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Updated catch-per-unit-effort indices for hoki (*Macruronus novaezelandiae*) on the west coast South Island, Cook Strait, Chatham Rise, and sub-Antarctic for the years 1990 to 2001

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EXECUTIVE SUMMARY

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This report updates estimates of standardised CPUE indices for the west coast South Island and Cook Strait spawning hoki fisheries, and the Chatham Rise and sub-Antarctic non-spawning hoki fisheries up to the end of 2001. Indices were calculated using lognormal models of catch per tow for sub-groups of vessels. This report describes both the data and the methods of calculation of CPUE indices, and briefly compares the CPUE indices resulting from analysis of sub-groups of the available data.

For the west coast South Island spawning fishery, the indices derived from the fillet core vessels climb from 1990 to 1994, drop in 1995, and then show a trend of increase to 2000 (and a large degree of variation), before dropping in 2001. The indices for the dressed core vessels climb from 1990 to 1992, drop until 1995, then increase until 2000. The index for 2001 also shows a sharp decline. Indices for the surimi core vessels were calculated up to 1998 only, due to the lack of data in more recent years.

The indices for the Cook Strait spawning fishery suggest a stable, or slightly decreasing, trend in abundance since 1993. There is no strong indication of a decline in 2001. The indices for the Chatham Rise fishery suggested a continuous decline in abundance since the early 1990s, while the indices for the sub-Antarctic suggest a steeper decline.

In general, the models developed were unable to capture the extremes in catch rate observed in the fishery. The predictive models generally under estimated the observed catches at the upper extreme of the observed range of catches, while over estimating the catch from trawls at the lower range. In all cases model fits were poor and suggested serious departure from model assumptions (i.e., normally distributed constant variance residual errors), indicating that the model structure may be inadequate to reliably determine the indices. There were considerable differences in some of the indices derived from different sets of catch effort data.

Acoustic and trawl data for the fisheries allow some comparison with the CPUE indices of abundance, if issues of timing and the relative selectivity are ignored. The acoustic indices for the west coast South Island and Cook Strait show little evidence of a relationship with the respective CPUE indices. The biomass indices derived from the trawl survey series for the Chatham Rise are strongly correlated with the CPUE indices for both the core vessels and fillet core vessels analysis; all series suggest a decline in abundance since the early 1990s. However, the decline in recent years is steeper for the trawl survey series than for the CPUE indices. The biomass indices derived from the trawl survey series for the sub-Antarctic are correlated, to a lesser extent, with the CPUE indices for fillet core vessels analysis; both series suggest a decline in abundance since the early 1990s. However, the decline in recent years is steeper for the trawl survey series than for the CPUE fillet core vessels indices.

1. INTRODUCTION

Hoki *(Macruronus novaezelandiae)* is the most abundant commercial fish species in New Zealand waters and has been New Zealand's largest fishery for many years. In recent years, catches have been in the region of 200 000–250 000 t per year (Annala et al. 2001). Although managed as a single stock, hoki have been assessed as two stocks — western and eastern (Annala et al. 2001), though the stock structure of hoki is still not fully understood (Ballara et al. 2000). The current hypothesis of stock structure suggests that there are two main spawning grounds, west coast South Island and Cook Strait, primarily supported by mature fish from the sub-Antarctic (western stock) and Chatham Rise (eastern stock) respectively (Livingston 1990, Livingston et al. 1992), The bulk of the juvenile biomass is found on the Chatham Rise, where juveniles from both spawning stocks mix and subsequently recruit, as they approach sexual maturity, to their respective stocks (Livingston & Schofield 1997). Large spawning fisheries for hoki occur on the west coast of the South Island and in Cook Strait during the winter months. Lesser, non-spawning fisheries occur for the remainder of the year both on the Chatham Rise and in the sub-Antarctic. Only a small proportion of the total catch is taken outside these regions.

This report presents standardised CPUE indices for the west coast South Island and Cook Strait spawning hoki fisheries up to the end of the 2001 calendar year, and the Chatham Rise and sub-Antarctic non-spawning fisheries up to the end of the 2000–01 fishing year. Estimates of the CPUE indices are calculated using lognormal generalised linear models, described by Vignaux (1994), using methods described by Gavaris (1980).

Standardised CPUE indices of abundance have previously been calculated for the hoki fishery based on spawning aggregations of hoki off the west coast South Island and in Cook Strait (Vignaux 1993, 1994, Ballara et al. 1997, 1998a, 1998b, 2000, Dunn 2001, Langley et al. 2001), and, more recently, for non-spawning season hoki in the Chatham Rise and sub-Antarctic fisheries (Dunn & Harley 1999, Langley et al. 2001). Langley et al. (2001) recalculated CPUE indices for hoki in each of the four fisheries up to the end of 1999 using an improved methodology, where they estimated the CPUE indices from sub-groups of the data (i.e., "core" vessels). The estimates of Langley et al. (2001) were updated, for the west coast South Island fishery only, by Dunn (2001) up to the end of 2000. This report employs similar methods to Langley et al. (2001), but excludes Fishery Statistics Unit data from 1986–87 to 1988–89 and includes all TCEPR data up to the end of 2001. Updated indices are presented for the west coast South Island, Cook Strait, Chatham Rise, and sub-Antarctic fisheries. The areal boundaries of the four fisheries assumed for this analysis are shown in Figure 1.

This report fulfils Objective 1 of Ministry of Fisheries Project HOK2001/06, "To update the standardised CPUE analysis for hoki, by inclusion of data up to the end of the 2000–01 fishing year".

2. METHODS

2.1 Data selection and definition of the fisheries

The analyses of catch effort data use the individual tow records recorded in the Ministry of Fisheries Trawl Catch Effort Processing Return (TCEPR) database. An extract of all tows (369 547) that recorded hoki as the target species or that caught hoki within the New Zealand EEZ between 1 October 1989 and 31 December 2001 (although records were incomplete for November and December 2001) was provided by the Ministry of Fisheries Information Management Group. Vessel registration data, recorded for all vessels present within the extracted TCEPR forms were obtained, and matched with individual TCEPR tow records for each year using the Ministry of Fisheries anonymous vessel key number.

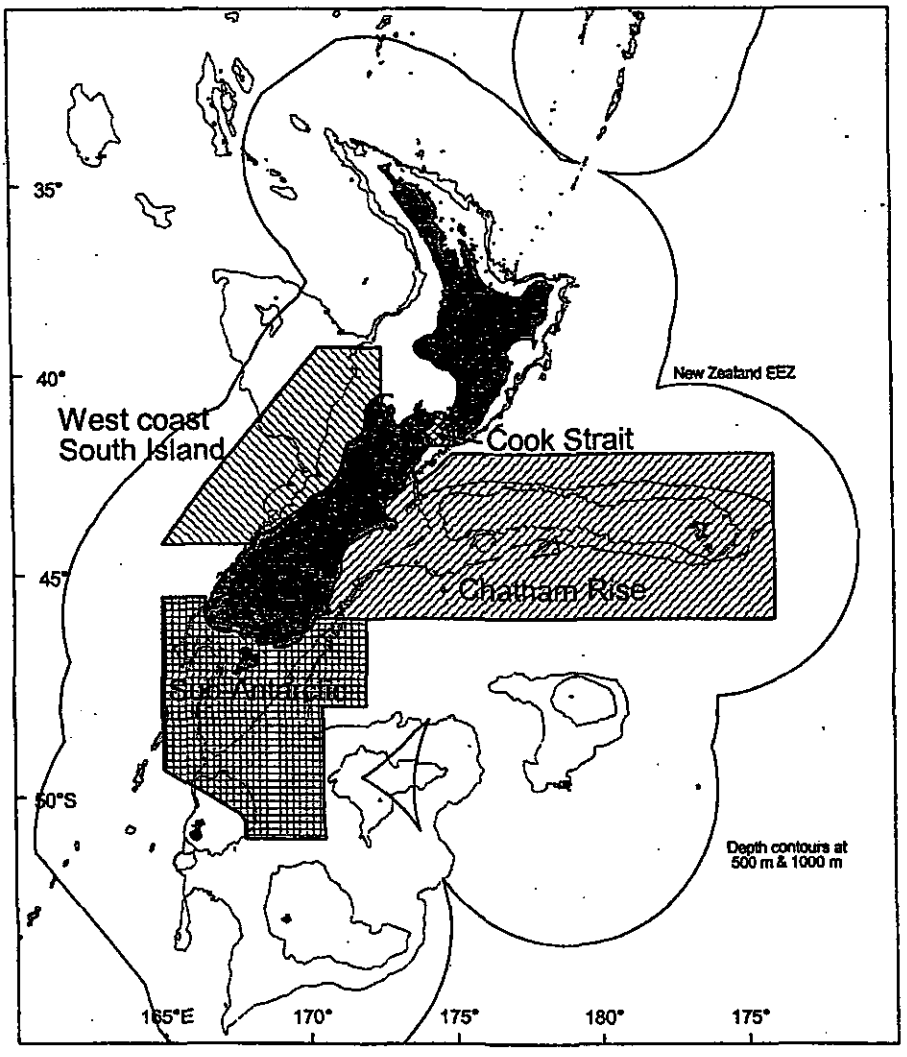

Figure 1: Areal boundaries of the west coast South Island, Cook Strait, Chatham Rise, and the sub-Antarctic hoki fisheries within the New Zealand EEZ.

Individual tow records were assigned to the four main hoki fisheries based on the location and month of each tow. Records were retained or excluded from further analysis based on the following criteria.

- The latitude and longitude of the start of each tow were inside the area defined as being either the west coast South Island, Cook Strait, Chatham Rise, or sub-Antarctic.
- The tow was conducted during the 1990 to 2001 calendar years inclusive, for west coast South Island and Cook Strait, or 1989–90 to 2000–01 fishing years for the Chatham Rise, or 1990–91 to 2000–01 fishing years for the sub-Antarctic.
- The tow occurred during June to October for the west coast South Island and Cook Strait (and defined as the spawning season), and from October to June inclusive for the Chatham Rise and sub-Antarctic (and defined as the non-spawning season).

The numbers of tows extracted for each fishing year are shown in Table 1. The definitions for the areal boundaries used in the analyses were based on those derived by Langley et al. (2001). However, the areal boundary for the Cook Strait region was modified to exclude the northeast coast of the South Island. This analysis excludes, as did the analysis of Langley et al. (2001), hoki catch data south of about 51° S from the sub-Antarctic fishery.

The TCEPR data contain a total of about 370 000 tows that either targeted hoki or recorded a hoki catch between 1 October 1989 and 31 December 2001, with between 160 000 t and 250 000 t of hoki caught annually. The largest proportion of the catch is from the west coast South Island during the spawning season (49%), with 14% during the spawning season in Cook Strait (and another 1% during the non-spawning season). The second largest fishery is the Chatham Rise (22%) with over 90% of this catch recorded during the non-spawning season. The sub-Antarctic fishery accounts for about 11% of the total catch (80% of this during the non-spawning season). About 3% of the total hoki caught and recorded on TCEPR forms is outside the four fisheries, mostly on the east coast of the North Island during the summer. About 0.5% of all catch cannot be allocated to an area because of errors in the recorded tow latitude or longitude.

Table 1: Number of tow records extracted by fishing year and area for 1989–90 to 2000–01.

Fishing year	West coast South Island	Cook Strait	Chatham Rise	Sub-Antarctic	Other	Total
1989–90	8 063	1 075	3 306	3 492	2 221	18 157
1990–91	8 190	2 083	5 640	5 121	3 894	24 928
1991–92	6 202	1 660	8 500	6 874	4 042	27 278
1992–93	7 038	1 694	8 489	6 263	3 062	26 546
1993–94	8 531	2 157	6 030	3 248	4 750	24 716
1994–95	7 998	2 981	9 185	3 138	3 886	27 188
1995–96	6 767	6 243	10 649	3 641	5 596	32 896
1996–97	8 174	6 266	12 124	4 962	6 615	38 141
1997–98	8 044	3 839	15 869	4 968	6 052	38 772
1998–99	7 154	3 466	14 684	4 228	6 014	35 546
1999–00	7 356	3 037	12 928	5 670	7 174	36 165
2000–01	8 355	2 596	12 211	5 946	6 664	35 772
Total	91 872	37 097	119 615	57 551	59 970	366 105

In addition to the tow data extracted from the TCEPR database, and vessel details, Daily Processing Summary (DPS) data were extracted from the TCEPR database for each day of fishing by vessels targeting and/or catching hoki for 1989–90 to 2000–01. The number of records extracted is shown in Table 2. These data include the total green weight of hoki processed to each gazetted process state code. For each year, the total catch of hoki processed into each of the main product types was determined for each vessel from the DPS section of the TCEPR. Four main product types were identified: surimi, dressed (head-and-gut), fillet, and all other (predominately unprocessed or "green"). Individual tow records for that vessel in that year were assigned to the main processing category determined for each vessel in each year.

The remainder of this report uses the convention that the label used to denote the year of each record is defined as the most recent calendar year within each fishing year for the non-spawning fisheries (Chatham Rise and sub-Antarctic), or the calendar year for the spawning fisheries (west coast South Island and Cook Strait). For example, the fishing year 1 October 2000 to 30 September 2001 is denoted by 2001 for the Chatham Rise and sub-Antarctic, and the calendar year 1 January 2001 to 31 December 2001 is denoted by 2001 for the west coast South Island and Cook Strait.

Table 2: Number of DPS records[1] extracted by fishing year and area for 1989–90 to 2000–01.

Fishing year	West coast South Island	Cook Strait	Chatham Rise	Sub-Antarctic	Other	Total
1989–90	5 617	75	1 523	1 656	1 084	9 955
1990–91	6 168	90	2 805	2 664	1 705	13 432
1991–92	4 966	26	3 887	3 647	1 595	14 121
1992–93	4 011	34	3 740	3 137	1 109	12 031
1993–94	6 569	48	3 176	2 097	1 619	13 509
1994–95	6 904	83	5 167	2 265	1 146	15 565
1995–96	6 105	291	6 097	2 430	1 910	16 833
1996–97	8 030	608	7 324	3 836	1 983	21 781
1997–98	8 660	761	11 598	4 376	2 857	28 252
1998–99	8 405	1 096	13 940	4 265	3 198	30 904
1999–00	8 987	495	12 476	6 131	5 122	33 211
2000–01	9 209	485	12 389	6 778	6 553	35 414
Total	83 631	4 092	84 122	43 282	29 881	245 008

1. Note that an individual vessel can record multiple records for each day, and that the processing categories recorded by a vessel on each day need not be unique.

2.2 Description of the variables

The information extracted for each tow included time, location, catch details, and fishing gear parameters. Additional variables were calculated from the variables provided in the TCEPR data. Most of the variables are self-explanatory; variables, variable types, and descriptions are summarised in Table 3.

For the west coast South Island and Cook Strait spawning fisheries, *season* was calculated as the difference in days between the mid-season peak date in each year (see Table 3) and the date of the tow (this variable was described by Langley et al. (2001) as *day of year*). Season was defined as the number of days since the beginning of the non-spawning season for the Chatham Rise and sub-Antarctic non-spawning fisheries. The variables *sunrise* and *sunset* were included as a possible explanatory term to account for diurnal changes in catchability over the fishing season at various longitudes and latitudes. The time of tow relative to the time of sunrise and sunset was determined for each record in the data set based on the date and start location of each tow. Estimates of the sunrise and sunset time at the tow location and tow date were made using an algorithm from Meeus (1998).

Similarly, variables *moon cycle* and *moon intensity* were included as possible explanatory terms to account for changes in catchability over the fishing season at various longitudes and latitudes with changes in the lunar cycle. The relative phase (0–1) of the moon (*moon cycle*) was determined for each record in the data set based on the start date and start location of each tow, using an algorithm from Meeus (1998). This was subsequently transformed into an estimate of relative moon light intensity (*moon intensity*), using a simple sine transformation.

Tow *duration* was calculated as the difference (in hours) between the recorded *start time* and *finish time*. Tow *distance* was calculated as the product of *duration* and *speed* of the tow.

Langley et al. (2001) defined *sub-areas* based on subjective assessment of the geographical distribution of fishing effort, the general bathymetry of each area, and areal trends in catch rate. They defined three *sub-areas* for the west coast South Island; Hokitika Canyon (south of 42° 24'S), Central (between 42° 24'S and 41° 42'S), and North (north of 41° 42'S). This analysis complements these sub-areas with the four areas defined from the acoustic survey strata used for the west coast South Island (i.e., strata 1 & 2, 4, 5a and 5b, 6 and 7, see Figure 2).

Table 3: Types and descriptions of the variables used to model CPUE (calculated variables are distinguished from provided data by *).

Variable	Type	Description
*CPUE**	Continuous	CPUE measured in kilograms of hoki caught per tow
Longitude	Continuous	Longitude in decimal degrees at the start of the tow
Latitude	Continuous	Latitude in decimal degrees at the start of the tow
*Year**	Categorical	Calendar year
Season	Continuous	Number of days from the mid season peak (spawning fisheries) or the since the start of the season (non-spawning fisheries)
Start time	Continuous	Time of day at the start of the tow
Finish time	Continuous	Time of day at the end of the tow
*Duration**	Continuous	Duration of the tow in hours
*Sub-area**	Categorical	Sub-area (see later for definitions)
Bottom depth	Continuous	Depth in metres of the seafloor at the start of the tow
Headline height	Continuous	Headline height in metres of the net at the start of the tow
*Net height**	Continuous	Height in metres of the net above the sea floor at the start of the tow
Net depth	Continuous	Depth in metres of the groundrope at the start of the tow
*Sunrise**	Continuous	The start time of the tow relative to the time of the sunrise
*Sunset**	Continuous	The start time of the tow relative to the time of the sunset
*Moon intensity**	Continuous	Sin transformation of *moon cycle*, with range 0–1
*Moon cycle**	Continuous	Cycle of the moon (new to old), with range 0–1
Gear type	Categorical	Type of trawl, either midwater or bottom trawl
Gear width	Continuous	Width of the net doors at time of tow
Speed	Continuous	Recorded speed (in knots) of the vessel at the start of the tow
Vessel	Categorical	Unique vessel code
*Processing type**	Categorical	Computed processing type of each vessel in each year
*Experience**	Continuous	Number of years that each vessel had participated in the fishery, since 1983 (west coast South Island), or 1990 (all other fisheries)

The *sub-areas* for the Chatham Rise and sub-Antarctic are based on those defined by Langley et al. (2001) and those subsequently derived by Phillips (2002) in the analysis of catch effort data from the hake fishery. As for the west coast South Island, these areas were based on subjective assessment of the geographical distribution of fishing effort, catch rates, and the general bathymetry of the each area. No *sub-areas* were defined for Cook Strait. The regions and *sub-areas* (where defined) in the four fisheries, together with the locations of hoki catch over the periods defined for each fishery, are shown in Figure 2.

Gear type records the nature of the gear used, either midwater or bottom trawl gear. No data are available on the use of twin- or triple-rigged trawl nets, though anecdotal evidence suggests that only few vessels were using such gear before 2000. Some anecdotal evidence exists for increased use of such gear in more recent years, but such tows cannot be identified from the recorded catch effort data.

Daily Processing Summary data recorded with TCEPR data were also extracted for each day of fishing by vessels catching hoki for 1990 to 2000, as described earlier. Hence, the primary *processing type* of each vessel, for each fishing year, was determined. The actual licensed processing type of each vessel, as recorded by the Ministry of Fisheries, was ignored.

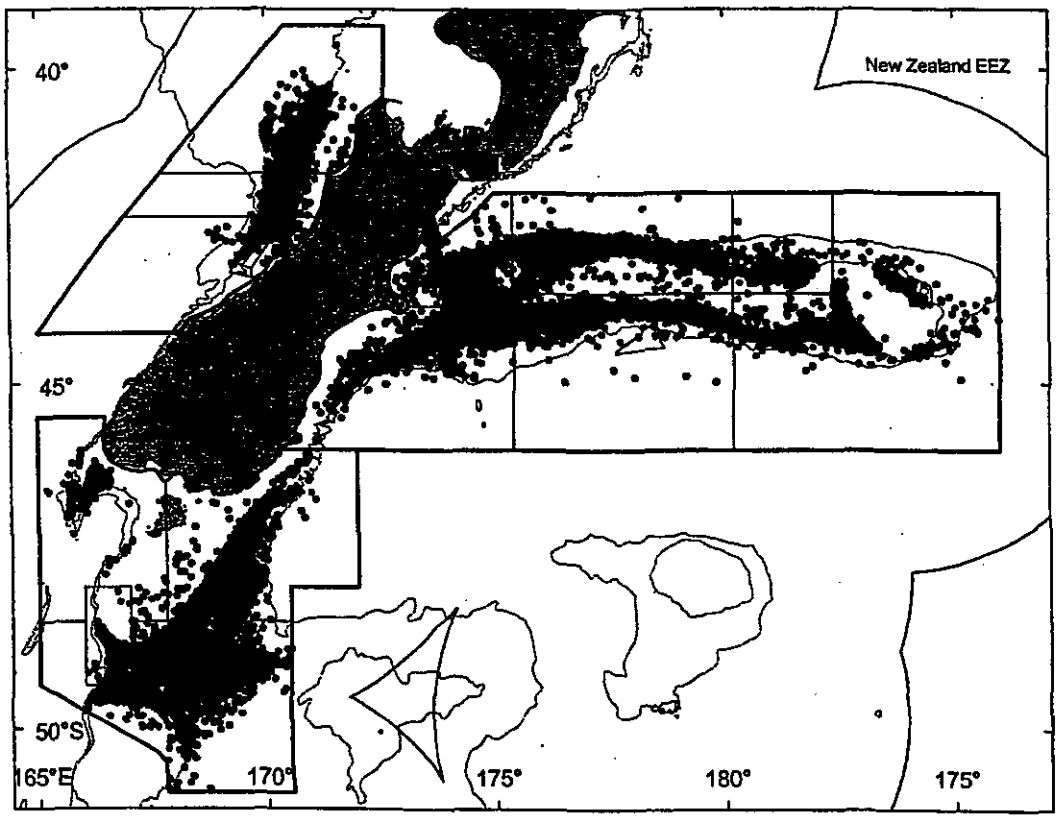

Figure 2: The four fisheries, sub-areas, acoustic strata boundaries on the west coast South Island, and the position of non-zero catches within each fishery for years 1990–2001 (midwater tows for the west coast South Island and Cook Strait, and bottom tows for the Chatham Rise) or 1991–2001 (bottom tows, sub-Antarctic).

2.3 Error checking and data cleaning

In general, catch effort data often contain a large amount of error, most commonly in the form of invalid codes, and missing or implausible values. Data were checked for error, using simple checking and imputation algorithms, before further analysis. This process of checking, validating, and cleaning these data is described below.

Range checks were defined for each attribute to identify outliers in the data. The error checks for each of the four fisheries are described below in Table 4. The range checks were determined from an exploratory analysis of the data from each fishery by Langley et al. (2001) and Dunn (2001) and were reported as being generally consistent with error checking procedures used in earlier analyses of hoki catch effort data (Vignaux 1993, 1994, Ballara et al. 1997, 1998a, 1998b, Dunn & Harley 1999), although less intensive.

Vessel details were checked separately for all vessels recorded in the individual tow records for each year. The vessel data were checked for consistency, and where there was more than one set of values for an attribute for an individual vessel, the data were examined and appropriately corrected. Records with no vessel key data were excluded from further analysis.

Tow locations were investigated and, where possible, errors were corrected using median imputation. All tows for each vessel on each fishing day where the start/finish latitude or start/finish longitude was more than one degree different from the median start/finish latitude or start/finish longitude for that vessel on that day were replaced with the median start/finish latitude or start/finish longitude.

Table 4: Error range checks used for the west coast South Island, Cook Strait, Chatham Rise and sub-Antarctic.

Fishery	Error description
West coast South Island	*Distance* < 0 or > 100 kilometres *Duration* < 0 or > 12 hours *Speed* < 2.5 or > 6.5 knots *Bottom depth* < 250 m or > 900 m *Net depth* < 250 m or > 900 m *Gear type* was midwater tow and *headline height* < 10 m or > 100 m *Gear type* was bottom tow and *headline height* > 10 m *Gear type* was midwater tow and *gear width* < 30 m or > 160 m *Gear type* was bottom tow and *gear width* < 10 m or > 70 m *Gear type* was bottom tow and the difference between *net* and *bottom depth* > 50 m Hoki catch > 200 t
Cook Strait	*Distance* < 0 or > 100 kilometres *Duration* < 0 or > 5 hours *Speed* < 2.5 or > 6.5 knots *Bottom depth* < 100 m or > 900 m *Net depth* < 100 m or > 900 m *Gear type* was midwater tow and *headline height* < 10 m or > 100 m *Gear type* was bottom tow and *headline height* > 10 m *Gear type* was midwater tow and *gear width* < 30 m or > 160 m *Gear type* was bottom tow and *gear width* < 10 m or > 70 m *Gear type* was bottom tow and the difference between *net* and *bottom depth* > 50 m Hoki catch > 80 t
Chatham Rise	*Distance* < 0 or > 100 kilometres *Duration* < 0 or > 12 hours *Speed* < 2.5 or > 6.5 knots *Bottom depth* < 200 m or > 1000 m *Net depth* < 200 m or > 1000 m *Gear type* was midwater tow and *headline height* < 10 m or > 100 m *Gear type* was bottom tow and *headline height* > 10 m *Gear type* was midwater tow and *gear width* < 30 m or > 160 m *Gear type* was bottom tow and *gear width* < 10 m or > 70 m *Gear type* was bottom tow and the difference between *net* and *bottom depth* > 50 m Hoki catch > 80 t
Sub-Antarctic	*Distance* < 0 or > 100 kilometres *Duration* < 0 or > 12 hours *Speed* < 2.5 or > 6.5 knots *Bottom depth* < 200 m or > 1000 m *Net depth* < 200 m or > 1000 m *Gear type* was midwater tow and *headline height* < 10 m or > 100 m *Gear type* was bottom tow and *headline height* > 10 m *Gear type* was midwater tow and *gear width* < 30 m or > 160 m *Gear type* was bottom tow and *gear width* < 10 m or > 70 m *Gear type* was bottom tow and the difference between *net* and *bottom depth* > 50 m Hoki catch > 80 t

Tows where the *net depth* was recorded as being greater than the *bottom depth* had these two fields transposed. Tow *speed*, *net depth*, and *bottom depth* were investigated and corrected using median imputation, using an algorithm similar to that for the tow locations above. All tows for each vessel on each fishing day where the variable was missing or invalid were replaced with the median value of that variable for that subset of tows. Variables with values

missing or invalid after this process were set to median values for that variable over all vessels and all years.

Gear width and *headline height* were investigated as above, and corrected using median imputation, using an algorithm similar to that for the tow locations above — except that all midwater and bottom tows for each vessel in each fishing year, where the variable was missing or invalid, were replaced with the median value of that variable for that subset of tows. Variables with values missing or invalid after this process were set to median values for that variable over all vessels and all years.

No attempt was made to correct *duration*, as there was often more than one interpretation as errors in values recorded for the start and finish time of tow, other than range checks detailed earlier. Similarly, no attempt was made to correct *distance* or the recorded hoki catch, other than range checks detailed earlier.

2.4 Definition of core vessels and zero tows

Many of the vessels operating in the hoki fishery either participate in the fishery throughout the year or are dedicated to fishing for hoki for a considerable period during the year. However, in each year, a small number of catch effort records exist for vessels completing a limited number of tows in a specific fishery. These records may have been assigned to the incorrect fishery due to an error in the tow location, or may represent sporadic fishing effort by individual vessels with limited experience in the fishery. On this basis, the tow records for vessels completing less than 10 tows in a fishery during a specific year, or completed less than 100 tows in all years were excluded from the catch effort data. Similarly, tows for which CPUE could not be calculated (as the catch information was not available for that record) were excluded. These records accounted for only a very small proportion of all the extracted catch effort records; 0.06% for the west coast South Island, 0.15% for Cook Strait, 0.09% for the Chatham Rise, and 0.04% for the sub-Antarctic. Further, for this analysis, we define zero tows as those tows that caught either no hoki, or some negligible amount, and hence define zero tows as those tows that recorded a hoki catch of less than 0.15 t.

Catch effort data were analysed by Langley et al. (2001) for 1986–87 to 1998–99 using two general approaches: (a) data were analysed using methods similar to that employed in previous years (see Ballara et al. 2000), and (b) using methods based on subsets of the data (sub-group analysis) following the recommendations of Quinn II & Sullivan (1999). This report updates the west coast South Island CPUE indices presented by Langley et al. (2001) and Dunn (2001) for (b) only, i.e., the sub-group analysis of "core" vessels. Indices for the Cook Strait, Chatham Rise, and sub-Antarctic are updated using the core vessels analysis described by Langley et al. (2001). Core vessels are defined below.

A large proportion of the fleet that participated in the fishery over the study period have been involved only for a limited period or conducted only a limited number of tows. Core vessels are defined, for each fishery, as those which have participated in the fishery for some minimum qualifying period. This is similar to the definition used by Langley et al. (2001). Hence, the core vessels data set for each fishery comprises only those tows associated with core vessels. Specifically, core vessels were defined as those that had participated for at least 3 years (for the west coast South Island), 7 years (Cook Strait), or 5 years (the non-spawning fisheries) and had recorded a minimum of 10 tows in each of those years and at least 100 tows since 1990. The choice of 3 qualifying years for the west coast South Island differs from the definition used by Langley et al. (2001) or Dunn (2001); they used a qualifying period of 5 years.

The individual vessel coefficients derived from a CPUE model are more likely to reflect the relative fishing power of individual vessels than using a proxy for fishing performance such as the nationality of the vessel or the vessel's power rating. However, in developing a CPUE model based on the performance of individual vessels, it is necessary to ensure that the CPUE data set includes a sufficient number of records to reliably determine the vessel coefficient for an individual vessel. Further, these data should be distributed over a number of years so that the resulting vessel coefficients are not unduly influenced by the performance of the fishery in a particular year and, thereby, strongly alias the individual year effect.

For the west coast South Island fishery, the core vessels were split into sub-groups of the surimi core vessels, dressed core vessels, and fillet core vessels in a manner similar to that described by Langley et al. (2001). These sub-groups were defined from the processing type of each vessel. Exploratory analysis suggested that there were significant differences in the fishing strategies between vessels of the three largest processing types. For example, surimi vessels conducted tows of longer duration and yielded larger catches than either the dressed and fillet vessels, and different annual trends in tow duration and mean catch size were also evident between the dressed and fillet vessels. Further, vessels of length less than 43 m were excluded from the core vessels on the west coast South Island. Hence the data, and any resulting indices, represent vessels fishing outside the 25 nautical mile restricted line on the west coast South Island. Only a few vessels (with a limited number of tows) were assigned to the surimi core vessels for the west coast South Island after 1998. We exclude all data for the surimi core vessel data after 1998 in the CPUE models below.

Langley et al. (2001) defined core vessels for the Chatham Rise and sub-Antarctic as those vessels that had a minimum qualifying period and minimum number of tows, as described above, and had a processing type of "fillet". I define Chatham Rise and sub-Antarctic core vessels as all qualifying vessels, irrespective of processing type. Further I define fillet core vessels as core vessels with a processing code of fillet.

Exploratory analysis suggested that the relationship between tow catch rate, *gear* characteristics (i.e., *net depth*, *bottom depth*, and *headline height*), and other explanatory variables (e.g., *start time* and *season*) differed substantially between midwater and bottom tows. It is likely that a single parameterisation of these variables within a simple model would be inadequate to describe the catch rate of the two methods combined. In addition, most tows within each area were predominately either midwater or bottom tows. For example, 80% of all tows and 90% of all hoki caught were from midwater tows on the west coast South Island. Similarly, for Cook Strait, the equivalent numbers were 83% of tows and 90% of total catch. For the Chatham Rise and sub-Antarctic, most tows were bottom tows (83% of tows and 81% of catch for the Chatham Rise, and 92% of tows and 91% of catch for the sub-Antarctic). Hence, analysis was restricted to data from midwater trawls only for the spawning fisheries (west coast South Island and Cook Strait), or bottom tows only for the non-spawning fisheries (Chatham Rise and sub-Antarctic).

2.5 Model structure

Estimates of relative year effects were obtained from a stepwise multiple regression method in which the data were modelled using a lognormal generalised linear model. A forward stepwise multiple regression fitting algorithm was employed (Chambers & Hastie 1991, Venables & Ripley 1994). The algorithm generates a final regression model iteratively and was implemented using the term *year* as the initial model. The reduction in residual deviance relative to the null deviance (denoted r^2) is calculated for each single term added to the base model. The term that results in the greatest reduction in residual deviance is added to the base model if this would result in an improvement in the residual deviance of more than 1%. The algorithm then repeats this process, updating the base model, until no new terms can be

added. A stopping rule of 1% change in residual deviance was employed as this resulted in a relatively parsimonious model with moderate explanatory power. Alternative stopping rules were not investigated, although Dunn & Harley (1999) reported that less conservative stopping rules tended to result in models with a greater number of terms with only small changes in the estimated relative year effects.

Previous analyses (Vignaux 1993, 1994, Ballara et al. 1997, 1998a, 1998b, Dunn & Harley 1999) used the combined binomial/lognormal model as proposed by Vignaux (1993, 1994). However, as the proportion of zero tows in the west coast South Island, Cook Strait, and sub-Antarctic data was small (about 2.4, 2.0, and 5.5% respectively), the contribution from the binomial component is likely to be negligible. The proportion of zero tows on the Chatham Rise was higher (10.1%), but is likely to have only a small effect on the combined indices. Hence zero catch tows were excluded from the CPUE models.

The model indices are presented using a canonical form. Model fits were investigated using standard residual diagnostics, and, for each model, plots of model residuals and fitted values were investigated for evidence of departure from model assumptions. In addition, plots of the expected catch rate resulting from the models for each of the explanatory variables fitted to the model are shown in Appendices A–D.

3. RESULTS

3.1 West coast South Island spawning fishery

The west coast South Island hoki fishery is conducted almost exclusively during June–October off the northern west coast of the South Island. The fishery developed from the early 1980s and increased rapidly following an increase in the TACC in 1986 (Ballara et al. 2000). The number of tows targeting hoki on the west coast South Island has fluctuated between 6500 and 9000 since the late 1980s (Langley et al. 2001). The number of zero tows has remained low, with only about 1–2% of midwater tows recording a zero catch. Table 5 shows the number of tows by year, the number of tows that targeted hoki, number of midwater tows, and the number of non-zero midwater tows for each year from 1990 to 2001.

A total of 231 vessels fished on the west coast South Island between 1990 and 2001 that recorded a positive catch of hoki from a midwater tow. Analysis of the core vessel data was based on 91 of these vessels that participated in the fishery for at least 3 fishing years since 1990. The number of tows for each of the core vessel types, by year, is given in Table 5.

As described earlier, CPUE models were estimated for three sub-groups of the west coast South Island fishery core vessels: surimi core vessels, dressed core (i.e., head-and-gut) vessels, and fillet core vessels. Only main effect models were considered. The data are described below, and model estimates for the surimi, dressed, and fillet core vessel analyses are also described. Descriptive plots and tables for all vessels, and each of the three groups of core vessels are given in Appendix A as Tables A1–A4 and Figures A1–A3.

3.1.1 Surimi core vessels

Surimi vessels dominated the west coast South Island fishery during the early years (1986–87 to 1989–90) (Kendrick 1999, Langley et al. 2001), but the number of these vessels participating in the fishery has declined markedly. A much reduced fleet of surimi vessels continues to operate in the fishery, with only 16 vessels participating in the fishery for at least three of the years since 1990 (Appendix A, Table A2). Only one such vessel operated in the

fishery in 2000 and 2001 seasons, recording 43 midwater tows in 2000 and only 8 midwater tows in 2001.

Table 5: Number of tows, hoki target tows, hoki target midwater tows, non-zero tows, and core vessel tows by year and type, for the west coast South Island fishery 1990–2001.

		Hoki	Mid-	Non-						
	All	target	water	zero	Surimi vessels		Dressed vessels		Fillet vessels	
Year	tows	tows	tows	catch	All	Core	All	Core	All	Core
1990	8 055	7 855	6 773	6 680	1 403	644	4 088	937	1 339	1 339
1991	8 183	8 029	6 727	6 662	806	768	5 102	1 692	1 975	1 830
1992	6 212	5 919	5 180	5 085	376	376	4 170	2 095	1 396	1 396
1993	6 978	6 611	5 257	5 126	156	156	4 038	3 028	2 160	2 160
1994	8 493	8 236	7 030	6 922	520	520	5 171	4 211	2 250	2 245
1995	7 943	7 651	6 630	6 488	428	428	5 707	4 897	1 534	1 534
1996	6 751	6 654	5 163	5 042	333	333	4 302	3 725	1 891	1 891
1997	8 172	8 000	6 744	6 584	385	385	4 995	4 302	1 915	1 912
1998	7 998	7 905	6 712	6 571	498	498	4 669	4 382	2 270	2 270
1999	7 014	6 830	5 247	5 138	146	146	3 905	3 880	2 439	2 439
2000	7 345	7 071	5 276	5 232	43	43	3 455	3 306	3 320	2 652
2001	8 244	8 025	5 874	5 737	8	8	3 628	3 150	3 360	2 509
Total	91 388	88 786	72 613	71 267	5 102	4305	53 230	39 605	25 849	24 177

The surimi core vessels accounted for most of the tows conducted by all surimi vessels, with about 140–750 tows annually between 1990 and 1998. In 1999, this had declined to 150 tows, and further declined in 2001 to only one vessel with 8 tows (Appendix A, Figure A1).

Most of the effort recorded by surimi core vessels was concentrated during July and August. Very limited fishing was recorded during September, with none in October. Since 1997, there has been a steady decline in the number of tows recorded before July. In 1992 and 1993, only a few tows were recorded after July — possibly attributable to the early departure of the surimi vessels to the southern blue whiting fishery in those years (G. Patchell, Sealord Group Ltd., pers. comm.).

Since 1990, there was a trend of increasing *headline height* of midwater tows, increasing from a median of about 50 m to 70 m in 1990. The *net depth* increased from about 400 m to 500 m in 1990, but was shallower (with less variation) in subsequent years. The median tow *duration* has stayed relatively constant at about 6 hours over all years, and the median catch per tow has fluctuated around 30–50 t per tow.

3.1.2 Dressed core vessels

After 1990, the west coast South Island fleet was dominated by vessels processing hoki in the dressed state (Langley et al. 2001); dressed vessels account for about 43% of all catch on the west coast South Island. Between 20 and 40 dressed vessels operated in the fishery in most years, with between 10 and 32 core vessels operating annually (Appendix A, Table A3).

The proportion of tows recorded by dressed core vessels in the dressed fleet had increased from about a third in 1990 to about more than two-thirds in more recent years. Most of the fishing effort was during July and August, with very limited fishing in June or October (Appendix A, Figure A2).

The recorded *headline height* decreased in the mid 1990s, but has since increased back to a median of about 60 m. The median catch rate has fluctuated between 5 and 14 t per tow,

declining in the mid 1990s, and increasing up to 2000. In 2001, the median catch rate again declined from 11.3 t per tow to 7.5 t per tow.

3.1.3 Fillet core vessels

Since 1990, between 9 and 20 fillet vessels operated in the fishery in each year. A number of New Zealand registered fillet vessels entered the fishery in 1996–97, increasing the total fleet to about 20 vessels in recent years. A core group of 31 vessels had recorded tows in at least three years (Appendix A, Table A3). Fillet vessels have accounted for about 25% of all hoki catch on the west coast South Island since 1990.

The fillet core vessels recorded almost all (94%) tows from fillet vessels between 1990 and 2001. Most fishing was recorded during July and August. Since 1991, there has been a steady increase in the proportion of the number of tows recorded during August and, to a lesser extent, during September — with a corresponding decline during June and July (Appendix A, Figure A3).

The median *headline height* remained relatively constant (between 40 and 50 m) up to 1995. Since then, median *headline height* steadily increased to between 75 and 80 m in 1999 and 2000. The median tow *duration* has remained relatively constant at about 3–4 hours over all years. Median catch per tow for these vessels declined from 1990 to 1995, and increased tin recent years. There was only a small decline (from 12 to 11 t per tow) from 2000 to 2001.

3.1.4 Catch-per-unit-effort indices

For each of the three west coast South Island vessel sub-groups, the resulting models included, as main effects, the variables *vessel*, *season*, *year*, and either *sunrise* or *start time*. For the surimi models, tow *longitude* was also included. The models returned an overall r^2 of 43%, 32%, and 30%, for the surimi core, dressed, and fillet vessel data sets respectively. CPUE model fits for surimi core, dressed, and fillet vessels are given in Table 6. Diagnostic plots of the model fits are given in Appendix A, Figures A4–A6. Model estimates of CPUE indices are given in Table 7 and are plotted in Figure 3.

The estimates of *vessel* coefficients for the surimi model suggested that the relative fishing power of the different vessels was similar, with expected catch rates ranging between about 40 and 100 t per tow (Appendix A, Figure A7) In contrast, *vessel* coefficients from both the dressed (5 to 35 t per tow, Appendix A, Figure A8) and fillet models (5 to 40 t per tow, Appendix A, Figure A9) indicated greater variation in the relative fishing power between vessels. In general, the vessel coefficient for the dressed and fillet vessels decreased for vessels with less recorded effort in the fisheries, although there was much greater variation from dressed vessels with relatively small amounts of total recorded effort.

The estimated coefficients for *season* were similar between the three vessel sub-groups, showing a consistent pattern of increasing catch rates up to the peak season, before declining to zero at about 60 days after the peak season.

All the models include a variable that aliases the time of the tow, either expressed as *sunrise* or *start time*. However, for all three data sets the diurnal trend in catch rate was comparable, with highest catch rates occurring from tows commencing about 2–3 hours after sunrise (roughly equivalent to 0600 h., although this depends on the time of year). Catch rates decline through the afternoon to reach a minimum around midnight. The diurnal trend in catch for the fillet data set has slightly more contrast than the relationship derived from the surimi data set. This may be related to the longer tow *duration* of surimi vessels; a factor that may mask this

effect (Appendix A, Figures A7–A9). The tow *duration* was also included as a significant variable in the models for the surimi core vessels, with model coefficients showing increasing catch rate with tow *duration*. *Duration* was not a factor for either dressed or fillet core vessels.

Table 6: Variables selected by order of selection for the surimi, dressed, and fillet core vessel models for the west coast South Island fishery.

	Surimi model		Dressed model		Fillet model	
Order	Variable	r^2	Variable	r^2	Variable	R^2
1	*Year*	1.2	*Year*	3.9	*Year*	3.3
2	*Season*	37.0	*Season*	23.5	*Season*	19.7
3	*Vessel*	39.0	*Vessel*	30.1	*Vessel*	26.2
4	*Duration*	40.6	*Start time*	32.3	*Sunrise*	30.1
5	*Longitude*	41.9				
6	*Sunrise*	43.0				

Table 7: Relative year effects (and 95% confidence intervals) by year for the surimi, dressed, and fillet core vessel models for the west coast South Island fishery, 1990–2001.

Year	Surimi		Dressed		Fillet	
1990	1.09	(0.98–1.21)	0.97	(0.90–1.06)	0.86	(0.79–0.93)
1991	1.20	(1.11–1.30)	1.14	(1.07–1.21)	0.97	(0.90–1.04)
1992	0.91	(0.82–1.01)	1.39	(1.32–1.46)	1.22	(1.14–1.31)
1993	1.10	(0.93–1.30)	0.91	(0.87–0.96)	1.10	(1.03–1.17)
1994	0.87	(0.79–0.97)	0.89	(0.86–0.92)	1.17	(1.11–1.24)
1995	0.91	(0.83–1.00)	0.74	(0.71–0.76)	0.65	(0.62–0.69)
1996	1.13	(1.01–1.26)	0.78	(0.75–0.81)	1.03	(0.97–1.09)
1997	0.92	(0.83–1.01)	0.89	(0.85–0.92)	0.79	(0.75–0.83)
1998	0.93	(0.85–1.03)	1.10	(1.06–1.14)	1.05	(0.99–1.11)
1999	–	–	1.16	(1.11–1.20)	1.08	(1.02–1.15)
2000	–	–	1.38	(1.33–1.44)	1.37	(1.29–1.45)
2001	–	–	0.89	(0.85–0.93)	0.93	(0.87–1.00)

None of the models represented a good fit to the available data. Model diagnostics were poor and showed strong evidence of poor fit. There are also some consistent trends in the residuals. For example, the residuals from the surimi model suggest that catch from tows early in the season during the earlier years of the time-series may be underestimated. This is similar to the results found by Dunn (2001) and Langley et al. (2001).

As found by Langley et al. (2001), the indices estimated from each of the core vessel models differ — particularly the surimi series when compared with either the fillet or dressed series. Figure A10 in Appendix A compares the indices calculated by both Langley et al. (2001) and Dunn (2001) with those presented in this report. There are only subtle differences detectable for the years where the two sets of indices overlap, in the dressed and fillet analyses. More considerable differences are discernible in the surimi analysis, but the loss of data, due to the years included with the analysis of the surimi core vessels between the analyses, is the most likely explanation for the difference. Both the fillet core and dressed vessels suggest an increase in abundance from about 1995 to 2000, with a marked decline in 2001.

Comparison of the CPUE indices with the relative biomass estimates from the west coast South Island acoustic indices (R. O'Driscoll, NIWA, pers. comm.) shows little evidence of a relationship. The comparison is plotted in Appendix A, Figure A11.

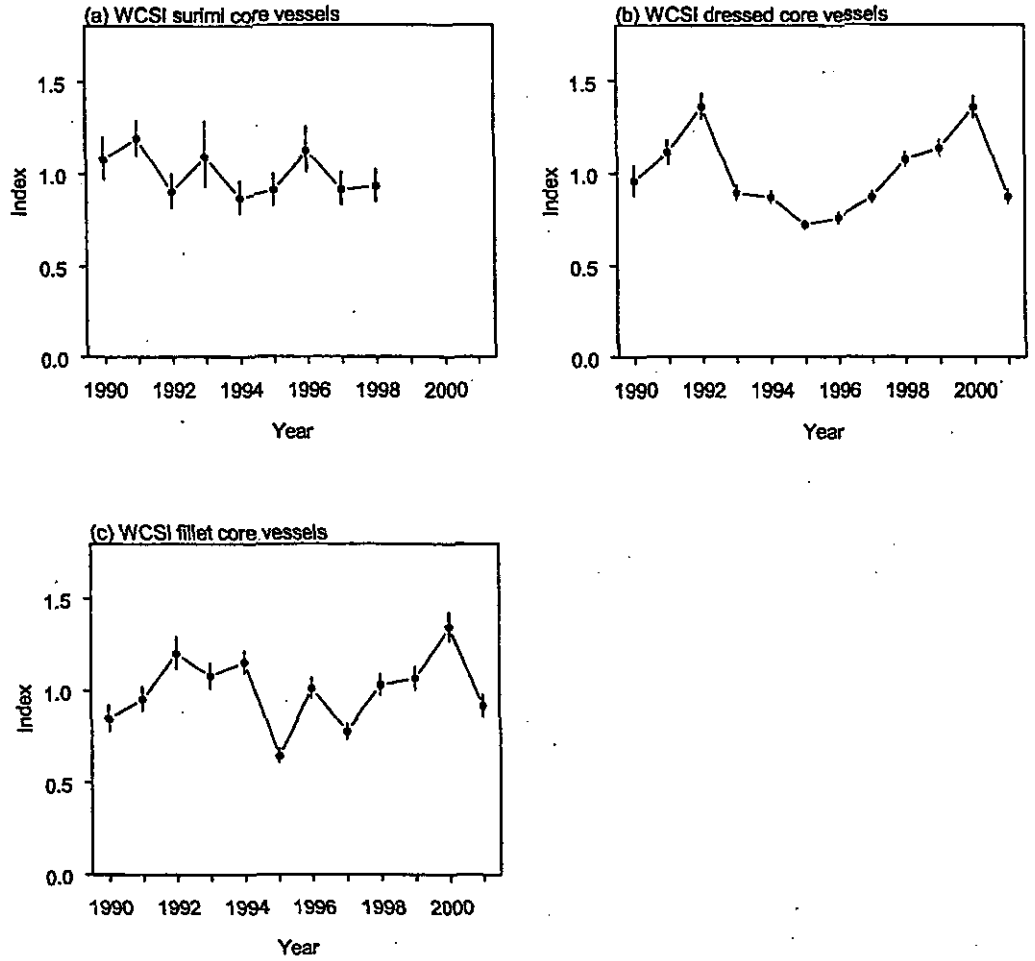

Figure 3: Relative indices (scaled to have mean 1) for the west coast South Island (a) surimi, (b) dressed, and (c) fillet core vessel models. Approximate 95% confidence intervals are shown as vertical lines.

3.2 Cook Strait spawning fishery

The Cook Strait hoki fishery is conducted during June–October in the canyons of Cook Strait, and has been developed only since about 1989–90 (Langley et al. 2001). The number of tows targeting hoki has fluctuated between about 1000 and 4500 since 1990 (Table 8). The total hoki catch recorded on TCEPR records from the Cook Strait increased from 11 500 t in 1990 to a peak of 44 400 t in 1997, since declining to 23 500 t in 2001. Table 8 shows the number of tows by year, the number of tows that targeted hoki, number of midwater tows, and the number of non-zero tows for each year from 1990 to 2001.

A total of 66 vessels fished in Cook Strait between 1990 and 2001 that recorded a positive catch of hoki from a midwater tow. Analysis of the core vessel data was based on 18 of these vessels that participated in the fishery for at least 7 fishing years since 1990; these accounted for about two-thirds of the total catch recorded by TCEPR records for Cook Strait. Most of this fishing is concentrated on or near Cook Strait Canyon.

In recent years, there has been an increase in larger vessels operating within the fishery. During 1990 and 1991, most vessels were about 25 m in length, with only a few vessels at about 30 m. Since then the number of 30 m vessels has increased, and vessels of over 40 m have moved into the fishery. With the increase in larger vessels, there has been a corresponding increase in the *headline height*, and a reduced median *duration* of tows. Raw

catch rates have fluctuated about 10 to 15 t per tow since 1993, with a small reduction from 14.0 to 12.6 t per tow from 2000 to 2001.

CPUE models were estimated only for the core vessel sub-group of the Cook Strait fishery. Only a main effect model was considered. The data are described below, and model estimates are also described. Descriptive plots and tables for all vessels and core vessels are given in Appendix B as Table B1 and Figure B1.

Table 8: Number of tows, hoki target tows, hoki target midwater tows, non-zero tows, and core vessel tows by year and type, for the Cook Strait fishery 1990–2001.

Year	All tows	Hoki target tows	Mid-water tows	Non-zero catch	Core vessels
1990	1 062	1 061	1 040	1 035	373
1991	2 077	2 077	2 059	2 022	990
1992	1 601	1 591	1 578	1 550	785
1993	1 516	1 514	1 487	1 461	814
1994	1 941	1 932	1 781	1 755	1 025
1995	2 408	2 403	2 072	2 040	1 394
1996	4 414	4 388	3 031	2 970	1 682
1997	4 594	4 584	3 266	3 177	1 789
1998	2 862	2 857	2 251	2 219	1 505
1999	2 522	2 515	1 985	1 962	1 437
2000	2 170	2 167	1 867	1 848	1 384
2001	1 856	1 850	1 760	1 710	1 114
Total	29 023	28 939	24 177	23 749	14 292

3.2.1 Catch-per-unit-effort indices

The CPUE model for the Cook Strait core vessels included, as main effects, the variables *vessel*, *season*, and *year*. The model returned an overall r^2 of 22%. The CPUE model fit is given in Table 9. Diagnostic plots of the model fit are given in Appendix B, Figure B2. Model estimates of CPUE indices are given in Table 10 and are plotted in Figure 4.

The comparison of the *vessel* coefficients suggested that the relative fishing power of the different vessels was broadly similar, although expected catch rates ranged between about 7 to 20 t per tow (Appendix B, Figure B3). The estimated coefficients for *season* were similar between the three vessel sub-groups, showing a consistent pattern of increasing catch rates up to the peak season, before declining to zero at about 60 days after the peak season.

None of the models represented a good fit to the available data. Model diagnostics were poor and showed strong evidence of poor fit. Diagnostic plots are shown in Appendix B, Figure B2. In particular, smaller catches were poorly modelled.

Figure B4, Appendix B, compares the indices calculated by Langley et al. (2001) with those presented in this report. The key difference between the estimated indices is that for the 1992 year. This is a consequence of the revised choice of area of the fishery, i.e., from removing tows along the northeast coast of the South Island from the analysis. Otherwise, the standardised indices reflect little change in abundance since 1993.

Comparison of the CPUE indices with the relative biomass estimates from the Cook Strait acoustic indices (R. O'Driscoll, NIWA, pers. comm.) show little evidence of a relationship. The comparison is plotted in Appendix B, Figure B5.

Table 9: Variables selected by order of selection for the core vessel model for the Cook Strait fishery.

	Core vessel model	
Order	Variable	r^2
1	*Year*	2.1
2	*Season*	16.4
3	*Vessel*	22.4

Table 10: Relative year effects (and 95% confidence intervals) by year for the core vessel model for the Cook Strait fishery 1990–2001.

Year	Core vessel model	
1990	0.96	(0.87–1.06)
1991	0.71	(0.66–0.76)
1992	1.61	(1.49–1.73)
1993	1.03	(0.96–1.11)
1994	1.10	(1.03–1.17)
1995	1.12	(1.06–1.18)
1996	1.02	(0.97–1.07)
1997	0.90	(0.85–0.94)
1998	0.96	(0.91–1.01)
1999	0.88	(0.84–0.93)
2000	1.04	(0.98–1.10)
2001	0.90	(0.85–0.96)

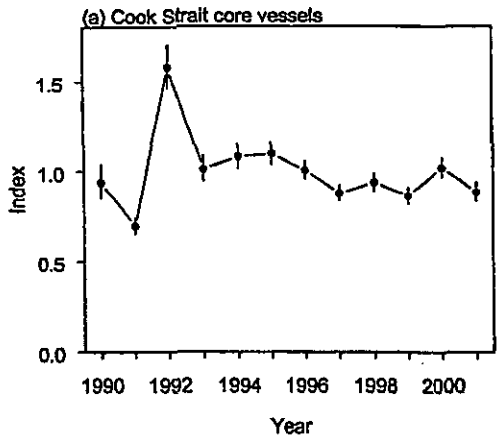

Figure 4: Relative indices (scaled to have mean 1) for the Cook Strait core vessel model 1990–2001. Approximate 95% confidence intervals are shown as vertical lines.

3.3 Chatham Rise non-spawning fishery

The annual catch recorded by TCEPR records on the Chatham Rise steadily increased from about 12 000 t in 1990 to about 56 000 t in 1999. This reduced to about 41 000 t in 2000 and 2001. Table 11 shows the number of tows by year, the number of tows that targeted hoki, number of midwater tows, and the number of non-zero tows for each year from 1990 to 2001.

A total of 172 vessels that fished on the Chatham Rise between 1990 and 2001 recorded a positive catch of hoki from a bottom tow. Analysis of the core vessel data was based on 61 of these vessels that participated in the fishery for at least 5 fishing years since 1990. The analysis of the fillet core vessel data was based on 18 of these vessels, and accounted for

about 85% of the catch from all core vessels. Data from the Chatham Rise fishery was dominated by tows using bottom gear, and these accounted for more than three-quarters of all tows since 1990. The number of tows for core vessels and for fillet core vessels, by year, is given in Table 11.

In recent years, there has been an increase in larger vessels operating within the fishery. During 1990 and 1991, most vessels were about 25 m in length, with only a few vessels at about 30 m. Since then the number of 30 m vessels has increased, and vessels of over 40 m have moved into the fishery. With the increase in larger vessels, there has been a corresponding increase in the *headline height*, and a reduced median *duration* of tows. Raw catch rates have fluctuated around 10–15 t per tow since 1993, with a small reduction from 14.0 to 12.6 t per tow from 2000 to 2001.

CPUE models were estimated for the core vessel and the fillet core vessel sub-groups of the Chatham Rise fishery. Only main effect models were considered. The data are described below, and model estimates are also described. Descriptive plots and tables for all vessels, core vessels , and fillet core vessels are given in Appendix C as Table C1 and Figure C1.

Table 11: Number of tows, hoki target tows, hoki target midwater tows, non-zero tows, core vessel, and fillet core vessel tows by year and type, for the Chatham Rise fishery, 1990–2001.

Year	All tows	Hoki target tows	Bottom Tows	Non-zero Catch	Core vessels	Core fillet vessels
1990	2 800	1 730	2 777	2 402	865	238
1991	4 995	3 921	4 088	3 767	1 415	876
1992	7 754	5 403	7 347	5 833	3 009	1 373
1993	8 006	5 769	7 017	5 627	3 644	2 259
1994	5 650	3 752	4 600	3 235	2 578	1 881
1995	8 040	6 668	6 190	5 418	4 688	3 855
1996	9 408	8 176	7 455	6 696	5 064	4 066
1997	10 738	9 498	8 632	7 898	6 818	5 627
1998	14 214	13 071	10 905	10 017	9 109	8 206
1999	13 835	12 660	11 683	10 857	9 258	8 294
2000	11 964	10 818	9 534	8 733	6 980	6 040
2001	11 163	9 608	10 278	9 441	6 828	5 978
Total	108 567	91 074	90 506	79 924	60 256	48 693

3.3.1 Catch-per-unit-effort indices

For the two sub-groups the resulting models included identical terms as main effects; namely *vessel, sub-area, year, start time,* and *duration*. The models returned an overall r^2 of 43.9% and 14.5% for the core vessel and fillet core vessel data sets respectively.

CPUE model fits for both models are given in Table 12. Diagnostic plots of the model fits are given in Appendix C, Figures C2 and C4. Model estimates of CPUE indices are given in Table 13 and are plotted in Figure 5.

Comparison of the *vessel* coefficients suggested that the relative fishing power of the different vessels was similar, with a decreasing expected catch rate with a decreasing involvement in the fishery (Appendix C, Figure C3 and C5). Sub-area estimates were all similar, except in Statistical Area 404 — historically a hake fishery. Both models included a variable that represented the time of day of the tow and the duration of the tow. Neither of the models represented a good fit to the available data. Model diagnostics were poor and showed some evidence of poor fit. Diagnostic plots for the two models are shown in Appendix C, Figures C2 and C4.

Table 12: Variables selected by order of selection for the core vessel and fillet core vessel models for the Chatham Rise fishery.

	Core vessel model		Fillet core vessel model	
Order	Variable	r^2	Variable	r^2
1	*Year*	0.6	*Year*	1.3
2	*Vessel*	39.1	*Vessel*	5.2
3	*Start time*	41.0	*Sub-area*	9.4
4	*Sub-area*	42.7	*Start time*	12.9
5	*Duration*	43.9	*Duration*	14.5

Table 13: Relative year effects (and 95% confidence intervals) by year for the core vessel and fillet core vessel models for the Chatham Rise fishery 1990–2001.

Year	Core vessel model		Fillet core vessel model	
1990	1.01	(0.94–1.08)	1.21	(1.06–1.38)
1991	1.11	(1.06–1.17)	1.04	(0.97–1.11)
1992	1.32	(1.27–1.37)	1.19	(1.13–1.25)
1993	1.25	(1.21–1.29)	1.18	(1.13–1.23)
1994	0.94	(0.90–0.98)	0.88	(0.84–0.93)
1995	0.90	(0.88–0.93)	0.93	(0.90–0.97)
1996	0.99	(0.96–1.02)	1.04	(1.00–1.07)
1997	0.94	(0.92–0.97)	0.93	(0.91–0.96)
1998	0.91	(0.89–0.94)	0.92	(0.89–0.94)
1999	1.02	(1.00–1.05)	1.05	(1.02–1.08)
2000	0.88	(0.85–0.90)	0.88	(0.85–0.91)
2001	0.83	(0.81–0.86)	0.83	(0.80–0.86)

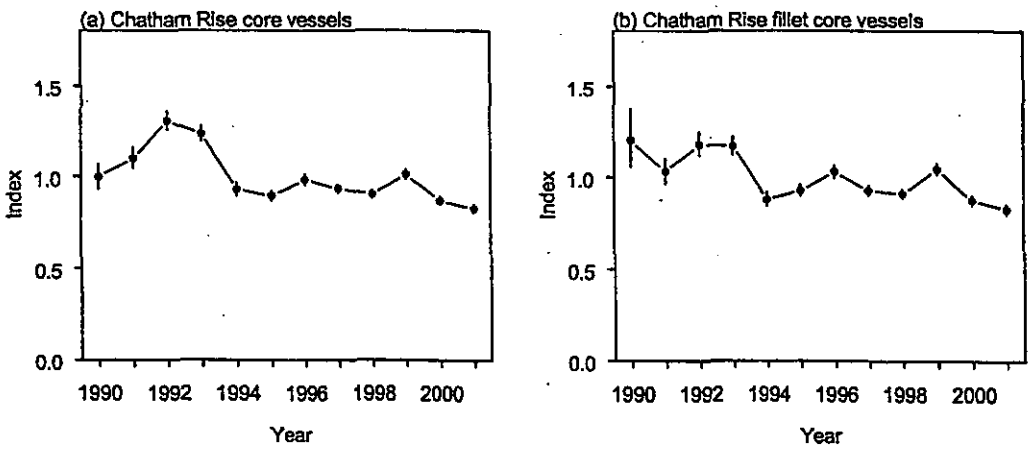

Figure 5: Relative indices (scaled to have mean 1) for the Chatham Rise (a) core vessel and (b) fillet core vessel models 1990–2001. Approximate 95% confidence intervals are shown as vertical lines.

Estimated indices from the two models were very similar, except in the base year (1990). Figure C6, Appendix C, compares the indices calculated by Langley et al. (2001) with those presented in this report. There are only subtle differences detectable for the years where the two sets of indices overlap, except for a small difference in the index for the fillet core vessel model in 1990. The standardised indices suggest a slight decline in abundance since about 1992, with a steeper, more recent, decline since 1999.

Comparison of the CPUE indices with the relative biomass estimates from the Chatham Rise trawl survey series (Annala et al. 2001) are strongly correlated with the CPUE indices for both the core vessels and fillet core vessels analysis; all series suggest a decline in abundance

since the early 1990s. However, the decline in recent years is steeper for the trawl survey series than for the CPUE indices. The comparison is plotted in Appendix C, Figure C7.

3.4 Sub-Antarctic non-spawning fishery

The hoki fishery in the sub-Antarctic region developed in the early 1990s, with a total annual catch between 1991–92 and 1992–93 of about 30 000 t. Catches declined to about 12 000 t over the following three years, before increasing to about 25 000 t from 1996–97 to 1998–99 (Annala et al. 2001). The number of tows targeting hoki in the sub-Antarctic has fluctuated from about 2000 to just over 4000 since 1990–91 (Table 14). The proportion of zero tows recorded has remained both low and constant at about 1.3%.

A total of 119 vessels that fished in the sub-Antarctic between 1991 and 2001 recorded a positive catch of hoki from a bottom tow. Analysis of the core vessel data was based on 27 of these vessels that participated in the fishery for at least 5 fishing years since 1991. The analysis of the fillet core vessel data was based on 11 of these vessels, and accounted for about 90% of the catch from all core vessels. Data from the sub-Antarctic fishery was dominated by tows using bottom gear, and these accounted for most (90%) tows since 1991. The number of tows for the core vessels and fillet core vessels, by year, is given in Table 14.

In recent years, there has been a decrease in very large vessels operating in the fishery. Between 1991 and 1993, a sizable proportion of the fleet was over 80 m in length, Since then the fishery has been dominated by vessels between about 60 and 70 m in length. With the decrease in larger vessels, there has been a corresponding reduction in the median *headline height*, although tow *duration* has remained relatively constant at around 4–5 hours. Raw catch rates have fluctuated about 2 to 4 t per tow, with only a small reduction from 4.3 to 3.5 t per tow from 2000 to 2001.

CPUE models were estimated for both the core vessel and fillet core vessel sub-groups of the sub-Antarctic fishery. Only main effect models were considered. The data are described below, and model estimates are also described. Descriptive plots and tables for all vessels, core vessels, and fillet core vessels are given in Appendix D as Table D1 and Figure D1.

Table 14: Number of tows, hoki target tows, hoki target midwater tows, non-zero tows, core vessel, and fillet core vessel tows by year and type, for the sub-Antarctic fishery, 1991–2001.

Year	All tows	Hoki target tows	Bottom tows	Non-zero catch	Core vessels	Fillet core vessels
1991	3 712	3 149	3 599	3 320	648	358
1992	5 479	5 013	5 390	5 262	2 030	1 935
1993	5 560	4 993	5 041	4 863	2 363	2 193
1994	2 367	1 952	2 027	1 821	1 212	1 043
1995	2 823	2 545	2 538	2 456	1 829	1 548
1996	2 909	2 523	2 543	2 357	1 620	1 390
1997	3 748	3 128	3 496	3 159	2 621	1 985
1998	4 386	3 833	4 239	3 962	2 843	2 384
1999	3 530	2 964	3 230	3 024	1 581	1 088
2000	5 224	4 736	4 865	4 692	3 035	2 111
2001	5 165	4 669	4 563	4 420	2 585	1 855
Total	44 903	39 505	41 531	39 336	22 367	17 890

3.4.1 Catch-per-unit-effort indices

For the two sub-groups, the resulting models included similar terms as main effects; namely *vessel*, *year*, *start time*, *season*, and either *net* or *bottom depth*. *Duration* and *headline height*

were additional, minor, main effects for the fillet core vessel model. The models returned an overall r^2 of 38.4% and 22.3% for the core vessel and fillet core vessel data sets respectively.

CPUE model fits are given in Table 15. Model estimates of CPUE indices are given in Table 16 and are plotted in Figure 6.

Comparison of the *vessel* coefficients suggested that the relative fishing power of the different vessels was strongly correlated with the total effort recorded by each vessel. The *vessel* coefficients for all core vessels appear to fall into two separate groups — the first of which are primarily the fillet core vessels. The coefficients of the other common terms between the two models were similar. Both models included a variable that represented the season and the time of day of the tow. Neither of the models represented a good fit to the available data. Model diagnostics were poor and showed some evidence of poor fit. Diagnostic plots for each of the models are shown in Appendix D, Figures D2 and D7.

Table 15: Variables selected by order of selection for the core vessel model for the sub-Antarctic fishery.

	Core vessel model		Fillet core vessel model	
Order	Variable	r^2	Variable	r^2
1	*Year*	1.3	*Year*	2.2
2	*Vessel*	30.2	*Bottom depth*	7.4
3	*Start time*	33.6	*Start time*	12.5
4	*Season*	36.8	*Season*	16.7
5	*Net depth*	38.4	*Vessel*	19.8
6			*Headline height*	21.2
7			*Duration*	22.3

Table 16: Relative year effects (and 95% confidence intervals) by year for the core vessel model for the sub-Antarctic fishery 1991–2001.

Year	Core vessel model		Fillet core vessel model	
1991	0.72	(0.66–0.78)	0.66	(0.59–0.73)
1992	1.06	(1.01–1.11)	1.30	(1.23–1.37)
1993	0.97	(0.93–1.01)	1.07	(1.02–1.13)
1994	0.98	(0.93–1.04)	1.18	(1.11–1.26)
1995	0.94	(0.90–0.98)	1.11	(1.06–1.17)
1996	0.93	(0.89–0.98)	1.02	(0.96–1.07)
1997	1.16	(1.12–1.21)	1.18	(1.12–1.23)
1998	1.09	(1.05–1.14)	1.06	(1.01–1.11)
1999	1.13	(1.07–1.19)	0.95	(0.89–1.01)
2000	1.12	(1.08–1.17)	0.93	(0.88–0.98)
2001	0.98	(0.94–1.03)	0.74	(0.70–0.79)

The standardised indices for the core vessels suggest no strong change in abundance since 1992. However, the fillet core vessels suggest a continuous decline in abundance since 1992. Figure D6 in Appendix D compares the fillet core indices calculated by Langley et al. (2001) with those presented in this report. There are only subtle differences detectable for the years where the two sets of indices overlap.

The biomass indices derived from the trawl survey series for the sub-Antarctic (R. O'Driscoll, NIWA, pers. comm.) are correlated, to a lesser extent, with the CPUE indices for fillet core vessels analysis; both series suggest a decline in abundance since the early 1990s. However, the decline in recent years is steeper for the trawl survey series than for the CPUE fillet core vessels indices. The comparison is plotted in Appendix D, Figure D5.

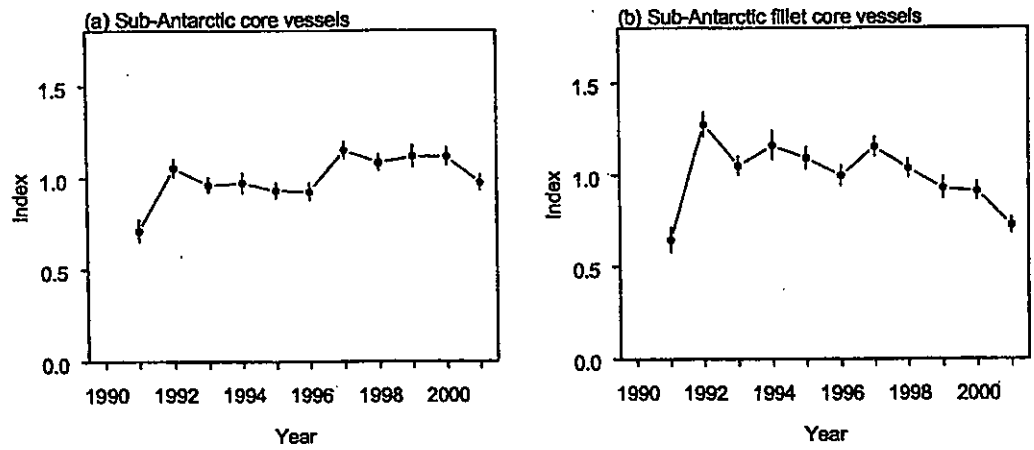

Figure 6: Relative indices (scaled to have mean 1) for the sub-Antarctic (a) core vessel and (b) fillet core vessel models, 1991–2001. Approximate 95% confidence intervals are shown as vertical lines.

4. CONCLUSIONS

The indices derived from the sub-group CPUE analyses for each of the fisheries suggest different trends in each of the fisheries. For the west coast South Island spawning fishery the indices derived from the fillet core vessels climb from 1990 to 1994, drop in 1995, and then show a trend of increase to 2000 (and a large degree of variation), before dropping in 2001. The indices for the dressed core vessels climb from 1990 to 1992, drop until 1995, then increase until 2000. The index for 2001 also shows a sharp decline. Indices for the surimi core vessels were calculated up to 1998 only, due to the lack of data in more recent years. The CPUE analyses are restricted to the area beyond the 25 nautical mile exclusion zone — hence a significant and potentially variable proportion of the hoki biomass is unavailable to the component of the fleet considered in these analyses.

The indices for the Cook Strait spawning fishery suggest a stable, or slightly decreasing, trend in abundance since 1993. There is no strong indication of a decline in 2001. The indices for the Chatham Rise fishery suggested a continuous decline since the early 1990s in abundance, while the indices for the sub-Antarctic suggest a steeper decline.

Since 1990, there were several obvious changes in the fleet composition and behaviour that may have influenced the trends in the CPUE indices, including the introduction of a number of new vessels into the fishing fleet between 1992 and 1994. Distribution of effort has also changed considerably. Between 1992 and 1995, fishing effort was concentrated in the northern grounds. Otherwise, fishing appeared more concentrated in the southern area of the grounds. In contrast, the geographic distribution of fishing effort by the surimi fleet was mainly concentrated around the Hokitika Canyon through that period.

It is unknown whether differences in the distribution of fishing effort between years by the different vessels in the fishing fleet reflect differences in fishing strategy or in fish abundance on the grounds. The former proposition would contradict the assumptions of the analysis, i.e., that a constant proportion of the biomass on the grounds was vulnerable to the fishing effort each year. However, this would also apply if the spatial distribution of the hoki varied substantially between years, while the distribution of fishing effort remained relatively constant — as observed for the surimi vessels on the west coast South Island.

It is difficult to confirm the calculated CPUE indices as indices of abundance by any external information. Strong year classes that were believed to enter the fishery in the mid 1990s may be

reflected in estimated CPUE indices for both the fillet and dressed vessel analyses for the west coast South Island. As noted by Langley et al. (2001), more advanced modelling approaches need to be examined to improve the analysis.

There are a number of similarities between all the models developed for each of the four hoki fisheries. All the models included *vessel* as a significant main effect, although the relative importance of this variable differed between fisheries and vessel processing types. The catching capacity of fillet core vessels is largely constrained by the processing capacity of the factory. Consequently, the catch rate of an individual vessel is likely to be largely governed by the size and efficiency of the individual vessel's factory. In the two non-spawning fisheries, where we compared core vessels and fillet core vessels, the *vessel* effect was always considerably smaller for the fillet sub-group, suggesting that such sub-groups contain a more "consistent" set of vessels than the entire fleet.

The models for all four areas reveal a consistent seasonal trend in catch rates. For the non-spawning fisheries, catch rates increase from a low level in October to reach a peak in February and decline over the following three months. The seasonal trend in catch rates corresponds to the general assumptions regarding the annual migration of hoki to the spawning grounds. However, the magnitude of this seasonal effect is relatively weak in both fisheries. Catch rates for the sub-Antarctic fishery also remain at a higher level from March to May compared to the Chatham Rise fishery. This is consistent with the assumed migration pattern of hoki recruiting to the western stock from the nursery grounds on the Chatham Rise to reside in the sub-Antarctic area. The seasonal trend in catch rates is magnified in the two spawning fisheries, Cook Strait and west coast South Island, as fish aggregate in these areas to spawn. The fishing seasons start in early June and reach a peak season around mid August in both areas.

Langley et al. (2001) noted that some vessels may maintain constant catch rates, even at relatively low stock abundance, by modifying fishing strategy. In such cases, it may be more informative to develop alternative indices of abundance to monitor the fishing performance of vessels in each of the fleets. For example, such alternative indices could include changes in the number of tows in a day, tows per trip, or distance between successive tows. Consideration of suitable indices would need to be based on an understanding of the operation of individual fishing vessels in response to changes in fish abundance, and may allow the development of quantitative indices that better reflect the underlying trends in stock abundance.

Model diagnostics for all models were poor, suggesting evidence of poor fit. This poor performance suggests that there are important factors not accounted for by the model that contribute to the catch rate of individual tows. These may include information concerning fishing strategy, availability of hoki, and the spatial patterns of abundance (i.e., aggregations). In general, the models developed for each of the fisheries were unable to capture the extremes in catch rate observed in the fishery. The predictive models generally underestimated the observed catches at the upper extreme of the observed range of catches, and overestimated the catch from trawls at the lower range.

Acoustic and trawl data for the fisheries allow some comparison of the CPUE indices of abundance, if issues of timing and the relative selectivity are ignored. The acoustic indices for the west coast South Island and Cook Strait show little evidence of a relationship between the respective indices. The biomass indices derived from the trawl survey series for the Chatham Rise are strongly correlated with the CPUE indices for both the core vessels and fillet core vessels analysis; all series suggest a decline in abundance since the early 1990s. However, the decline in recent years is steeper for the trawl survey series than for the CPUE indices. The biomass indices derived from the trawl survey series for the sub-Antarctic are correlated, to a lesser extent, with the CPUE indices for fillet core vessels analysis; both series suggest a

decline in abundance since the early 1990s. However, the decline in recent years is steeper for the trawl survey series than for the CPUE fillet core vessels indices. However, the change in relative abundance suggested by the CPUE indices cannot be validated. And, as noted by Harley et al. (2001), even if the relative change in CPUE indices did represent abundance, there is considerable evidence that this relationship is, in general, non-linear.

5. ACKNOWLEDGMENTS

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Appendix A: West coast South Island spawning fishery

Table A1: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all vessels by year.

												Year	Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	
Number vessels	69	66	60	57	62	59	59	77	66	56	51	62	231
Total catch ('000 t)	144	114	88	80	98	71	62	79	92	74	79	79	1 059
Number of tows	6 689	6 672	5 095	5 135	6 931	6 503	5 055	6 600	6 577	5 144	5 238	5 755	71 394
Median tow duration (h)	4.2	4.0	3.5	3.2	3.0	3.4	3.5	3.7	3.5	3.1	2.8	2.6	3.4
Median catch per tow (t)	10.0	10.0	12.0	10.0	8.5	5.0	6.8	7.5	10.0	10.0	12.0	9.3	9.5
Median catch per hour (t/h)	2.6	2.5	3.5	3.8	3.1	1.5	1.9	2.0	2.8	3.4	4.5	3.6	2.7

Table A2: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all surimi vessels and for surimi core vessels by year.

												Year	Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	
All vessels													
Number vessels	12	8	7	3	6	6	4	5	5	2	1	1	16
Total catch (t)	67 185	42 484	17 883	9 053	26 653	21 874	15 769	17 535	18 750	7 070	2 673	581	247 509
Number of tows	1 298	781	368	140	503	416	325	383	434	114	43	8	4 813
Median tow duration (h)	7.0	6.3	6.1	7.2	6.0	6.7	6.7	6.6	6.8	4.8	6.8	5.6	6.5
Median catch per tow (t)	40.0	45.0	36.5	52.5	43.4	35.0	30.0	33.2	25.2	35.0	39.0	74.8	38.5
Median catch per hour (t/h)	5.7	6.2	5.5	6.6	6.3	5.0	5.3	5.4	4.7	6.9	5.3	8.2	5.7
Core vessels													
Number vessels	5	7	7	3	6	6	4	5	5	2	1	1	9
Total catch (t)	27 044	40 312	17 883	9 053	26 653	21 874	15 769	17 535	18 750	7 070	2 673	581	205 196
Number of tows	561	747	368	140	503	416	325	383	434	114	43	8	4 042
Median tow duration (h)	6.3	6.1	6.1	7.2	6.0	6.7	6.7	6.6	6.8	4.8	6.8	5.6	6.3
Median catch per tow (t)	34.0	43.0	36.5	52.5	43.4	35.0	30.0	33.2	25.2	35.0	39.0	74.8	36.6
Median catch per hour (t/h)	5.1	6.3	5.5	6.6	6.3	5.0	5.3	5.4	4.7	6.9	5.3	8.2	5.7

Table A3: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all dressed vessels and for dressed core vessels by year.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Year 2001	Total
All vessels													
Number vessels	41	43	42	34	38	38	38	40	34	27	21	23	155
Total catch (t)	34 106	49 800	47 927	43 678	46 679	37 232	25 704	36 860	42 559	38 222	40 015	35 165	477 947
Number of tows	3 612	4 606	3 647	3 433	4 495	4 760	3 165	4 066	3 975	3 238	2 810	2 990	44 797
Median tow duration (h)	3.7	3.8	3.2	2.8	2.7	3.2	3.2	3.7	3.2	2.8	2.5	2.7	3.1
Median catch per tow (t)	7.0	8.0	10.0	10.0	8.0	5.0	5.2	6.0	8.0	9.8	11.6	7.6	7.9
Median catch per hour (t/h)	1.9	2.1	3.5	3.9	3.0	1.5	1.7	1.7	2.3	3.1	4.3	2.9	2.4
Core vessels													
Number vessels	10	16	23	25	29	32	30	32	30	25	20	20	58
Total catch (t)	9 168	19 599	27 298	31 636	37 943	31 587	22 823	33 121	39 707	37 859	37 969	30 722	359 432
Number of tows	743	1 391	1 807	2 453	3 548	4 072	2 743	3 512	3 763	3 214	2 663	2 519	32 428
Median tow duration (h)	3.7	3.8	3.3	2.8	2.6	3.2	3.2	3.6	3.2	2.8	2.7	2.8	3.0
Median catch per tow (t)	9.9	11.0	14.1	10.0	8.0	5.0	5.5	6.3	7.9	9.7	11.3	7.5	8.0
Median catch per hour (t/h)	2.7	3.1	4.1	3.6	3.1	1.5	1.7	1.8	2.3	3.0	4.0	2.5	2.5

Table A4: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all fillet vessels and for fillet core vessels by year.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Year 2001	Total
All vessels													
Number vessels	8	12	8	12	12	10	11	15	17	16	19	19	39
Total catch (t)	10 354	15 001	14 136	19 993	20 391	10 978	14 721	16 749	22 303	19 025	27 027	23 332	214 010
Number of tows	766	1 048	845	1 135	1 525	1 227	1 347	1 546	1 641	1 336	1 954	1 618	15 988
Median tow duration (h)	4.3	4.0	4.2	4.2	3.7	4.0	3.9	4.0	3.9	3.5	3.2	3.6	3.8
Median catch per tow (t)	10.0	10.1	12.0	14.0	9.1	5.0	8.0	8.0	11.2	11.7	11.5	10.5	10.0
Median catch per hour (t/h)	2.2	2.8	3.0	3.7	2.8	1.2	2.0	1.8	3.0	3.3	3.8	2.9	2.7
Core vessels													
Number vessels	8	11	8	12	11	10	11	14	17	16	16	14	31
Total catch (t)	10 354	14 858	14 136	19 993	20 386	10 978	14 721	16 687	22 303	19 025	21 777	16 687	201 904
Number of tows	766	1 026	845	1 135	1 520	1 227	1 347	1 543	1 641	1 336	1 477	1 126	14 989
Median tow duration (h)	4.3	4.0	4.2	4.2	3.7	4.0	3.9	4.0	3.9	3.5	3.7	4.2	4.0
Median catch per tow (t)	10.0	10.4	12.0	14.0	9.1	5.0	8.0	8.0	11.2	11.7	12.0	11.0	10.0
Median catch per hour (t/h)	2.2	2.8	3.0	3.7	2.8	1.2	2.0	1.8	3.0	3.3	3.3	2.6	2.5

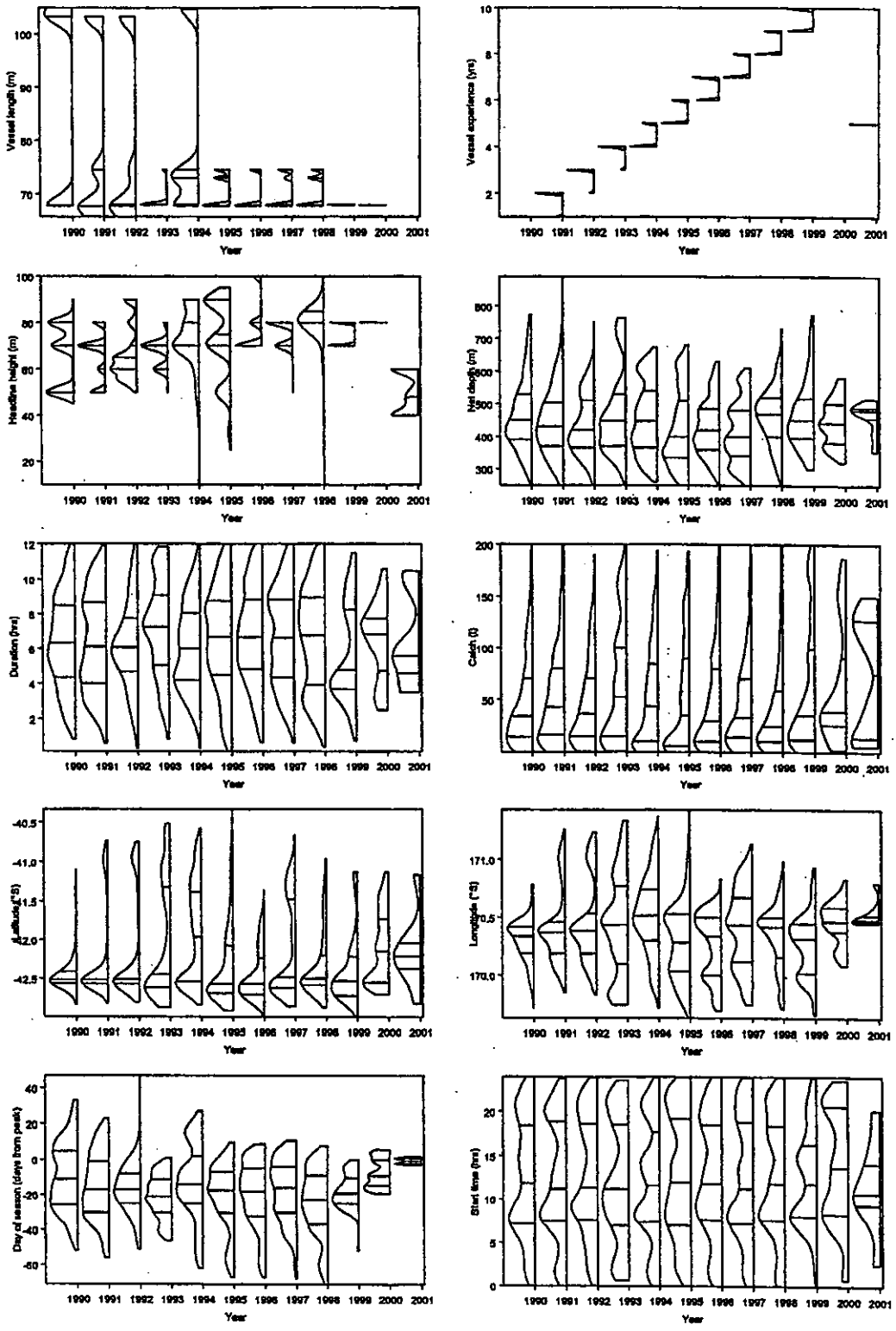

Figure A1: Distribution plots of relative frequency for all west coast South Island surimi core vessel non-zero hoki midwater tows for *vessel length*, vessel *experience*, *headline height*, *net depth*, tow *duration*, hoki catch, start *latitude* and *longitude*, *season*, and *start time* of tow, 1990–2001. Approximate frequencies are plotted by year, with horizontal lines indicating the upper quartile, median, and lower quartile respectively.

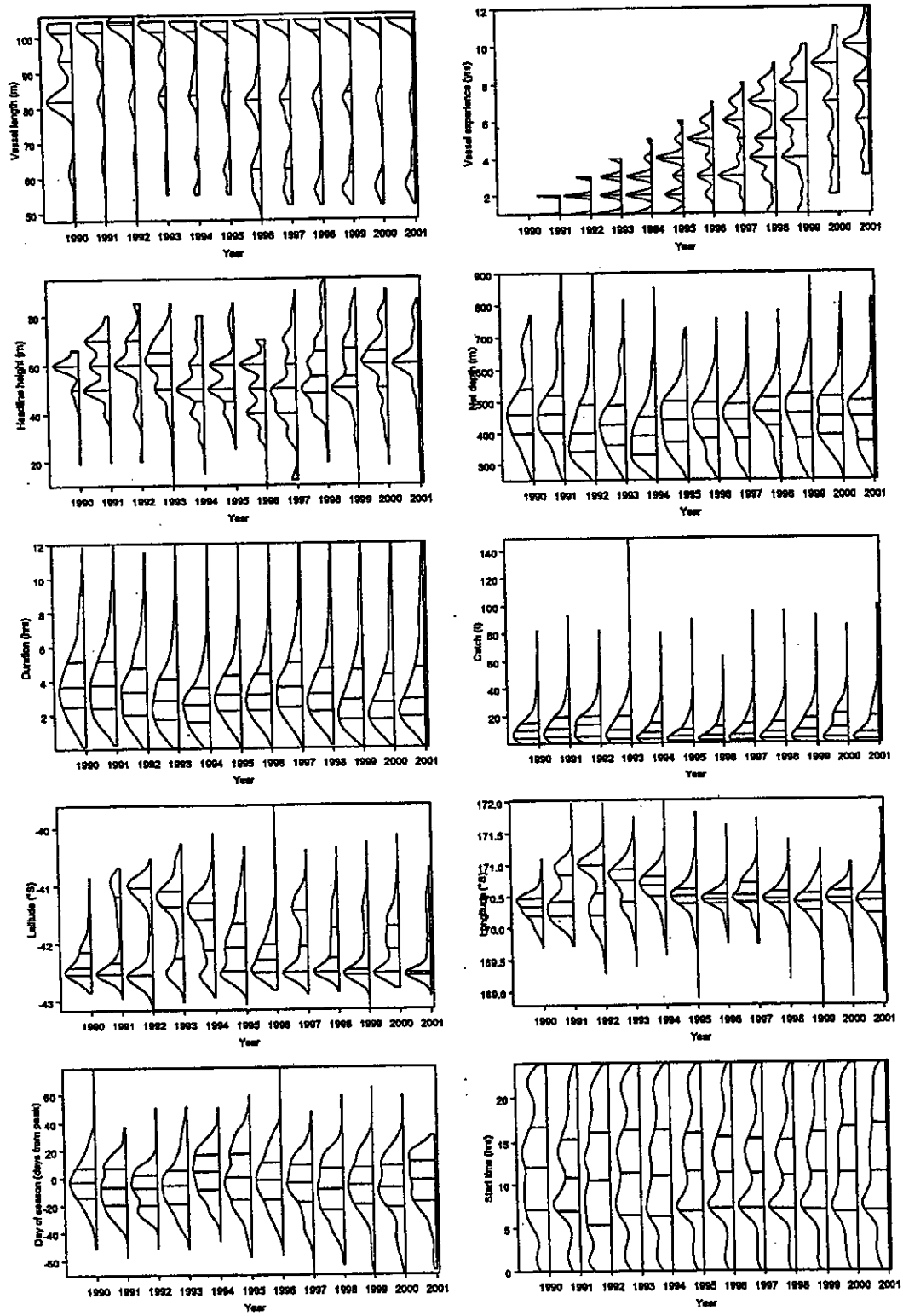

Figure A2: Distribution plots of relative frequency for all west coast South Island dressed core vessel non-zero hoki midwater tows for *vessel length*, vessel *experience*, *headline height*, *net depth*, tow *duration*, hoki catch, start *latitude* and *longitude*, *season*, and *start time* of tow, 1990–2001. Approximate frequencies are plotted by year, with horizontal lines indicating the upper quartile, median, and lower quartile respectively.

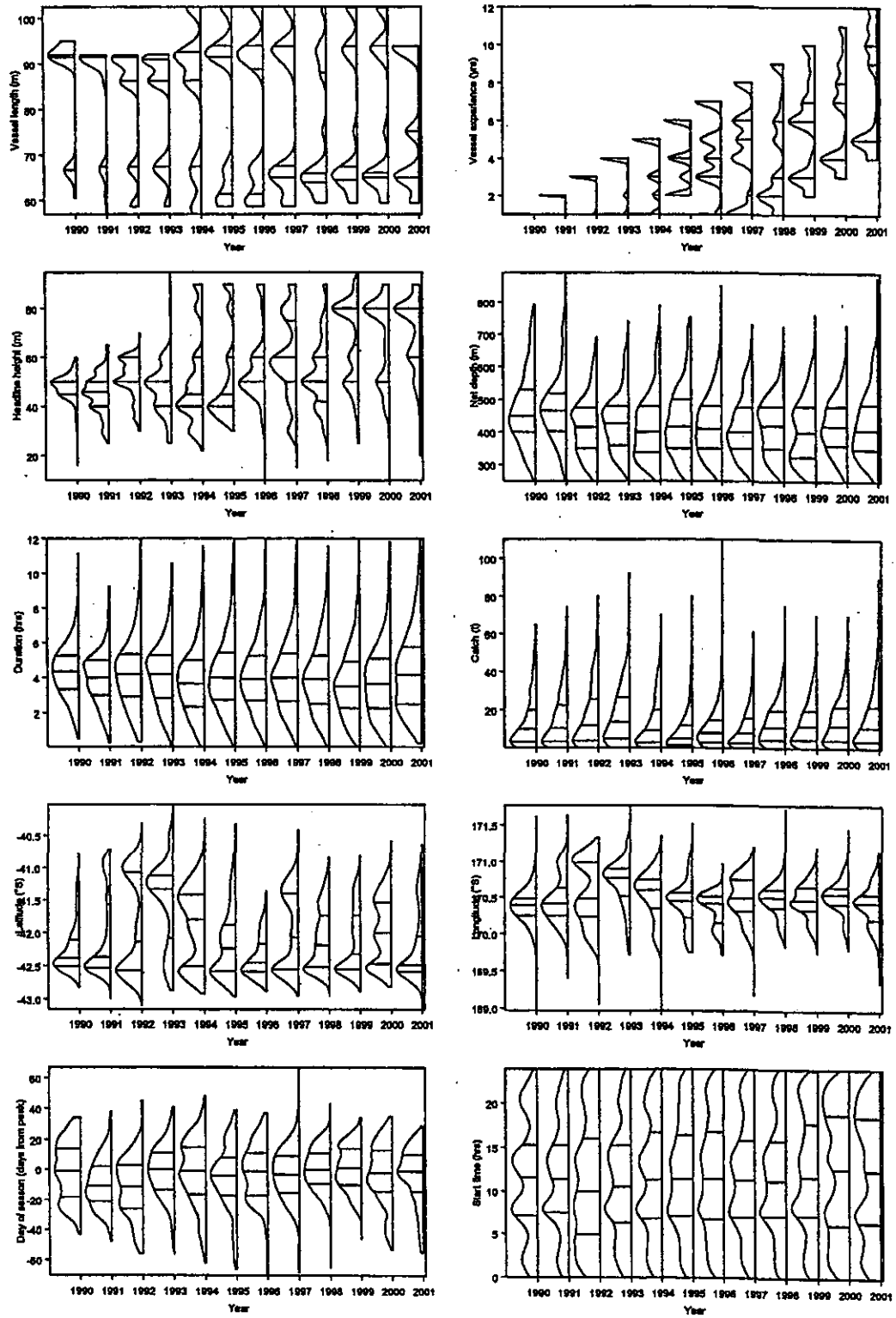

Figure A3: Distribution plots of relative frequency for all west coast South Island fillet core vessel non-zero hoki midwater tows for *vessel length*, vessel *experience*, *headline height*, *net depth*, tow *duration*, hoki catch, start *latitude* and *longitude*, *season*, and *start time* of tow, 1990–2001. Approximate frequencies are plotted by year, with horizontal lines indicating the upper quartile, median, and lower quartile respectively.

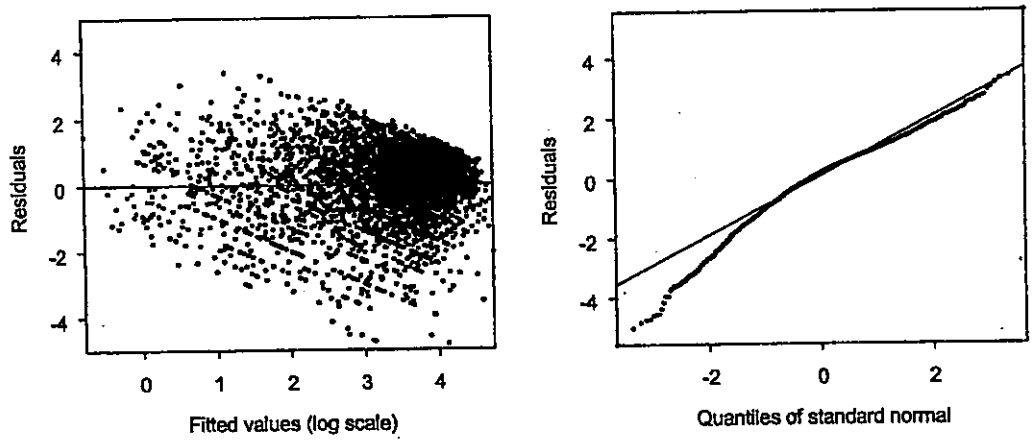

Figure A4: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the surimi core vessels model for the west coast South Island.

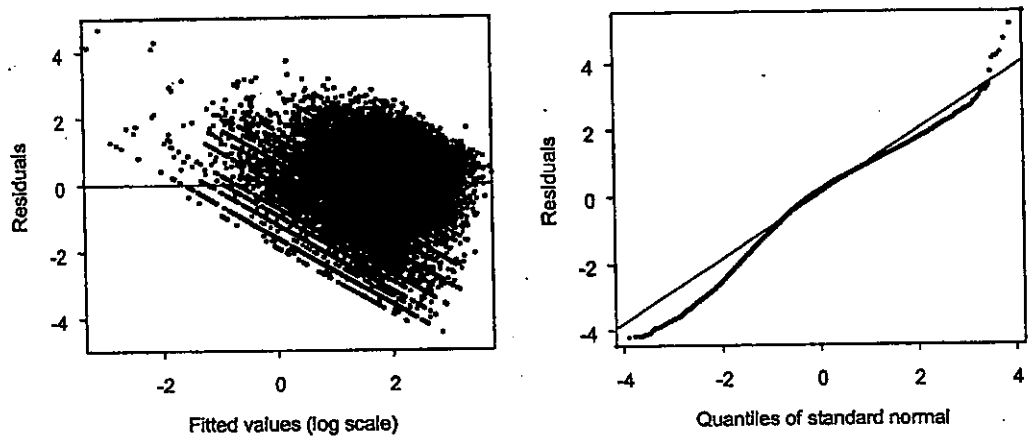

Figure A5: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the dressed core vessels model for the west coast South Island.

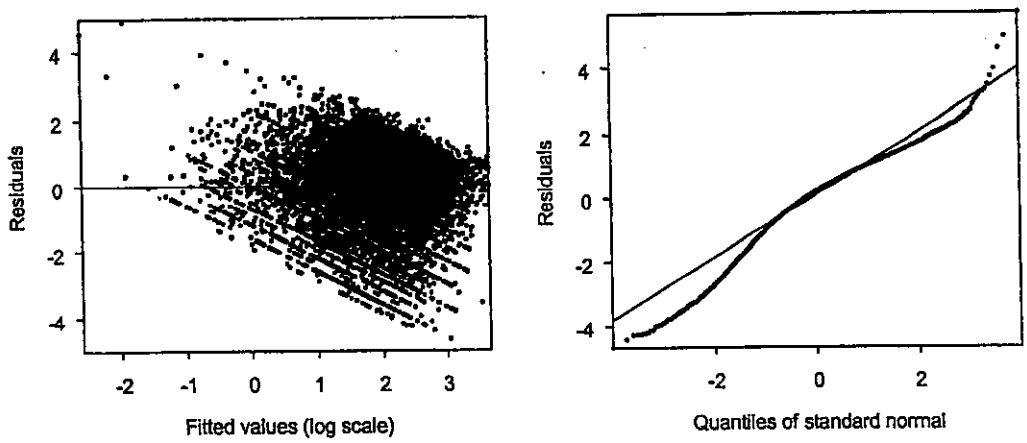

Figure A6: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the fillet core vessels model for the west coast South Island.

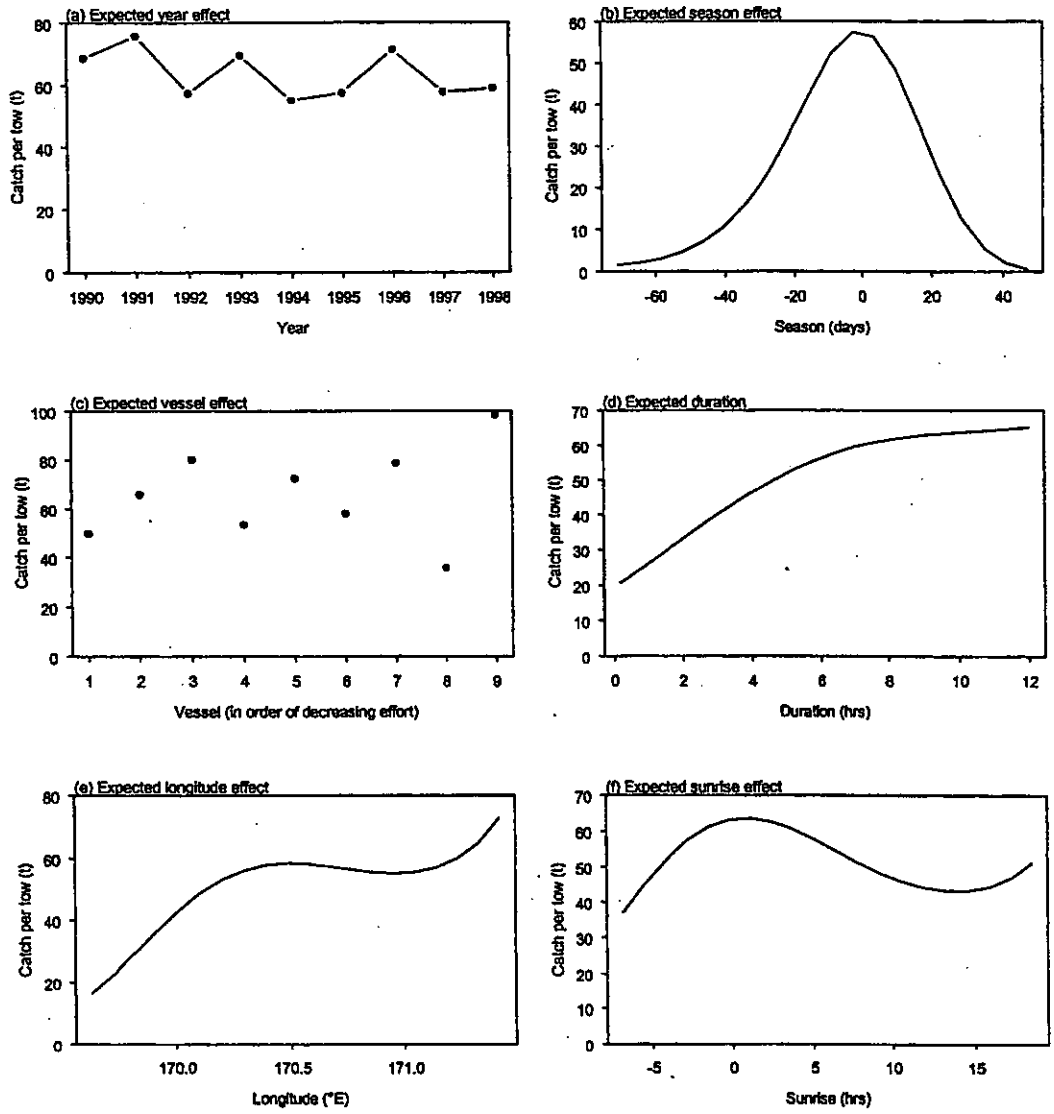

Figure A7: Expected catch rates (t per tow) for median values of fixed parameters for the surimi core vessels model for the west coast South Island (*Year*=1997, *Season*=0, *Duration*=6.5, *Vessel*=6, *Sunrise*=5.0, *Longitude*=170.4°E).

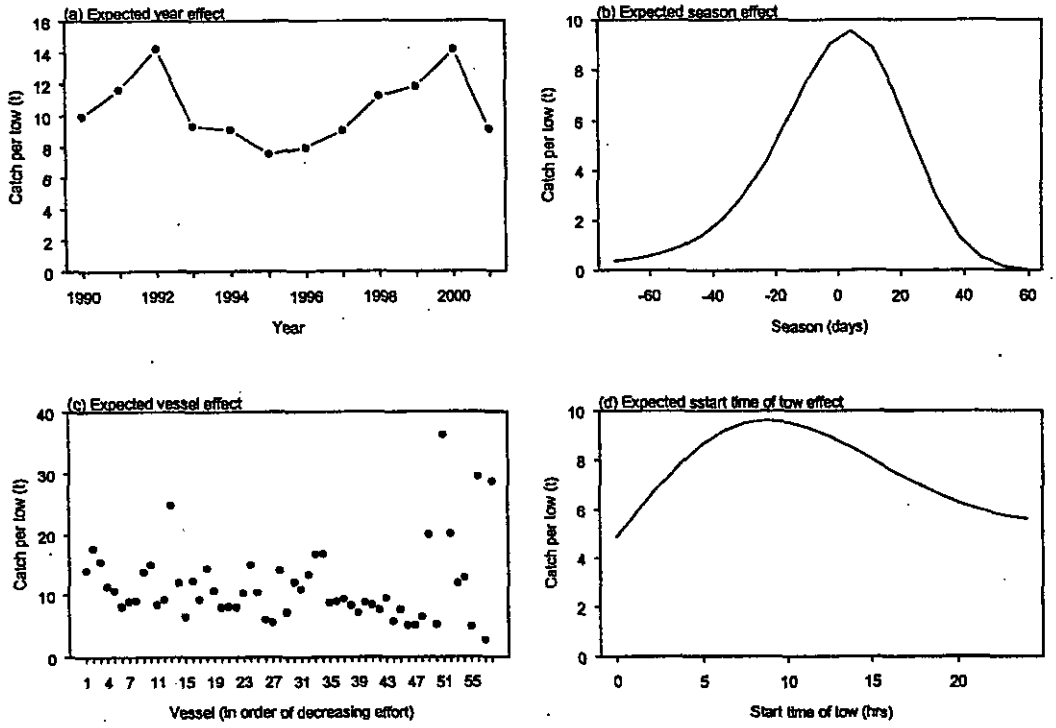

Figure A8: Expected catch rates (t per tow) for median values of fixed parameters for the dressed core vessels model for the west coast South Island (*Year*=1993, *Season*=0, *Vessel*=37, *Start time*=11.2).

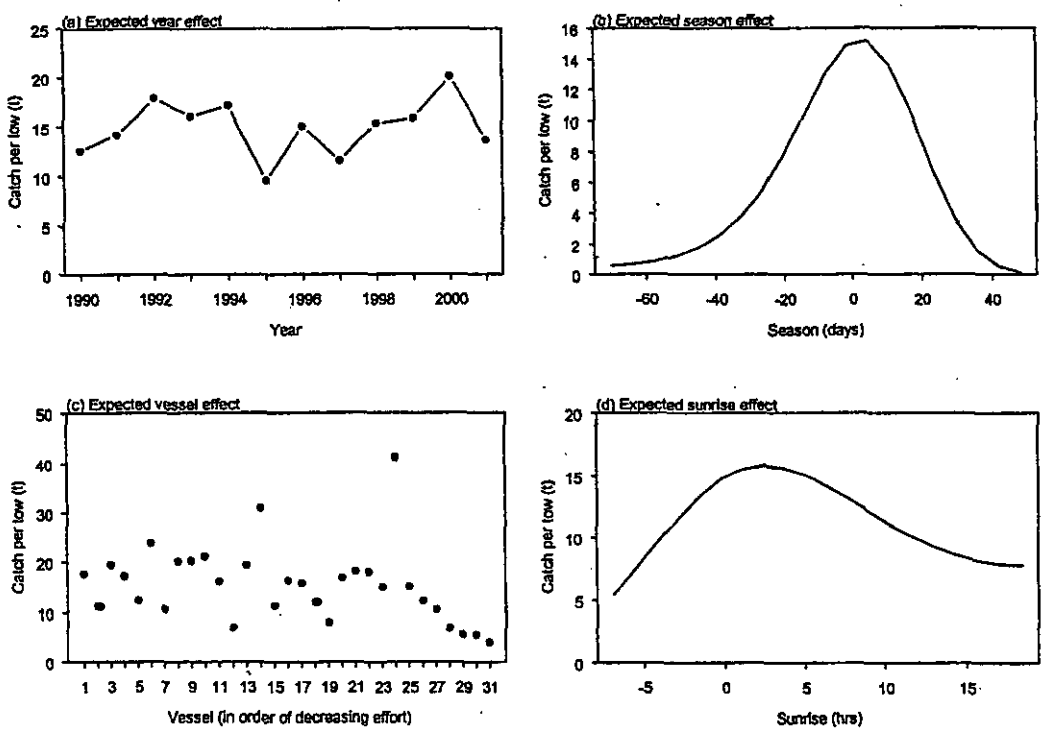

Figure A9: Expected catch rates (t per tow) for median values of fixed parameters for the fillet core vessels model for the west coast South Island (*Year*=1996, *Season*=0, *Vessel*=23, Sunrise=5.0).

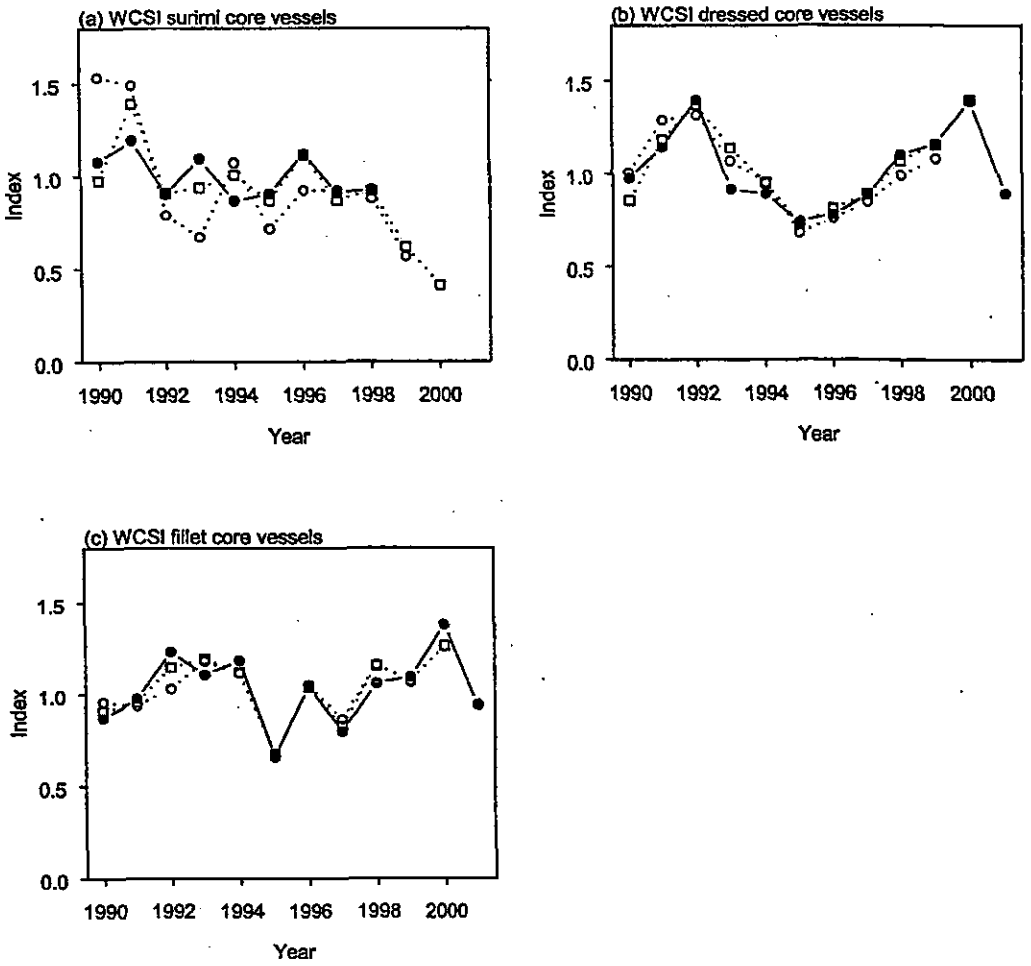

Figure A10: Relative indices (scaled to have mean 1 for the years 1990–1999) for the surimi, dressed, and fillet core vessels for the west coast South Island fishery (filled circles), and the equivalent indices from Langley et al. (2001) (open circles) and Dunn (2001) (squares).

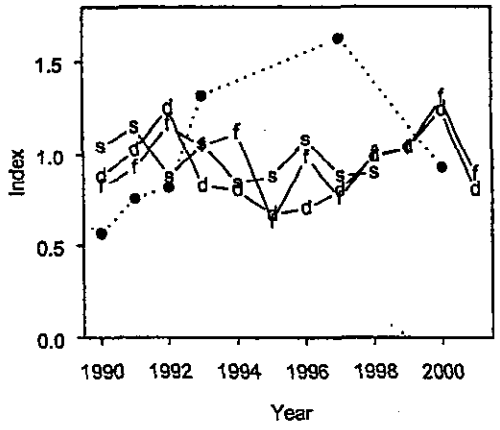

Figure A11: Relative indices (scaled to have mean 1 for the years in common) for the surimi (s), dressed (d), and fillet (f) core vessels for the west coast South Island fishery, and from the west coast South Island acoustic surveys (filled circles).

Appendix B: Cook Strait spawning fishery

Table B1: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all vessels and for core vessels by year.

	Year												Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	
All vessels													
Number vessels	17	21	22	18	28	24	36	33	29	21	21	25	66
Total catch (t)	11 327	21 326	17 242	16 420	23 358	23 304	39 007	37 608	28 127	27 194	26 961	22 719	294 591
Number of tows	1 035	2 026	1 553	1 464	1 755	2 043	2 974	3 180	2 220	1 964	1 849	1 714	23 777
Median tow duration (h)	1.2	1.5	1.2	1.0	1.0	0.8	0.5	0.7	0.8	0.7	0.5	0.6	0.8
Median catch per tow (t)	8.8	8.0	8.0	8.5	11.3	8.5	11.0	10.0	11.2	13.4	13.0	12.0	10.0
Median catch per hour (t/h)	8.0	5.2	6.7	7.8	12.5	13.2	20.0	15.0	13.3	17.0	24.0	18.0	12.5
Core vessels													
Number vessels	7	9	12	10	13	15	18	16	15	14	14	13	18
Total catch (t)	4 345	9 540	9 219	10 287	15 692	19 356	25 067	20 888	18 789	19 511	20 830	15 934	189 455
Number of tows	373	993	786	814	1 025	1 396	1 685	1 791	1 505	1 438	1 385	1 116	14 307
Median tow duration (h)	1.0	1.5	1.2	1.0	1.0	0.8	0.6	0.7	0.8	0.6	0.5	0.6	0.8
Median catch per tow (t)	10.0	7.0	8.0	10.0	13.9	11.8	13.1	10.0	10.9	11.9	14.0	12.6	11.0
Median catch per hour (t/h)	11.9	4.8	6.8	9.2	13.3	18.0	21.7	15.0	14.2	17.0	25.0	20.8	14.6

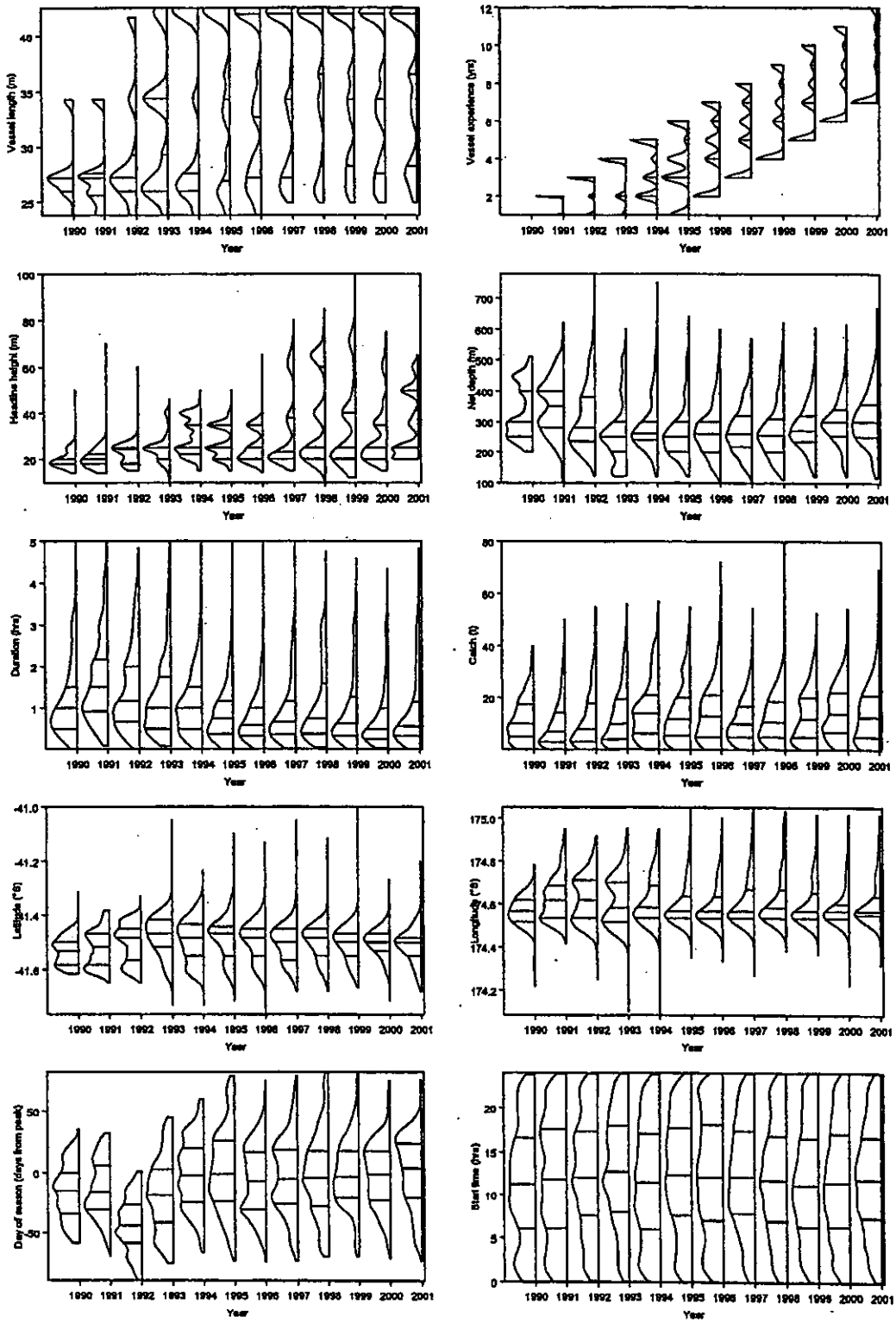

Figure B1: Distribution plots of relative frequency for all Cook Strait core vessel non-zero hoki midwater tows for *vessel length*, vessel *experience*, *headline height*, *net depth*, tow *duration*, hoki catch, start *latitude* and *longitude*, *season*, and *start time* of tow, 1990–2001. Approximate frequencies are plotted by year, with horizontal lines indicating the upper quartile, median, and lower quartile respectively.

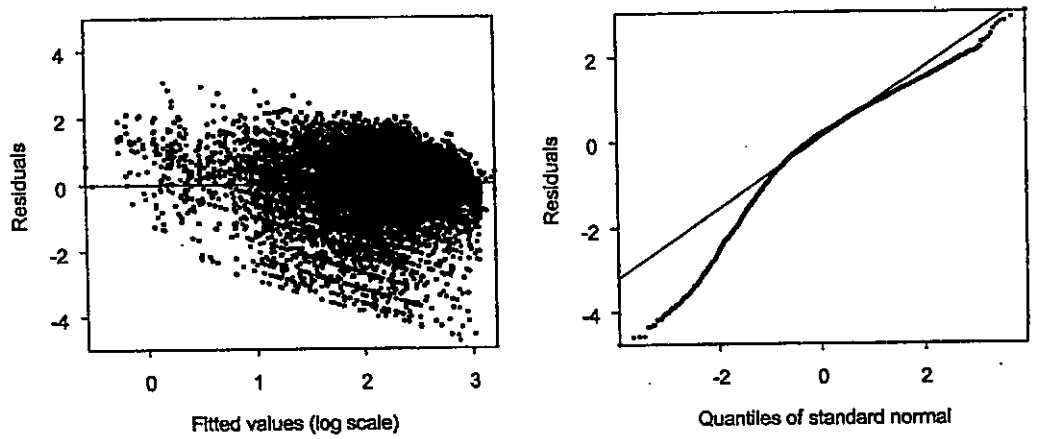

Figure B2: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the core vessels model for the Cook Strait.

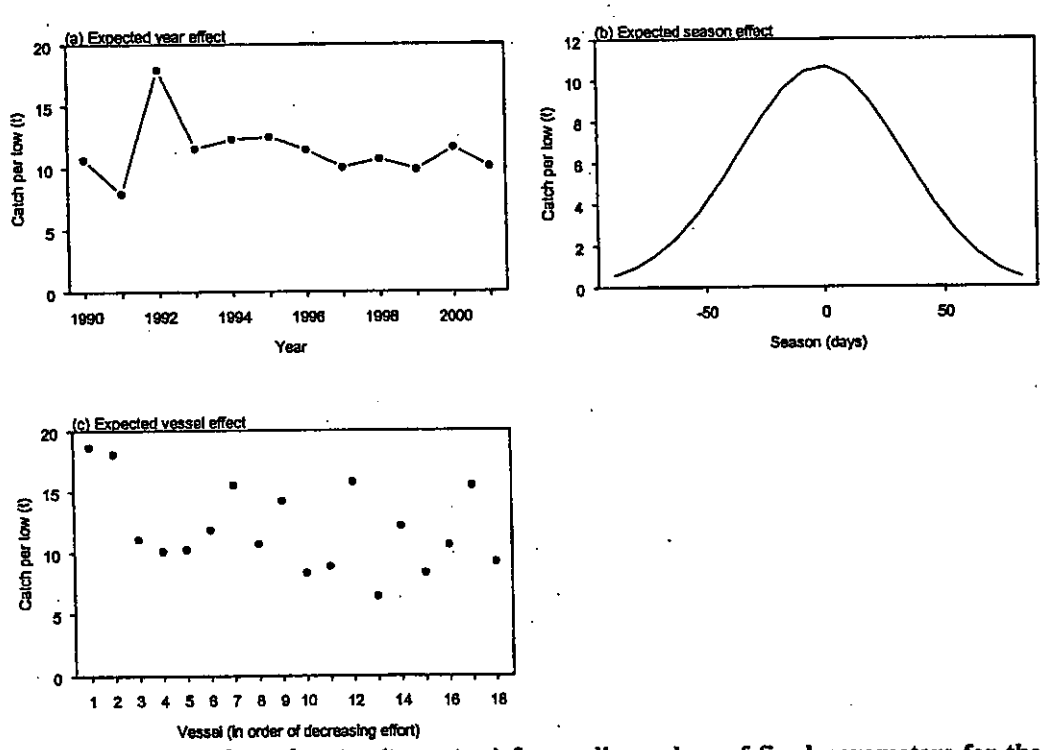

Figure B3: Expected catch rates (t per tow) for median values of fixed parameters for the core vessels model for the Cook Strait (*Year*=1996, *Season*=0, *Vessel*=8).

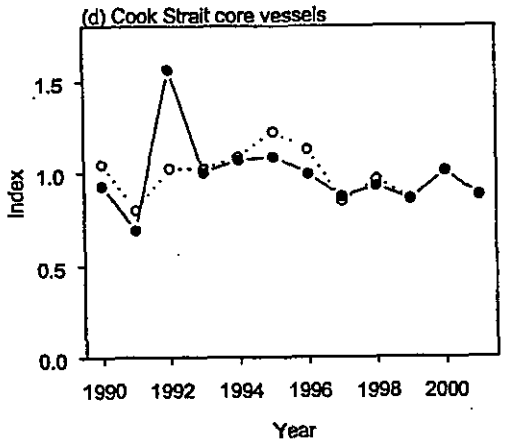

Figure B4: Relative indices (scaled to have mean 1 for the years 1990–1999) for the core vessels for the Cook Strait (filled circles), and the equivalent indices from Langley et al. (2001) (open circles).

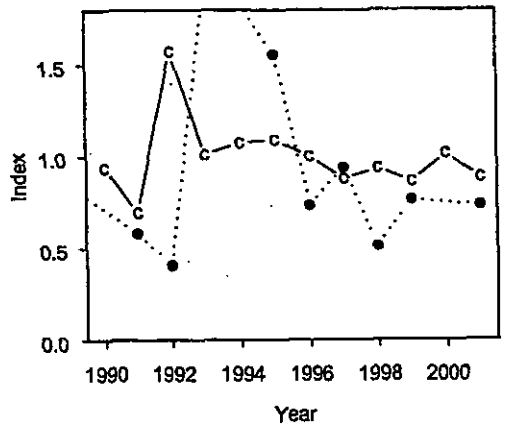

Figure B5: Relative indices (scaled to have mean 1 for the years in common) for the core vessels (c) for the west coast South Island fishery, and from the Cook Strait acoustic surveys (filled circles).

Appendix C: Chatham Rise non-spawning fishery

Table C1: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all vessels, core vessels, and fillet core vessels by year.

												Year	Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	
All vessels													
Number vessels	39	47	58	49	51	53	61	78	73	62	50	53	172
Total catch (t)	11 659	15 930	39 257	35 804	14 699	23 872	29 756	35 146	46 576	56 449	41 090	41 466	391 703
Number of tows	2 442	3 789	5 892	5 645	3 292	5 450	6 721	7 943	10 053	10 888	8 755	9 486	80 356
Median tow duration (h)	4.0	4.0	3.9	3.6	3.3	3.5	3.5	3.7	4.0	4.0	4.1	4.5	4.0
Median catch per tow (t)	2.5	2.7	4.8	4.8	3.5	3.6	3.2	3.5	3.9	4.3	3.8	3.5	3.9
Median catch per hour (t/h)	0.7	0.7	1.3	1.4	1.1	1.0	1.0	1.0	1.0	1.1	0.9	0.8	1.0
Core vessels													
Number vessels	12	15	29	28	33	33	37	49	45	40	38	35	61
Total catch (t)	6 565	7 859	21 452	21 186	11 738	20 781	25 062	32 289	44 369	48 994	32 134	29 081	301 511
Number of tows	891	1 427	3 048	3 658	2 629	4 716	5 081	6 838	9 136	9 283	7 002	6 862	60 571
Median tow duration (h)	3.8	4.0	4.0	3.7	3.3	3.5	3.5	3.8	4.0	4.0	4.1	4.5	4.0
Median catch per tow (t)	4.9	3.2	5.0	4.6	3.8	3.7	4.0	4.0	4.0	4.5	3.8	3.2	4.0
Median catch per hour (t/h)	1.3	0.9	1.3	1.3	1.1	1.0	1.1	1.0	1.0	1.1	0.9	0.8	1.0
Fillet core vessels													
Number vessels	2	3	7	5	9	10	10	16	17	14	11	11	18
Total catch (t)	2 004	5 901	8 843	12 505	8 661	18 306	22 867	29 573	42 598	47 174	29 885	27 054	255 370
Number of tows	238	876	1 373	2 259	1 881	3 855	4 066	5 627	8 206	8 294	6 040	5 978	48 693
Median tow duration (h)	4.0	4.0	3.7	3.4	3.2	3.3	3.5	4.0	4.0	4.0	4.1	4.5	4.0
Median catch per tow (t)	7.0	5.0	5.0	4.9	4.0	4.0	4.5	4.2	4.0	5.0	4.0	3.6	4.0
Median catch per hour (t/h)	1.9	1.4	1.4	1.5	1.3	1.2	1.3	1.2	1.1	1.2	1.0	0.8	1.1

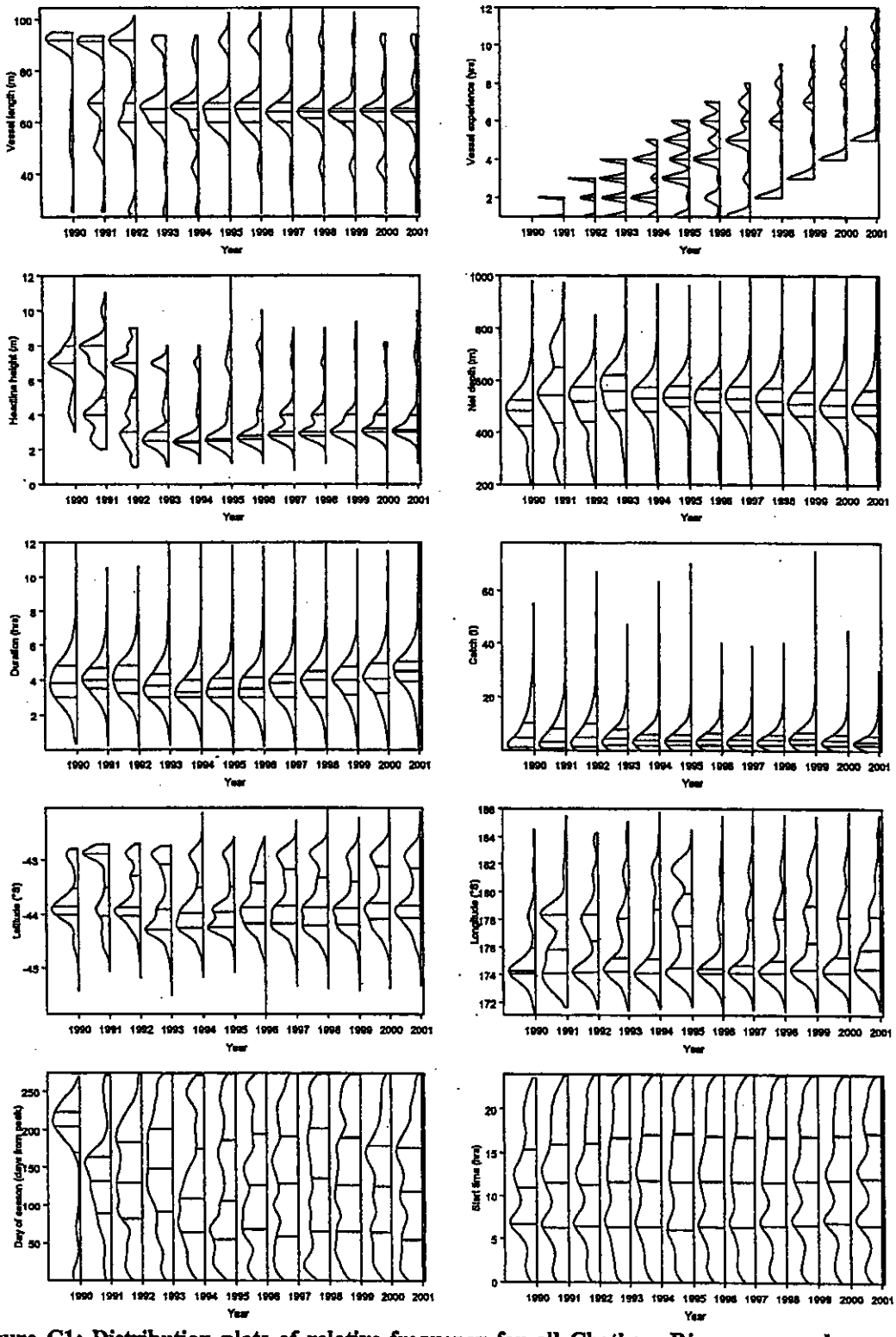

Figure C1: Distribution plots of relative frequency for all Chatham Rise core vessel non-zero hoki bottom tows for *vessel length*, vessel *experience*, *headline height*, *net depth*, tow *duration*, hoki catch, start *latitude* and *longitude*, *season*, and *start time* of tow, 1990–2001. Approximate frequencies are plotted by year, with horizontal lines indicating the upper quartile, median, and lower quartile respectively.

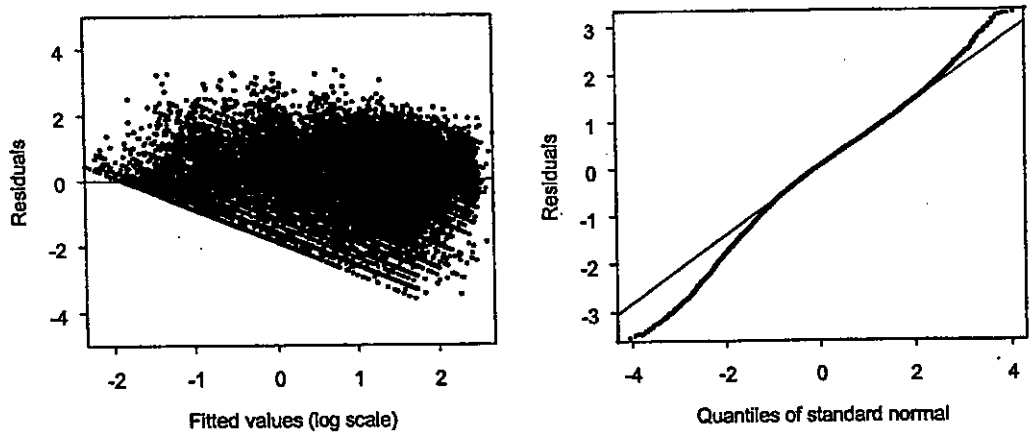

Figure C2: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the core vessels model for the Chatham Rise.

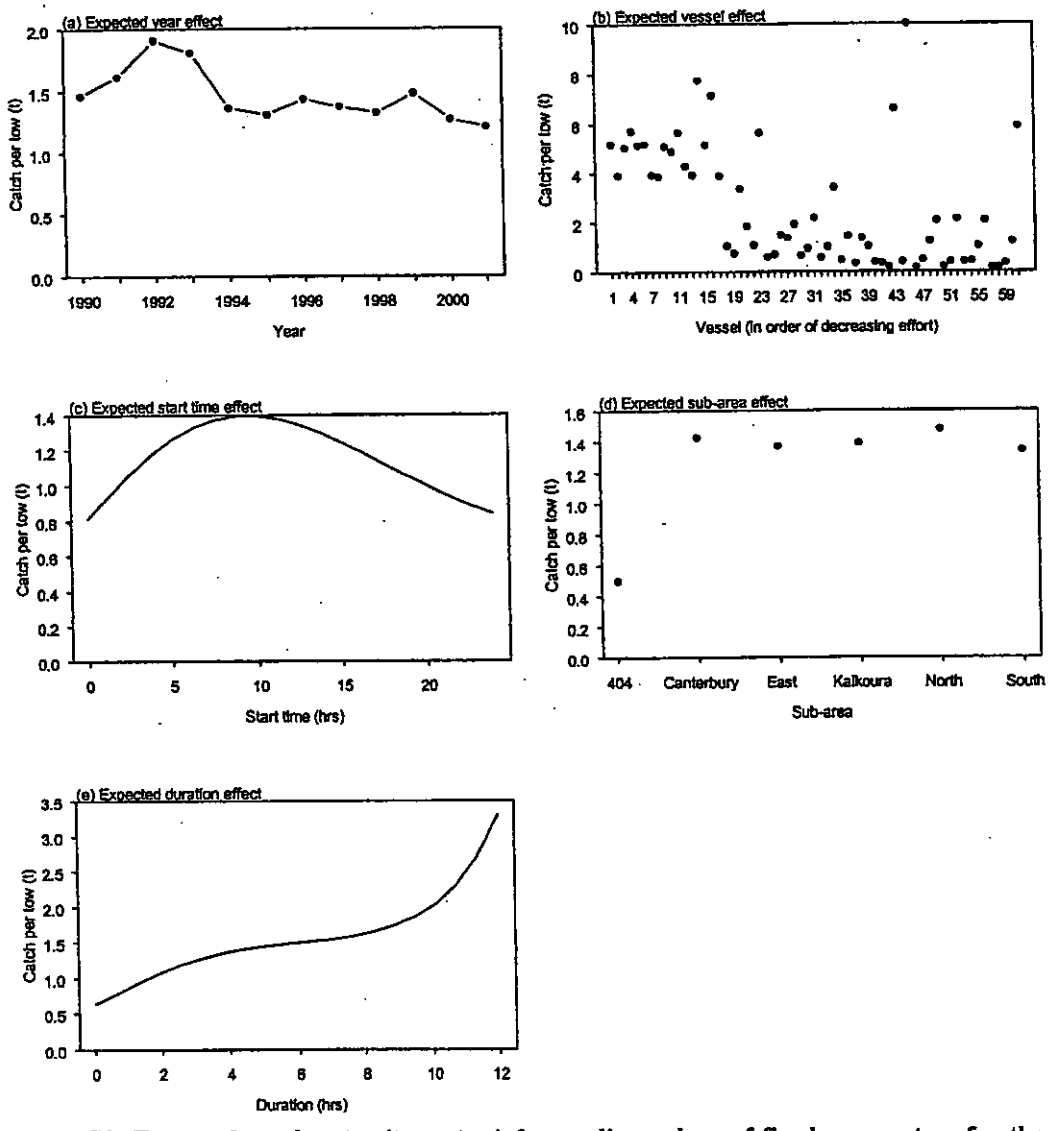

Figure C3: Expected catch rates (t per tow) for median values of fixed parameters for the core vessels model for the Chatham Rise (*Year*=1997, *Vessel*=27, *Start time*=11.7, *Duration*=4, *Sub-area*=East).

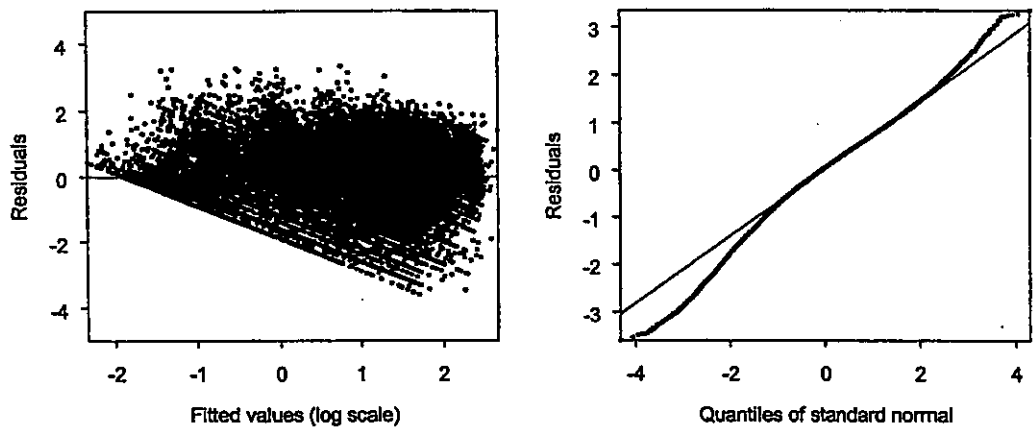

Figure C4: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the fillet core vessels model for the Chatham Rise.

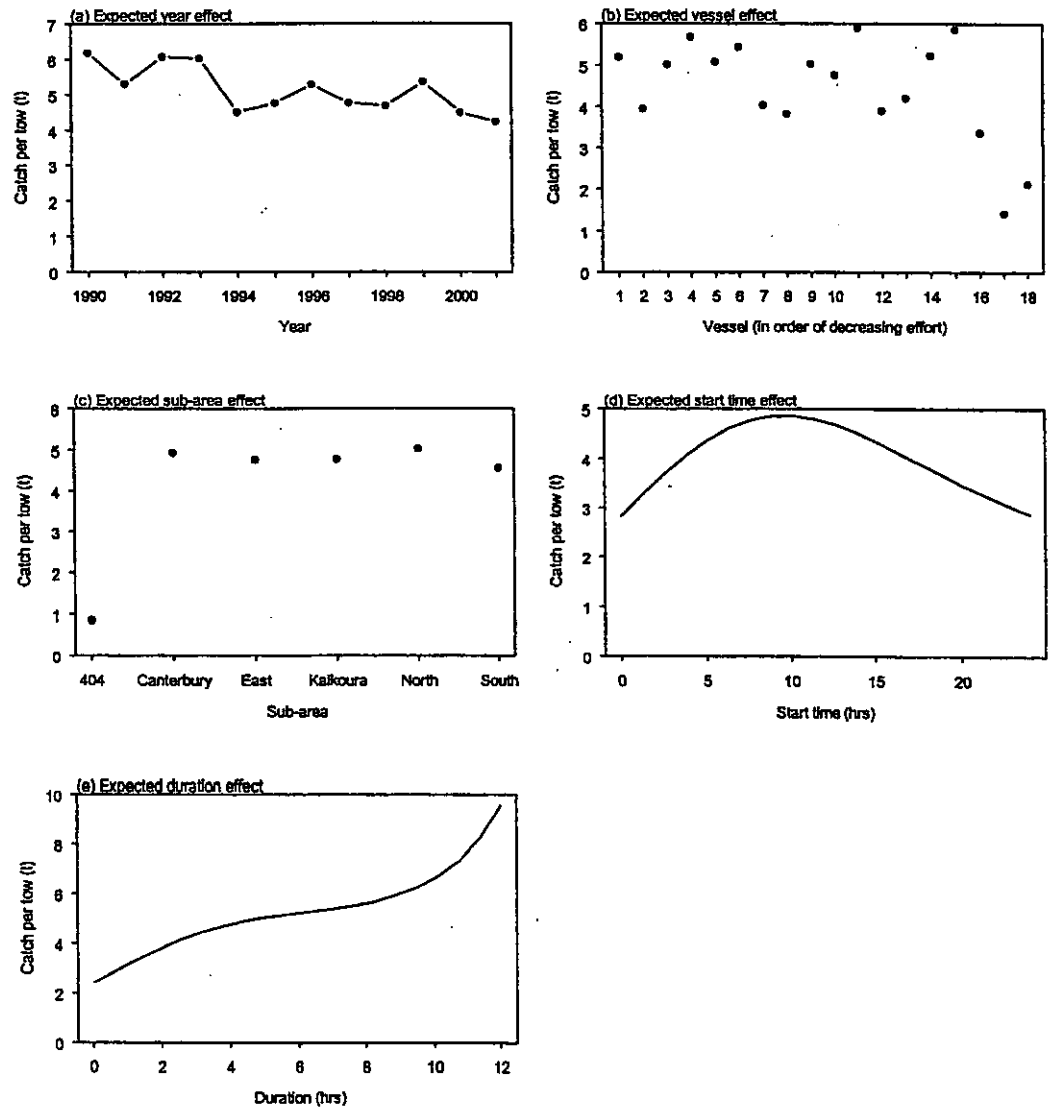

Figure C5: Expected catch rates (t per tow) for median values of fixed parameters for the fillet core vessels model for the Chatham Rise (*Year*=1995, *Vessel*=10, *Start time*=11.8, *Duration*=4, *Sub-area*=East).

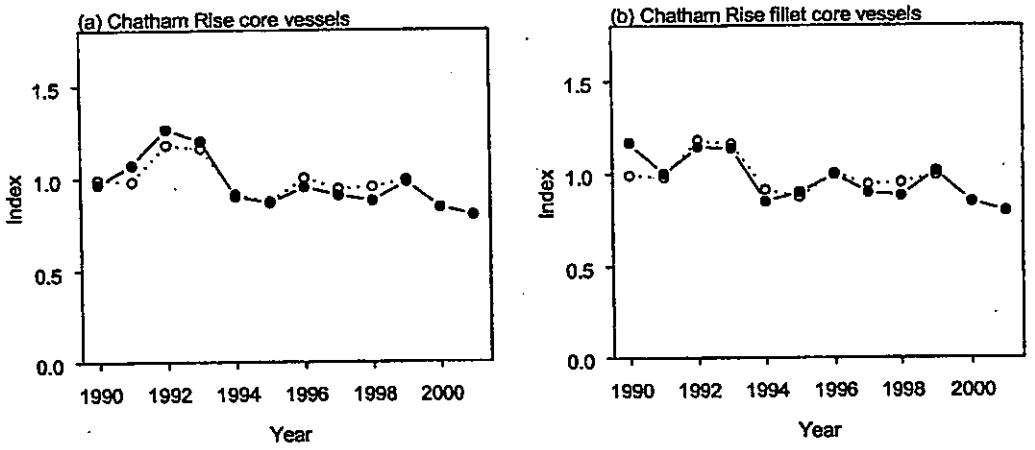

Figure C6: Relative indices (scaled to have mean 1 for the years 1990–1999) of the core vessels for the Chatham Rise (filled circles), and the equivalent indices from Langley et al. (2001) (open circles).

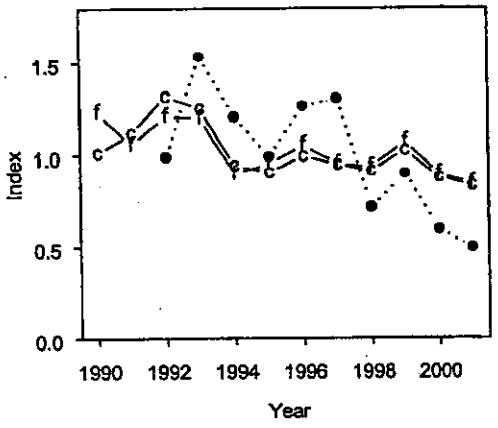

Figure C7: Relative indices (scaled to have mean 1 for the years in common) for the core vessels (c) and fillet core vessels (f) for the Chatham Rise fishery, and from the Chatham Rise trawl surveys for strata 300–800 m (open circles).

Appendix D: Sub-Antarctic non-spawning fishery

Table D1: Number of non-zero hoki midwater tows, vessels, median tow duration, catch per tow, and catch per hour for all vessels, core vessels, and fillet core vessels by year.

											Year	Total
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	
All vessels												
Number vessels	34	35	30	35	27	33	44	39	38	33	34	119
Total catch (t)	14 325	27 528	20 434	7 404	11 717	9 372	16 039	18 776	15 509	24 564	19 956	185 623
Number of tows	3 340	5 271	4 867	1 836	2 463	2 382	3 179	3 980	3 038	4 709	4 436	39 501
Median tow duration (h)	4.1	4.1	3.8	3.9	4.1	4.0	4.2	4.3	4.6	4.4	4.5	4.2
Median catch per tow (t)	3.0	4.0	3.0	3.0	3.7	3.0	4.0	3.6	3.5	3.5	3.0	3.5
Median catch per hour (t/h)	0.7	1.0	0.9	0.8	0.9	0.8	1.0	0.9	0.8	0.8	0.7	0.8
Core vessels												
Number vessels	8	10	14	12	14	14	24	21	17	18	17	27
Total catch (t)	3 825	10 531	10 399	4 803	7 799	6 492	14 417	13 299	7 132	13 680	9 660	102 037
Number of tows	649	2 034	2 365	1 222	1 835	1 634	2 630	2 852	1 588	3 045	2 595	22 449
Median tow duration (h)	4.0	4.0	3.8	4.0	4.0	4.0	4.2	4.5	4.7	4.4	4.7	4.2
Median catch per tow (t)	3.0	4.0	3.1	3.0	3.0	3.0	4.4	3.5	3.0	3.0	2.5	3.0
Median catch per hour (t/h)	0.8	1.0	0.9	0.8	0.8	0.8	1.1	0.8	0.7	0.7	0.6	0.8
Fillet core vessels												
Number vessels	2	5	6	4	5	6	8	11	8	8	8	11
Total catch (t)	1 282	10 257	10 034	4 612	7 465	6 286	12 520	12 835	5 962	12 108	8 364	91 724
Number of tows	358	1 935	2 193	1 043	1 548	1 390	1 985	2 384	1 088	2 111	1 855	17 890
Median tow duration (h)	4.0	4.0	3.8	3.8	4.0	3.9	4.0	4.4	4.4	4.1	4.5	4.0
Median catch per tow (t)	3.0	4.2	3.5	3.0	4.0	3.7	5.0	4.0	4.0	4.3	3.5	4.0
Median catch per hour (t/h)	0.8	1.1	0.9	1.0	1.0	1.0	1.2	1.0	0.9	1.0	0.8	1.0

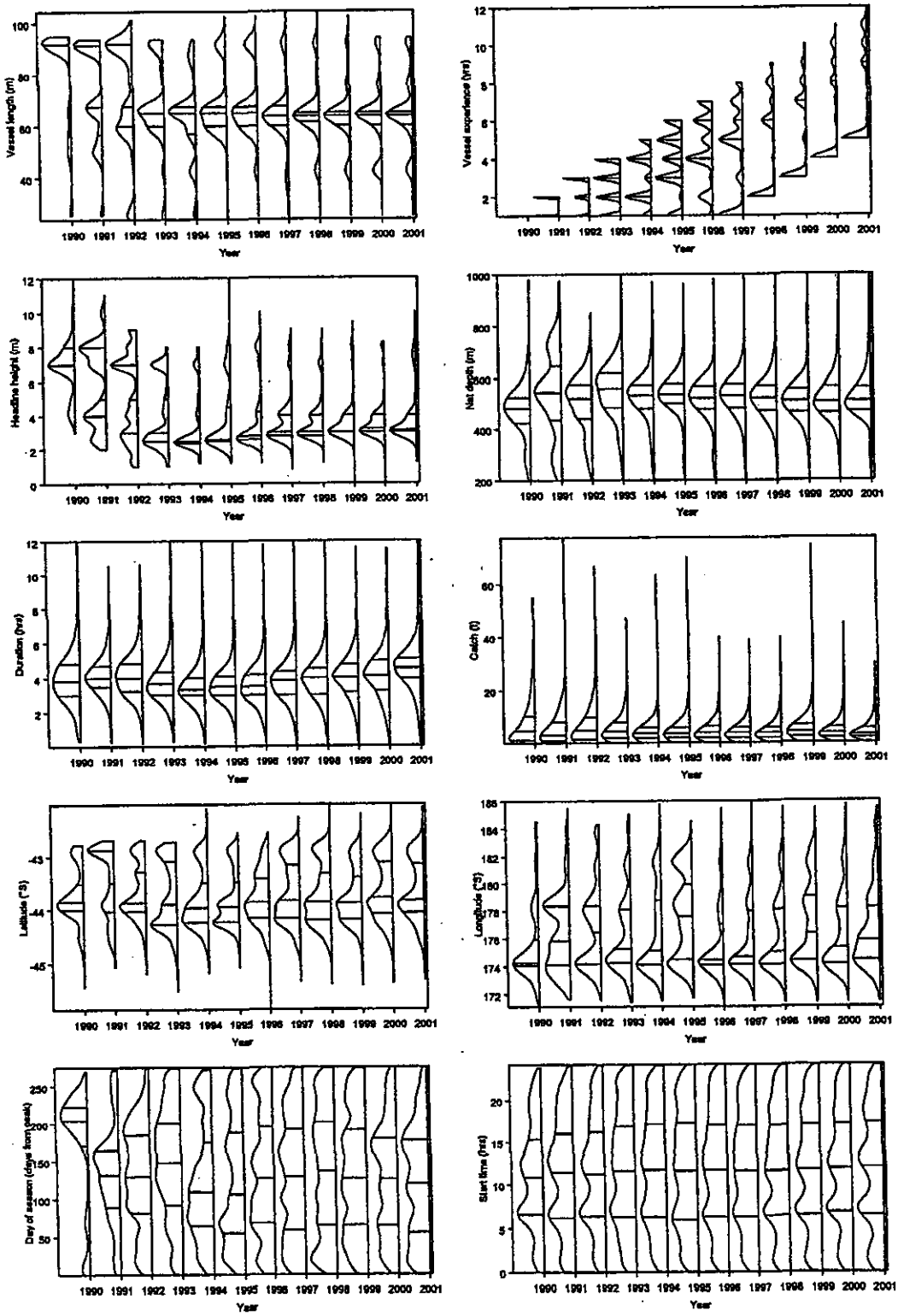

Figure D1: Distribution plots of relative frequency for all sub-Antarctic core vessel non-zero hoki bottom tows for *vessel length*, vessel *experience*, *headline height*, *net depth*, tow *duration*, hoki catch, start *latitude* and *longitude*, *season*, and *start time* of tow, 1991–2001. Approximate frequencies are plotted by year, with horizontal lines indicating the upper quartile, median, and lower quartile respectively.

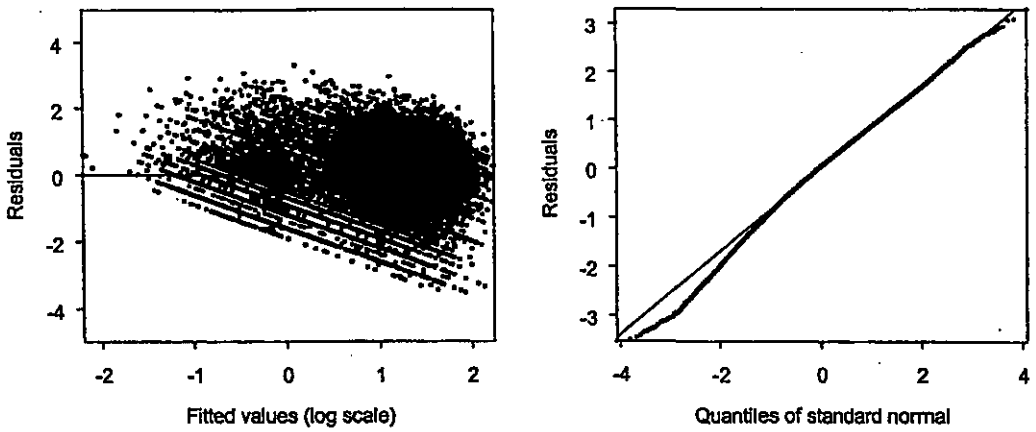

Figure D2: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the core vessels model for the sub-Antarctic.

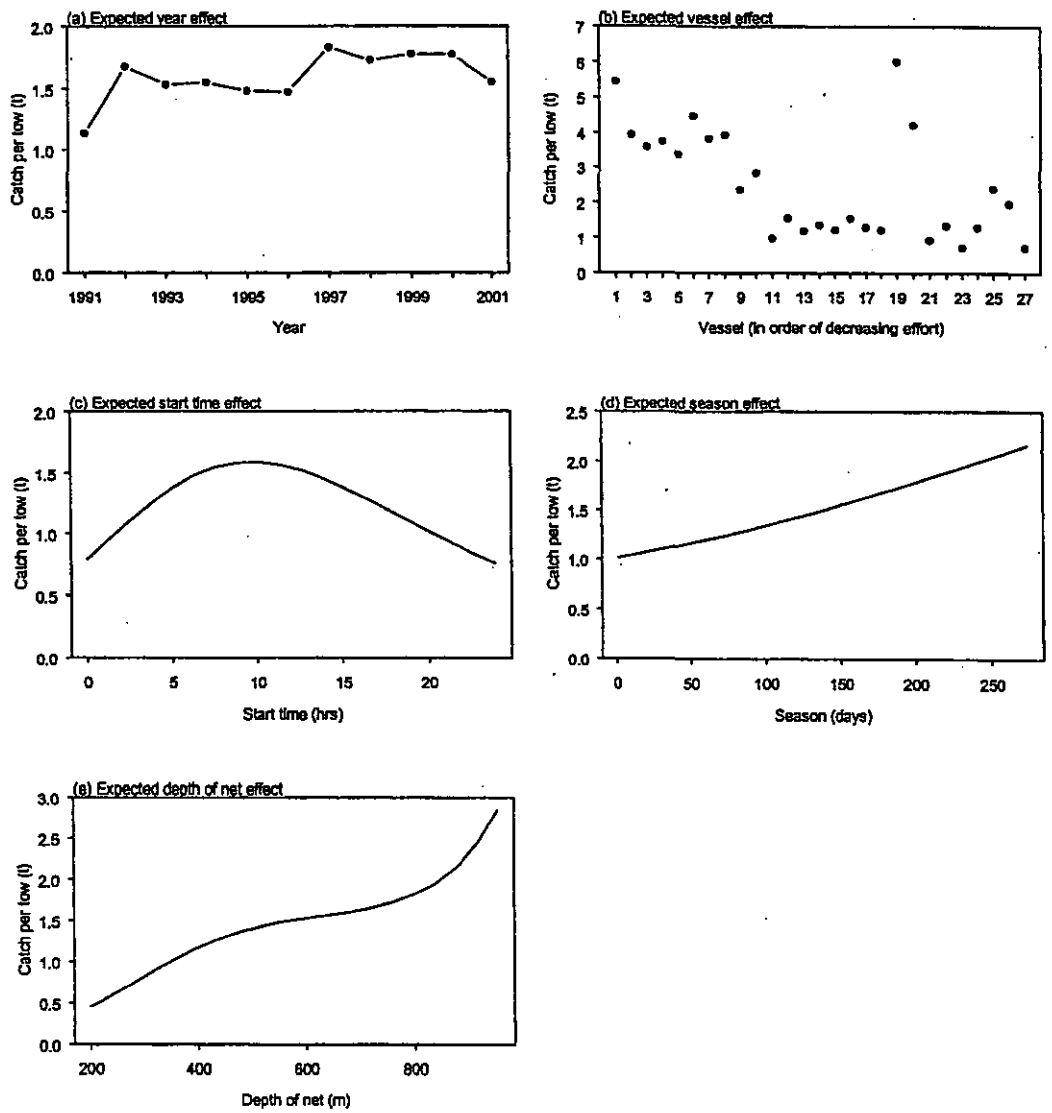

Figure D3: Expected catch rates (t per tow) for median values of fixed parameters for the core vessels model for the sub-Antarctic (*Year*=1994, *Vessel*=12, *Start time*=12, *Season*=150, *Net depth*=618).

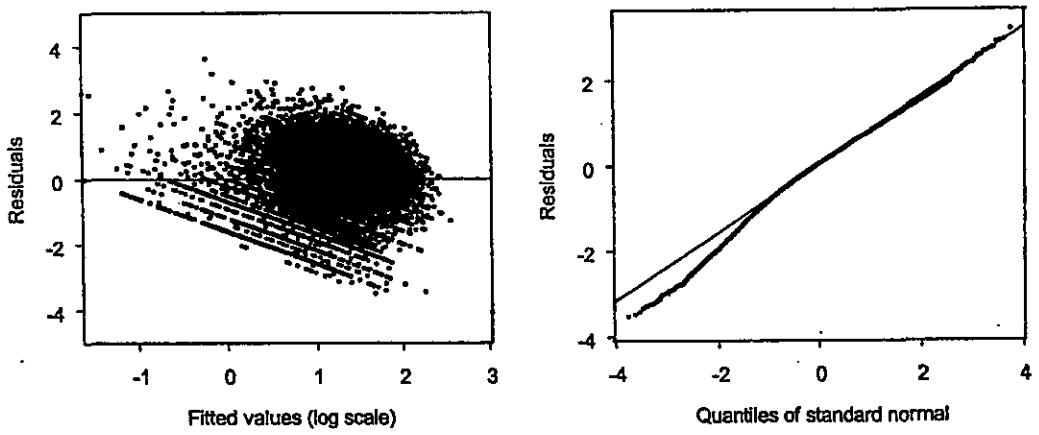

Figure D4: Distribution of the linear predictor (fitted values) against residuals and normalised residuals against standardised residuals for the fillet core vessels model for the sub-Antarctic.

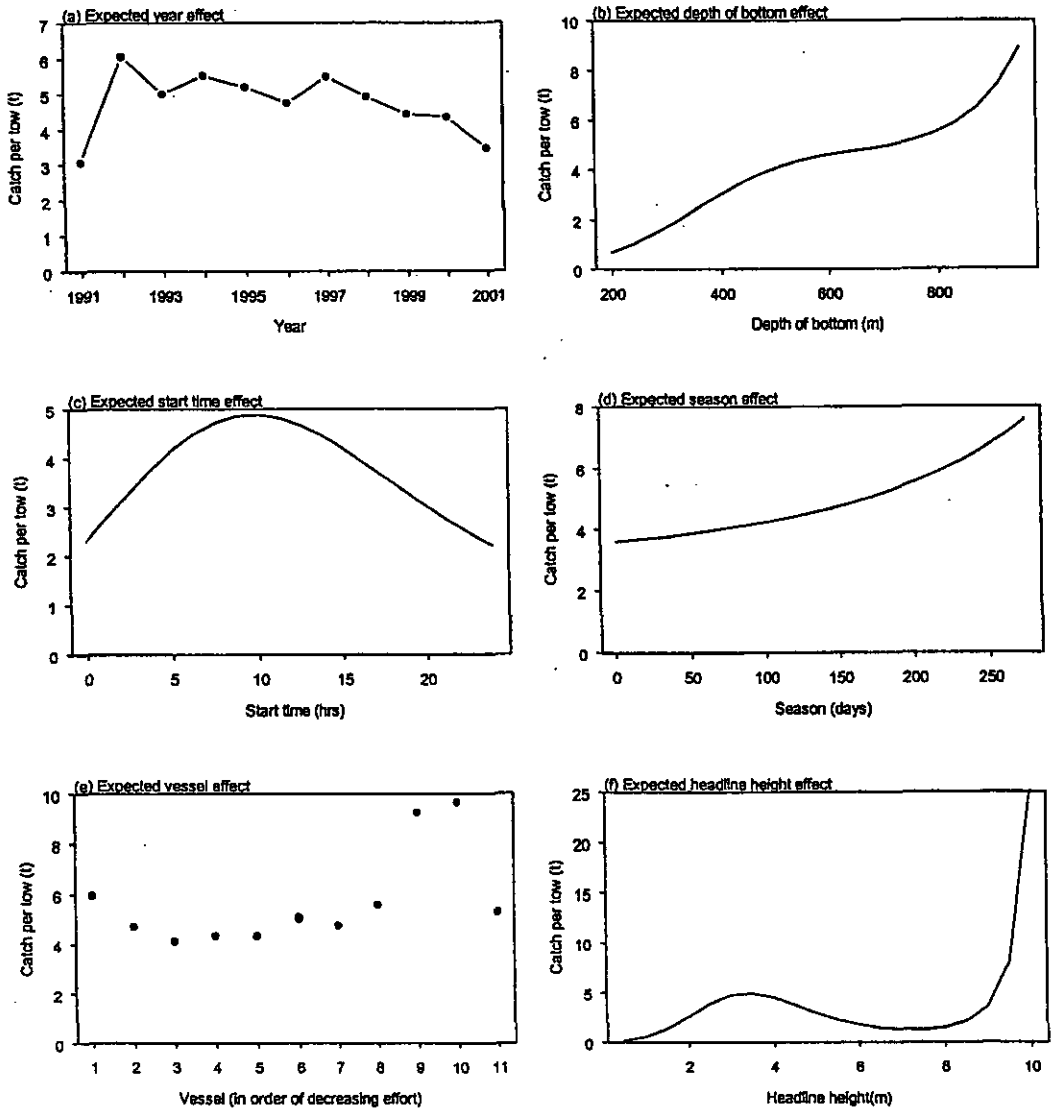

Figure D5: Expected catch rates (t per tow) for median values of fixed parameters for the fillet core vessels model for the sub-Antarctic (*Year*=1996, *Bottom depth*=645, *Start time*=11.9, *Season*=150, *Vessel*=7, *Headline height*=3, *Duration*=4).

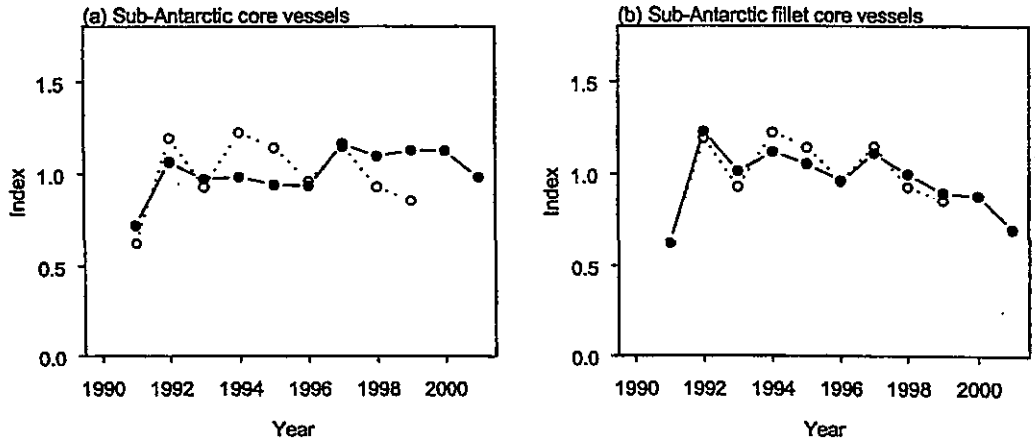

Figure D6: Relative indices (scaled to have mean 1 for the years 1991–1999) of the core vessels for the sub-Antarctic (filled circles), and the equivalent indices from Langley et al. (2001) (open circles).

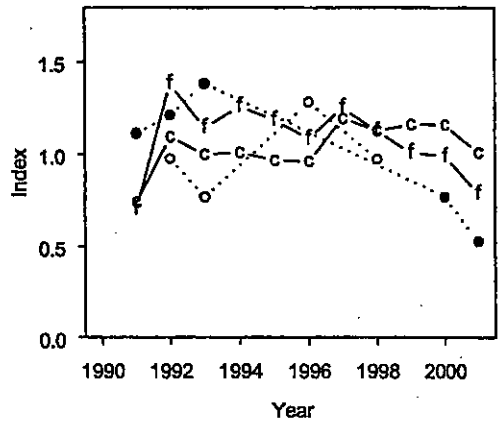

Figure D7: Relative indices (scaled to have mean 1 for the years in common) for the core vessels (c) and fillet core vessels (f) for the sub-Antarctic fishery, and from the sub-Antarctic summer (filled circles) and winter (open circles) trawl surveys for strata 300–800 m.

Appendix E: Summary of catch and tows of hoki within the New Zealand EEZ from TCEPR data

Table E1: Total hoki catch (TCEPR) by area[1] and season (Sp=spawning season, NSp=non-spawning season, W=winter months (Jun–Nov), S=summer months (Dec–May)) (%), the total catch (t), and the number of tows by calendar year.

Year	West coast S.I.		Cook Strait		Chatham Rise		Sub-Antarctic		South		East coast		West coast		Unknown	Total catch		Total
	Sp	NSp	Sp	NSp	Sp	NSp	Sp	NSp	W	S	W	S	W	S		Total	t	tows
1989[2]	0.0	0.0	0.0	0.0	0.0	79.2	0.0	19.4	0.5	0.0	0.5	0.4	0.0	0.0	0.0	100.0	2 790	1 261
1990	76.1	0.0	5.7	0.0	0.5	7.3	4.3	5.6	0.1	0.0	0.1	0.1	0.0	0.0	0.2	100.0	204 718	20 568
1991	59.5	0.0	10.2	0.0	1.2	15.2	2.9	9.9	0.1	0.0	0.1	0.2	0.1	0.0	0.6	100.0	210 027	26 409
1992	48.6	0.0	8.6	0.1	1.5	22.4	2.6	14.5	0.1	0.2	0.6	0.2	0.1	0.0	0.4	100.0	201 801	27 660
1993	54.5	0.0	9.8	0.2	1.3	21.2	1.6	10.5	0.0	0.0	0.4	0.4	0.0	0.0	0.1	100.0	170 338	25 597
1994	60.4	0.1	14.0	1.0	0.9	13.6	2.5	4.8	0.0	0.0	0.6	1.3	0.1	0.0	0.6	100.0	178 075	26 134
1995	46.7	0.0	15.8	3.0	2.8	19.6	0.8	8.0	0.0	0.0	0.5	1.4	0.2	0.0	1.1	100.0	164 457	27 888
1996	35.7	0.0	25.0	2.7	2.7	22.4	1.9	6.1	0.1	0.1	0.8	1.7	0.0	0.0	0.9	100.0	187 266	33 366
1997	36.6	0.0	19.5	2.8	2.4	23.8	3.6	7.5	0.1	0.0	1.1	2.0	0.1	0.0	0.7	100.0	229 055	39 734
1998	40.2	0.1	13.4	1.7	3.0	27.1	1.3	7.5	0.2	2.1	0.8	2.2	0.1	0.0	0.5	100.0	247 608	38 350
1999	40.2	0.0	14.7	1.4	1.1	28.1	1.8	8.1	0.9	1.4	0.5	1.4	0.0	0.0	0.3	100.0	218 357	35 611
2000	43.8	0.1	13.2	1.0	1.6	20.1	1.4	12.9	0.9	2.8	0.7	1.2	0.0	0.0	0.3	100.0	223 624	35 876
2001	48.9	0.0	11.8	1.0	2.8	17.8	3.6	10.2	1.2	0.8	0.4	1.1	0.0	0.0	0.3	100.0	198 943	31 093
Total	48.8	0.0	13.5	1.2	1.8	20.2	2.4	8.8	0.3	0.7	0.5	1.1	0.1	0.0	0.5	100.0	2 437 058	369 547

1. The definition for the area "South" is all locations, not already defined as one of the four fisheries, south of latitude 44.3° S; "East coast" is all locations east of a line drawn through New Zealand from Cape Reinga to Bluff, and north of latitude 44.3° S; and "West coast" is the remaining area west of the line drawn through New Zealand, and north of 44.3° S.
2. The year 1989 refers only to the period from 1 October to 31 December 1989.