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Assessment of hake (*Merluccius australis*) stocks for the 1991–92 fishing year

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1. INTRODUCTION

1.1 Overview

This paper reviews the assessment of stocks of the New Zealand hake (*Merluccius australis*). The fisheries are briefly described, literature relevant to the stock assessments is reviewed, and the results of research on hake fisheries in New Zealand waters are presented. These include the results of trawl surveys, cpue analysis, and length data. Estimates of biomass and yield are derived for three separate areas.

1.2 The Fishery

Hake are widely distributed through the middle depths (200 to 800 metres) of the New Zealand Exclusive Economic Zone (EEZ) south of about 40° South. They are most commonly taken as bycatch in fisheries targeting on other species such as southern blue whiting (*Micromesistius australis*) and, in particular, hoki (*Macruronus novaezealandiae*). Only off the west coast of the South Island in 1976 and 1977, and to a lesser extent on the Chatham Rise in some years, has there been successful target fishing on hake stocks.

By far the largest of the fisheries for hake is that which takes place off the west coast of the South Island in the months of June to September. In this fishery the principal species taken is hoki; hake is the most important by-catch species. Other, smaller fisheries exist on the Chatham Rise (both as bycatch and as a small target fishery in November and early December), and on the Campbell Plateau as bycatch of the southern blue whiting fishery in August and September. In September and October 1990 considerable quantities of hake were also taken as bycatch by trawlers fishing for hoki to the north-east of the Auckland Islands.

For the 1989–1990 fishing year the TAC for hake was 6930 tonnes of which 3310t was available off the west coast of the South Island, 1000t was available on the Chatham Rise, 10t was available in the Kermadec area, and 2609t was available in all other areas including the Subantarctic.

1.3 Review of Literature

Colman and Livingston (1988) and Colman (1988) included a brief review of biological information and assessment of stocks for the 1987–88 and 1988–89 fishing years, with references to the taxonomic status of New Zealand hake (Inada, 1981), its biology (Patchell, 1985), the West Coast fishery (Patchell, 1981), and stock identity (Smith *et al.*, 1979).

Biomass trawl surveys, which included data on hake, carried out in the New Zealand EEZ between 1980 and 1984 were summarised by Hurst and Fenaughty (1985). More recent trawl surveys in 1986 (Livingston, Uozumi and Berben, 1991), 1989 and 1990 (Hurst and Schofield 1990, 1991) have provided further data on hake stocks in southern waters and on the Chatham

Rise, and a short survey off the west coast of the South Island in July 1990 provided some data (unpublished as yet) on hake stocks in that area.

2 REVIEW OF THE FISHERIES.

2.1 Catch Histories.

Overall hake catches in the New Zealand EEZ since 1975 are shown in Table 1.

2.1.1 West Coast Fishery (HAK7)

In the most important New Zealand hake fishery, off the west coast of the South Island, catches rose rapidly after the discovery of hake concentrations in the area by Japanese fishing vessels in 1975, reaching a peak in 1977. The declaration of the EEZ in 1978 and the failure of the Japanese to conclude a fishing agreement with New Zealand before the 1978 season contributed to a low catch in 1978. Catches increased again in 1979, though not to the 1977 level, and the imposition of quotas from 1980 onwards has had the effect of restricting catches since then. Throughout most of this period the TAC for west coast hake has been about 3000 tonnes, but from 1982 to 1986 it was set at 1000 tonnes.

Since 1986 scientific observers have been placed on vessels operating in the West Coast hoki fishery. Data collected by these observers show that the bycatch levels reported by vessels which carried observers were consistently higher than those reported by vessels which did not carry observers. It was clear, therefore, that the hake by-catch of the fleet had been under-reported, provided that the assumption that the real hake by-catch was similar among similar vessels with or without observers is valid.

The hake by-catch was therefore re-estimated, assuming that the hoki catch was correctly estimated, by the following calculation:

Estimated Hake Catch = Observed Hake Catch * Total Hoki Catch/Observed Hoki Catch (see Table 2)

where Observed Hake Catch is the total hake catch recorded by vessels which carried observers;
Total Hoki Catch is the total catch of hoki from all vessels for the season;
Observed Hoki Catch is the hoki catch recorded by vessels which carried observers.

Surimi processing vessels were taken separately from other categories of vessel because the proportions of hake bycatch differed between these classes of vessel. The total estimated hake catch was the sum of the estimated hake catches of each class of vessel taken separately; these estimated catches (see Table 1) are believed to be the most accurate estimate of hake catch for the years during which the observer programme has been in operation.

In 1988 only the surimi processing vessels carried observers. The hake catch by the head-and-gut vessels could not therefore be estimated in the same way as in the other years. In estimating the head-and-gut vessels' catch of hake in 1988 it was assumed that the ratio of the percentage of hake in the head-and-gut vessels catch to the percentage in the surimi vessels catch was the average of the 1987 (3.58 ÷ 2.12 = 1.69) and 1989 (7.36 ÷ 4.12 = 1.79) ratios, i.e. 1.74. The estimated hake/hoki ratio for head-and-gut boats for 1988 was therefore 1.45 (% of hake in surimi vessels catch) x 1.74, or 2.5%.

For the last four seasons (1987 to 1990) the hake TAC for the west coast has been over-caught, by only small amounts in 1987 and 1988 but by over 6000 tonnes in 1989 and by nearly 5000 tonnes in 1990). This is due mainly to the very large increase in fishing effort that has occurred in the west coast fishery as a result of the TAC for hoki being raised between 1985 and 1987 from 20 000t for the west coast hoki fishery to 250 000t for the whole EEZ. Because most of the hoki catch in the EEZ is taken off the west coast, this resulted in a ten-fold increase in the hoki catch in this area, and a correspondingly large increase in fishing effort.

2.1.2 Chatham Rise Fishery (HAK4)

On the Chatham Rise hake catches have generally been small, and the area is subject to a TAC of 1000 tonnes. This TAC has never been exceeded but catches have been increasing steadily over the last five years and may soon approach the level of the TAC.

2.1.3 Hake Fisheries in other areas (HAK1)

Hake catches in areas other than the West Coast and the Chatham Rise have been increasing over the last decade, and in the 1989–90 fishing year the catch was about 80% of the TAC for hake fisheries management area 1 (HAK1: all areas other than the west coast of the South Island and the Chatham Rise). Indications are that some fishing companies are now having difficulty in matching their catches of hake with their quotas in HAK1, and in the current fishing year, for the first time, the existence of quotas in HAK1 appears to be acting as a constraint on fishing operations.

2.2 Catch per Unit Effort

2.2.1 West Coast Fishery (HAK 7)

Seasonal and annual variations in hake catches in most areas are caused mainly by changes in fishing effort targeted at other species. Because of this, and because there is evidence that not all hake by-catch is fully reported, the interpretation of catch per unit effort data on hake in most areas is difficult. However, scientific observers deployed on vessels in the west coast hoki fishery have collected reliable data on catch and effort in this fishery since 1986, including data on hake by-catch levels, and these data were analysed to see if there are any trends in the cpue data for hake.

The majority of hake were taken in waters to the south of 42° South during the months of June and July. Both the catch and the catch per unit effort of hake were very low in more northern areas at all times of the season, and only in some years (particularly in 1989) were catch rates of hake in the southern area sustained into the second half of the season.

Analysis of catch per unit effort was therefore concentrated on the data from June and July in each year in waters to the south of 42° South.

The data were stratified by vessel size in 10m bands, with day and night catches being taken separately (Table 3); for the purposes of this analysis daytime was taken to be between 0800 and 1700 hours, and nighttime was between 1700 and 0800 hours. Data from vessels less than 80 m in length are not presented here; the numbers of vessels observed were small, and the cpue figures were highly variable.

There was clear evidence of a relationship between size of vessel and catch rate. Also, daytime and nighttime catch rates showed some differences, with daytime catch rates almost always being higher than nighttime catch rates. Nighttime tows were often very long and apparently not accurately targeted on concentrations of fish, whereas daytime tows appeared to be targeted to some extent on concentrations of hoki.

A further breakdown of catches by depth of bottom (Table 4 shows the breakdown for one class of vessel fishing at night) showed that fishing effort was generally concentrated in areas where the depth was between 400 and 700 metres, though in 1986 it was concentrated rather deeper, mainly in 600 to 700 metres. The distribution of hake varied from year to year, with catch rates being highest in the deeper strata in 1986, 1989 and 1990 but much more even throughout the depth range in 1987 and 1988. The combination of high cpue of hake in the deeper strata and concentration of fishing effort in rather deeper water than usual led to a high overall cpue index for 1986.

Catch and effort data from 1986 to 1990 were used in a General Linear Model to derive "between-years" cpue indices for these five years (see Appendix 1). Because most hake are taken in waters between 42° and 43° South, data used in the model were restricted to data from those waters. Data included vessel tonnage in two size classes (greater or less than 1500 GRT, roughly equivalent to 70 m length), and data on each tow including time of day (day or night), duration and speed of tow, depth of bottom, latitude, and catch of hake. The resulting cpue indices, standardised to 1.0 for 1986 were:

1986: 1.0
1987: 0.64
1988: 0.65
1989: 0.70
1990: 0.62

2.2.1 Other Areas (HAK 1 and HAK 4)

No analysis of cpue data has been carried out.

2.3 Biological Data

Hake exploited in the west coast fishery are virtually all sexually mature fish from about 70 to 90cm (males), and 75 to 110cm (females) in total length (Fig. 1). The majority of males from the West Coast are in running-ripe condition throughout the fishing season but during June and July the hake females are in pre-spawning condition, and spawning probably does not take place until late July or August.

Hake on the Chatham Rise are scattered through the middle depths, mainly on the northern side of the Rise, for most of the year. In November to January spawning takes place in a small area about 100 miles west-northwest of the Chatham Islands. These spawning fish are similar in size to the west coast fish.

In southern waters the hake are, on average, of larger size, with females frequently reaching lengths of over 110cm (Kerstan and Sahrhage 1981; Hurst and Schofield 1990, 1991). Little is known about spawning grounds, but the presence of juveniles on the Campbell Plateau (Patchell 1981) and the reported occurrence of adults in spawning condition at times indicates that spawning probably occurs in the Campbell Plateau area as well as on the Chatham Rise and off the west coast of the South Island.

2.4 Maori and Recreational Fisheries.

There are no records of significant Maori or recreational involvement in the fisheries for New Zealand hake.

3 RESEARCH.

3.1 Stock structure.

Inada (1981) established the specific status of the New Zealand hake, but he did not investigate whether the species consisted of only one, or more than one, stock. Smith *et al.* (1979) were unable to find evidence from the analysis of data on enzyme polymorphisms for more than one stock, but studies of morphometric differences and of mitochondrial DNA are in progress and may help to resolve the question. In addition there seem to be some differences in parasite loading between hake from the West Coast and from the Chatham Rise (J.B. Jones, pers. comm.). The occurrence of adults in spawning condition and juveniles at times on the Campbell Plateau as well as on the Chatham Rise and off the West Coast also supports the hypothesis of there being more than one stock, but it is not clear how well any stocks are separated or where the stock boundaries may be.

3.2 Resource Surveys.

Patchell (1981) used data from the commercial fleet to derive an estimate of the standing stock of hake off the west coast of the South Island in 1979. Biomass trawl surveys carried out in the New Zealand EEZ between 1980 and 1984 were summarised by Hurst and Fenaughty (1985). In June and November 1986 two further biomass surveys were carried out on the Stewart-Snares shelf, but these did not cover as large a depth range as other surveys (generally 200–800 m) and in fact few hake were caught. Further surveys have been carried out on the Chatham Rise in July 1986 (Livingston, Uozumi and Berben, in press) and in December 1989 (unpublished data at FRC), and in southern waters in October-November 1989 (Hurst and Schofield 1990), July-August 1990 and November-December 1990 (Hurst and Schofield 1991). In addition a short survey of the west coast hake was carried out in July 1990 (unpublished data at FRC).

Data from these surveys are summarised in Table 5, with the exception of the Stewart-Snares surveys which did not adequately sample hake.

3.3 Length and Age Data.

Length data are available from the above surveys and from research cruises in many parts of the EEZ. In addition, data are available from the scientific observer programme, particularly from hake in the West Coast fishery.

For areas other than the West Coast data are patchy, but hake on the Campbell Plateau generally reach a larger size (females quite commonly over 110cm in length) than elsewhere. In the Chatham Rise and the west coast fisheries, hake males are typically between about 70 and 90 cm in length, and females between about 75 and 110 cm.

Age data held at FRC are shown in Table 6. These data were from samples of hake collected in 1976 on the Chatham Rise and off the West Coast of the South Island by the *Shinkai Maru*. The maximum age reached by hake appears to be about 27 years, though very few seem to survive beyond about age 23 (females) or 21 (males). Applying the formula

$$M = \frac{\mathrm{Log}_e\ 100}{\text{Maximum Age (0.01)}},$$

where Maximum Age (0.01) is the age at which only 1% of the population survives, and using 23 for females and 21 for males, provides estimates of M = 0.20 (females) and M = 0.22 (males). These values are similar to those obtained for this species in South American waters (Ellen Pikitch, pers.comm.).

Early growth is not well documented. Isolated samples of juvenile hake collected by N.W. Bagley off the West Coast provide the following data:

Date	Number	Mean Length (cm)	Range (cm)
6 Apr 82	16	12.6	10.6 – 15.0
7 Apr 82	9	11.6	9.9 – 13.7
9 Apr 82	14	12.0	9.3 – 17.3
10 Apr 82	33	10.9	9.3 – 13.1
15 May 82	8	13.7	12.8 – 14.2
16 May 82	3	12.5	12.2 – 12.7
17 May 82	7	14.9	12.0 – 20.0
27 Oct 82	16	4.7	4.1 – 5.9
1 Nov 82	24	4.9	3.1 – 7.5
12 Jan 83	19	9.6	7.5 – 11.7
18 Jan 83	10	9.7	7.8 – 10.4
22 Feb 83	34	11.0	9.7 – 12.9
6 Mar 83	18	12.1	11.1 – 13.0
7 Mar 83	5	13.1	12.3 – 14.0
23 Mar 83	34	12.5	10.9 – 14.6

These data indicate a mean length for 0-group hake of about 5cm in November, 10cm in January, 12cm in March, and about 14cm in May at which time the fish would be about 9 months old. A mean length of about 15 to 20cm is therefore indicated at the age of one year (taking 1 August as the "birthday")

Among hake collected off the West Coast in July 1990 (Fig. 2) a clear length mode at about 35cm appeared to comprise two-year old fish, and a further mode at about 44cm (males) and 48cm (females) was interpreted as representing three-year old fish.

Age determination of larger fish depends on reading otoliths, a method which has not yet been adequately validated for the New Zealand hake. From the results of such otolith readings (Table 6) the indications are that males of 65 to 70cm and females of 70 to 75cm (which are the size at which hake begin to appear in the commercial catches) are at least six or seven years old, and may not be fully recruited until about 10 years old. Von Bertalanffy growth equations derived from the data summarised in Table 6 yield values of

l_∞ = 133 cm (males) and 146 cm (females)
k = 0.050 (males) and 0.046 (females)
t_0 = –4.69 years (males) and –5.02 years (females)

Length data collected by observers during the 1987, 1988 and 1989 seasons show little change in mean length during the season, and little change between seasons. Data from 1990 are also similar to these, though there are possibly fewer large fish present in 1990 than in earlier years.

While there are some between-year variations (the modal length for both sexes in 1988, for example, is larger than in either 1987 or 1989), no consistent change in the size of the fish is detectable.

3.4 Estimates of Biomass

Estimates of biomass on the Chatham Rise and in southern waters depend heavily on the results of trawl surveys. Assessment of the west coast fishery depends mainly on analysis of data from commercial vessels, including an estimate of biomass made in the 1979 season and catch and effort data for the last five seasons, particularly from surimi vessels carrying observers. Some data are also available from a short survey of part of the West Coast fishing grounds in 1990.

Earlier FRC estimates of biomass which were derived from the results of trawl surveys used the average of two biomass estimates, one made under the assumption that the area swept was the area between the doors and one made under the assumption that the area swept was the area between the wing-ends (see Hurst 1985). Vertical and areal availability, in the absence of any data on which to base a realistic estimate, were usually assumed to be 1.0. Depending on the lengths of the sweeps and bridles this resulted in estimates of overall catchability of fish between the doors of 0.36 to 0.44, and between-wings catchability of about 1.4 to 1.7.

Even allowing for the herding effect of sweeps and bridles, this estimate of between-wings catchability appears to be high. Sissenwine (1988) derived estimates of catchability from results obtained by other workers (Edwards 1968, Uzmann *et al.* 1977, Clark and Brown 1977, Collie and Sissenwine 1983, Sissenwine and Bowman 1978) in studies of North-West Atlantic fisheries. His estimates were discussed by Hurst (1988), and for most species the estimates of between-wings catchability were less than 0.5.

There is a danger in translating Sissenwine's conclusions directly to the New Zealand situation because of differences in fish behaviour and in gear specifications and performance between the North-West Atlantic and New Zealand. Even in the North-West Atlantic large changes in catchability were demonstrated by Pinhorn (1988) as a result of changes in gear technology. The nets used for trawl surveys in New Zealand waters have been in general much larger than the research trawls used by the authors named above. The catchability of fish is therefore likely to be higher than in the relatively small and low-headline nets used by the authors named above, though catchabilities of over 1.0 for fish between the wings appear to be improbable, especially for large, active species such as the New Zealand hake.

For the purposes of this paper the recommendations of Francis (1989) are followed for assessing biomass from the trawl survey results. The area swept is defined as the area between the trawl doors; vulnerability of hake between the doors is assumed to be 0.25 (which, for a doorspread to wingspread ratio of 4.0 is equivalent to between-wings vulnerability of 1.0); vertical and areal availability are assumed to be 1.0 unless otherwise stated.

This approach differs from that used previously in that the between-doors vulnerability is assumed to be 0.25 rather than about 0.4 as was assumed in previous stock assessments. This brings assumptions about vulnerability more into line with the estimates of vulnerability derived from the results of the workers listed above.

3.4.1 Chatham Rise (HAK4)

For the Chatham Rise the results of four trawl surveys since 1983 are available. These provide estimates of biomass of hake between 25200t (July 1986) and 48400 t (March 1983), with two other estimates of 38000t (Nov-Dec 1989) and 38800t (Nov-Dec 1983).

Except for the 1989 survey for which the c.v. was 65%, all c.v. values were low at 12 to 13%. The high 1989 c.v. was caused by a large catch of hake being taken at one station which accounted for about half of the total hake catch for the survey. If this one station is excluded, the estimate for 1989 is reduced to less than half of the 1983 estimates, which is in line with other evidence which suggested that the gear used in 1989 was not sampling very effectively (Hurst and Schofield 1990).

It could therefore be argued that these data are consistent with a decline in the hake stock since 1983, with stocks remaining low from 1986 to 1989. If so, however, such a decline could not have been caused by fishing; hake catches from this stock averaged only about 250 tonnes per annum from 1983 to 1988 inclusive. If the population were so small as to be affected by such small catches it could not have supported the catches that have been reported from 1989 onwards. Also, if the stocks were so small, the values of vulnerability of hake to the gear used in the trawl surveys would have to be impossibly high. Even for a stock size of 6100 tonnes (able to sustain the current TACC of 1000 t at a rate of exploitation where

F = M = 0.2), the catchability of hake in the trawl surveys would need to be of the order of 1.5 between the doors, or about 6.0 between the wing-ends.

It was therefore concluded that the trawl survey results did not support the hypothesis that the stock had been reduced through fishing. Any appreciable change in stock level could only be through natural causes. As these are neither known nor predictable, it was decided to use the trawl survey data to estimate the long-term average stock levels, assuming vulnerability and availability of hake as indicated above (paragraph 3.4), in a situation where fishing mortality is lower than natural mortality.

Except for the Nov-Dec 1983 survey, all of these surveys included part of the HAK1 area as well as HAK4. The estimated biomass in each area at the time of each survey is given below:

			Hake Biomass
Survey Date	in Survey Area	in HAK4	in HAK1
March 1983	48400	39800	8600
Nov-Dec 83	38800	38800	–
July 1986	25200	20400	4800
Nov-Dec 89	38000	36300	1700

From this the mean value for hake biomass in HAK4 is 33800 tonnes, taken over four surveys. In addition, from the results of the three surveys which included parts of HAK1, an average of 5000t was present in those parts of the HAK1 area which were surveyed.

For the most recent survey in 1989 the hake biomass was estimated at 38000 tonnes of which 36300t were in HAK4. This is not significantly different from the average, and as the 1989 estimate had a very high c.v. it may be better to take the average of 33800 as an estimate of current biomass in HAK4.

Because reported catches from the Chatham Rise area have never been large (annual catches have exceeded 1000 t only once, and have averaged less than 500 t since 1975), it is likely that the unexploited biomass would have only been slightly higher than the current biomass. Running the Francis (1990) model (for biological parameters see section 3.4.3 below) shows that for values of B_0 between 30000t and 40000t the average biomass (B_{av}) from 1983 to 1989 would have been about 2800t less than B_0. If B_{av} is taken as 33800 (see above), B_0 would have been about 36600t. For the purposes of this paper B_0 has been rounded to 35000 tonnes.

3.4.2 Southern and Eastern Stocks (HAK1)

The results of seven trawl surveys covering all or part of the southern parts of the New Zealand EEZ are available. Two of these covered only the areas round the Snares shelf and the Auckland Islands and provided estimates of hake biomass of 18000 and 25200 tonnes for these areas. The remaining five surveys covered a wider area and provided estimates of between 10600 and 59200 tonnes of hake (see Table below).

Survey Date	Hake Biomass in Survey Area	Hake Outside Survey Area	Total Hake in HAK 1
Mar-Apr 1982	24 400	5 500	29 900
Oct-Nov 1983	59 200	5 500	64 700
Oct-Nov 1989	10 600	5 500	16 100
Jul-Aug 1990	17 400	5 500	22 900
Nov-Dec 1990	23 800	5 500	29 300
Mean (all surveys)	27 080	5 500	32 580
Mean (excluding 1989 survey)	31 200	5 500	36 700

There are reasons (see Hurst and Schofield, 1990) for believing that the low estimate of 10600 tonnes resulting from the 1989 survey was due, at least in part, to problems with the gear used for that particular survey. If the 1989 survey is excluded the average of the other four surveys which covered the whole area is about 31000 tonnes.

Similarly to the HAK 4 stock, catches from the HAK 1 stock have been small (less than 500 t per annum up to 1985, though increasing since then). There is no indication from the trawl survey data of a decline in abundance which can be attributed to fishing.

Vulnerability of hake probably varied from survey to survey, possibly being higher for the 1983 survey and lower for the 1990 surveys. However, with little information to go on with respect to comparing vulnerability, it is assumed here that the between-doors vulnerability was 0.25 for each survey, and the average biomass (31200 tonnes) over the surveys in 1982, 1983 and 1990 is taken to be representative of the average biomass in the area surveyed.

In addition, from three surveys on the Chatham Rise in 1983, 1986 and 1989 which included part of the HAK1 area (see above, 3.4.1), a mean value of 5000 tonnes of hake was present in the HAK1 areas surveyed. Together with a further 500t to allow for hake being present in areas which were not surveyed at all, a total of 5500t should therefore be added to the figure of 31200t (see previous paragraph), to give an estimate of 36700t for the average hake biomass in the whole HAK 1 area in 1982, 1983 and 1989. Because hake catches in this area have been small until quite recently it is likely that the unexploited biomass would have been only slightly higher than this; B_0 is therefore estimated at 37000 t.

If some allowance is made for recent catches (about 7000 tonnes over the last five years), it seems likely that the current biomass would be about 30000 to 35000 tonnes. A run of the Francis (1990) model with B_0 set at 37000 tonnes gives an estimate of 30300 tonnes for the 1990 mid season biomass. However, if only the average (20600 tonnes) of the 1990 surveys is used, plus 5000 tonnes from surveyed areas on the Chatham Rise and Canterbury Bight, and 500 tonnes as an estimate of hake in unsurveyed areas, an estimate of current biomass is 26100 tonnes. The current (1990) biomass is therefore estimated as being from 26100t to 30300t.

3.4.3 West Coast of the South Island (HAK 7)

There have been no comprehensive research surveys of the west coast hake stocks. Patchell (1981) derived an estimate of the hake biomass from catch and swept area data from four commercial vessels in 1979, however, and this estimate was used by Colman (1988) to derive an estimate of the unexploited biomass.

Colman (1988) used the average of the doorspread and wingspread estimates as outlined by Hurst (1985), and eliminated a vulnerability factor of 0.46 which Patchell (1981) had incorporated into his assessment. This resulted in an estimate of the 1979 biomass of 12000 tonnes. Reworking Patchell's data (assuming between-doors vulnerability of 0.25 as indicated earlier) changes the estimate of the 1979 biomass to 17900 tonnes. If Patchell's vulnerability factor of 0.46 is accepted, then the estimate of 1979 hake biomass is about 39000 tonnes.

A short survey of the west coast grounds was carried out in 1990; preliminary results are available from the cruise report on GIL9001, held at the Fisheries Research Centre, Wellington. The results are not comparable with those of Patchell (1981). Hake were widespread rather than concentrated in a small area, and it was clear from the results of the survey and from data collected by observers on the commercial fleet that a substantial part of the hake population was well above the bottom and not sampled by the bottom trawl used for the random trawl stations. Also, it was clear that hake existed outside the area surveyed, particularly to the south, and possibly also in deeper water, over 1000 m in depth, to the west of the survey area. Therefore any estimate of biomass from this survey must be considered to be low.

Within the survey area the estimate of hake biomass was 5400 tonnes, if it is assumed that the whole stock was available to the gear and that the vulnerability of hake between the doors was 0.25 as has been assumed for other surveys. However, midwater trawling during this survey indicated that only about a third, and possibly less, of the hake population was close enough to the bottom to be available. In deep water, too, where hake catches in the survey were relatively low, data from the commercial fleet indicated that hake were at least as abundant as in the medium depth strata sampled in the survey. It is probable, therefore that in the deeper strata of the survey an even smaller proportion of the hake were available to the bottom gear. Incorporating a vertical availability factor of 0.33, and assuming that only 60% of the hake population was within the area surveyed leads to a "most likely" biomass estimate of 27000 tonnes. However, because of the various estimates and assumptions that have to be made concerning areal and vertical availability it is difficult to compare the results of this survey with the results of the assessment of the 1979 stock or to have much confidence in the accuracy of this estimate.

Therefore the effects of including a range of possible estimates (from 5400 t which assumes vertical and areal availability of 1.0 to 54000 t which assumes vertical availability of 0.167 and areal availability of 0.6) were investigated.

The stock reduction method of Francis(1990) was used to derive an estimate of virgin biomass for the West Coast hake stock, incorporating the catch history of the fishery, the results of the trawl surveys, the cpue indices, and growth parameters derived from age and length data from the West Coast South Island hake in 1976. The catch history is given in Table 1, with estimated values being used from 1985–86 onwards. The expected catch for 1990–91 has been set at either 6000t or 7500t. The cpue indices were derived from a General Linear Model (see section 2.2). Age and growth parameters were as follows:

M : 0.22 (males) and 0.20 (females)
K : 0.05 (males) and 0.046 (females)
ℓ_∞ : 133 (males) and 146 (females)
t_0 : – 4.69 (males) and – 5.02 (females)
Age at maturity = Age at recruitment = 10

a = 2.75×10^{-6} (males) and 1.33×10^{-6} (females)) parameters of length-weight
b = 3.23 (males) and 3.41 (females)) relationship, with weight in
) kg, length in cm

stock recruitment "steepness" = 0.95

Estimates of B_0 were obtained from stock reduction analyses by using combinations of trawl survey biomass indices and commercial cpue data. Four combinations were used, each of which produced a different estimate of B_0 (Table 7).

If the cpue indices are left out it becomes impossible to find a "maximum likelihood" value for B_0 in any situation in which the B_{1990} is greater than the B_{1979}; probabilities continue to increase indefinitely with increasing values of B_0, though very slowly.

If the cpue indices are used without any trawl survey indices, however, the resulting "maximum likelihood" estimate for B_0 is 63000 t.

In cases where both sets of indices are used, the range of "maximum likelihood" estimates of B_0 is from 46000t (with B_{1979} at 17900 and B_{1990} at 5400t) to 130000t (with B_{1979} at 17900 and B_{1990} at 27000t). Any value of B_0 less than 38000t results in estimated catches in some years being less than the actual catches, a situation which clearly does not fit the available data well. Also, an estimate of B_0 = 130000t is less likely than lower estimates because this estimate is based on trawl survey figures indicating an increase in biomass from 1979 to 1990. This is not consistent with the Francis (1990) model and the cpue indices which both indicate decreases in biomass. Lower values of B_0, for which the available data are more consistent, appear to be more likely.

It is concluded, therefore, that B_0 could not have been lower than 38000 tonnes. Given the range of "most likely" estimates in Table 7, B_0 was probably within the range of 40000 to 60000 tonnes, but because of the uncertainty surrounding the accuracy and comparability of the trawl surveys, and the lack of contrast in the cpue data for the last four years, higher values cannot be ruled out.

3.5 Yield Estimates. (CAY).

3.5.1 HAK 1 and HAK 4.

For HAK 1 and HAK 4 the rate of exploitation appears to have been low to date, and catches are unlikely to have had a measurable effect on the stocks. It is not possible to fit a surplus production model to these fisheries. Estimates of MCY and CAY for these fisheries therefore depend on biomass estimates derived from the results of trawl surveys and on the estimate of M = 0.2.

3.5.1.1 Estimates of Maximum Constant Yield (MCY)

Estimates of unexploited biomass for HAK 4 and HAK 1 are respectively 35000t and 37000t (see above, 3.4.1 and 3.4.2). Assuming M = 0.2 and using MCY = $0.25MB_0$, the following values for MCY are obtained:

HAK 1 : MCY = 1850t
HAK 4 : MCY = 1750t

3.5.1.2 Estimates of Current Annual Yield (CAY)

The CAY for each stock is best estimated from the Baranov equation:

$$CAY = B_{current} * F/(F+M) * (1 - e^{-(F+M)})$$

With M = 0.2, and putting F = M, and $B_{current}$ being 33800t for the HAK4 stock and 26000t to 30300t for the HAK1 stock, the following estimates of CAY for the 1991–92 fishing year are derived:

HAK 1 : CAY = 4300 to 5000t
HAK 4 : CAY = 5600t

Strictly speaking, $B_{current}$ in the Baranov equation should be the beginning-of-year biomass for the 1991–92 year. For these hake stocks the timing of recruitment is not known, and fishing is not as highly seasonal as in the West Coast fishery. The biomass estimates derived from trawl surveys in the HAK 1 and HAK 4 areas have therefore been used as approximations to the beginning-of-year biomass.

3.5.2 HAK 7

3.5.2.1 Yield per recruit analysis

A yield per recruit analysis was carried out for hake, with growth, recruitment and mortality parameters as given in paragraph 3.4.3, in order to estimate $F_{0.1}$. The method of Hilborn *et al.* (1991) with a Beverton and Holt stock recruitment model was used for the computations. The resulting estimate of $F_{0.1}$ was 0.30. (This was not done for the other stocks because less is known about the age of recruitment and maturity.)

3.5.2.2 Estimation of MCY

MCY was estimated from the equation $MCY = 0.25F_{0.1}B_0$. The results are shown in Table 7, and ranged from 3450 to 4725t with a further value of 9750t which was considered to be unlikely.

3.5.2.3 Estimate of CAY

CAY was estimated from $CAY = Bio_{1992}\ (1 - e^{-F_{0.1}})$, where Bio_{1992} is the estimated hake biomass at the start of the 1991–92 fishing season. The results are shown in Table 7 and ranged from 3480 to 8000t with further values of 25500 and 25850t which were considered to be unlikely.

3.5.3 Summary of Biomass and Yield Estimates.

Estimates of B_0, $B_{current}$, MCY and CAY are summarised in the table below. For HAK 1 and HAK 4 $B_{current}$ is the biomass at the start of the fishing year; for HAK 7 it is the biomass at the start of the fishing season (about 1 July) on the West Coast), in each case for the 1991–92 year.

Stock	B_0(t)	$B_{current}$(t)	MCY(t)	CAY(t)
HAK 1	37000	26000-30300	1850	4300– 5000
HAK 4	35000	33800	1750	5600
HAK 7	46000-130000	13410-98380	3450-9750	3480–25850

4 MANAGEMENT IMPLICATIONS.

4.1 HAK 1 and HAK 4

These stocks appear to have been only lightly fished to date. The MCY estimate for HAK 1 is less than the current TACC, but similar to current catch levels. The MCY estimate for HAK 4 is greater than the current TACC and current catch levels. The estimates of CAY for both of these stocks are above the current TACCs which indicates that the current TACCs are sustainable. However, because stocks have been only slightly reduced compared with their unexploited levels, part of the CAY consists of fishing down an accumulated stock. The long term sustainable yields, once the "fishing down" phase is over, will be less than the CAY levels indicated in this paper.

4.2 HAK 7

The uncertainty about the current state of the HAK 7 stock is reflected in the wide range in the biomass and yield estimates. Because of this uncertainty, the plenary could not choose which of the options provided the best estimates. However, a value of B_0 = 38,000 t is the lowest estimate of B_0 consistent with the catch history of the fishery. Moreover, an estimate of B_0 = 130,000 t is unlikely because the biomass estimates from the simulation model using this value of B_0 do not support the increase in biomass from the trawl survey estimates between 1979 and 1990 that are used as data inputs in this option.

For all four options $CAY_{1991-92}$ is greater than $F_{0.1}$ yield, and the fishery is still in the fishing down phase. The current TACC of 3310 t is less than all four estimates of $F_{0.1}$ yield and is considered sustainable. However, the recent estimated catches of 8000–9000 t are greater than the $F_{0.1}$ yield for all options except option 4 (which was considered unlikely), and are probably not sustainable.

REFERENCES

Clark, S.H. and Brown, B.E. 1977: Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963 74, as determined from research vessel survey data. *Fishery Bulletin 75 (1)*: 1–21.

Collie, J.C. and Sissenwine, M.P. 1983: Estimating population size from relative abundance data measured with error. *Canadian Journal of Fisheries and Aquatic Science 40*: 1871–1879.

Colman, J.A. 1988: Hake. *New Zealand Fisheries Assessment Research Document 88/31.* 22 p.

Colman, J.A. and Livingston, M. 1988: Hake. *In* Baird,G.G., and McKoy,J.L. 1988: Papers from the workshop to review fish stock assessments for the 1987–88 New Zealand fishing year. 300p.(Preliminary discussion paper, held in Fisheries Research Centre library, Wellington).

Edwards, R.L. 1968: Fishery resources of the North Atlantic area. *In* Gilbert, D.W. (Ed.) The future of the fishing industry of the United States. *University of Washington Publications in Fisheries, New Series, Vol 4*, pp 52–60.

Francis, R.I.C.C. 1989: A standard approach to biomass estimation from bottom trawl surveys. *New Zealand Fisheries Assessment Research Document 89/3*. 4p.

Francis, R.I.C.C. 1990: A maximum likelihood stock reduction method. *New Zealand Fisheries Assessment Research Document 90/4.*

Hatanaka, H., Uozumi,Y., Fukui,J., Aizawa, M., and Livingston, M.E., 1989: Trawl survey of hoki and other slope fish on the Chatham Rise, New Zealand, November-December 1983. *New Zealand Fisheries Technical Report No 17.* 31p.

Hilborn, R., M. McAllister and E. Pikitch. 1991: A general method for stock assessment with an age and sex structured model. Unpublished MS.

Hurst, R.J. 1985: Estimation of yields from trawl survey data. *In* Colman, J.A., McKoy, J.L. and Baird, G.G. (Comps. and Eds.) 1985: Background papers for the 1985 Total Allowable Catch recommendations. Fisheries Research Division, N.Z. Ministry of Agriculture and Fisheries. 259 p. (Unpublished report, held in Fisheries Research Centre library, Wellington).

Hurst, R.J. 1988: The estimation of catchability in the interpretation of bottom trawl survey data. *Fisheries Research Centre Internal Report 109.* 53 p. (Draft report held in Fisheries Research Centre library, Wellington.)

Hurst, R.J. and Fenaughty, J.M. 1985: Report on biomass surveys 1980–84: summaries and additional information. *Fisheries Research Internal Report No. 21.* 53 pp.

Hurst, R.J. and Schofield, K.A. 1990: Preliminary biomass estimates of hoki and selected species from trawl surveys of Southland/Subantarctic and the Chatham Rise, Oct-Dec 1989, and comparison with previous *Shinkai Maru* surveys. *N.Z. Fisheries Research Assessment Document 90/6.*

Hurst, R.J. and Schofield, K.A. 1990: Preliminary biomass estimates of hoki and other main species from trawl surveys of Southland/Sub-Antarctic, Jul-Aug and Nov-Dec 1990. *New Zealand Fisheries Research Assessment Document 91/XX.*

Inada,T. 1981: Studies on the Merlucciid fishes. *Far Seas Fisheries Research Laboratory Bulletin 18.* 172 pp.

Kerstan, M. and Sahrhage,D. 1980: Biological investigations on fish stocks in the waters off New Zealand. *Mitteilungen aus dem Institut fur Seefischerei der Bundesforschungsanstalt fur Fischerei, Hamburg, No. 29.* 187 pp.

Livingston, M.E., Uozumi, Y., and Berben, P.H. 1991: Abundance, distribution and spawning condition of hoki and other mid-slope species on the Chatham Rise, July 1986. *New Zealand Fisheries Technical Report 25.* 47 pp.

Patchell, G.J. 1981: The Westland Hake Fishery. *Fisheries Research Division Occasional Publication No. 31.* 18 pp.

Patchell, G.J. 1985: Hake. *In* Colman, J.A., McKoy, J.L. and Baird, G.G. (Comps. and Eds.) 1985: *op.cit.*

Pinhorn, A.T. 1988: Catchability in some of the major groundfish fisheries off the east coast of Canada. *Journal of Northwest Atlantic Fisheries Science, 8*: 15–23.

Schofield, K.A. 1990: Report of a trawl survey of hoki and other middle depth species by the *Amaltal Explorer* on the Southern Plateau, October-November 1989. *MAF Fisheries Greta Point Internal Report No. 146*. 39p.

Sissenwine, M.P. 1988. The efficiency of trawl survey gear. Appendix 2 *in* Hurst, R.J. 1988: The estimation of catchability in the interpretation of bottom trawl survey data. *MAF Fisheries Greta Point Internal Report No.109*. 53p.

Sissenwine, M.P. and Bowman, E.W. 1978: An analysis of some factors affecting the catchability of fish by bottom trawls. *ICNAF Research Bulletin No 13*: 81–87.

Smith, P.J., Patchell, G.J., and Benson, P.G. 1979: Glucosephosphate isomerase and isocitrate dehydrogenase polymorphisms in the hake (*Merluccius australis*). *N.Z. Journal of Marine and Freshwater Research 13 (4)*: 545–7.

Uzmann, J.R., Cooper, R.A., Theroux, R.B. and Wigley, R.L. 1977: Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: submersible vs camers sled vs otter trawl. *Marine Fisheries Review 39 (12)*: 11–19.

Table 1. Hake catches (tonnes) : 1975 to 1989/90
Data for 1975 to 1983 are from MAF; data from 1983–84 to 1985–86 are from the FSU; subsequent data are from the QMS.

Fishing Year	WCSI (HAK7)		Chat Rise (HAK4)	Other areas (HAK1)	Area Kermadec (HAK10)	Total (t)	
	(Estimated)	(Reported)				(Reported)	(Estimated)
1975*		71	150	161		382	
1976*		5005	303	466		5774	
1977*		17806	1250	410		19466	
1978–79#		498	6	790		1294	
1979–80#		4737	560	413		5710	
1980–81#(1)		3600	750	350		4700	
1981–82#		2565	976	293		3834	
1982–83#		1625	357	418		2400	
1983**		745	202	548		1495	
1983–84##		945	180	886		2011	
1984–85		965	399	670		2034	
1985–86	1918(2)	1695	133	1047		2875	3098
1986–87	3755(2)	2909	200	1022		4131	4977
1987–88	3967(2)	3019	288	1381		3688	5636
1988–89	9488(2)	6835	554	1487		8876	11529
1989–90	8175(2)	4735	763	2092		7590	11030
1989–90 TAC: Gazetted		3004	1000	2513	10	6527	
Actual		3310	1000	2610	10	6930	

* Calendar year
\# April 1 to March 31
** April 1 to Sept 30
\## Oct 1 to Sept 30 (1983–84 onwards)

(1) Provisional.

(2) Catches for the west coast fishery have been adjusted by scaling up reported catches of hake by the whole fleet according to the proportion of hake to hoki in catches of vessels carrying observers (see text, section 2.1.1. and Table 2).

Table 2. Catches (t) of hoki taken by all vessels, and catches (t) of hake and hoki taken by vessels carrying observers in the West Coast hoki fishery from 1986 to 1990. Estimated hake catches are also shown, estimated from: Observed hake catch x Total hoki catch/Observed hoki catch.

	1986	1987	1988	1989	1990
Total hoki (tonnes)	65 000	140 000	220 000	188 000	165 000
Surimi vessels					
Total hoki	25 000	86 000	146 000	134 000	112 000
Obs. hoki	17 900	86 000	146 000	36 400	42 000
Obs. hake	600	1 823	2 117	1 498	2 235
Obs. hake/obs. hoki (%)	3.35	2.12	1.45	4.12	5.32
Est. hake	838	1 823	2 117	5 515	5 960
Unobserved hake/hoki (%)	N/A	0	0	N/A	N/A
Head and Gut Vessels					
Total hoki	40 000	54 000	74 000	54 000	53 000
Obs. hoki	19 600	26 100	–	12 000	6 700
Obs. hake	529	934	–	883	280
Obs. hake/obs. hoki (%)	2.70	3.58	–	7.36	4.18
Est. hake	1 080	1 932	1 850	3 974	2 215
Unobserved hake/hoki (%)	N/A	0.54	1.22	N/A	N/A
All Vessels					
Est. hake	1 918	3 755	3 967	9 488	8 175
Observed hake/hoki (%)	3.01	2.46	1.45	4.92	5.16
Unobserved hake/hoki (%)	2.06	0.54	1.22	3.19	1.91

Table 3. Catch per unit effort (tonnes per 1000 km towed) of hake in June and July each year in waters to the South of 42° South by vessels of different length classes (observed vessels only), together with number of tows and number of vessels observed

		Size–class (metres LOA)			
Year		80–90	90–100	100–110	110+
(a) Daytime					
1986	cpue	51.1	35.8	122.5	–
	no. of tows	108	31	114	0
	no. of vessels	3	5	2	0
1987	cpue	63.6	56.9	129.3	103.3
	no. of tows	331	130	268	94
	no. of vessels	9	4	6	2
1988	cpue	36.3	–	57.9	75.9
	no. of tows	85	0	254	123
	no. of vessels	3	0	7	4
1989	cpue	29.6	65.0	118.1	89.4
	no. of tows	77	43	124	48
	no. of vessels	2	2	5	1
1990	cpue	46.6	100.0	78.7	104.8
	no. of tows	67	44	93	73
	no. of vessels	2	1	2	2
(b) Night–time					
1986	cpue	41.2	47.9	105.7	–
	no.of tows	107	47	150	0
	no. of vessels	3	5	2	0
1987	cpue	37.2	33.2	56.7	46.0
	no. of tows	359	152	339	125
	no. of vessels	9	4	6	2
1988	cpue	23.6	–	39.5	42.5
	no. of tows	101	0	311	128
	no. of vessels	3	0	7	4
1989	cpue	13.5	36.0	44.3	56.2
	no. of tows	87	54	168	37
	no. of vessels	2	2	5	1
1990	cpue	19.8	30.6	42.2	70.1
	no. of tows	86	55	117	88
	no. of vessels	2	1	2	2

Table 4. cpue (tonnes per km x 10^3 towed), number of tows, and total distance (km) towed by 100–110 m vessels at night in June and July each year, south of 42° South off the West Coast of the South Island.

		Depth							
		300–400	400–500	500–600	600–700	700–800	800–900	900+	All
1986	cpue	0	37.8	71.8	128.8	95.7	100.6	0	105.7
	no. tows	1	14	20	66	33	12	1	150
	km towed	7	182	244	1 169	244	76	4	1 955
1987	cpue	75.6	74.1	45.3	62.3	66.6	24.9	52.6	57.0
	no. tows	11	82	128	68	21	9	2	338
	km towed	251	1 467	2 628	1 467	471	225	24	6 852
1988	cpue	47.9	32.1	39.6	40.6	46.7	41.7	36.2	39.5
	no. tows	20	77	105	59	28	10	4	311
	km towed	667	2 502	3 315	1 902	1 262	452	160	10 489
1989	cpue	11.9	23.4	27.8	25.4	56.7	77.2	131.1	44.3
	no. tows	6	29	42	30	20	10	10	167
	km towed	208	1 468	2 222	1 357	1 091	471	434	7 972
1990	cpue	2.9	25.7	49.3	57.7	55.8	70.1	52.2	42.3
	no. tows	8	25	24	24	10	3	1	108
	km towed	204	773	804	883	235	77	29	3 477

Table 5. Summary of estimates of hake standing stock (in tonnes) made from the results of trawl surveys (vertical and areal availability are assumed to be 1.0)

Area	Depth Range (m)	Survey Dates		Source	Vessel	Biomass Est. using spread of Doors (v=0.25)	cv%
West Coast S.I.	600–700	Jul-Aug	1979	Patchell (1981)	Several commercial	17900	18
West Coast S.I	300–900	Jul	1990	Unpub FRC	*Giljanes*	5400	17
Chatham Rise	200–800	Mar	1983	Hurst and Fenaughty (1985)	*Shinkai Maru*	48400	13
Chatham Rise	200–800	Nov-Dec	1983	Hurst and Fenaughty (1985)	*Shinkai Maru*	38800	12
Chatham Rise	200–800	Jul	1986	Livingston *et al.* in press	*Shinkai Maru*	25200	12
Chatham Rise	200–800	Nov-Dec	1989	Hurst and Schofield (1990)	*Amaltal Explorer*	38000	65
Snares and Auckland Is.	200–800	Feb	1981	Hurst and Fenaughty (1985)	*Shinkai Maru*	25200	38
Snares and Auckland Is.	200–800	Apr	1983	Hurst and Fenaughty (1985)	*Shinkai Maru*	18000	59
Campbell Plat.	200–800	Mar-Apr	1982	Hurst and Fenaughty (1985)	*Shinkai Maru*	24400	15
Campbell Plat.	200–800	Oct-Nov	1983	Hurst and Fenaughty (1985)	*Shinkai Maru*	59200	23
Campbell Plat.	200–800	Oct-Nov	1989	Hurst and Schofield (1990)	*Amaltal Explorer*	10600	21
Campbell Plat.	300–800	Jul-Aug	1990	Hurst and Schofield (1991)	*Amaltal Explorer*	17400	21
Campbell Plat.	300–1000	Nov-Dec	1990	Hurst and Schofield (1991)	*Amaltal Explorer*	23800	19

Table 6a. Numbers of female hake at age (sample from WCS and Chatham Rise 1976

Length (cm)	Age (years) 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Total
50			1																					1
52						1																		1
54		1																						1
56		1		1			1																	3
58		1	1			1																		3
60		1																						1
62																								
64			1			1																		2
66			1		1																			2
68																								
70				1		2				1														4
72				1					1		1													3
74							1	1		1	1													4
76					1			1			1													3
78						1				1		1	1											4
80				1		1	2	1			1	1												7
82								1	2		1					1			1					6
84						1						2			1									4
86							1		1		1	3	1	1	1									9
88					1				1		2		2	2	1			2						11
90						2		1		1	1	2			1			1						9
92							1		1	2				2				1						7
94							1		1		2				1									5
96						1			1	1	1													4
98					1									2	1		1							5
100								1			1		1											3
102															1									1
104								1	1															2
106													1		1		1					1		4
108																1								1
110														1				1						2
112												1	1	1				1					1	5
114									1								1							2
116											1					1	1	1						4
118																		1						1
120																	1							1
122																								
124																			1					1
126																		1						1
144																	1							1
Total		4	4	4	4	11	7	7	10	7	14	10	7	9	8	3	6	9	2	–	–	1	1	128
Mean length		57	60	70	82	76	80	87	91	85	88	88	94	96	94	102	116	104	103			100	112	

Table 6b: Numbers of male hake at age (sample from WCSI and Chatham Rise 1976)

Length (cm)	Age (years) 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
38	2																			2
40		1																		1
50																				
52																				
54	1	1		1																3
56	1		2	1																4
58			1	1																2
								1		2	1									4
62				1	1	2														4
64					2		1													3
66				2	2	1		1	1											7
68				2	1	1	2		2	2										10
70			1		2	2	2	2		1		1								11
72					1	1	2	1	1	1										7
74					2	2	3	2			3									12
76				3		1		1	1	1	1									8
78				1	1		1	3	2		2									10
80				1		4	3	2	2	3			3		1					19
82					1	4	1	4	1	2	2									15
84					1	3	1	4	1	1	2		1		1					15
86						1	2	1	1	1		2	2	1	1					12
88					2			1	1		2		3							9
90											1	2	1	1						5
92											1			1	2					4
94											1		1		2					4
96										1										1
98										1						1	2			4
100															1	1	1			3
102												1					1	1		3
104																				
106																			1	1
108																				
110								1												1
Total	4	2	4	13	16	22	19	23	13	16	17	5	11	4	8	3	3		1	184
Mean Length	46	47	60	68	73	76	73	78	77	78	82	84	86	92	90	100	99		106	

Table 7. Estimates of biomass and yield for West Coast (HAK 7) hake with different combinations of survey indices and expected catches ($Catch_{1991}$) in 1990–91

$Catch_{1991}$	Survey Index	"Most Likely" B_0	B_{1992}	$B(F_{0.1})$	MCY	CAY	$C(F_{0.1})$
6000	1	46 000	14 780	13 800	3 450	3 830	3 580
6000	2	57 000	26 120	18 810	4 275	6 770	4 880
6000	3	130 000	99 730	42 900	9 750	25 850	11 120
6000	4	63 000	32 240	20 790	4 725	8 360	5 390
7500	1	46 000	13 410	13 800	3 450	3 480	3 580
7500	2	57 000	24 760	18 810	4 275	6 420	4 880
7500	3	130 000	98 380	42 900	9 750	25 500	11 120
7500	4	63 000	30 880	20 790	4 725	8 000	5 390

Survey Indices:
1. B_{1979} = 17 900; B_{1990} = 5 400
2. B_{1979} = 39 000; B_{1990} = 27 000
3. B_{1979} = 17 900; B_{1990} = 27 000
4. No Survey Estimates

CPUE Indices: 1986–1990: 1.0, 0.64, 0.65, 0.70, 0.62.

$F_{0.1} = 0.30$. $B(F_{0.1}) = 0.33\ B_0$ ($B(F_{0.1})$ is the equilibrium biomass that would be reached under a longterm $F_{0.1}$ strategy)

$MCY = 0.25 * F_{(0.1)} * B_0$ ($= 0.075 * B_0$)

$CAY = B_{1992} * (1 - e(-F_{0.1})) = 0.02592 * B_{1992}$, where B_{1992} is the biomass at the start of the 1991–92 fishing season.

$C(F_{0.1}) = B(F_{0.1}) * F_{0.1}$

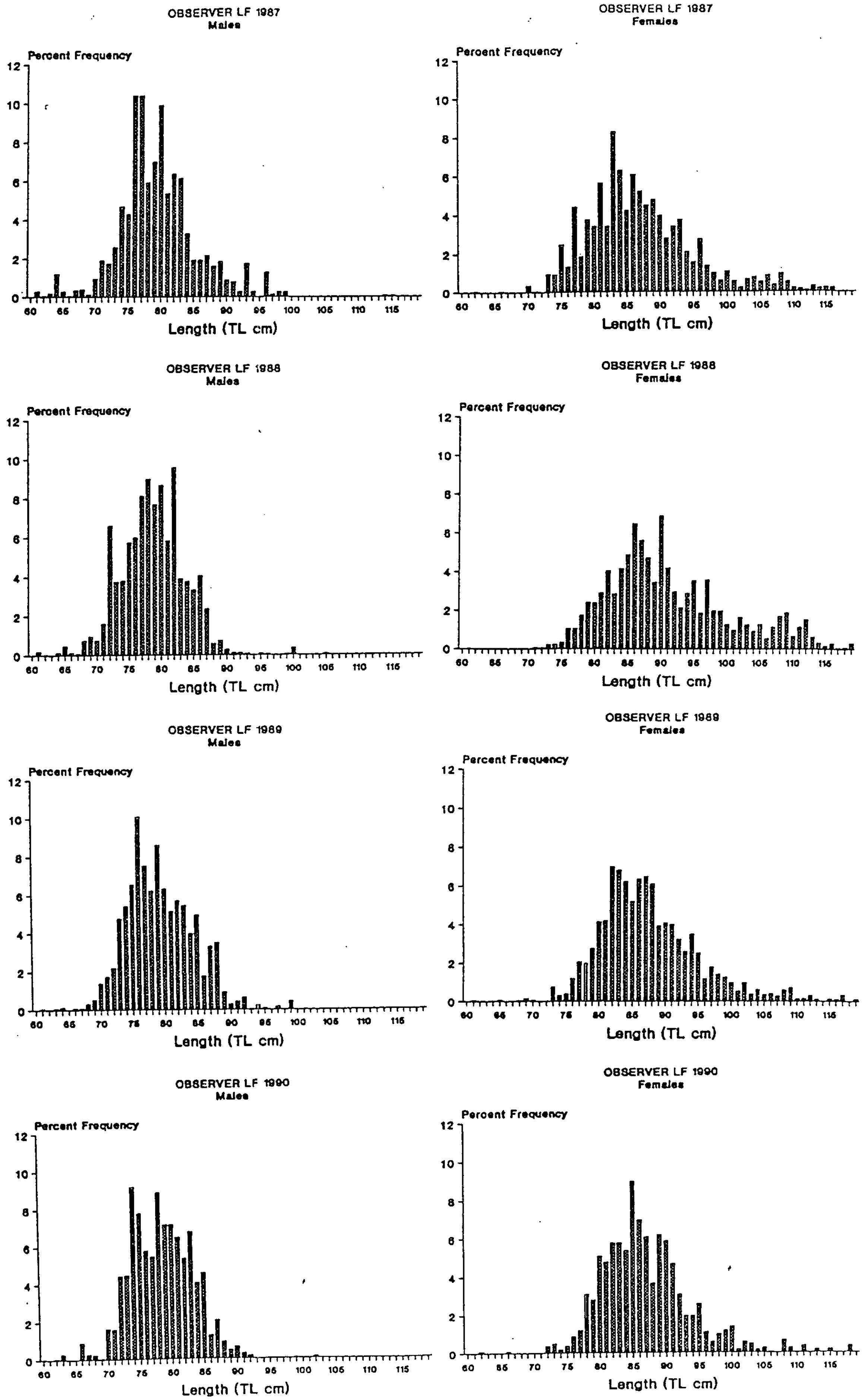

Figure 1. Length frequency distribution of male and female hake measured by observers on commercial vessels in the West Coast fishery in 1987, 1988, 1989 and 1990.

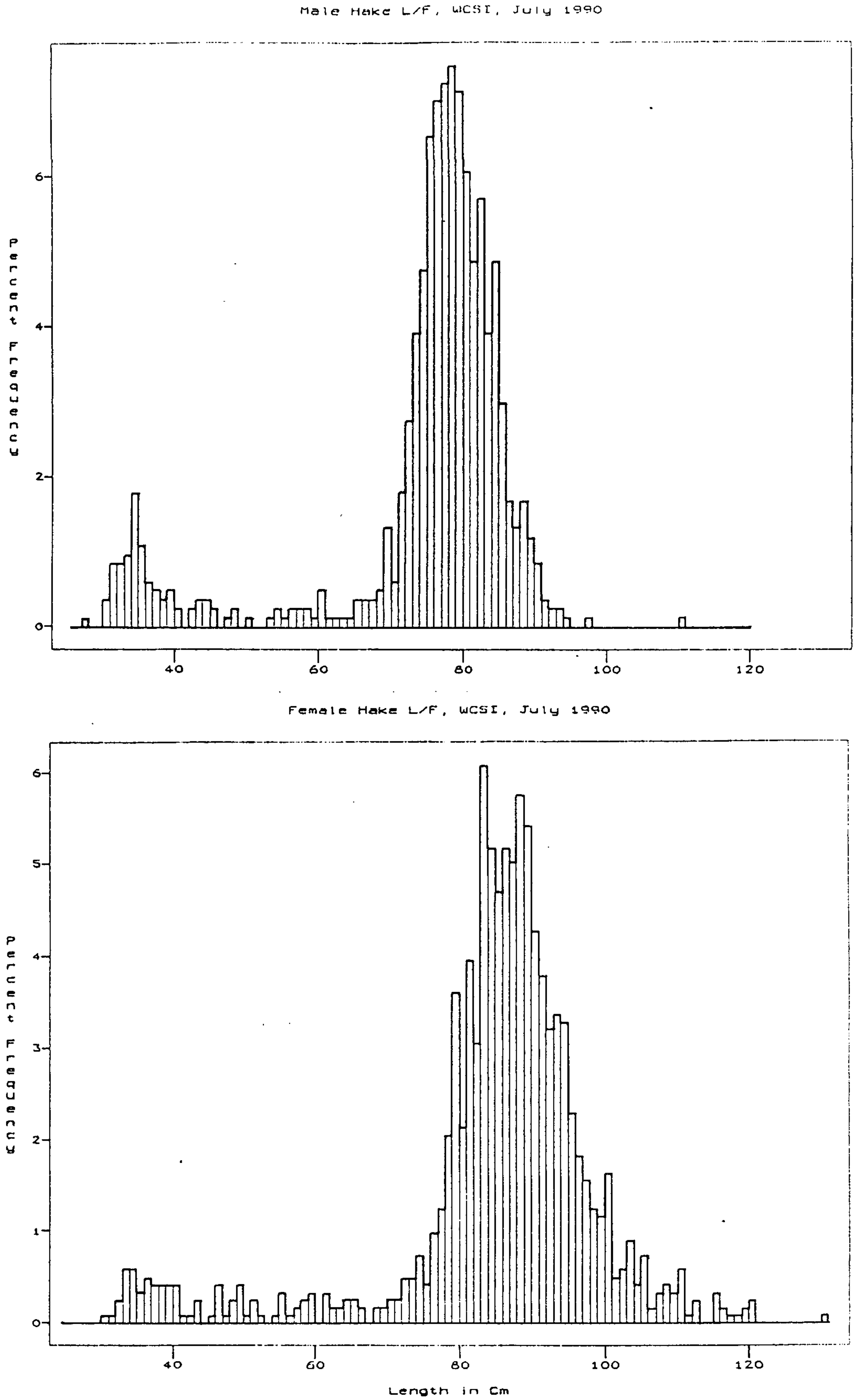

Figure 2. Length frequency distribution of male and female hake taken during a trawl survey of the West Coast fishing grounds in July 1990.

Appendix 1. Outline of GLIM model to derive "between-years" effect on cpue of hake

An index of abundance for Hake was obtained from observer CPUE data by a regression analysis using the statistical package GLIM[1]. Data from 7143 tows between 1986 and 1990, in latitudes 42.0 to 43.0° South and in depths from 300 to 1000 m were used in the analysis.

For each tow, information about the catch, the distance over which the fishing occurred, the size of the vessel, and the depth, position, speed and timing of the tow is available. The catch of hake (greenweight, kg) per nautical mile fished was used as the estimate of CPUE. Five factors were used in the regression: the gross tonnage of the vessel, the depth of the tow, the hour, the month and the year of the tow. Since catch may vary in a non-linear way with tonnage, depth, or hour, each of these factors was split into a number of strata over which the catch rate could be considered constant. For each factor, the effect of each stratum on the catch rate is assessed relative to the effect of the first stratum.

Hence these variables were used in the regression:

Factor	Value
Tons (1)	vessel ≤ 1500 tons
Tons (2)	vessel > 1500 tons
Depth (1)	tow ≥ 300 m and < 500 m
Depth (2)	tow ≥ 500 m and < 700 m
Depth (3)	tow ≥ 700 m and < 1000 m
Month (1)	tow in June
Month (2)	tow in July
Month (3)	tow in August
Dayn (1)	tow at night (before 8:00 or after 17:00)
Dayn (2)	tow during day (between 8:00 and 17:00)
Year (1)	1986
Year (2)	1987
Year (3)	1988
Year (4)	1989
Year (5)	1990

The model was of the form

$$log(CPUE_t) = C + To_{i_t} + De_{j_t} + Mo_{k_t} + Da_{l_t} + Y_{m_t} \qquad (1)$$

where $CPUE_t$ is the catch per unit effort of the tth tow (which is in the ith tonnage stratum, the jth depth stratum etc.), C is a constant, To_i is the effect of the ith tonnage stratum, De_j the effect of the jth Depth stratum, Mo_k the effect of the kth Month, Da_l the effect of the lth Daylight stratum, and Y_m the effect of the mth year. The model was fitted assuming that the y_t's, where $y_t = log(CPUE_t)$, are independent and have a normal distribution with mean

[1] GLIM (Generalised Linear Interactive Modelling), Baker, R.J. and Nelder, J.A., 1978. Numerical Algorithms Group, NAG Central Office, Mayfield House, 256 Banbury Road, Oxford OX2 7DE

$$\mu = C + To_{i_t} + De_{j_t} + Mo_{k_t} + Da_{l_t} + Y_{m_t} \quad (2)$$

and variance σ^2. The values of the effects (To_i, De_j, Mo_k, Da_l, Y_m) were chosen to minimise the residual sum of squares $\Sigma(y - \mu)^2$.

The effects for each of the strata are presented along with the standard error of the estimates.

Stratum	Effect	Standard Error
Constant	3.665	0.1163
Tons (1)	0	
Tons (2)	–0.1429	0.06918
Depth (1)	0	
Depth (2)	0.6408	0.04467
Depth (3)	1.133	0.06198
Month (1)	0	
Month (2)	0.05764	0.0806
Month (3)	–0.9452	0.0852
Dayn (1)	0	
Dayn (2)	0.2751	0.03754
Year (1)	0	
Year (2)	–0.4415	0.05830
Year (3)	–0.4295	0.06442
Year (4)	–0.3507	0.07151
Year (5)	–0.4782	0.06678

The residual sum of squares in this case was 16885, which with 11 fitted parameters leaves 7143–11=7132 degrees of freedom. This gives an estimate of σ^2 of 16885/7132=2.367. The total sum of squares (corrected for the mean only) was 20403, so the model explains R^2=(20403–16885)/20403=17% of the variation in $log(CPUE_t)$.

The index of abundance for hake, which is the effect on CPUE of the year effects, all other factors having been accounted for, is found by taking the anti-logarithm of the year effects.

Year	Year Index	Error
1986	1.000	0.000
1987	0.643	0.038
1988	0.651	0.042
1989	0.704	0.051
1990	0.620	0.042