37% hoki) (Table 10). The proportion of hoki was lower in shallower and deeper substrata. Average catch rates (all species combined) declined with increasing depth (Table 10).

Species decomposition based on catch rates in random bottom trawls and best estimates of acoustic TS (see Table 3) indicated that hoki contributed 7–25% of the backscatter from mixed species marks in Strata 1&2 and 4 (Tables 9–10). These values were used to scale measurements of acoustic backscatter in northern strata (see Section 3.3.1). The values of P(hoki) in this report differ from those used by Cordue (2002) (given in Table 9), mostly because we used a different TS-length relationship for hoki (see Section 2.4).

3.2.6 Targeted trawls

Of the 31 targeted midwater and bottom trawls, 9 were directed at hoki schools, 15 at hoki mix, and 7 at non-hoki marks. The catch composition by mark type is summarised in Table 11.

Trawls targeted at hoki schools caught 40–100% hoki by weight and catch rates were high (Table 11). Only two trawls targeted at hoki schools caught less than 80% hoki and these were both in Stratum 4 (Figure 10). The other seven tows averaged 94% hoki by weight. Trawls targeting hoki marks were carried out in Strata 4, 6, and 7 (Figure 10).

Trawls on hoki mix marks gave a similar catch composition to random bottom trawls, averaging 42% hoki by weight (Table 11). Nine of the 15 trawls on hoki mix were in northern strata (1&2, 4, and further north) (Figure 10). Hoki mix type marks were also observed south of Hokitika Canyon, with five trawls on this mark type in Stratum 6 averaging 44% hoki by weight, and one tow in Stratum 7, catching 79% hoki by weight (Figure 10).

The seven trawls targeted at non-hoki marks caught no hoki, with the catch mostly consisting of small mesopelagic species.

There was no targeted trawling in Hokitika Canyon (Strata 5A and 5B) because this area is relatively well sampled by the commercial fishery.

3.3 Acoustic data

3.3.1 Distribution of hoki backscatter

Expanding symbol plots show the fine-scale spatial distribution of hoki along each transect (Figure 11). The general pattern was similar in all five snapshots. Hoki were widespread throughout the survey area, with the exception of some of the shallower areas (less than 350 m depth). Hoki densities were always highest in the head of Hokitika Canyon (Stratum 5A). High densities were also recorded on the south side of the outer Hokitika Canyon (Stratum 5B) and down the eastern side of Stratum 6. Hoki densities were much lower in Strata 1&2 and 4, where the species mix correction was applied to hoki mix marks. A few, relatively small, areas of higher density were recorded in Strata 1&2 and 4 (Figure 11), and these corresponded to observations of hoki schools.

The impression of the distribution of backscatter in Strata 1&2 and 4 differed slightly depending on which method was used to calculate P(hoki). In Figure 11, the two methods are compared for Snapshot 1. For the other snapshots, distribution of backscatter is only presented when P(hoki) was calculated by snapshot and stratum.

3.3.2 Acoustic abundance estimates

Hoki abundance estimates by snapshot and stratum where P(hoki) was calculated by snapshot and stratum (see Table 9) are given in Table 12. Estimates from the re-analysis carried out in this paper were very similar to the results from the "standard" method of Cordue (2002), with the overall abundance index of 427 000 t calculated in this report, being 5% higher than the estimate of 407 000 t derived from Cordue (2002). Note that the biomass values presented by Cordue (2002) were adjusted for changes in the hoki TS (O'Driscoll 2002) and revisions in stratum areas (this paper) so that these could be compared to the new values (see footnote to Table 12). The similarity between the two biomass estimates is reassuring and suggests that the bottom definition and mark identification were relatively consistent in the two analyses.

Average biomass estimates in Strata 1&2 and 4 were similar for the two methods of estimating P(hoki), although there were differences in the estimated biomass by snapshot (Table 13). The remainder of this section refers only to the abundance estimates in Table 12.

Estimated hoki biomass was highest in Snapshot 1 (25–31 July) at 625 000 t, and then declined to between 350 000 and 400 000 t in Snapshots 2–5 (see Table 12). Estimated sampling c.v.s for all snapshots were low (see Table 12).

The highest proportion of the estimated hoki biomass was in Stratum 6 (see Table 12). When results from Table 12 were averaged over all snapshots, 41% of the hoki biomass was in Stratum 6, 18% in Stratum 5A, 13% in Stratum 5B, 11% in Stratum 4, 10% in Stratum 1&2, and 7 % in Stratum 7.

A relatively low proportion (16–36%) of the hoki biomass in each snapshot came from hoki schools (Table 14). Hoki schools were common only in Hokitika Canyon (Stratum 5A), where they accounted for 93% of the hoki backscatter. In all other strata, over half the biomass was from hoki mix type marks (Table 14). The problem of mixed species mix in the northern area (Strata 1&2 and 4) is well documented (Rose 1998, Cordue 2002, O'Driscoll 2002), and the 2000 survey was designed to account for this, with a large random trawling component to estimate, and correct for, species mix in these strata (Cordue 2002). However, as stated in Section 2.4, we assume that all backscatter from hoki marks (including hoki mix marks) in other strata is 100% hoki. This re-analysis suggests that low density hoki mix marks, similar to those observed in the northern areas, are common in Strata 5B, 6, and 7, and the old assumption that "characteristic hoki marks (schools) account for most of the biomass" (Coombs & Cordue 1995, p. 183) in these areas was clearly not valid in 2000. Further, targeted midwater trawls on mix marks in Strata 6 and 7 caught only 18–79% hoki by weight (see Figure 10), a similar proportion to bottom trawls on mix marks in northern areas. The assumption of 100% hoki in Strata 5B, 6, and 7 needs to be reconsidered, and future surveys should include increased trawling in these southern areas to assess the extent of the species mix problem.

3.4 Comparison with commercial catch data

The estimated commercial catch of hoki on the WCSI in 2000 was 103 000 t (Ballara et al. 2003). Of this, nearly 98 000 t was reported on TCEPR forms. The remaining 5000 t was reported on daily catch-effort-landing-returns (CELR) completed by smaller vessels, probably fishing inside the 25 n. mile exclusion area in the Hokitika Canyon. Commercial tow positions from TCEPR are plotted in Figure 12 and catches are summarised by acoustic strata in Table 15. In the absence of information on tow positions, we assumed all catch reported on CELR was from Stratum 5A.

Most (95%) of the commercial catch on the WCSI in 2000 was taken inside the acoustic survey area (Table 15). There were some tows in deepwater, to the west of the acoustic strata (Figure 12), and these accounted for much of the remaining 5% of catch. In other years there has been substantial fishing effort north of the acoustic survey area (O'Driscoll 2002), but there were few tows north of the Stratum 1&2 boundary in 2000 (Figure 12).

3.4.1 Comparison of commercial catch with biomass estimates

The ratio of the commercial catch to the acoustic biomass estimate in each stratum is given in Table 15. This ratio (C:A) varied between strata: C:A was very high (0.9) in Stratum 4, intermediate (0.17–0.40) in Strata 1&2, 5A, and 5B, and low (less than 0.05) in Strata 6 and 7 (Table 15). High values of C:A would occur in a stratum if the commercial fleet catches a lot of the available biomass (high exploitation rate), turnover rates are high, or acoustic biomass estimates are too low. Correspondingly, low values of C:A would occur if the exploitation rate is low, turnover rates are lower, or acoustic biomass estimates are too high. It is impossible to pick between these explanations on the basis of the data available. However, if we assume that turnover rates are the same in all areas, we can postulate about the extreme values of C:A in Strata 4, 6, and 7.

There was a lot of fishing effort in Stratum 4 (Figure 12), with 42% of all tows reported on TCEPR in 2000 occurring within this stratum. Consequently, we might expect a higher exploitation rate in Stratum 4 than in other areas. Stratum 4 is outside the 25 n. mile exclusion zone (Figure 12), and is therefore open to all vessels. The slope is suitable for trawling with both bottom and midwater trawls. There are also reasons why acoustic estimates of hoki biomass in Stratum 4 may be too low. Most of the hoki in Stratum 4 occur in mixed marks (see Table 14), and the acoustic backscatter is partitioned based on the species composition in bottom trawl catches (see Section 2.4). This decomposition estimates that only 7–25% of the backscatter from mix marks is hoki (see Tables 9 and 10). If these estimates of species composition are too low, then the estimate of hoki biomass in Stratum 4 will also be too low. There are a number of reasons to think that the values in Tables 9 and 10 are not good estimates of species composition. These include the assumptions that all species are sampled representatively in the trawl (i.e., similar trawl catchabilities), and also that catches in the bottom trawl are representative of species composition over the entire mixed layer, which may extend up to 100 m from the bottom (see Section 3.5).

Only 8000 t of hoki were caught in Strata 6 and 7, despite these two areas contributing nearly half the acoustic biomass estimate (Table 15). Stratum 7 and much of Stratum 6 are within the 25 n. mile exclusion zone, where fishing is restricted to vessels less than 43 m in length. These areas are therefore closed to much of the fleet, and this is reflected in the distribution of tows in Figure 12. This alone may explain the low values of C:A in these strata. High densities of hoki certainly occur in both Strata 6 and 7, and schooling hoki were observed in these areas during the 2000 survey. For example, Figure 10 shows high catch rates of hoki in targeted research trawls inside the 25 n. mile line. However, as described in Section 3.3.2, much of the acoustic estimate of hoki in Strata 6 and 7 is from hoki mix marks (see Table 14). We assume that these are 100% hoki, despite evidence to the contrary from targeted trawls, and this will likely mean our acoustic estimates of hoki in Strata 6 and 7 are too high.

Daytime trawl biomass estimates in Strata 1&2 and 4 were an order of magnitude lower than both acoustic estimates and commercial catches (Table 15). This suggests that trawl catchability (defined here as the product of the vertical availability and vulnerability to the trawl) for hoki was relatively low. The ratio of the trawl biomass estimate to the acoustic biomass estimate (T:A) was about 0.05 in both strata.

3.4.2 Comparison of CPUE with acoustic estimates and trawl catch rates

Figure 13 compares unstandardised CPUE (catch rate in t per km) from trawls within the acoustic survey area with acoustic density estimates and random research trawl catch rates for each snapshot. Visually, there was a general association between acoustics and CPUE, with the highest commercial catch rates occurring in the areas of high acoustic densities in Strata 5A, 5B, and 6 (Figure 13). However, there were also regions where the commercial fleet caught hoki but the acoustic survey indicated there were few fish. An example is the shallow (eastern) part of Stratum 4 during Snapshot 5 (Figure 13). There was no obvious relationship between CPUE and random trawl catch rates in northern strata. For example, in Snapshot 2, commercial tows were concentrated in the upper two thirds of Stratum 4 and the lower third of Stratum 1&2, while catch rates in random trawls were highest in the northern part of Stratum 1&2 (Figure 13).

When data were averaged by snapshot and stratum (i.e., data were first grouped into the 6–7 day periods corresponding to each acoustic snapshot and then assigned to acoustic strata based on their tow position), there was a significant positive correlation between CPUE and acoustic density estimates (Figure 14, Spearman's rank correlation, rho = 0.50, n = 24, $p \leq 0.05$). There was no correlation between CPUE and random trawl catch rates during the day (rho = 0.09, n = 10) or at night (rho = 0.01, n = 10) (Figure 14).

Correlations between CPUE and acoustic estimates averaged by snapshot are crude because snapshots lasted 6–7 days and the fishing fleet, research vessel, and fish move round during this period. Aggregations of fish and fishers also occur at spatial scales smaller than the areas of the acoustic strata. We attempted to examine correlation between CPUE and acoustics at much finer spatio-temporal scales (about 5 km and 6 h), but correlations were confounded by the very large number of empty cells (i.e., areas and times where there were no acoustic data and/or fishing effort). Ideally, correlations should be examined across a range of spatial and temporal scales, but there was insufficient time in the current project. Vertical distribution of acoustic backscatter and fishing effort (i.e., tow depth) should also be considered in future work comparing acoustic backscatter with CPUE

3.5 Comparison of trawl and acoustic estimates

When random trawl catch rates were compared to acoustic densities averaged by snapshot and stratum there was a general positive correlation (Figure 15). Random bottom trawls and acoustics both provide fisheries-independent estimates of abundance in the northern area. However, these estimates are not independent of each other because trawl data were used to partition acoustic backscatter, and there was a strong positive correlation (rho = 0.85) between the proportion of hoki in the catch (used to partition backscatter) and the hoki catch rate (used to estimate trawlable biomass). Consequently, there will also be an inherent correlation between trawl and acoustic biomass estimates, although simulations suggest that this is relatively weak (about 0.2).

As described in Section 3.2.3, estimates of hoki biomass from day trawls were much higher than estimates at night. This was probably related to the vertical distribution of fish. Acoustic data (Figure 16) show that there was a higher proportion of backscatter within 50 m of the bottom during the day (74%) than at night (59%). There may also have been other reasons for diurnal changes in trawl catchability, such as reduced herding by the trawl at night.

Because mixed species layers extend up to 100 m off the bottom (Figure 16), we were concerned that bottom trawls, with a headline height of less than 7 m (see Table 5), would not representatively sample fish throughout the vertical extent of the mixed layer. This would have implications for both the species mix corrections used to calculate acoustic estimates and the reliability of trawl biomass estimates. We explored this by comparing trawl catches with acoustic data collected during the trawls. To avoid the confounding correlation between (partitioned) acoustic estimates of hoki and trawl results, we examined the association between unpartitioned acoustic density estimates (i.e., total backscatter from the species mix layer) and trawl catch rates for all species. Trawl catch rates were scaled by their acoustic target strengths (see Table 3) to generate "predicted" backscatter to compare with the observed acoustic backscatter.

The results were strongly dependent on how far above the bottom the acoustic backscatter was integrated (Figure 17). Surprisingly, there was a low correlation (rho = 0.08) between expected backscatter from trawl catches and observed backscatter within 5 m of the bottom. Correlation improved as the integration height increased (Figure 17), suggesting that there was some vertical herding of fish by the bottom trawl. A correlation of about 0.2 was observed at integration heights between 10 and 50 m, but correlation decreased again beyond that (Figure 17). Although the data were variable and correlations were relatively low, we conclude that the bottom trawl may have been representatively sampling acoustic backscatter within 50 m of the bottom. We recommend that midwater trawls be used to investigate species composition in mixed layers more than 50 m off the bottom.

4. CONCLUSIONS

Further analyses of acoustic and trawl data from the 2000 WCSI survey were carried out to develop the acoustic technique and to evaluate survey design for a proposed 2004 WCSI survey. The acoustic abundance index from a complete re-analysis of raw data was within 5% of the existing estimate derived from Cordue (2002). This indicated that bottom definition and mark identification were relatively consistent between the original analysis and current "standard" methods based on those of O'Driscoll (2002).

There was a general association between acoustic estimates of hoki density and commercial CPUE at the scale of the acoustic strata. Acoustic densities and CPUE were highest in Hokitika Canyon (Strata 5A and 5B) and south (Stratum 6) and lower in northern areas (Strata 1&2 and 4). Over 95% of the commercial catch from the WCSI in 2000 was taken within the acoustic survey area.

The major source of uncertainty in acoustic estimates of hoki on the WCSI is related to the proportion of hoki in mixed species marks. Hoki mix marks occurred throughout the survey area, and accounted for over 70% of the biomass. The survey design in 2000 had a large random trawling component to estimate, and correct for, species mix in northern strata. Trawl catches indicated only 7–25% of the acoustic backscatter from mixed marks was from hoki in Strata 1&2 and 4. The method of species decomposition (the "standard" approach) assumes that the trawl representatively catches all species in the mixed layer and the TS of all species are known. These assumptions introduce considerable uncertainty, which is currently incorporated when estimating the survey c.v. (O'Driscoll 2002). Further research is required, including fishing with other gear types (e.g., finer mesh trawls) and midwater trawling on species mix layers away from the bottom to further investigate species composition in mixed species marks.

The current assumption is that most of the hoki biomass in the southern strata comes from hoki schools. This was not the case in 2000, and low density hoki mix marks, similar to those observed in the northern areas, were common in Strata 5B, 6, and 7. The assumption that these contain 100% hoki needs to be reconsidered, and future surveys should include increased trawling in these southern areas to assess the extent of the species mix problem.

To estimate hoki biomass in mixed species layers, any WCSI survey requires an extensive trawling component. If trawling is random, then trawls provide another fisheries independent estimate of hoki abundance. Estimated trawlable biomass of hoki in northern strata in 2000 was 4500 t with a c.v. of 22%. There was clear evidence of diurnal changes in catchability, with the biomass estimate from day trawls more than six times higher than the estimate from trawls at night. In future, any random trawls for biomass estimation should be carried out during the day. Random trawling may also provide useful abundance indices for other commercial species. Relatively precise (c.v. less than 25%) estimates of abundance were also obtained from day tows in 2000 for ling, hake, and silver warehou.

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Table 1: Stratum boundaries, areas, and transect allocation in the 2000 WCSI hoki acoustic survey. Stratum locations are shown in Figure 1.

		Area (km^2)		
Stratum	Boundary	This report	Cordue (2002)	Number of transects
1&2A	300–430	845	754	3–5
1&2B	430–500	759	711	3–5
1&2C	500–650	2 182	1 896	3–5
4A	300–430	786	1 010	7–9
4B	430–500	592	825	7–9
4C	500–650	1 455	1 685	7–9
5A	300–300	254	231	6–8
5B	position to position	529	528	3
6	250–750	1 878	1 807	8–10
7	position to position	565	519	4
Total		9 845	9 966	

Table 2: Summary of snapshots carried out during 2000 WCSI hoki acoustic survey. Snapshot 0 refers to the first leg of the survey, when there were no acoustic transects for biomass estimation.

				No. of trawls	
Snapshot	Start time	End time	No. of transects	Random	Targeted
0	28 Jun 03:40	4 Jul 12:20	0	32	8
1	25 Jul 11:40	31 Jul 10:00	31	22	1
2	31 Jul 12:10	6 Aug 15:20	39	22	5
3	6 Aug 16:30	14 Aug 09:40	38	22	3
4	16 Aug 07:30	22 Aug 02:30	34	18	8
5	23 Aug 03:40	30 Aug 00:00	33	18	6

Table 3: Mean fish size and derived target strength (TS) for species used in species decomposition. Smooth skate and sea perch were also an important part of the catch (see Table 4), but were not included in the species decomposition as it was assumed that these species were in the acoustic "deadzone" close to the bottom. Minor species were considered as a group ("Other"), and an average TS was assigned.

	Mean length	Mean weight	TS	TS-length relationship*	
Species name	(cm)	(kg)	(dB kg^{-1})	*a*	*b*
Hoki	70	1.1	-40.9	18	74
Ling	91	3.9	-34.3	20	68
Hake	79	3.8	-37.6	27.1	83.5
Silver warehou	48	2.1	-49.4	20	80
Spiny dogfish	76	1.9	-45.2	20	80
Javelinfish	35	0.1	-32.3	20	73.5
Bigeyed rattail	43	0.4	-33.5	20	70
Lookdown dory	27	0.5	-31.3	20	64
Silver dory	20	0.2	-30.3	20	64
Dark ghost shark	51	0.8	-44.6	20	80
Ribaldo	44	1.0	-30.6	21.7	66.7
Alfonsino	24	0.3	-34.8	20	68
Pale ghost shark	60	1.3	-45.3	20	80
School shark	121	8.1	-47.4	20	80
Deepwater spiny dogfish	126	14.0	-49.4	20	80
Shovelnosed dogfish	99	3.9	-46.0	20	80
Other	–	–	-35.3	–	–

* TS = $a \log_{10}$ (length) – b. Best estimates from *in situ* measurements, swimbladder modelling, or related species (Gavin Macaulay, pers. comm.)

Table 4: Catch of most abundant species (defined as catch over 100 kg) in the 2000 WCSI survey. Catch totals are for all tows including species mix trawls, random bottom trawls, and targeted trawls.

Species	Scientific name	Species code	Catch (kg)
Hoki	*Macruronus novaezelandiae*	HOK	48 614
Ling	*Genypterus blacodes*	LIN	17 773
Silver warehou	*Seriolella punctata*	SWA	10 502
Hake	*Merluccius australis*	HAK	6 858
Spiny dogfish	*Squalus acanthias*	SPD	2 096
Lookdown dory	*Cyttus traversi*	LDO	2 001
Smooth skate	*Dipturus innominatus*	SSK	1 947
Javelinfish	*Lepidorhynchus denticulatus*	JAV	1 536
Sea perch	*Helicolenus* spp	SPE	1 332
Bigeyed rattail	*Caelorinchus bollonsi*	CBO	1 244
Dark ghost shark	*Hydrolagus novaezealandiae*	GSH	1 084
Giant stargazer	*Kathetostoma giganteum*	STA	988
Alfonsino	*Beryx splendens*	BYS	950
Northern spiny dogfish	*Squalus mitsukurii*	NSD	916
School shark	*Galeorhinus galeus*	SCH	843
Ribaldo	*Mora moro*	RIB	842
Shovelnosed dogfish	*Deania calcea*	SND	772
Silver dory	*Cyttus novaezealandiae*	SDO	724
Deepwater spiny dogfish	*Centrophorus squamosus*	CSQ	634
Swollenhead conger	*Bassanago bulbiceps*	SCO	540
Silver roughy	*Hoplostethus mediterraneus*	SRH	480
Frostfish	*Lepidopus caudatus*	FRO	479
Slender smoothhound	*Gollum attenuatus*	SSH	425
Rubyfish	*Plagiogeneion rubiginosus*	RBY	320
Arrow squid	*Notodarus sloanii & N. gouldi*	SQU	267
Hapuku	*Polyprion oxygeneios*	HAP	246
Pale ghost shark	*Hydrolagus* sp B2	GSP	209
Gemfish	*Rexea solandri*	SKI	206
Tarakihi	*Nemadactylus macropterus*	TAR	191
Bluenose	*Hyperoglyphe antarctica*	BNS	179
Hairy conger	*Bassanago hirsutus*	HCO	172
Electric ray	*Torpedo fairchildi*	ERA	139
Red cod	*Pseudophycis bachus*	RCO	112
Carpet shark	*Cephaloscyllium isabellum*	CAR	105
Total catch			107 271

Table 5: Survey tow and gear parameters. Values are number of tows (n), and the mean, standard deviation (s.d.), and range of observations for each parameter in each of three bottom depth bins. Random bottom trawls include species mix trawls.

	n	Mean	s.d	Range
Random bottom trawls				
Tow parameters				
Tow length (n.miles)	134	2.95	0.20	2.00–3.09
Tow speed (knots)	134	3.5	0.06	3.2–3.7
Gear parameters (m)				
300–430 m				
Headline height	35	6.8	0.24	6.5–7.6
Doorspread	33	117.5	6.9	106.4–131.8
430–500 m				
Headline height	40	6.7	0.22	6.1–7.6
Doorspread	37	124.1	4.7	115.0–132.1
500–650 m				
Headline height	57	6.6	0.20	6.2–7.2
Doorspread	53	126.3	4.7	117.2–138.0
All stations 300–650 m				
Headline height	132	6.7	0.23	6.1–7.6
Doorspread	123	123.3	6.4	106.4–138.0
Target bottom trawls				
Tow parameters				
Tow length (n. miles)	11	2.48	0.88	0.69–3.43
Tow speed (knots)	11	3.5	0.13	3.4–3.9
Gear parameters (m)				
Headline height	11	6.6	0.22	6.2–7.0
Doorspread	10	122.1	4.6	115.8–132.3
Target midwater trawls				
Tow parameters				
Tow length (n. miles)	21	1.92	0.80	0.52–3.28
Tow speed (knots)	21	3.5	0.27	2.9–4.1
Gear parameters (m)				
Headline height	19	37.3	4.16	26.0–43.2
Doorspread	19	134.4	11.5	107.2–147.0

Table 6: Estimated biomass (t) and coefficients of variation (%, in parentheses) of the 13 major species* by substratum in species mix bottom trawls from 28 June to 4 July 2000.

	HOK	LIN	HAK	SWA	SPD	SSK	JAV	CBO	LDO	GSH	SPE	RIB	STA
Day tows													
Stratum													
1&2A	93	106	0	37	0	24	12	0	78	20	6	0	57
	(10)	(35)		(11)		(68)	(25)		(60)	(30)	(31)		(47)
1&2B	516	261	0	41	0	42	26	18	81	7	16	0	6
	(32)	(24)		(62)		(26)	(37)	(15)	(25)	(46)	(8)		(46)
1&2C	1 048	325	272	37	0	14	40	48	97	1	64	13	3
	(20)	(25)	(27)	(26)		(86)	(20)	(22)	(26)	(66)	(13)	(30)	(100)
Total	**1 658**	**692**	**272**	**115**	**0**	**79**	**78**	**66**	**256**	**28**	**86**	**13**	**66**
(All strata)	**(16)**	**(16)**	**(27)**	**(24)**		**(29)**	**(17)**	**(17)**	**(22)**	**(25)**	**(9)**	**(30)**	**(41)**

	HOK	LIN	HAK	SWA	SPD	SSK	JAV	CBO	LDO	GSH	SPE	RIB	STA
Night tows													
Stratum													
1&2A	53	125	0	9	0	2	1	0	13	22	3	0	24
	(39)	(44)		(21)		(100)	(20)		(44)	(7)	(37)		(65)
1&2B	152	78	4	16	0	10	2	2	6	3	6	0	1
	(21)	(8)	(100)	(54)		(80)	(13)	(28)	(15)	(61)	(9)		(100)
1&2C	715	181	275	7	0	19	32	9	20	1	35	14	3
	(20)	(10)	(21)	(82)		(52)	(24)	(32)	(17)	(78)	(7)	(30)	(70)
Total	**919**	**385**	**280**	**32**	**0**	**31**	**36**	**11**	**40**	**25**	**44**	**14**	**28**
1&2	**(16)**	**(15)**	**(20)**	**(33)**		**(42)**	**(22)**	**(26)**	**(17)**	**(9)**	**(6)**	**(30)**	**(56)**

* Species codes are given in Table 4

Table 7: Estimated biomass (t) and coefficients of variation (%, in parentheses) of the 13 major species* by substratum in random bottom trawls from 25 July to 29 August.

	HOK	LIN	HAK	SWA	SPD	SSK	JAV	CBO	LDO	GSH	SPE	RIB	STA
Day tows													
Stratum													
1&2A	393	549	2	284	1	22	11	4	20	16	9	0	26
	(58)	(34)	(100)	(46)	(72)	(72)		(47)	(68)	(46)	(17)	(31)	(49)
1&2B	899	236	58	406	1	47	17	22	14	4	6	2	1
	(30)	(31)	(37)	(45)	(100)	(41)	(38)	(17)	(30)	(33)	(29)	(90)	(100)
1&2C	812	190	218	41	0	39	64	71	47	1	38	44	0
	(46)	(26)	(23)	(48)		(66)	(31)	(17)	(21)	(100)	(10)	(40)	
Sub-total	**2 105**	**974**	**278**	**731**	**1**	**108**	**91**	**97**	**81**	**21**	**53**	**47**	**27**
1&2	**(25)**	**(21)**	**(19)**	**(31)**	**(59)**	**(33)**	**(24)**	**(13)**	**(18)**	**(15)**	**(10)**	**(38)**	**(47)**
4A	1 248	245	10	380	225	11	22	3	6	47	20	0	31
	(56)	(53)	(50)	(52)	(56)	(63)	(40)	(47)	(37)	(100)	(16)		(28)
4B	588	111	48	81	4	9	24	20	10	0	10	1	3
	(48)	(33)	(22)	(46)	(79)	(53)	(44)	(14)	(31)		(7)	(69)	(66)
4C	594	124	348	30	3	14	21	31	38	0	18	37	2
	(56)	(22)	(21)	(45)	(55)	(67)	(24)	(34)	(34)		(15)	(26)	(73)
Sub-total	**2 430**	**480**	**407**	**490**	**232**	**35**	**67**	**51**	**54**	**47**	**47**	**39**	**35**
4	**(34)**	**(29)**	**(19)**	**(41)**	**(54)**	**(37)**	**(22)**	**(21)**	**(25)**	**(52)**	**(9)**	**(26)**	**(25)**
Total (day)	**4 535**	**1 454**	**685**	**1 221**	**233**	**143**	**159**	**151**	**135**	**68**	**100**	**84**	**62**
1&2 and 4	**(22)**	**(17)**	**(14)**	**(25)**	**(54)**	**(27)**	**(17)**	**(11)**	**(14)**	**(36)**	**(7)**	**(24)**	**(25)**
Night tows													
Stratum													
1&2A	178	546	3	86	0	30	1	1	2	13	5	0	15
	(66)	(28)	(52)	(47)		(42)	(25)	(54)	(34)	(45)	(48)		(36)
1&2B	137	104	18	35	0	29	5	4	5	2	4	4	3
	(24)	(28)	(32)	(45)		(50)	(26)	(15)	(27)	(56)	(23)	(55)	(72)
1&2C	189	70	126	20	0	14	28	25	26	1	35	34	0
	(36)	(31)	(20)	(38)		(63)	(22)	(11)	(15)	(100)	(11)	(28)	
Sub-total	**505**	**720**	**146**	**141**	**0**	**73**	**34**	**30**	**33**	**16**	**44**	**38**	**17**
1&2	**(28)**	**(22)**	**(17)**	**(31)**		**(29)**	**(18)**	**(10)**	**(13)**	**(39)**	**(11)**	**(25)**	**(32)**
4A	36	45	2	378	116	12	1	2	1	69	12	0	30
	(19)	(28)	(68)	(70)	(48)	(63)	(47)	(93)	(100)	(42)	(36)		(34)
4B	95	51	36	64	10	6	3	6	3	0	4	1	7
	(37)	(23)	(41)	(49)	(54)	(52)	(25)	(19)	(15)		(15)	(68)	(56)
4C	84	90	161	5	4	4	35	7	13	0	12	50	3
	(38)	(24)	(32)	(63)	(74)	(64)	(23)	(24)	(19)		(9)	(29)	(53)
Sub-total	**214**	**187**	**199**	**447**	**130**	**22**	**38**	**14**	**16**	**69**	**29**	**50**	**41**
4	**(22)**	**(15)**	**(27)**	**(60)**	**(43)**	**(39)**	**(21)**	**(18)**	**(16)**	**(42)**	**(17)**	**(29)**	**(28)**
Total (night)	**719**	**907**	**345**	**587**	**130**	**95**	**73**	**45**	**49**	**84**	**73**	**88**	**58**
1&2 and 4	**(20)**	**(18)**	**(17)**	**(46)**	**(43)**	**(24)**	**(14)**	**(9)**	**(10)**	**(35)**	**(9)**	**(20)**	**(22)**

* Species codes are given in Table 4

Table 8: Estimated biomass (t) and coefficients of variation for hoki by snapshot in random bottom trawls from 25 July to 29 August. Substrata were combined (i.e., Substrata 1&2A, 1&2B and 1&2C = Stratum 1&2 and Substrata 4A, 4B and 4C = Stratum 4) as there were insufficient tows to calculate biomass by snapshot in each substratum.

		Day tows		Night tows	
Snapshot	Stratum	Biomass (t)	c.v. (%)	Biomass	c.v
1	1&2	2 250	59	1 286	48
	4	3 475	36	979	22
	Total	5 725	32	2 265	29
2	1&2	3 237	48	558	47
	4	452	61	277	49
	Total	3 689	43	834	36
3	1&2	933	38	350	53
	4	2 035	34	99	34
	Total	2 968	26	448	42
4	1&2	2 412	69	340	47
	4	5 044	92	157	16
	Total	7 456	66	497	33
5	1&2	2 766	55	127	30
	4	665	48	96	21
	Total	3 431	46	223	19

Table 9: Estimates of the proportion of acoustic backscatter from hoki (P(hoki)) in mixed species marks by snapshot and stratum. Mean catch rates (all species combined) in random bottom trawls and the average percentage of hoki by weight in the catch are also given.

Snapshot	Stratum	Mean catch (kg km^{-2})	% hoki in catch	P(hoki) This report	P(hoki) Cordue (2002)
0	1&2	834	42	0.18	–
1	1&2	1 027	38	0.20	0.45
	4	1 874	53	0.25	0.44
2	1&2	1 338	31	0.18	0.21
	4	722	18	0.07	0.15
3	1&2	803	21	0.08	0.21
	4	778	22	0.10	0.19
4	1&2	1 145	26	0.11	0.20
	4	1 395	25	0.16	0.23
5	1&2	983	25	0.14	0.21
	4	793	14	0.07	0.13

Table 10: Estimates of the proportion of acoustic backscatter from hoki (P(hoki)) in mixed species marks by substratum for all snapshots combined. Mean catch rates (all species combined) in random bottom trawls and the average percentage of hoki by weight in the catch are also given.

Substratum	Mean catch (kg km^{-2})	% hoki in catch	P(hoki)
1&2A	1 451	17	0.08
1&2B	1 355	40	0.23
1&2C	567	29	0.12
4A	2 023	21	0.16
4B	926	37	0.18
4C	657	20	0.08

Table 11: Catch composition and catch rates of hoki for trawls targeted on three acoustic mark types (see text for details).

		% hoki in catch			Catch rate hoki (kg km^{-2})		
Mark type	n	mean	min	max	mean	min	max
Hoki schools	9	87	40	100	4 934	56	23 574
Hoki mix	15	42	7	79	284	10	1 301
Non-hoki	7	0	0	0	0	0	0

Table 12: Hoki acoustic abundance estimates from the 2000 WCSI survey by snapshot and strata from the re-analysis described in this report compared to "standard" estimates from Cordue (2002), adjusted for changes in stratum areas and hoki TS*.

This analysis

	Stratum biomass ('000 t)						Total	Snapshot
Snapshot	1&2	4	5A	5B	6	7	('000 t)	c.v.
1	75	76	138	76	241	18	625	9
2	59	27	54	41	156	13	350	7
3	25	64	84	86	118	23	401	9
4	19	32	69	45	155	47	367	11
5	37	42	30	25	213	48	395	16
mean	43	48	75	55	177	30	427	5

Revised from Cordue (2002)*

	Stratum biomass ('000 t)						Total	Snapshot
Snapshot	1&2	4	5A	5B	6	7	('000 t)	c.v.
1	110	63	139	58	236	22	629	11
2	51	57	44	42	136	19	350	8
3	45	48	82	74	119	22	390	10
4	29	28	51	60	139	32	340	11
5	28	20	26	21	193	40	328	12
mean	53	43	69	51	165	27	407	5

*Biomass values presented by Cordue (2002) were adjusted for changes in the hoki TS and revisions in stratum areas so that these could be compared to the new values. The change in TS increased the mean snapshot biomass from 235 000 t (Cordue 2002, table 8) to 396 000 t (O'Driscoll, table 26, and the value currently used in the hoki assessment). The revised stratum areas described in this report further increased the estimate to 407 000 t.

Table 13: Hoki acoustic abundance estimates for Strata 1&2 and 4 for two alternative methods of estimating P(hoki). 'Snapshot' is where P(hoki) is estimated by snapshot and stratum (Table 9). 'Substratum' is where P(hoki) is estimated by substratum for all snapshots combined (Table 10).

	Stratum biomass ('000 t)			
	Snapshot		Substratum	
Snapshot	1&2	4	1&2	4
1	75	76	52	61
2	59	27	43	42
3	25	64	43	62
4	19	32	27	24
5	37	42	37	43
mean	43	48	40	46

Table 14: Percentage of hoki biomass from hoki school marks in each snapshot and strata.

	Proportion of hoki biomass in schools (%)						
Snapshot	1&2	4	5A	5B	6	7	Total
1	0	18	100	47	67	19	36
2	0	0	91	21	63	0	16
3	0	11	95	59	17	0	20
4	0	5	98	15	27	0	19
5	0	12	81	0	34	0	23
mean	0	9	93	29	41	4	23

Table 15: Commercial catch of hoki on the WCSI by acoustic stratum during 2000. Catches are from TCEPR and CELR. All catch reported on CELR (5000 t) was assumed to have come from Stratum 5A. Catches are compared to the acoustic (Table 12) and daytime trawl (Table 7) biomass estimates.

Acoustic stratum	Catch, C ('000 t)	Acoustic estimate, A ('000 t)	Trawl estimate ('000 t)	Ratio C:A
1&2	17	43	2.1	0.40
4	43	48	2.4	0.90
5A	13	75		0.17
5B	17	55		0.31
6	8	177		0.05
7	0	30		0
Other	5	–		
Total	103	427		0.24

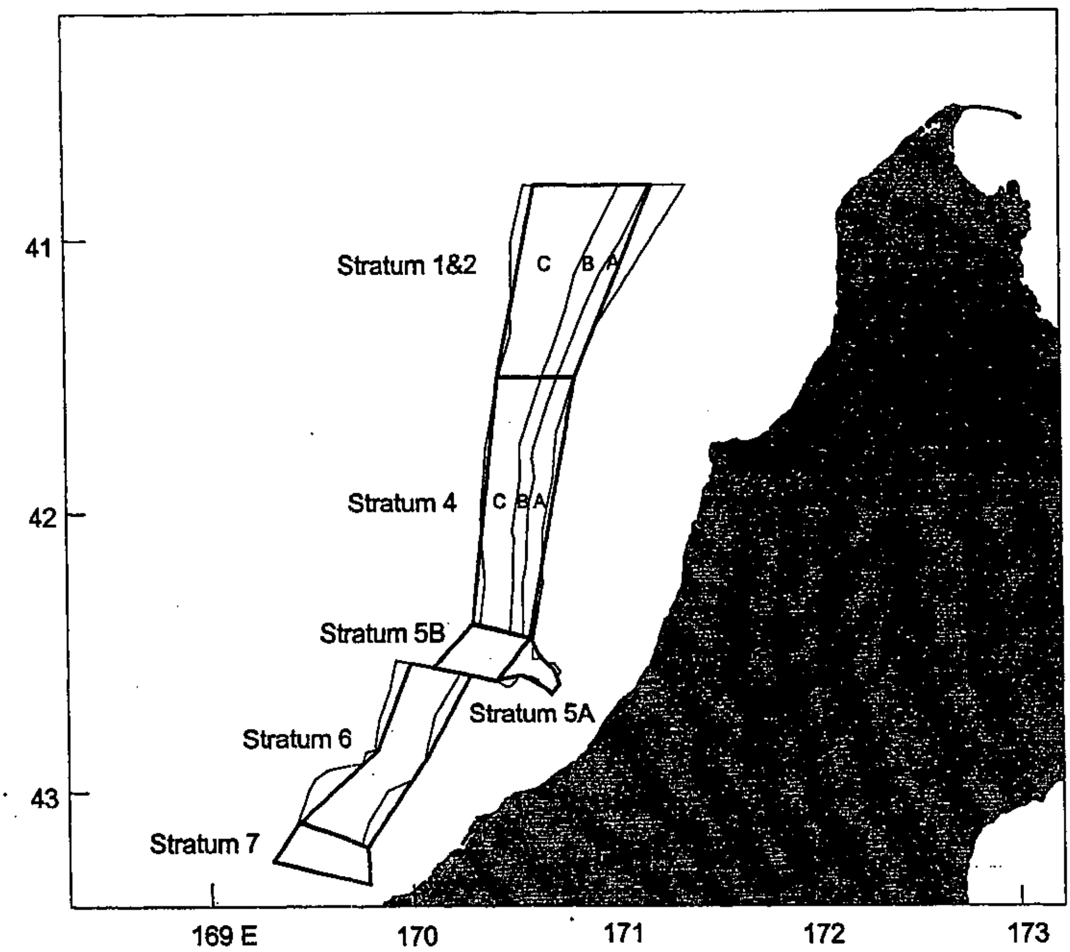


Figure 1: Revised (thin line) and old (bold line) boundaries for the 2000 acoustic survey of WCSI spawning hoki. Stratum areas are given in Table 1.

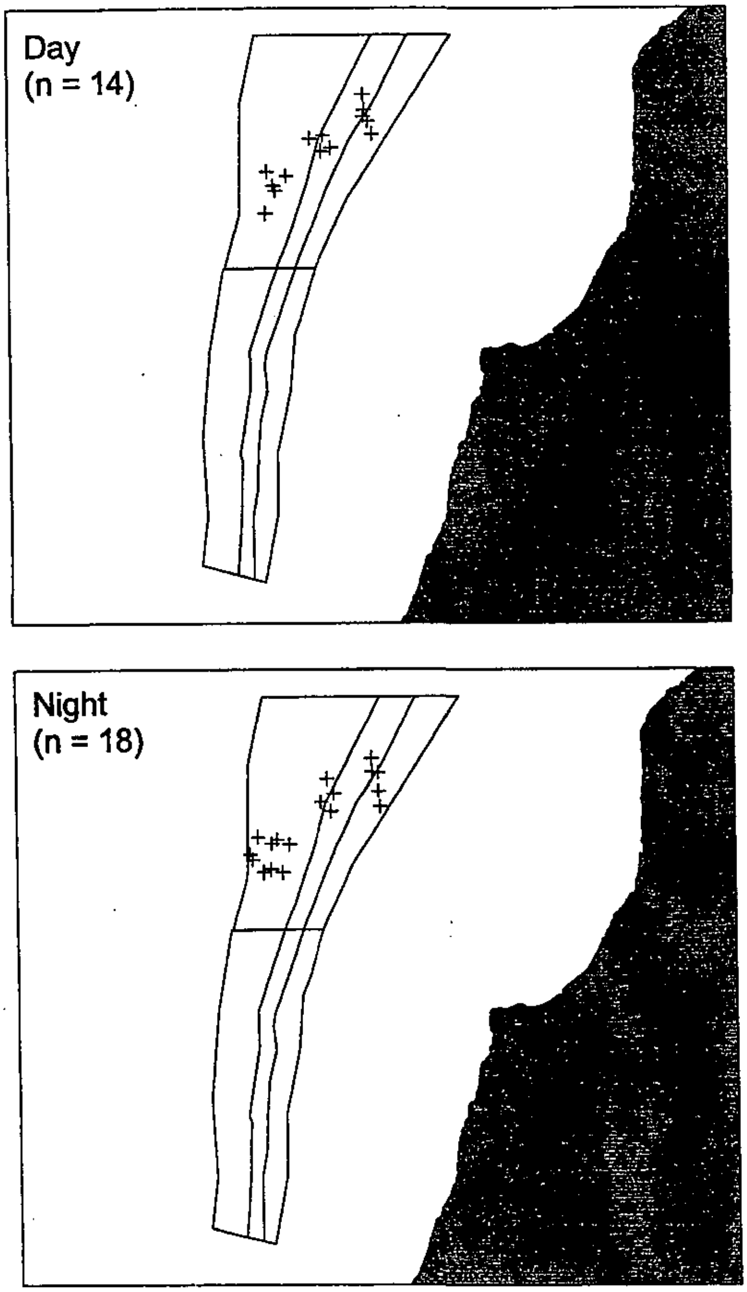


Figure 2: Location of species mix trawls carried out in Stratum 1&2 during the first leg of the survey from 26 June to 5 July 2000.

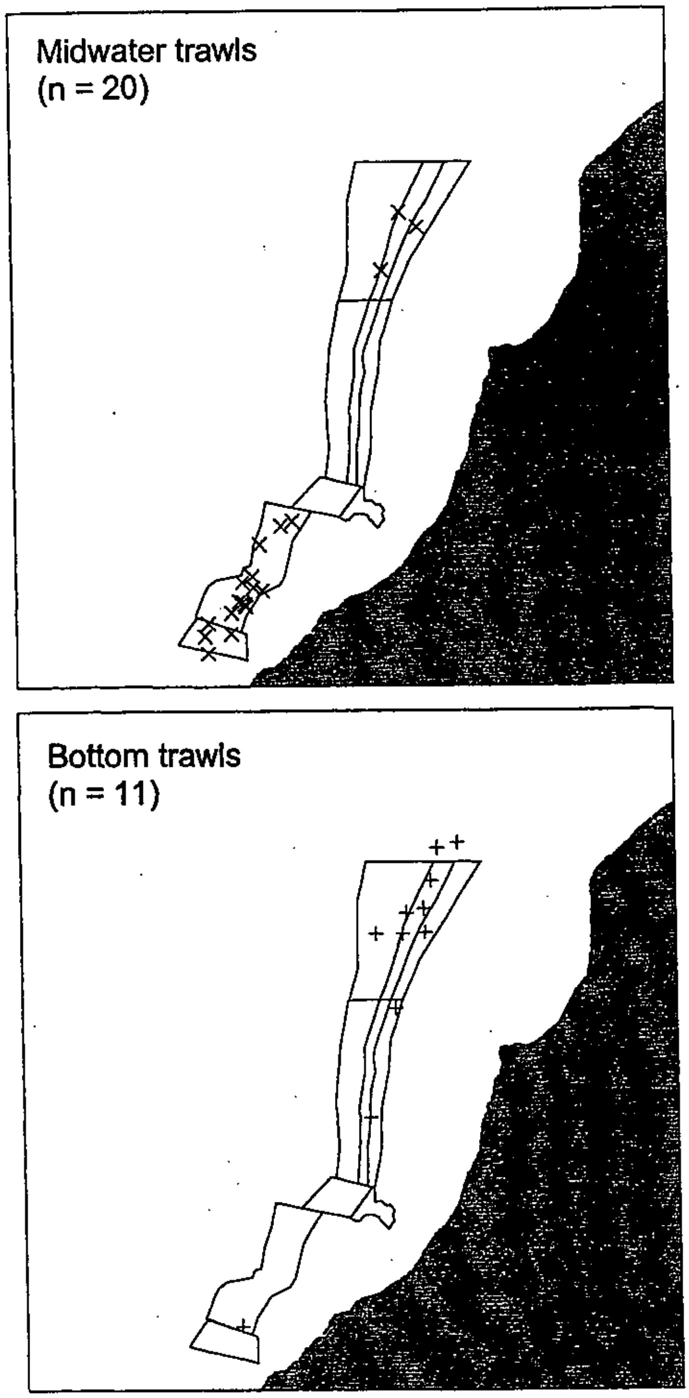


Figure 3: Location of targeted trawls carried out during both legs of the WCSI survey from 26 June to 31 August 2000.

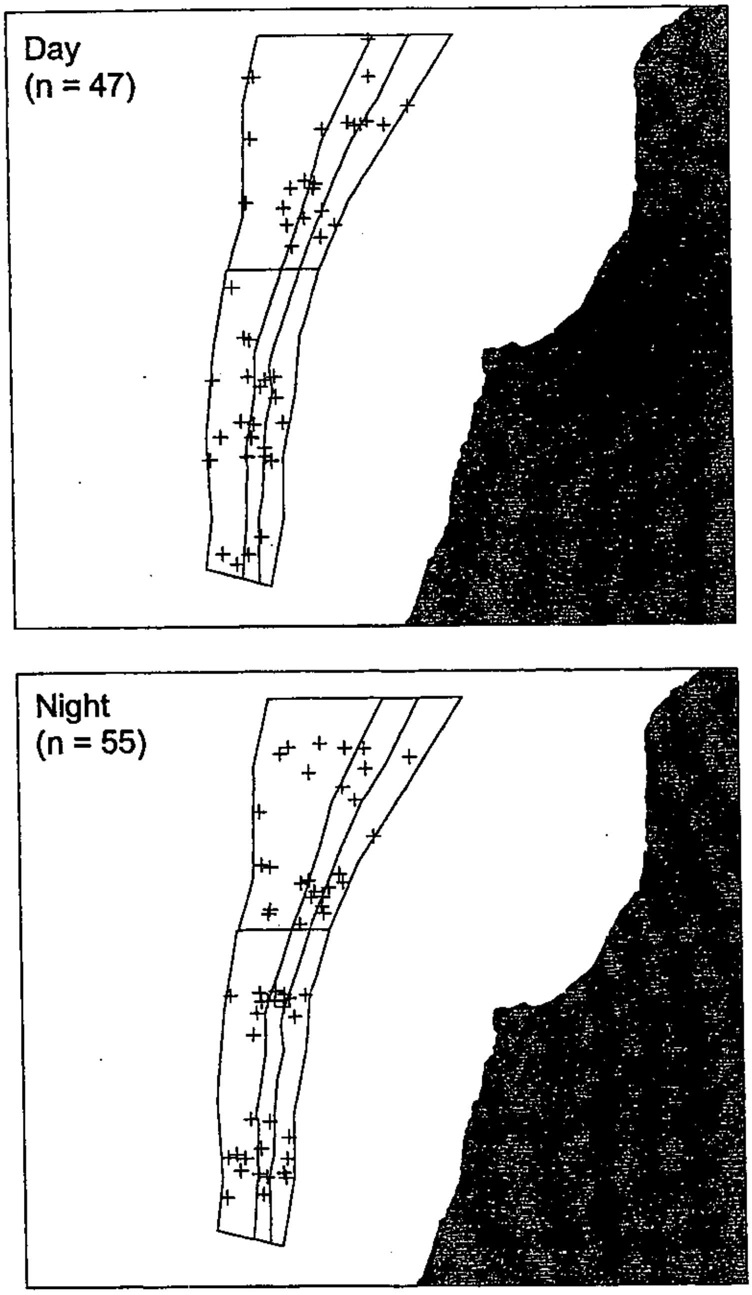
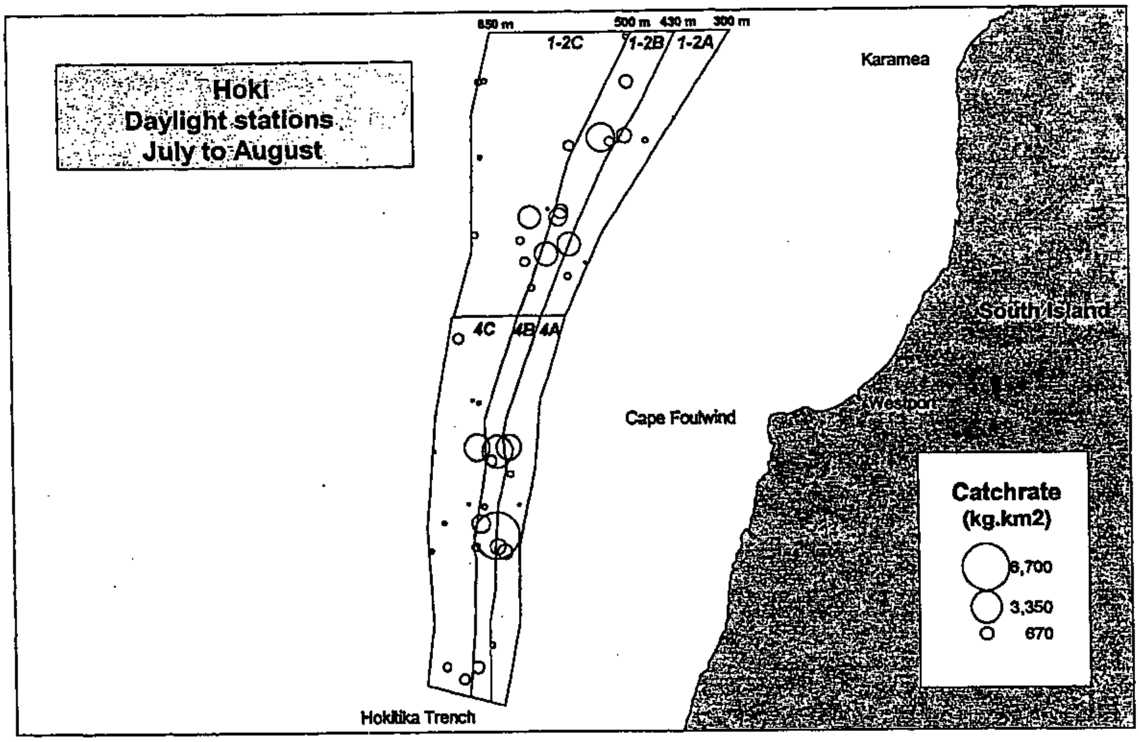


Figure 4: Location of random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.



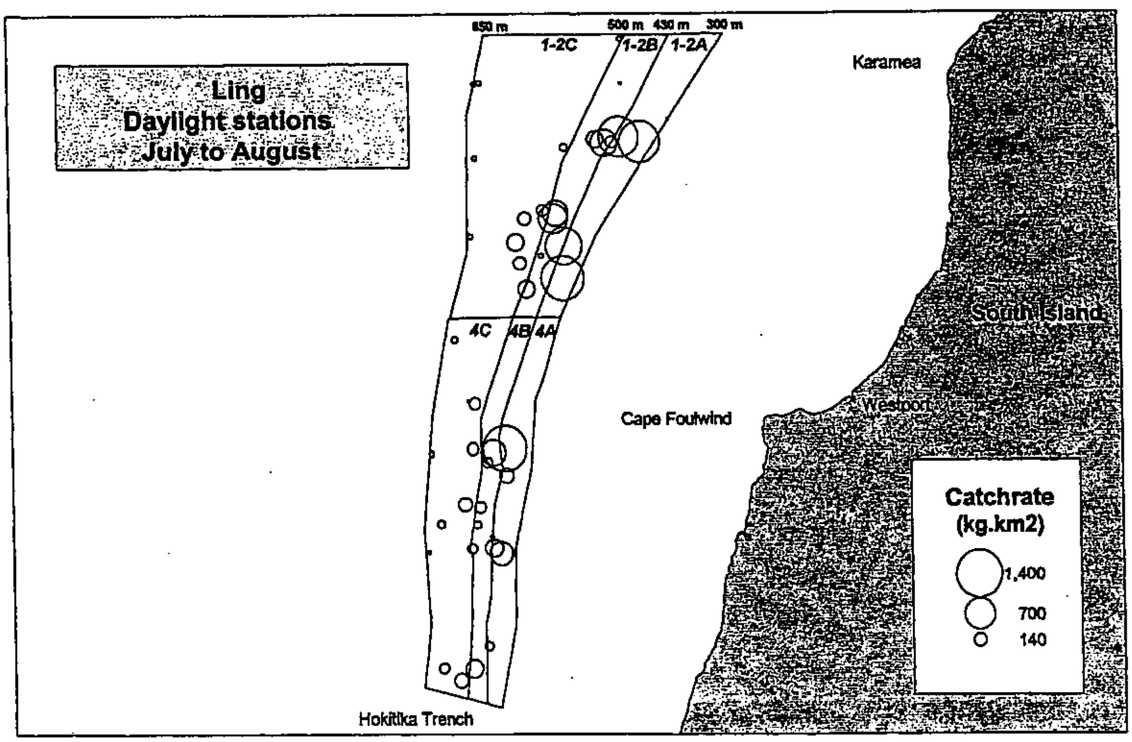
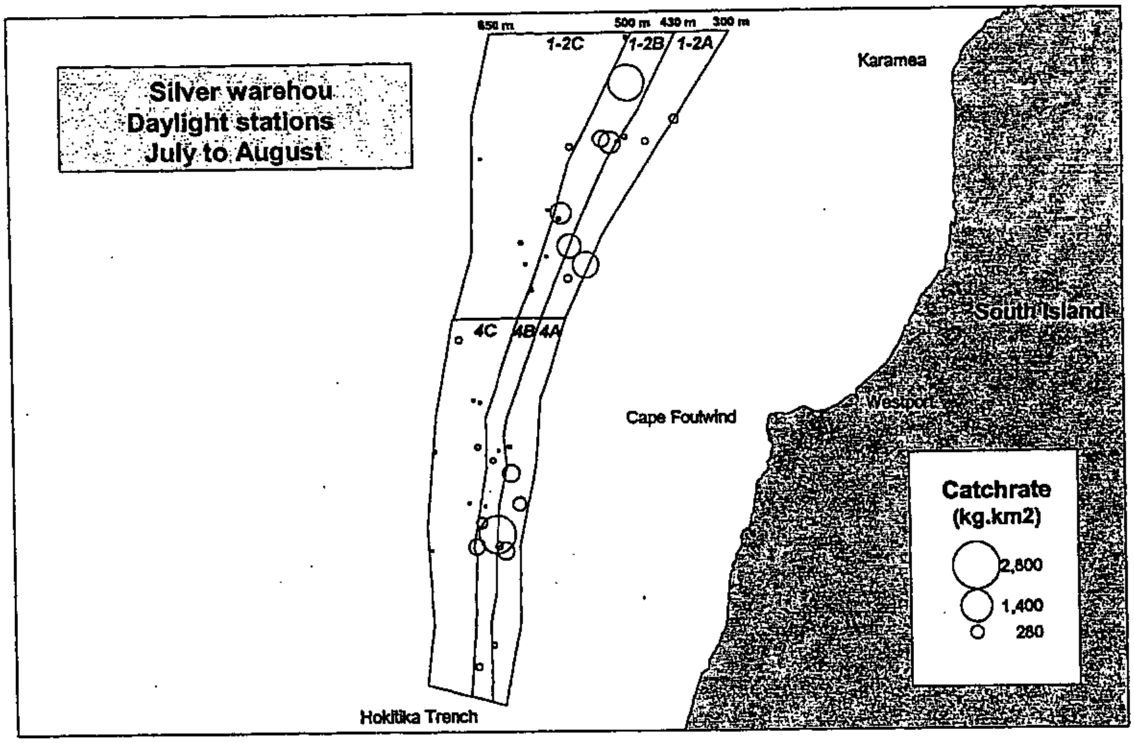


Figure 5: Catch rates of hoki and ling in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.



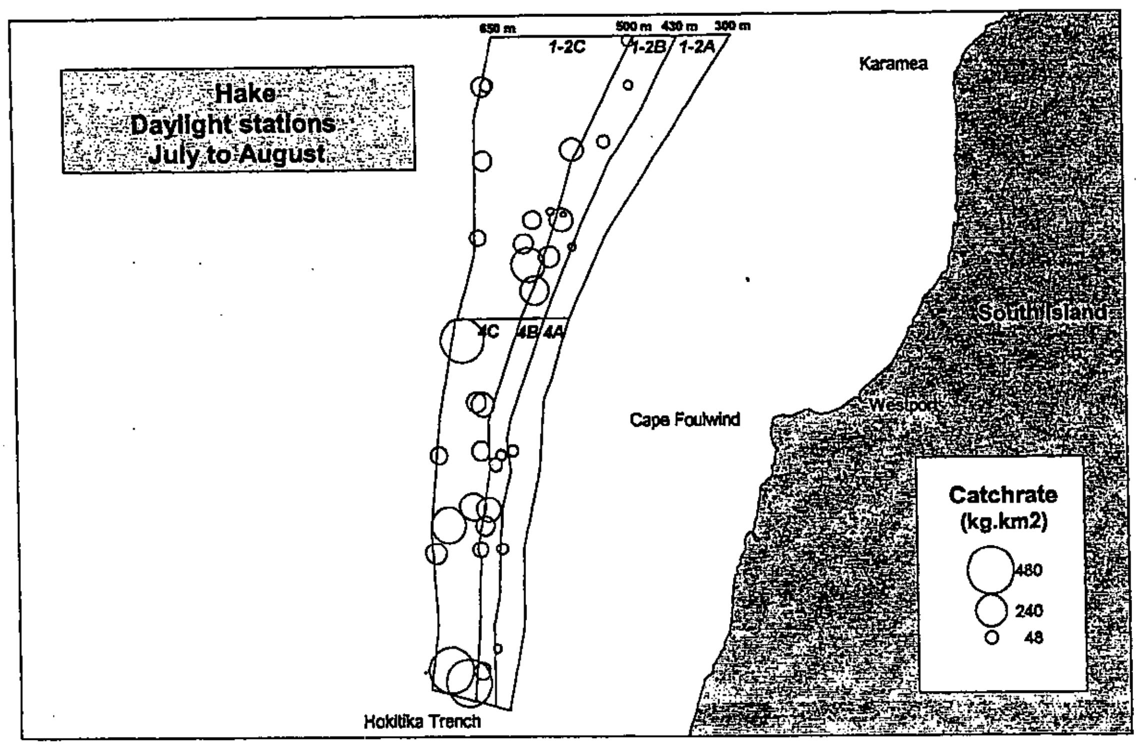
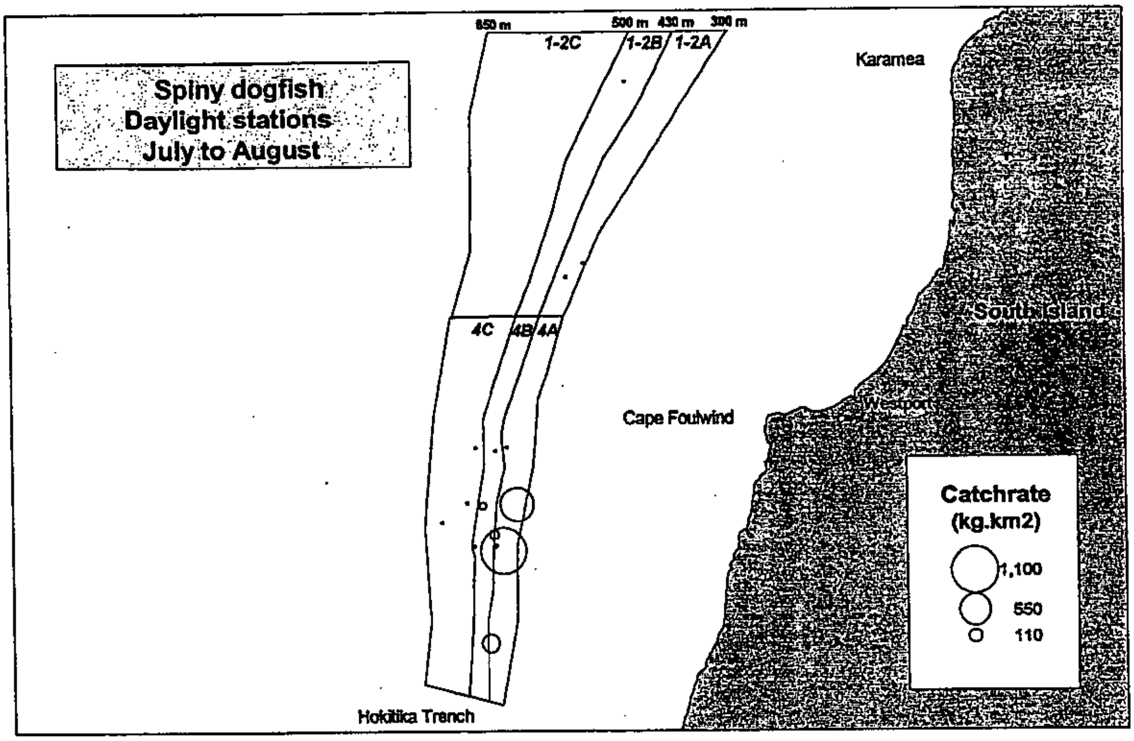


Figure 5 cont: Catch rates of silver warehou and hake in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.



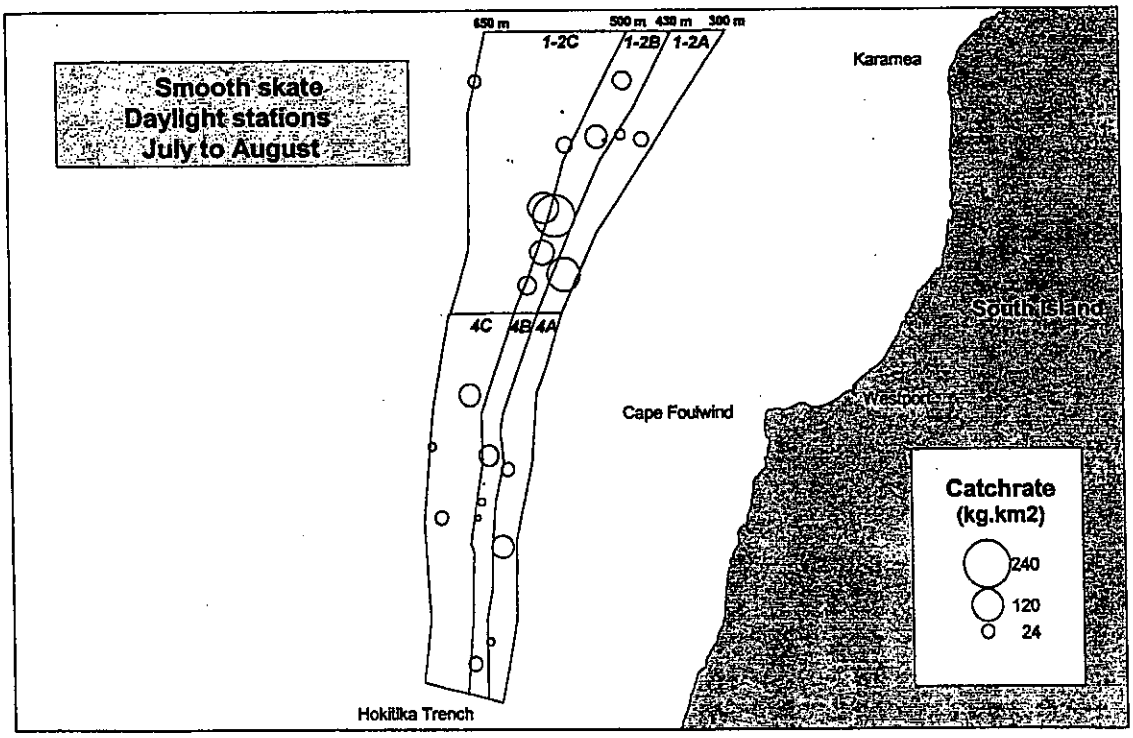
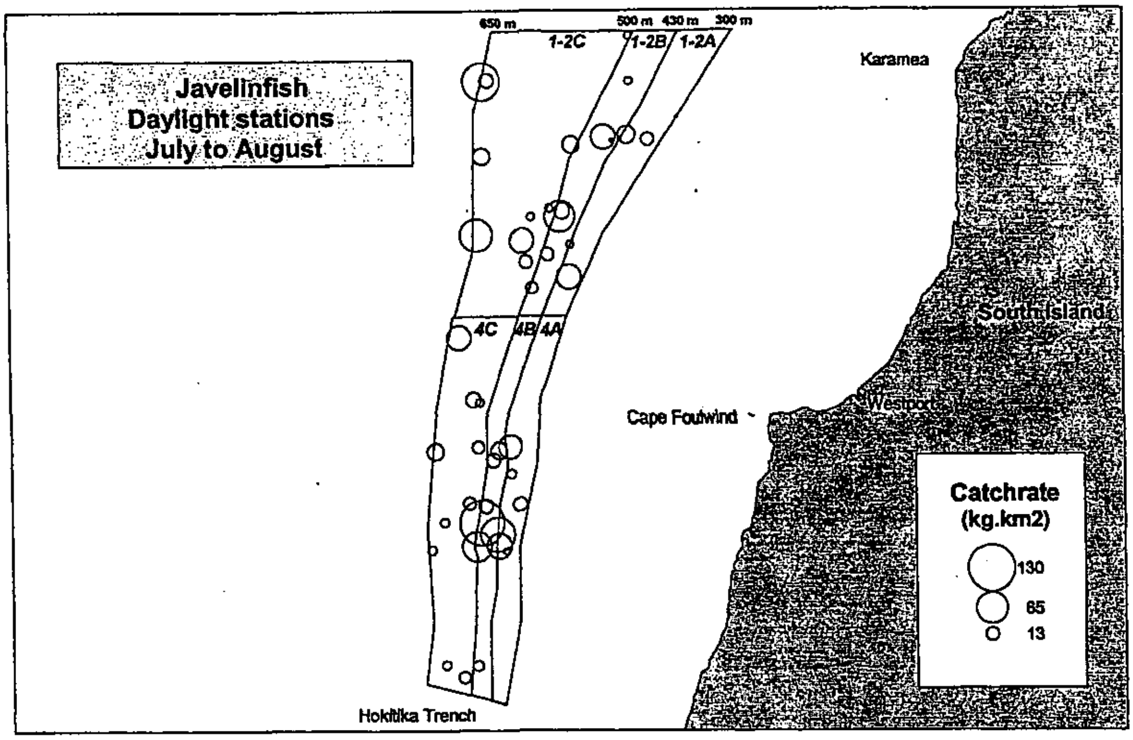


Figure 5 cont: Catch rates of spiny dogfish and smooth skate in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.



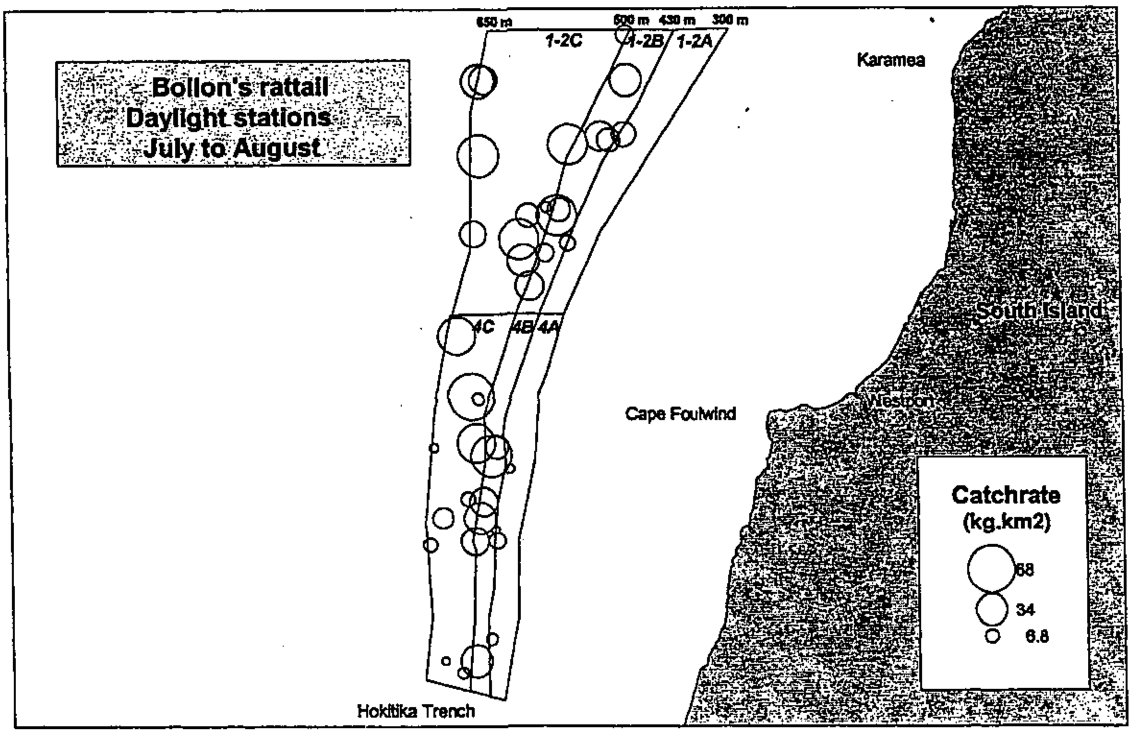
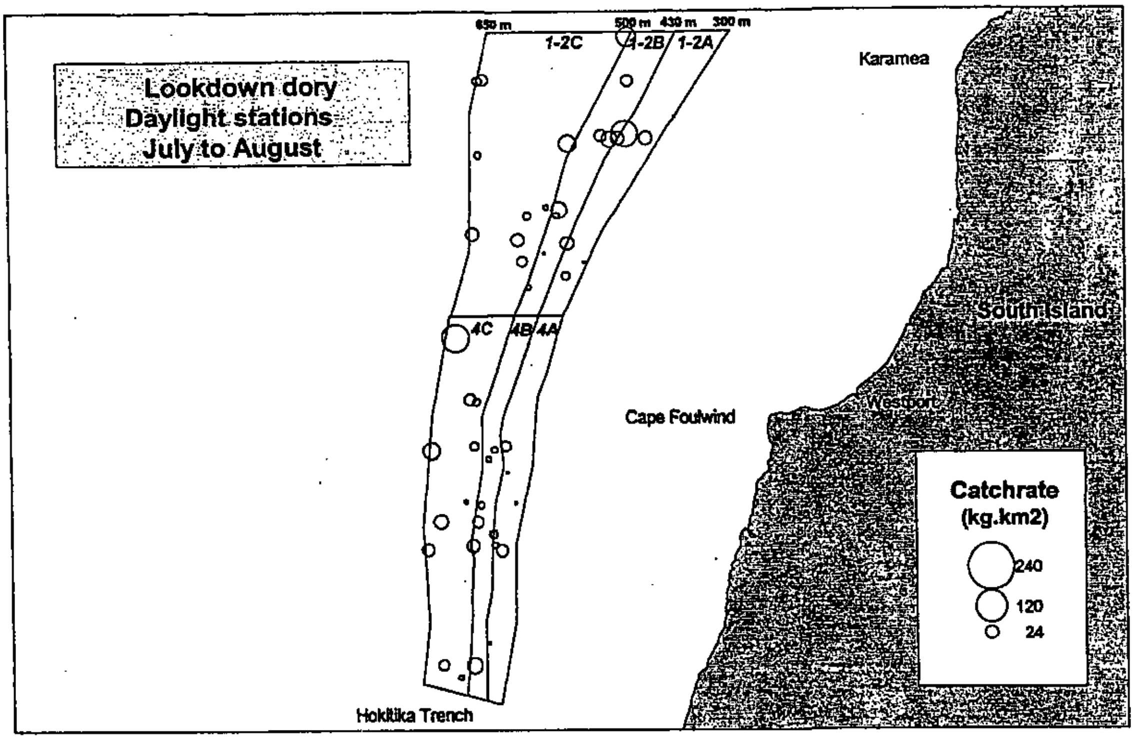


Figure 5 cont: Catch rates of javelinfish and bigeyed (Bollon's) rattail in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.



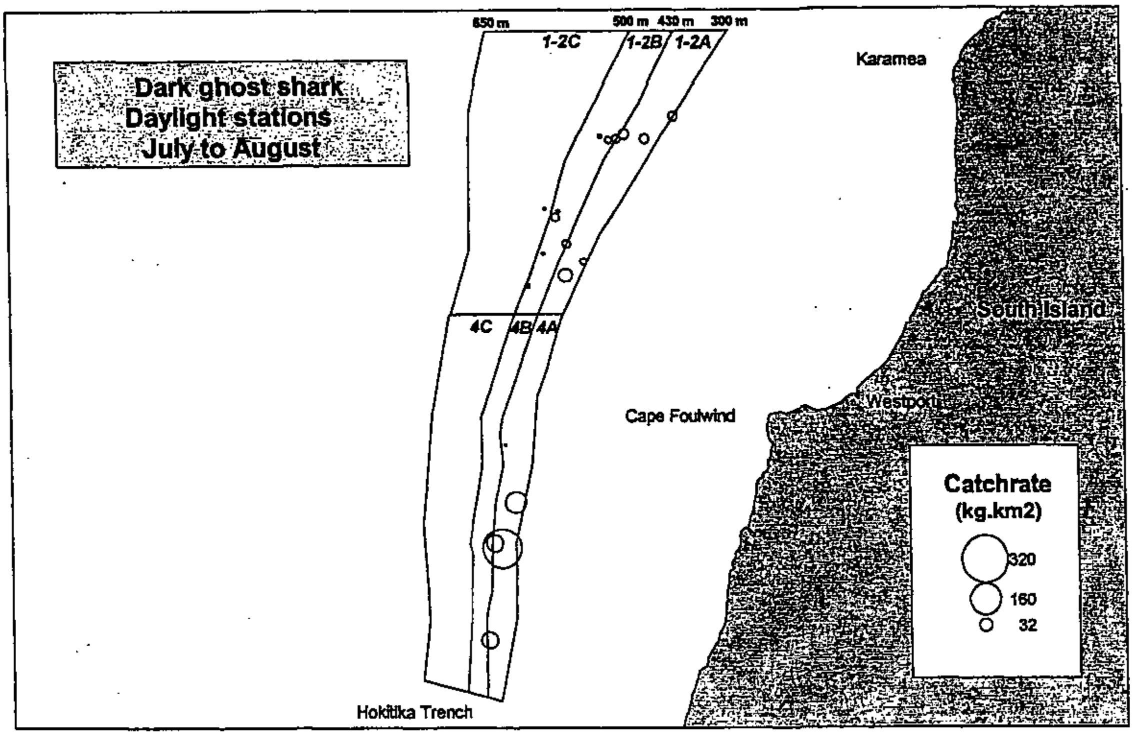
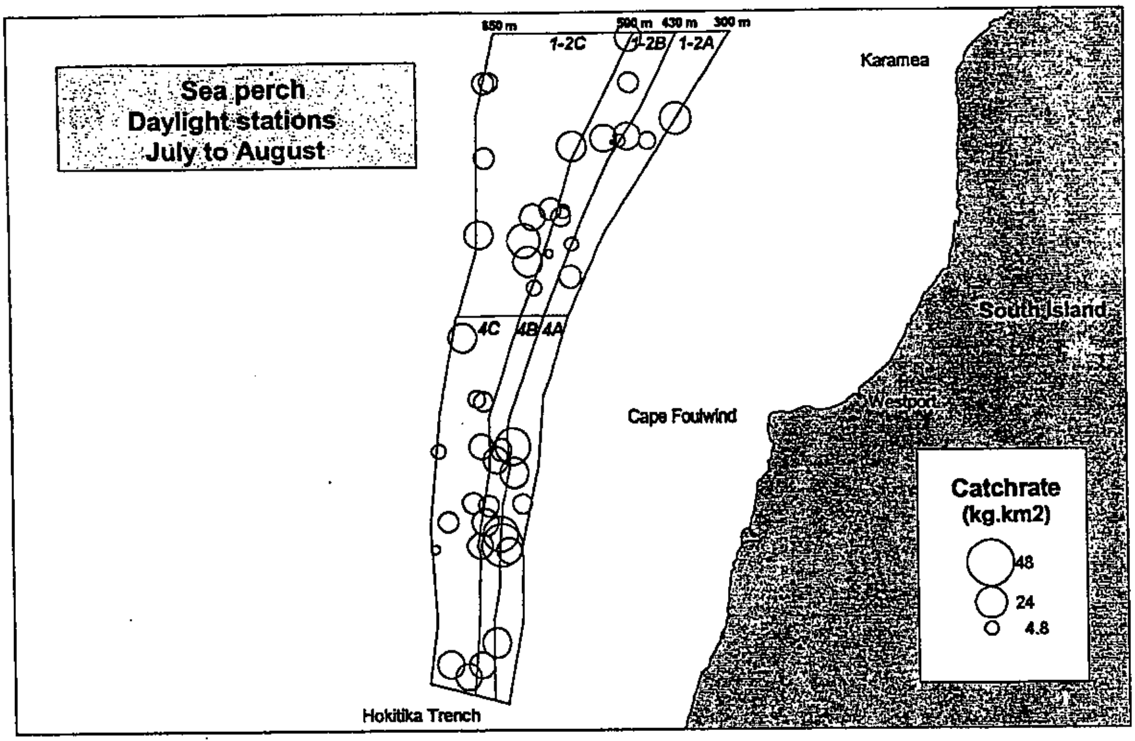


Figure 5 cont: Catch rates of lookdown dory and dark ghost shark in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.



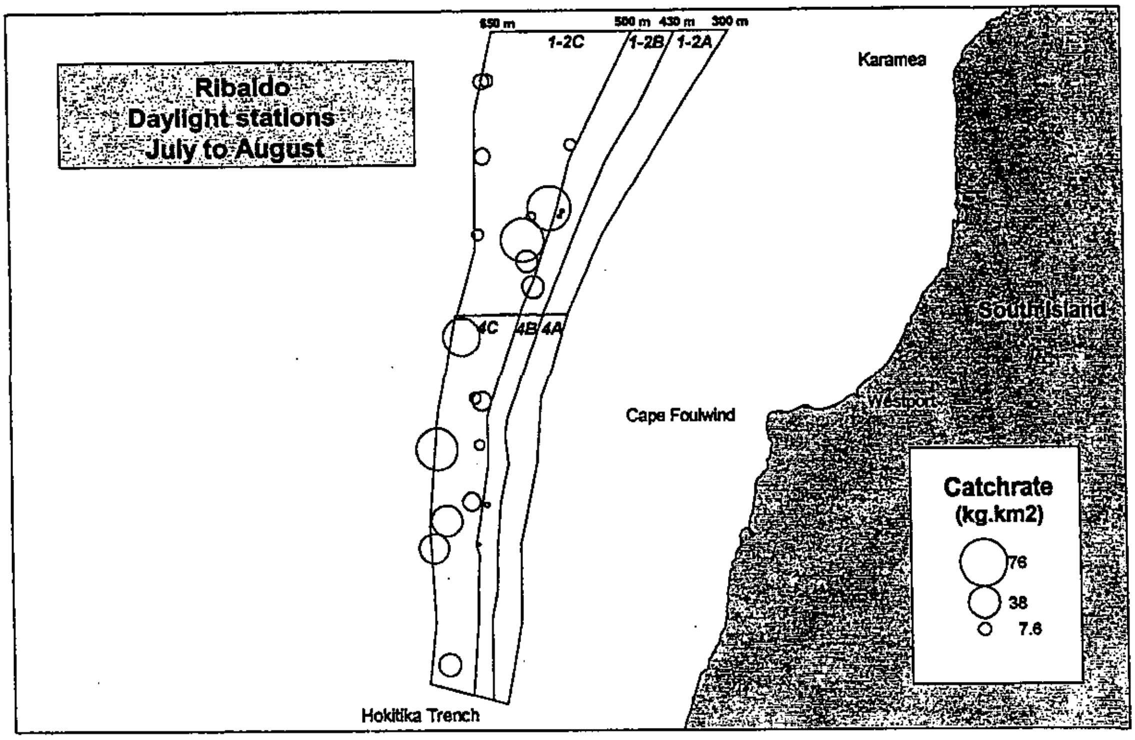


Figure 5 cont: Catch rates of sea perch and ribaldo in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.

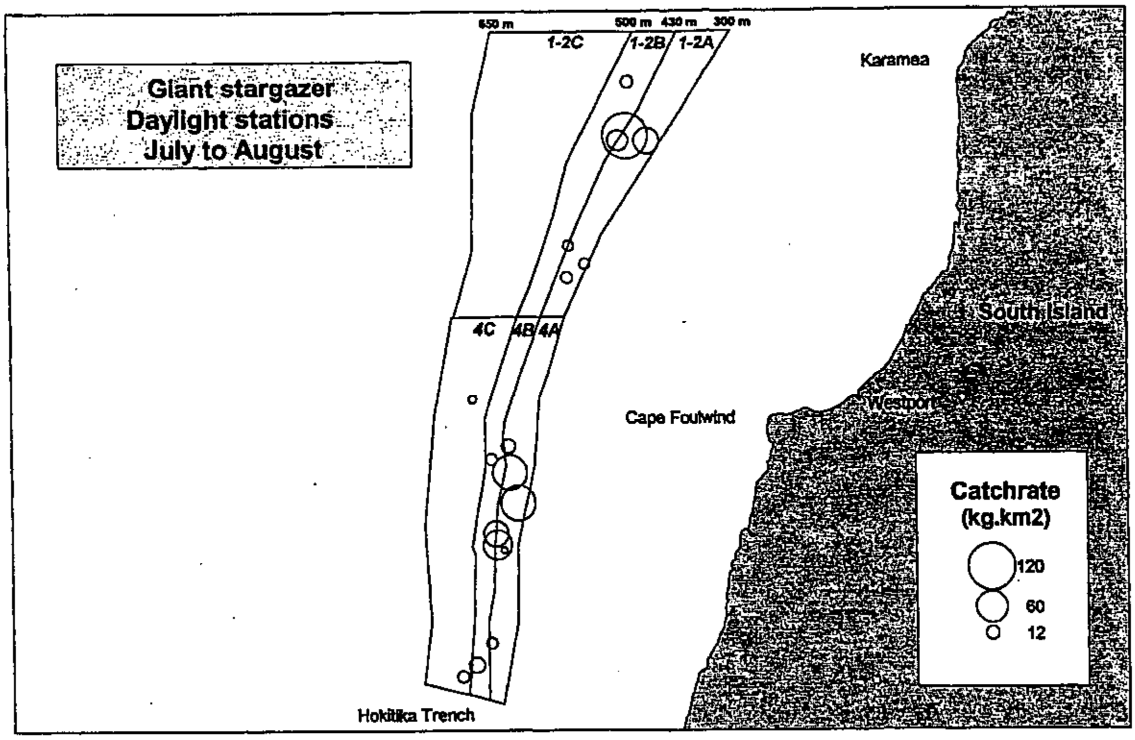


Figure 5 cont: Catch rates of giant stargazer in daytime random bottom trawls carried out in Strata 1&2 and 4 during the second leg of the WCSI survey from 24 July to 31 August 2000.

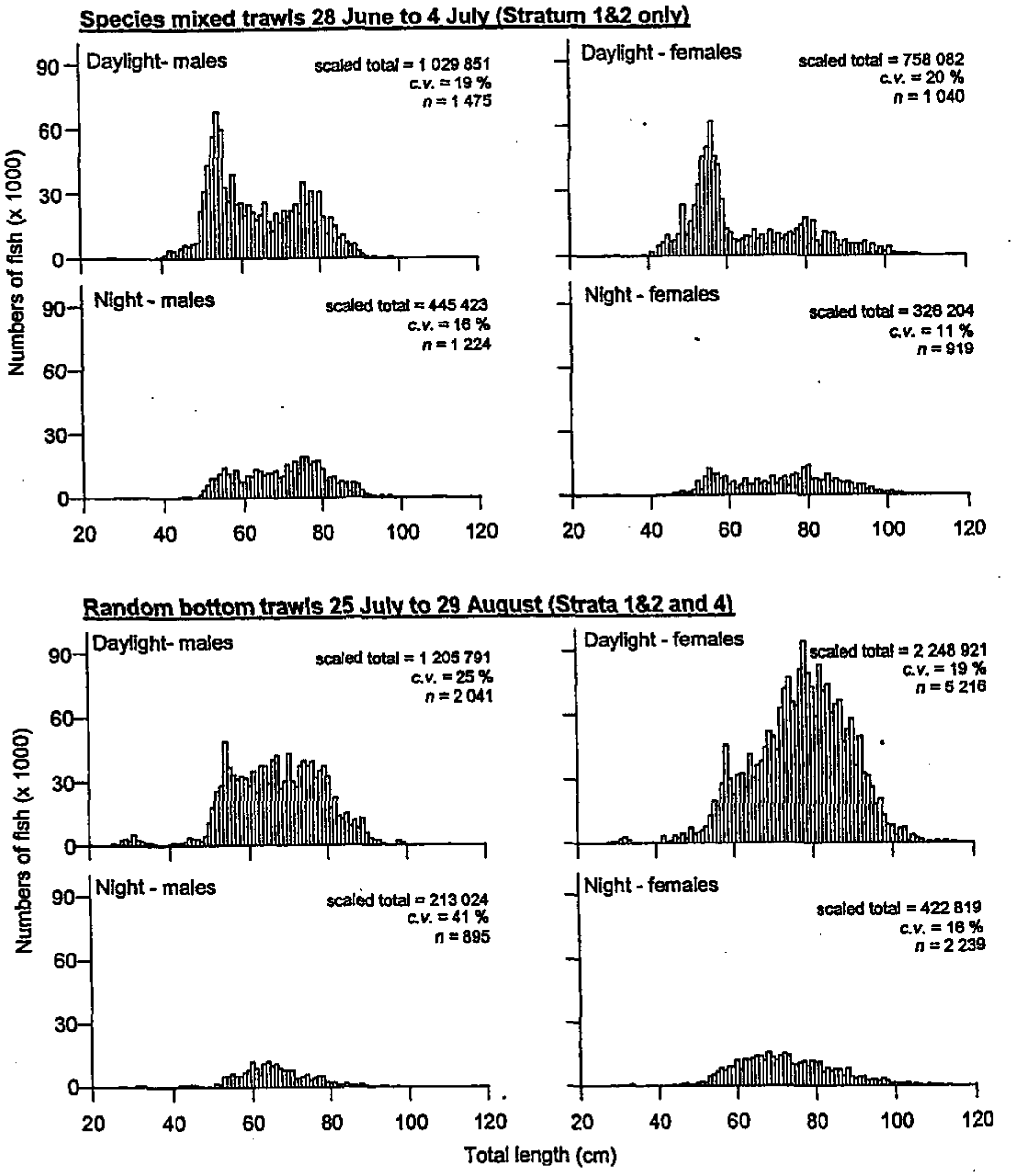


Figure 6: Scaled length frequencies for hoki from species mix trawls in Stratum 1&2 from 28 June to 4 July 2000 (upper four panels) and from random bottom trawls carried out in Strata 1&2 and 4 from 24 July to 31 August 2000 (lower panels).

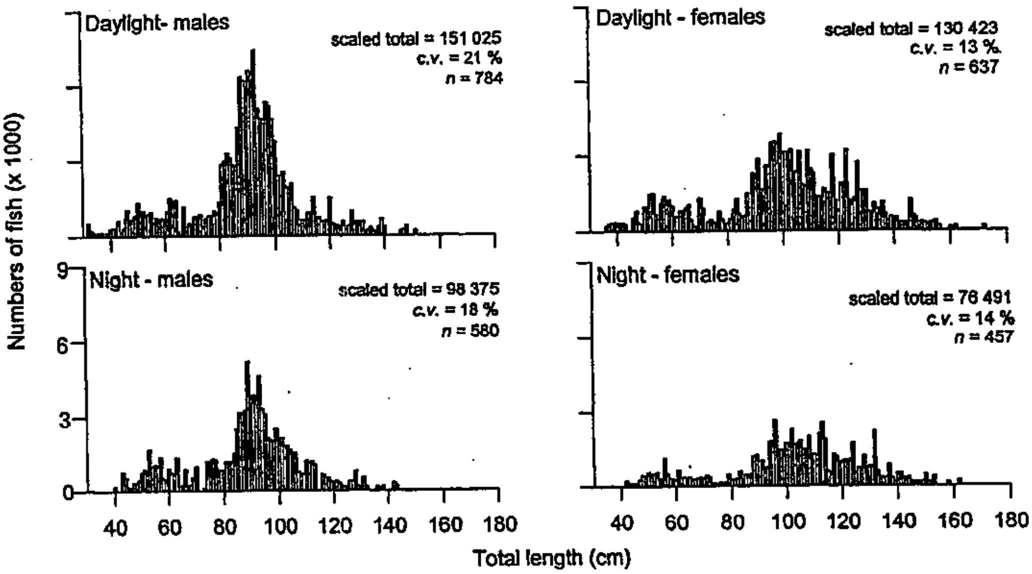


Figure 7: Scaled length frequencies for ling from random bottom trawls carried out in Strata 1&2 and 4 from 24 July to 31 August 2000.

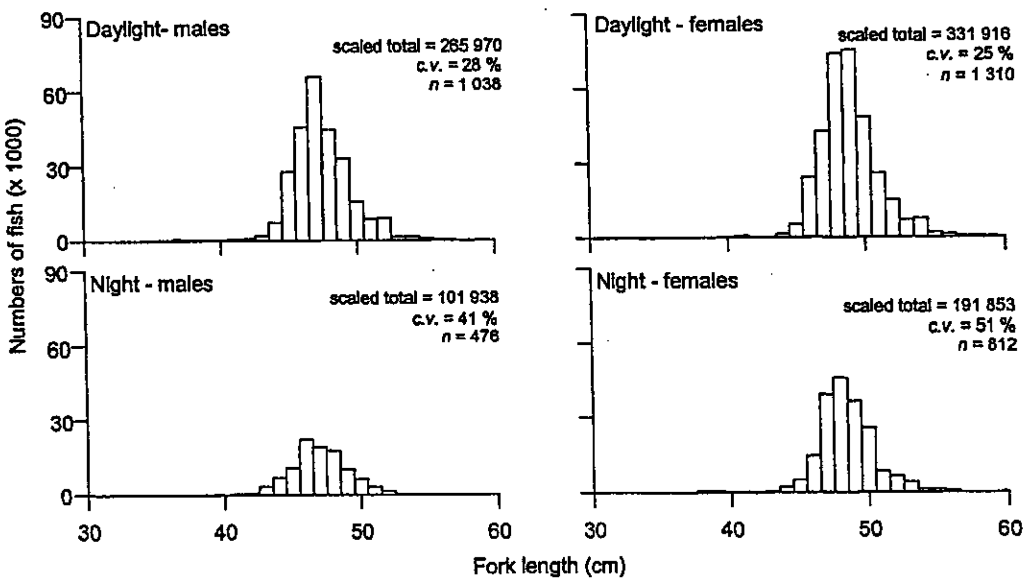


Figure 8: Scaled length frequencies for silver warehou from random bottom trawls carried out in Strata 1&2 and 4 from 24 July to 31 August 2000.

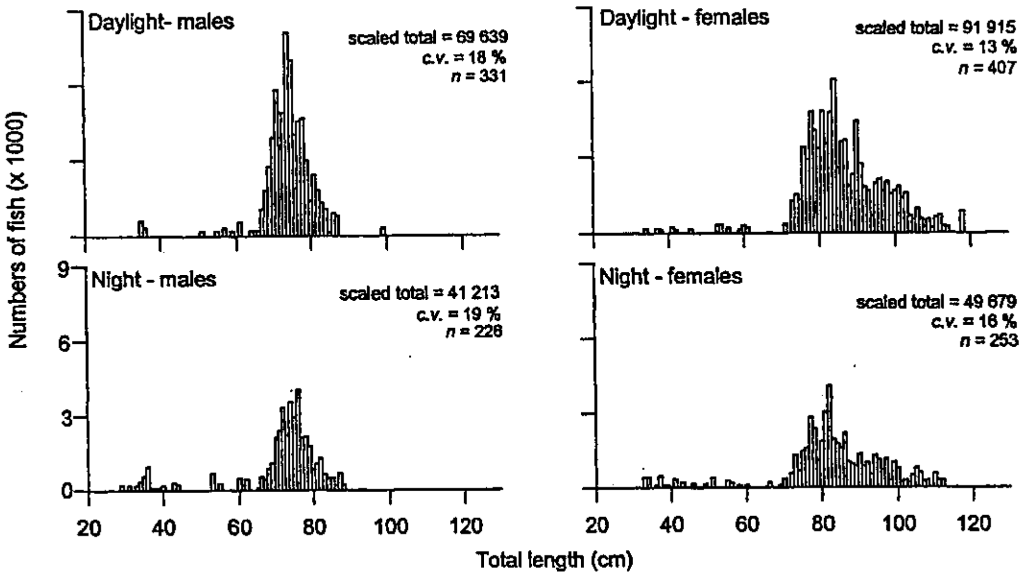


Figure 9: Scaled length frequencies for hake from random bottom trawls carried out in Strata 1&2 and 4 from 24 July to 31 August 2000.

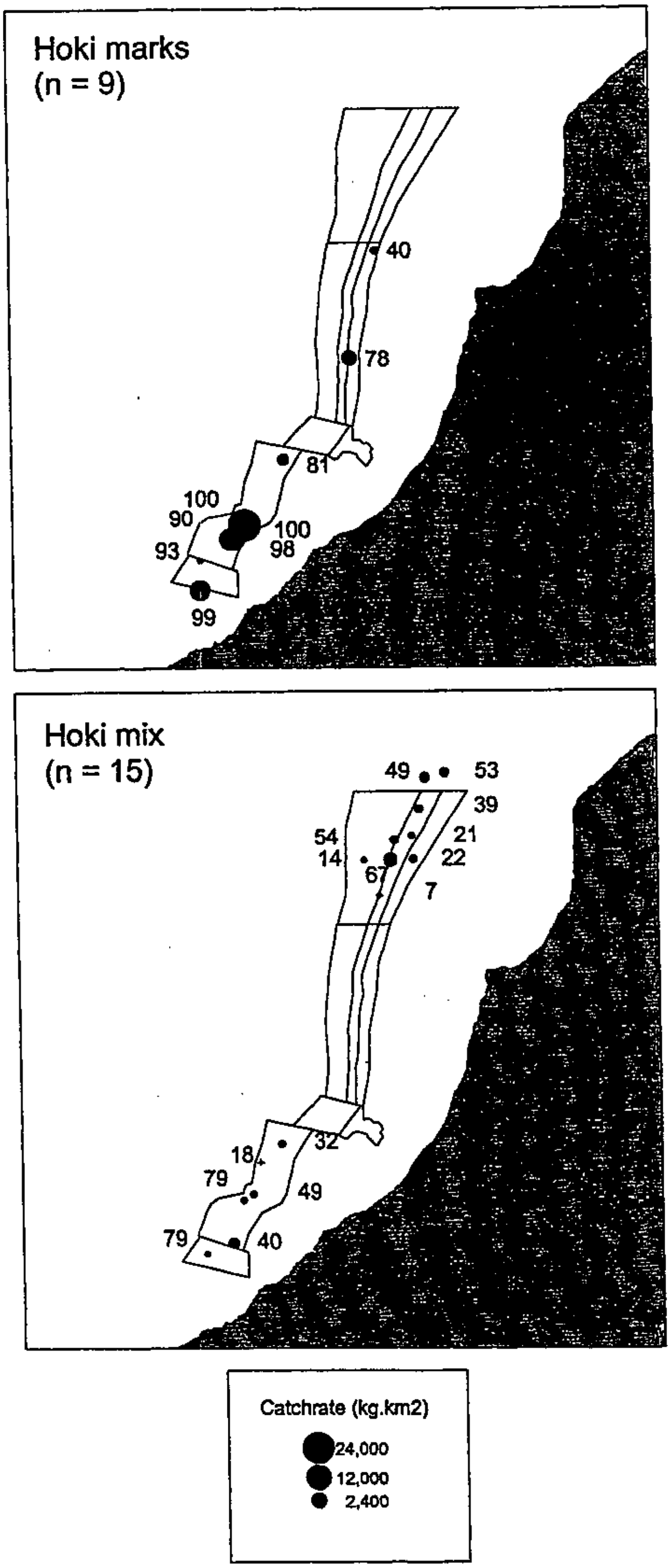


Figure 10: Catch rates of hoki in targeted trawls on hoki schools and hoki mix marks carried out during the 2000 WCSI survey. Symbol area is proportional to hoki catch rates, with numbers next to the symbols giving the percentage of hoki in the catch by weight.

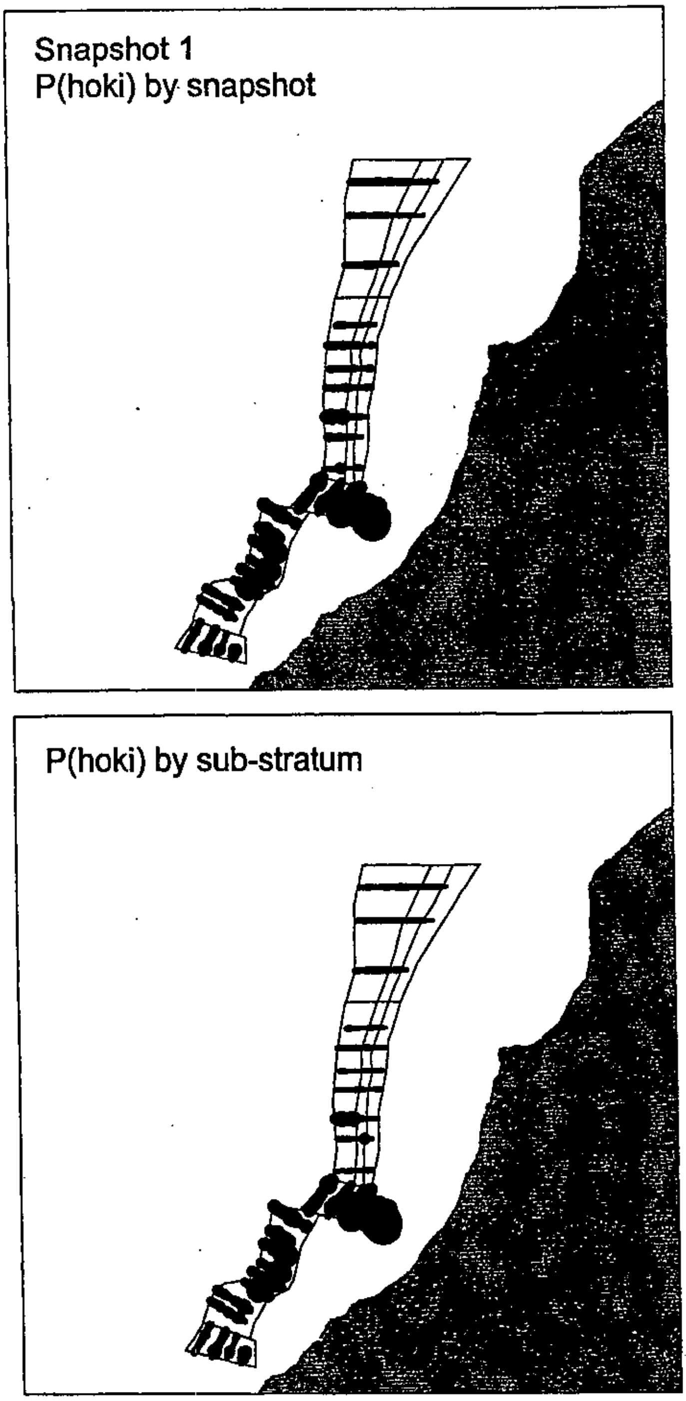


Figure 11: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshot 1. Symbol size is proportional to the log of the acoustic backscatter. Two different species mix correction were applied to acoustic backscatter from hoki mix marks in Strata 1&2 and 4. In the top panel P(hoki) was calculated by snapshot and stratum (see Table 9). In the lower panel P(hoki) was calculated by substratum for all snapshots combined (see Table 10). All backscatter from hoki mix in other strata, and hoki schools, was assumed to be 100% hoki.

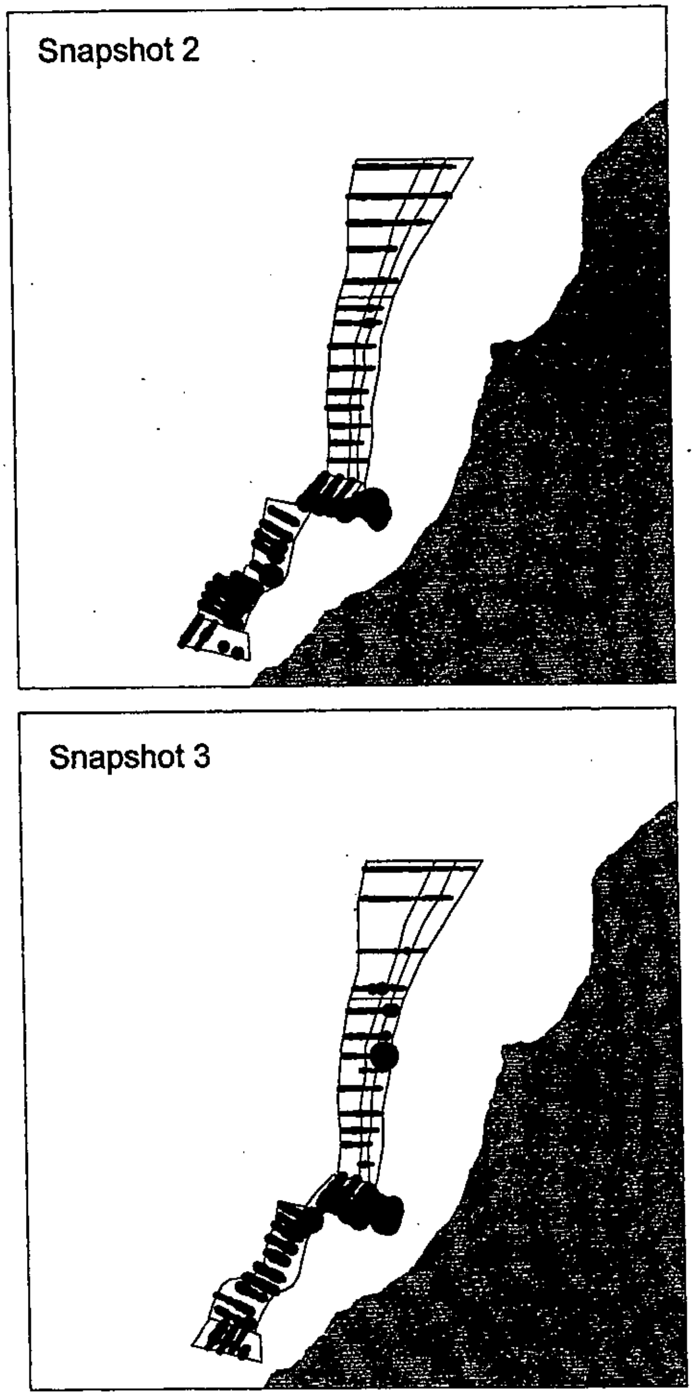


Figure 11 cont: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshots 2–3. P(hoki) in Strata 1&2 and 4 was calculated by snapshot and stratum (see Table 9). Symbol size is proportional to the log of the acoustic backscatter.

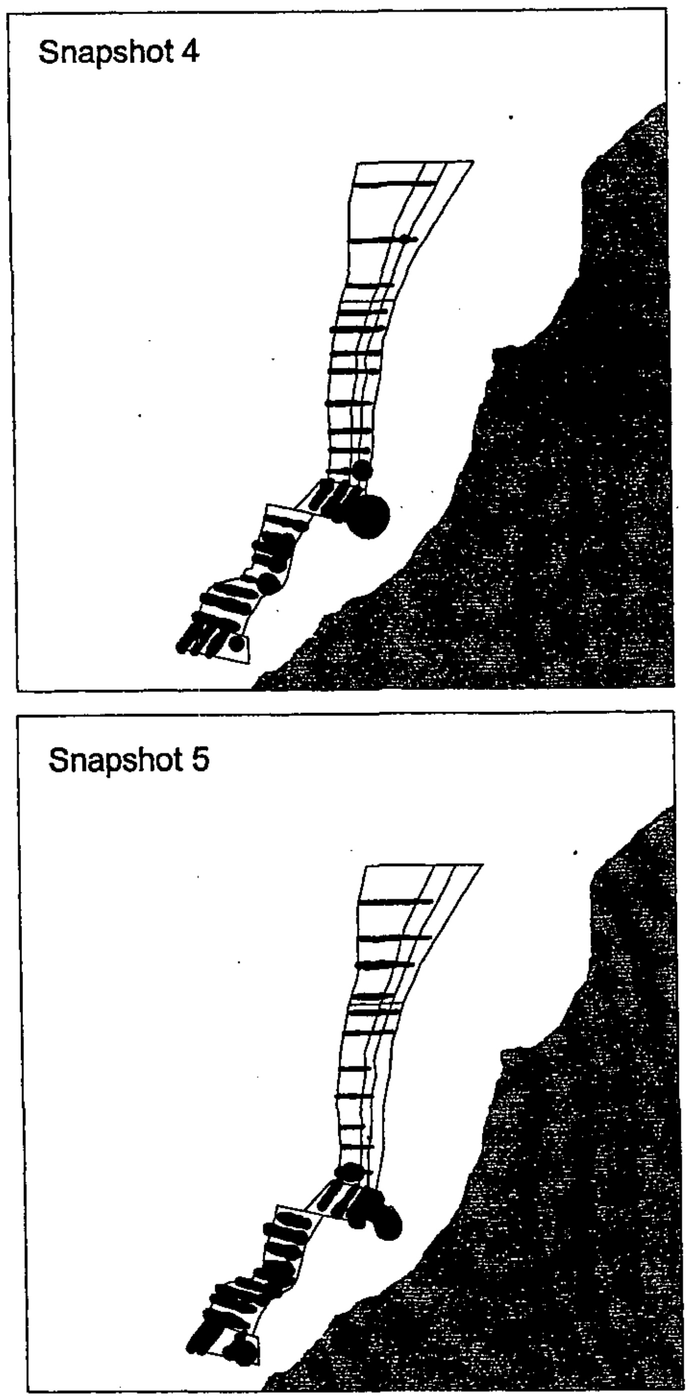


Figure 11 cont: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshots 4–5. P(hoki) in Strata 1&2 and 4 was calculated by snapshot and stratum (see Table 9). Symbol size is proportional to the log of the acoustic backscatter.

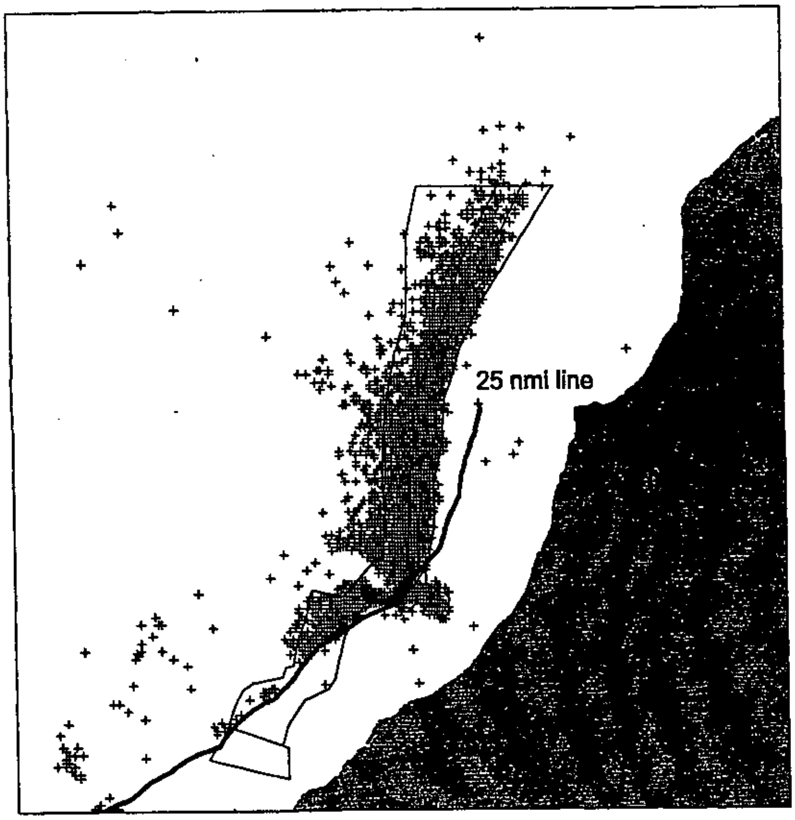


Figure 12: Start positions of all commercial tows that targeted and/or caught hoki reported on TCEPR from June–September 2000. Note that a single cross can represent many tows, so this plot may give a misleading impression of the density of effort. In 2000, 95% of the hoki catch was taken within the acoustic survey area.

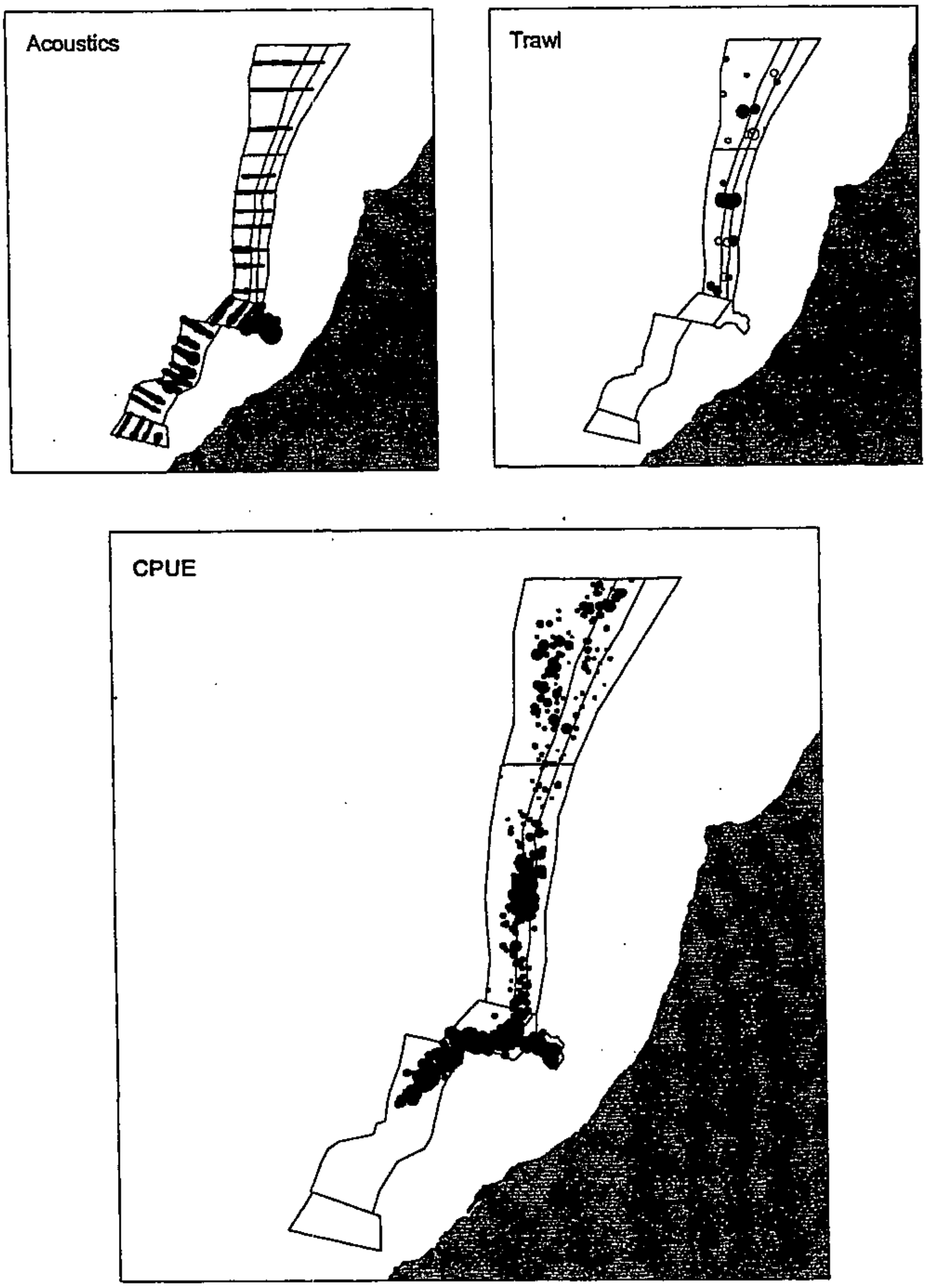


Figure 13: Comparison of CPUE from commercial tows during Snapshot 1 with acoustic density estimates and random trawl catch rates. In all panels symbol area is proportional to the density estimate. In top right panel, closed circles are day trawls and open circles are night trawls.

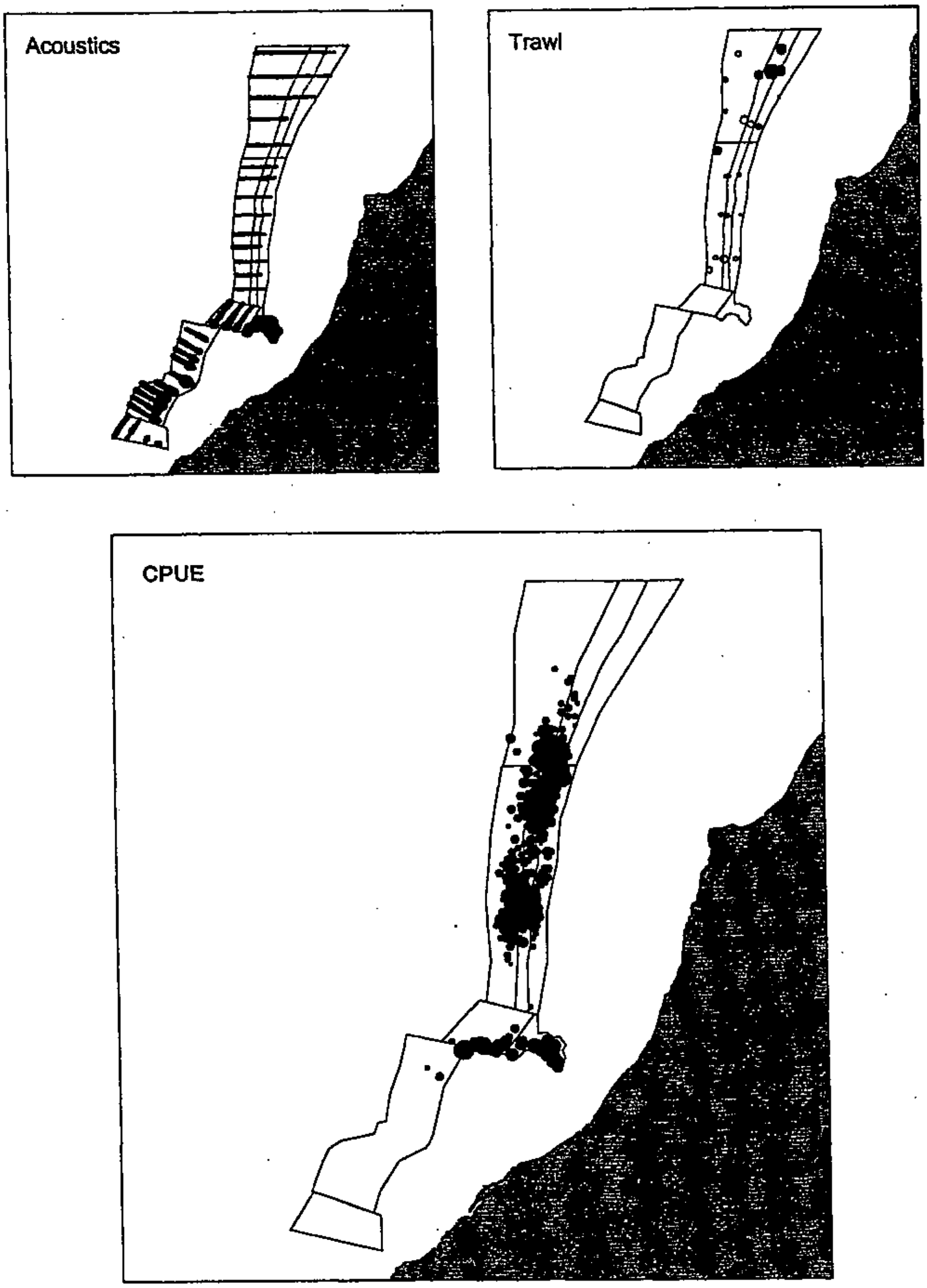


Figure 13 cont: Comparison of CPUE from commercial tows during Snapshot 2 with acoustic density estimates and random trawl catch rates. In all panels symbol area is proportional to the density estimate. In top right panel, closed circles are day trawls and open circles are night trawls.

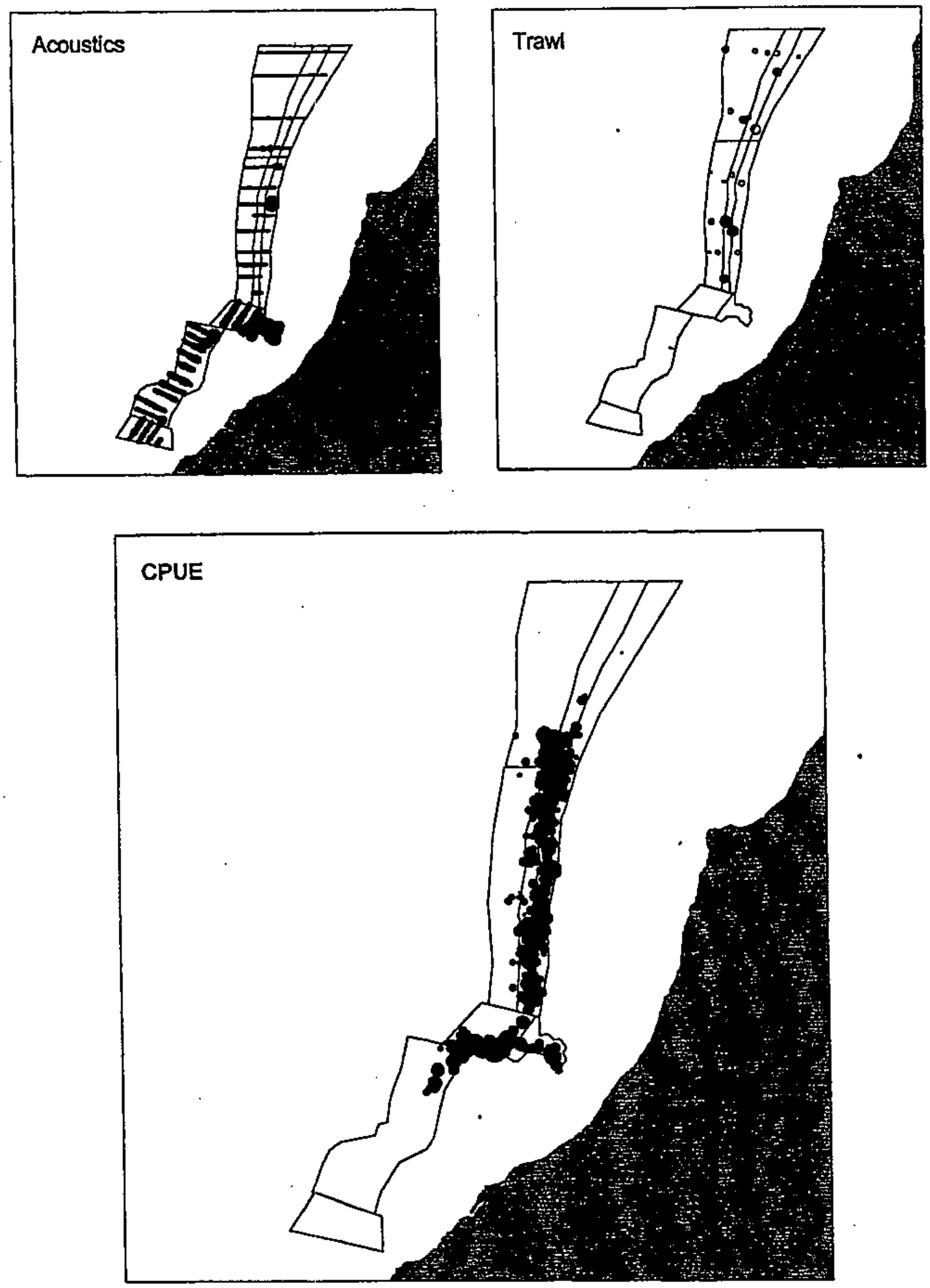


Figure 13 cont: Comparison of CPUE from commercial tows during Snapshot 3 with acoustic density estimates and random trawl catch rates. In all panels symbol area is proportional to the density estimate. In top right panel, closed circles are day trawls and open circles are night trawls.

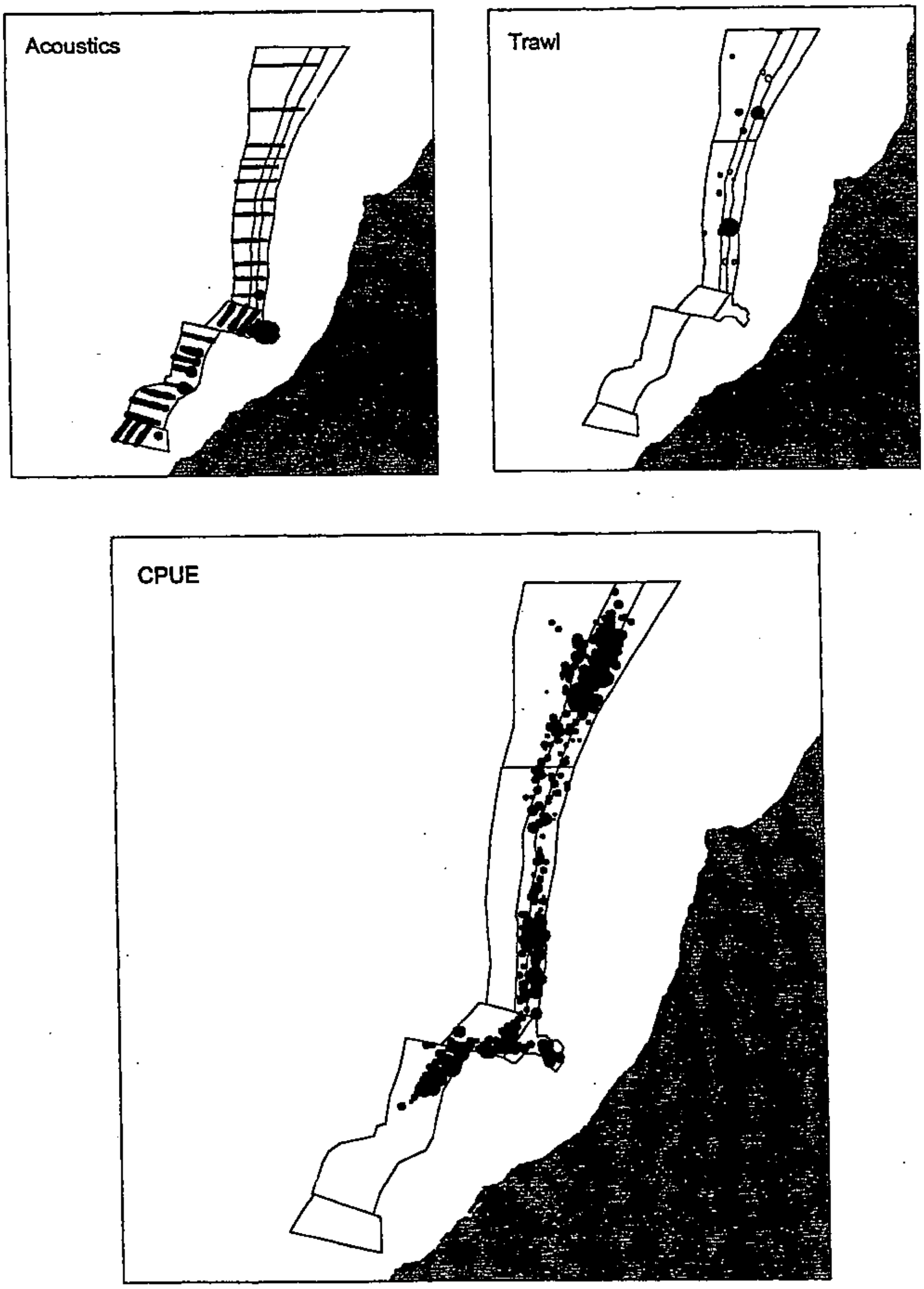


Figure 13 cont: Comparison of CPUE from commercial tows during Snapshot 4 with acoustic density estimates and random trawl catch rates. In all panels symbol area is proportional to the density estimate. In top right panel, closed circles are day trawls and open circles are night trawls.

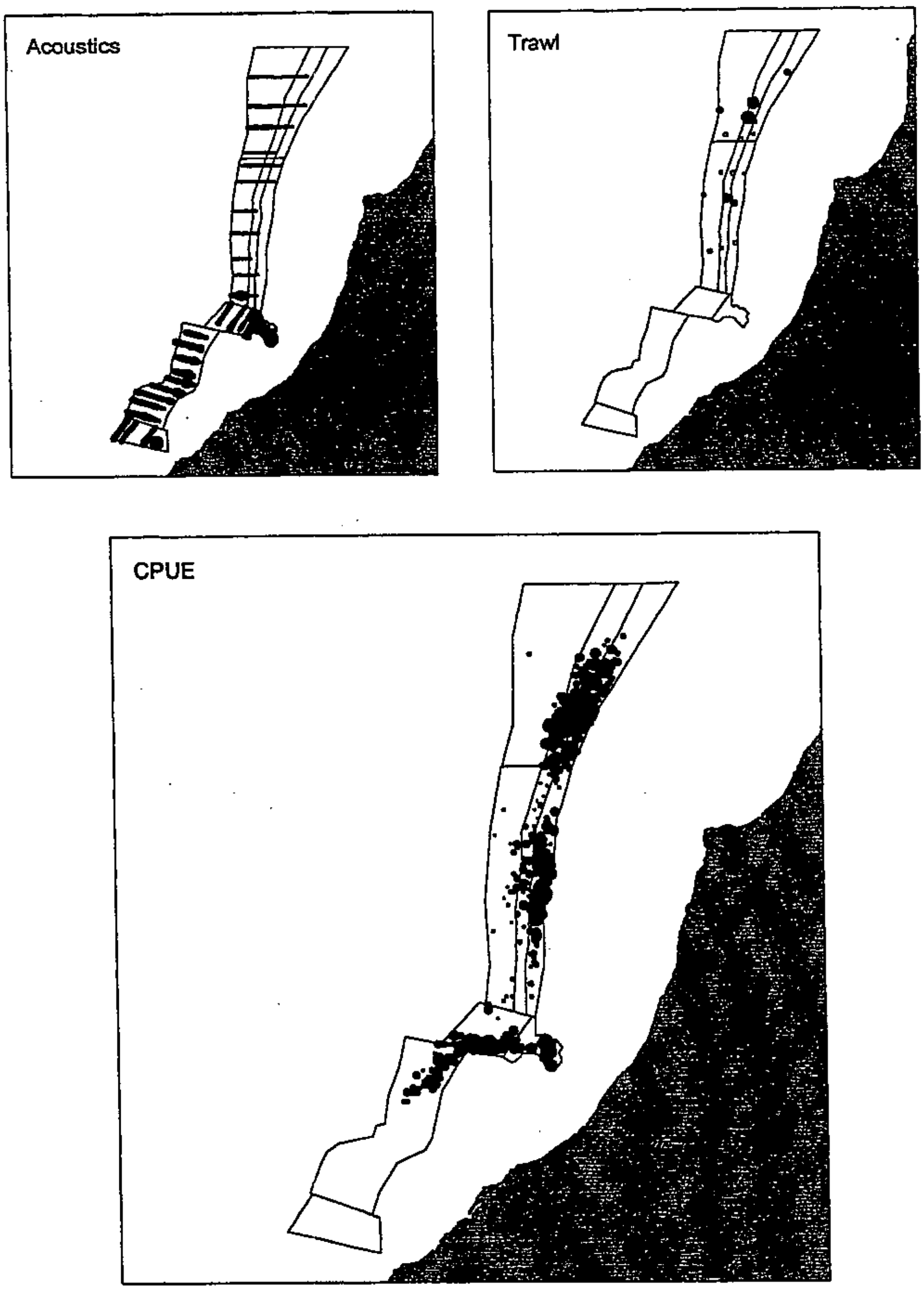


Figure 13 cont: Comparison of CPUE from commercial tows during Snapshot 5 with acoustic density estimates and random trawl catch rates. In all panels symbol area is proportional to the density estimate. In top right panel, closed circles are day trawls and open circles are night trawls.

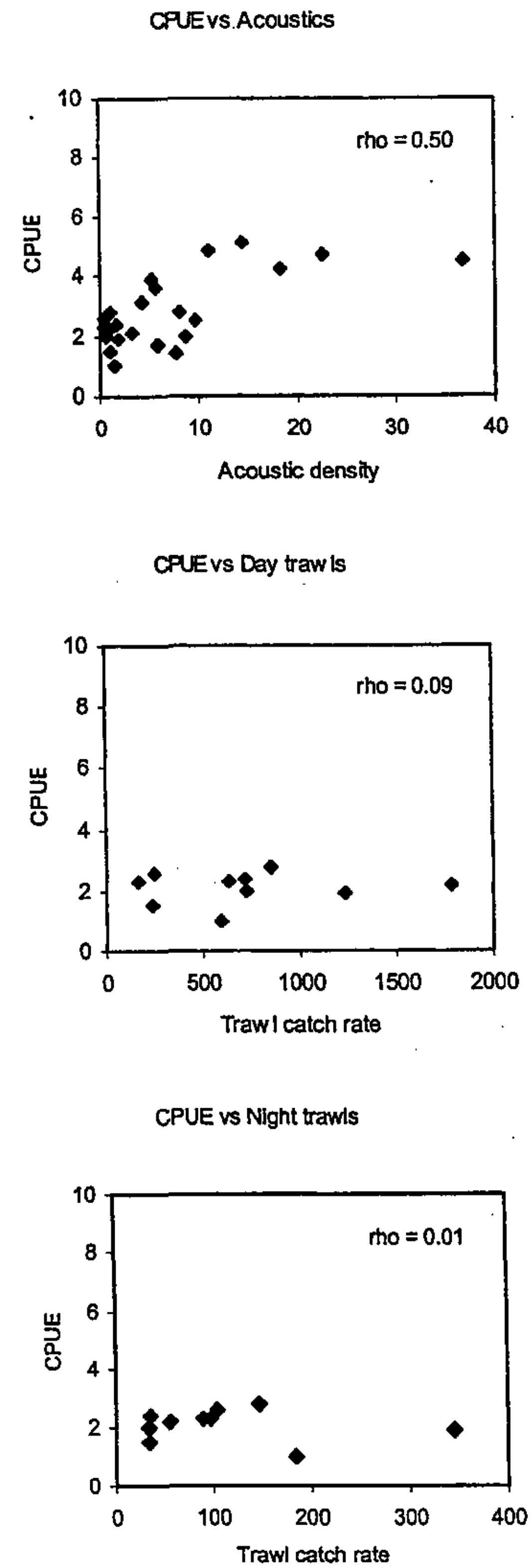


Figure 14: Correlation between commercial CPUE (t km^{-1}), acoustic density estimates (m^{2} km^{-2}) and catch rates in random trawls (kg km^{-2}) averaged by snapshot and stratum for the period 24 July to 31 August 2000. Rho values are Spearman's rank correlation coefficients.

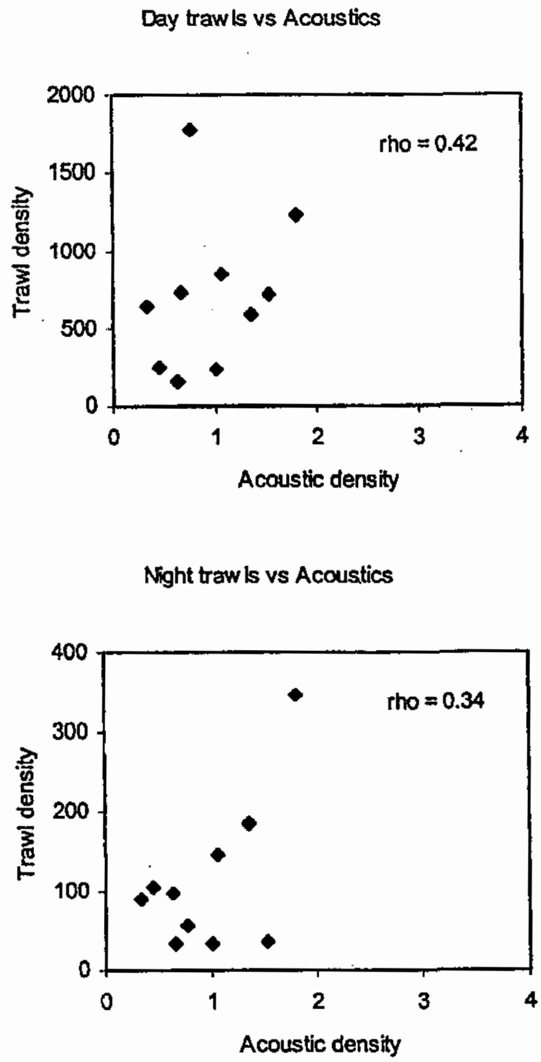


Figure 15: Correlation between catch rates in random trawls (kg km^{-2}) and acoustic density estimates (m^2 km^{-2}) averaged by snapshot and stratum for the period 24 July to 31 August 2000. Rho values are Spearman's rank correlation coefficients.

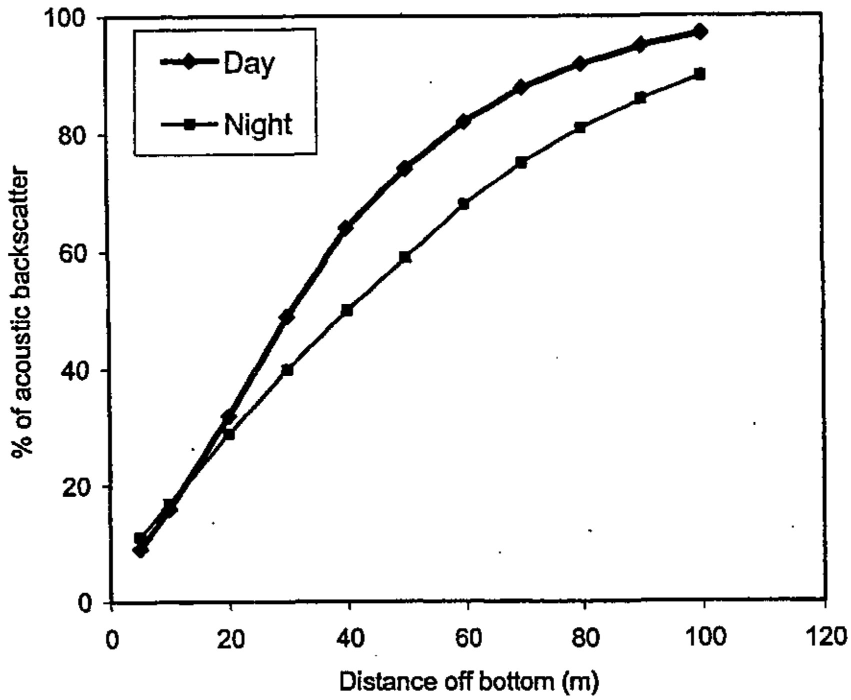


Figure 16: Vertical distribution of acoustic backscatter in mixed species layers in Strata 1&2 and 4 during the 2000 WCSI survey.

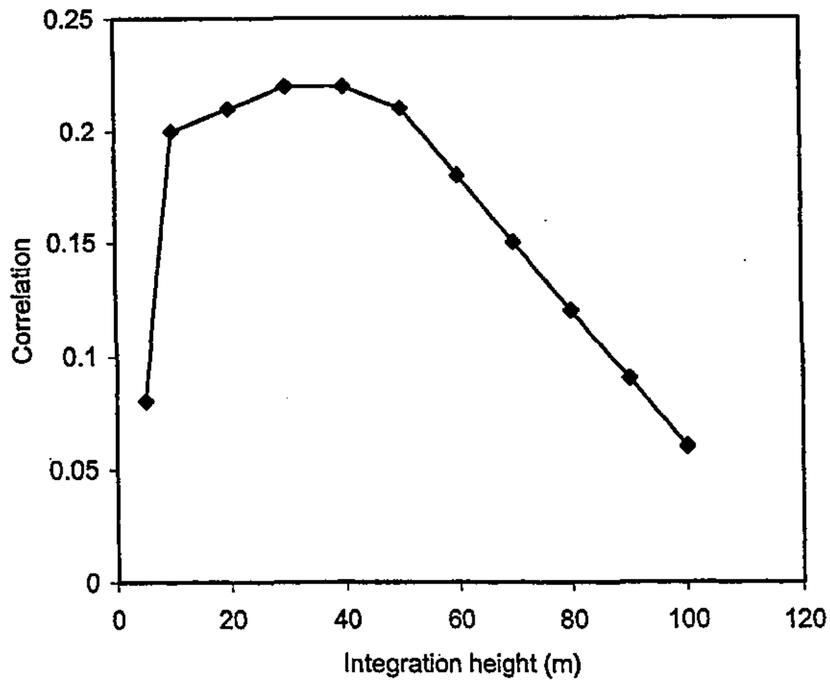


Figure 17: Spearman's rank correlation between predicted acoustic backscatter based on trawl catches of all species and observed backscatter in acoustic recordings made during the trawl. Observed backscatter was integrated at different heights above the bottom.