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Stock structure of New Zealand hoki, *Macruronus novaezelandiae*

M. E. Livingston

MAF Fisheries Greta Point
P O Box 297
Wellington

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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INTRODUCTION

New Zealand hoki are currently managed as a single stock (Sullivan and Livingston 1988, Hurst et al 1987, Patchell and Coombs 1986), largely on the basis of a single major spawning ground (Patchell 1982), and gel electrophoresis studies which showed no genetic distinctions from hoki sampled around the Exclusive Economic Zone (Smith et al 1981). However, research in 1987 found substantial quantities of spawning hoki in Cook Strait (Livingston and Berben 1987, Do and Ball 1988) and a domestic fishery has since been developing there (Sullivan and Cordue 1990). In addition, results from a plankton survey in 1985 show relatively high concentrations of hoki eggs and larvae on the Chatham Rise east of New Zealand at the same time as the spawning season on the West Coast of the South Island (Uōzumi 1988).

This simultaneous spawning of hoki in more than one area may be indicative of the existence of more than one stock, and therefore management of hoki as one stock may no longer be appropriate.

This paper discusses 'stock definition' and reviews information currently available that is relevant to hoki stock structure. An alternative management option which splits hoki into two stocks is presented.

USE OF THE TERM 'STOCK'

Stock definition for fisheries management is a particularly complex problem and the use of the term has varied historically in the scientific literature. For example, "the choice and definition of a unit stock can be considered as essentially an operational matter, being tied to the models being used ..." (Gulland 1983)...or," a stock is an intraspecific group of randomly mating individuals with temporal or spatial integrity" (Ihssen et al. 1981). Both authors consider that management requirements are used validly to define a stock. Larkin (1972) explicitly included the element of management feasibility in his definition of a unit stock as "a population of organisms which, sharing a common gene pool, is sufficiently discrete to warrant consideration as a self–perpetuating system which can be managed." Maclean and Evans (1981) suggest however, that it is more important to develop a stock concept from a genetic perspective as a basis for fisheries management.

Gulland (1983) also discussed the importance of assessing variability within a fish population.

> "The analytic models do distinguish individuals according to their sex, age, or size, but otherwise assume that each individual of a given size or age behaves in the same way. This is a necessary simplification in order to make the models workable. In fact fish differ; feeding may be better in one part of the range, resulting in a better growth; fishing is not distributed

uniformly, so that some fish are exposed to a greater intensity of fishing than others. Within a small area there may be sufficient and rapid mixing so that over a period it is reasonable to suppose that individuals are exposed to something approaching average conditions of feeding, or fishing intensity, and differences within the area can be ignored. For larger areas this may not be so reasonable; differences between different parts can be marked and consistent, amounting sometimes to clear genetic differences within a single species.
[emphasis added]

It can be a matter of some importance to choose an appropriate group of fish, the unit stock, that can be treated as a homogeneous and independent unit. Too large, and important differences within the unit stock may be neglected; too small, and interactions with other groups of fish may be important and the need to consider these interactions may add considerably to the complexities of analysis."

Gulland goes on to caution against insufficient attention being given to the question of what constitutes a unit stock. If a fishery is in fact based on several independent stocks, or exploits only part of a large stock, the assumption of a unit stock may have important consequences.

For example, if there are several independent stocks, each may behave in a different way. Alternatively, if a fishery is based on one part of the stock only, it will give a weighted average of the events in this particular population (Gulland 1983). A change in fishing pattern, particularly one that exploits new stocks may be serious in either case.

INDICATORS OF STOCK STRUCTURE

There are a number of possible indicators that can be used to derive a model of stock structure:

1. Distribution of fishing

A gap in the fishing area may be indicative of a gap in the distribution of fish, which may correspond to a separation of stocks.

2. Spawning areas

Genetic separation of stocks requires separation of spawning groups, even if the fish intersperse at other times.

3. Values of population parameters

If there are stock differences of importance, there may be differences in some population parameters such as growth or mortality.

4. Behavioural/physiological characteristics

Maturation time, courtship behaviour, migratory patterns could all be expected to differ among different stocks since the location of spawning and environmental conditions will be different.

5. Morphology and meristics

Different stocks can show differences in morphology and meristics. These may be genotypic or phenotypic, and may be indicative of separate stocks.

6. Tagging

This should in theory provide the clearest evidence of stock inter–relationships. However, while the existence of mixing is clearly shown by interchange of tagged fish, the failure of tagged fish to show up on other fishing grounds is not conclusive evidence of separation.

7. Calcified structures

Scales, otoliths, and other skeletal bones, show various patterns of deposition during the life cycle of fish. Fish exposed to different environmental conditions and food sources may show differences in depositional patterns, which can be indicative of different stocks.

8. Genetics

Cytogenetics and electrophoresis are techniques recently developed to show up enzyme and DNA differences among groups of fish. However, the rapidity of mixing remains an important factor.

9. Parasitic fauna

Fish that live as separate stocks in different areas may have different parasites and rates of infestation. As with tagging, a clear difference, in this case, of parasite loading, may indicate separate stocks, but a lack of difference does not necessarily indicate the converse.

Characteristics that are genetically determined (eg. see Cushing, 1964) can provide clear evidence that two groups are distinct, but genetic separation can in principle exist without this being evident in the characteristics examined. Further, mixing can proceed fast enough to achieve genetic uniformity while still being slow enough for different groups to be separate stocks for practical assessment purposes (Gulland 1983). Therefore the broader concept of defining groups of fish as distinct stocks for management purposes is considered a viable approach, and the definition of Larkin (1972) is adopted here as the most appropriate.

HOKI - BACKGROUND INFORMATION

Hoki is a merluccid hake which dominates trawl catches at 200-800m depths around most of New Zealand (Clark and King 1989, Francis 1981, Francis and Fisher 1979). Commercial quantities are mostly taken around the South Island, particularly on the west coast during the spawning season (Sullivan and Livingston 1988).

Major spawning grounds have been identified off the west coast of the South Island (WCSI), and hoki eggs and larvae are believed to be carried north and south in surface currents to all areas of New Zealand (Patchell 1982). Small juvenile hoki (< 65cm TL) dominate depths of 200-600m on the Chatham Rise (Patchell 1982, Fenaughty and Uozumi 1989, Livingston et al. in press), and although they have also been found on the WCSI (Kerstan and Sahrhage 1980), and on the Stewart and Snares shelf (van den Broek et al. 1984, Uozumi et al. 1987), the Chatham Rise has been identified as a major nursery ground for hoki (Hurst et al. 1988, Livingston et al. in press). Outside the WCSI spawning season, the bulk of adult biomass appears to reside on the Southern Plateau, south of New Zealand (Sullivan and Livingston 1988).

There were some early reports of hoki spawning activities outside the WCSI (Blagodyorov and Nosov 1978, Kuo and Tanaka 1984a) but few data were presented to support the statement by Blagodyorov and Nosov (1978) that there are major spawning grounds on the Chatham Rise. Bottom trawling during surveys of the Chatham Rise in 1979 (Kerstan and Sahrage 1980) and along the east coast of the South Island during 1980–81 (Fenaughty and Bagley 1981) and 1982–83 (Paul and Kucerans 1984) did not yield evidence of spawning hoki. Thus although it was conceded that sporadic spawning may occur outside the WCSI, the only spawning grounds of major importance were believed to be on the WCSI (Patchell 1982). Gel electrophoresis studies failed to show genetic separation of hoki collected from different areas (Smith et al 1981), so it was concluded that New Zealand hoki were essentially a single stock, with adult fish migrating from all areas of the EEZ to the west coast to spawn (Fig.1 after Patchell 1986, 1981). Small quantities of maturing hoki recorded in northern Cook Strait in August 1968 (Webb 1972) and at various locations in southern Cook Strait (Patchell 1986), were taken as evidence that hoki migrate through the area en route to the WCSI.

Total Allowable Catches (TACs) set after the declaration of the Exclusive Economic Zone in 1978 restricted hoki catch to 60 000 tonnes total, of which only 20 000 tonnes could be taken from the WCSI. However the TAC was raised to 120 000 tonnes in 1986 and subsequently to 250 000 tonnes (Sullivan and Livingston 1988). The areal restriction applying to the WCSI was removed as hoki was believed to be a single stock (Patchell and Coombs 1986).

In September 1986, high densities of hoki eggs and larvae were captured in Cook Strait, indicating a hoki spawning event in the vicinity (Fig 2, after Murdoch and Chapman 1989).

Shortly after this observation, the results from a random trawl survey of the Chatham Rise in July 1986 found that 25% of adult female hoki had been undergoing early spawning maturation (Fig 3). Since the 1986 spawning season was already well underway on the WCSI, it was thought unlikely that these fish would move as far as the WCSI to spawn (Livingston et al. in press).

In late August–early September 1987, an exploratory trawl survey of the Cook Strait area, southeast coast of the North Island (ECNI) and northeast coast of the South Island (ECSI), found a large school of spawning hoki in the Cook Strait Canyon and smaller quantities of spawning hoki in Narrows Basin, Pegasus Canyon, and the Conway Trough (Fig 4, after Livingston and Berben 1987).

In December 1987, Japanese scientists forwarded the results of a plankton survey which found significant quantities of hoki eggs near Pegasus Canyon at the western end of the Chatham Rise in August 1985 (Fig 5, after Uozumi 1988).

Other information was recently supplied by scientific observers, who recorded hoki containing roe caught just south of Banks Peninsula in September 1985 and recorded the presence of spawning fish there in September 1987 (W. Tatham Observer Programme, pers comm.).

During the 1988 winter season, small domestic vessels (<43m total length) investigated the Cook Strait Canyon and found commercial concentrations there in August and September (Table 1). The 'James Cook' also briefly surveyed Cook Strait on 28 August 1988 and found spawning hoki in both Cook Strait Canyon and Nicholson Canyon just off the Wellington Harbour entrance (Livingston 1988). In 1989 and 1990, commercial catches were again taken from Cook Strait (Table 1).

This information collectively indicates that hoki have spawned annually in Cook Strait since 1986 and that some spawning occurs off the ECSI.

It is unlikely that spawning in any of these areas is an entirely new phenomenon, particularly since spawning in some of them had already been reported by Blagodyorov and Nosov (1978), and Kuruwa (1985). However the extent and frequency of spawning in these locations is uncertain. It is quite conceivable that spawning concentrations in Cook Strait escaped attention in the past as the hoki are highly localised and inaccessible to a bottom trawl. Furthermore, large vessels (>43m) cannot fish inside the 25 mile fishing zone and small vessels usually target hoki off the WCSI in winter (Fenaughty and Bagley 1981). Alternatively, the extent of spawning in these areas may have increased in recent years due to some shift in environmental conditions or other factor affecting hoki behaviour.

While there have been research surveys in Cook Strait and along the ECSI in the past (June 1978, July 1979, September 1980, June 1981), these surveys were not aimed at searching specifically for spawning hoki and certainly no large schools of hoki were mentioned in the respective cruise reports. However, the occasional fish with ripening gonads was caught, and a considerable number of hoki (gonad state unspecified) were caught in Cook Srait Canyon during acoustic gear trials in July 1979 (R. Coombs, personal communication).The other surveys above were not at the peak time of the hoki spawning season and the absence of fish schools cannot be taken as conclusive evidence that substantial spawning did not occur in Cook Strait in those years.

That hoki are spawning simultaneously in commercial quantities in Cook Strait and off the WCSI is unquestionable. How long it has been going on is less certain.

HOKI STOCK STRUCTURE

Essentially two hypotheses about hoki stock structure emerge from the above information:

Hypothesis 1.Hoki form a single stock.

> i.e., The hoki population in New Zealand waters form a single self–perpetuating system, with one common gene pool.

Hypothesis 2. Hoki form a multiple stock.

> i.e., hoki in New Zealand waters form at least two self–perpetuating systems which although perhaps sharing a common gene pool, are sufficiently discrete to warrant separate management.

For most deepwater fisheries in New Zealand, there is little or no information on stock structure. They are, however, managed by "Fishstock Areas". These management areas usually separate the known spawning grounds of a particular species, but the boundaries may bear little relationship to the wider distribution of that particular stock, which is usually unknown. This approach has been adopted to safeguard different spawning stocks, which may or may not be genetically distinct, from over–exploitation. In some cases, the management areas bear little relationship to fish distribution, but have been retained, again to prevent over–exploitation in a particular region. However, hoki has been managed as a single stock resulting in a single Fishstock Area (i.e., the entire EEZ).

A summary of evidence for hoki stock structure is given below under the headings listed earlier (after Gulland 1983).

1. Distribution of fishing

The fishery has focussed on the exploitation of spawning adults on the WCSI, particularly over the past four years since the increase in TAC to 120,000t and then 250,000t (Table 2). The fishery has, therefore, been operating unevenly because it does not take in substantial quantities of non spawning adults (usually taken in the Subantarctic, but also to some extent on the Chatham Rise) and juvenile hoki (usually taken on the Chatham Rise). With the discovery of commercial concentrations of spawning fish in

Cook Strait, there has been a marked shift in the fishing effort of small domestic vessels to this area (Table 1).

2. Spawning areas

Winter spawning has been confirmed in five separate locations, viz. WCSI, Puyseger Bank, Cook Strait, Chatham Rise (west), and Kaikoura. Of these, only the WCSI, Puysegur, and Cook Strait have yielded catch rates of commercial significance in recent years.

3. Population parameters

Length frequency data from Cook Strait and the WCSI show different size distributions between the two areas, and length–weight relationships from the two areas are slightly different (Livingston and Schofield 1989). However, this may not be significant as the data from Cook Strait was collected from a limited part of the season, and we know there is a progressive decrease in mean size of hoki caught during the WCSI season (Sullivan and Coombs 1989). Otoliths have been collected from both areas, but the age data are not yet available for analytical comparison. If the spawning grounds do reflect different spawning stocks, the fishing mortality rates would be expected to differ as the two areas have been subjected to different fishing pressures.

Kuo and Tanaka (1984b) found a significant difference between growth rates of hoki from the Chatham Rise and from other areas around the South Island. However, they also pooled male and female data on the basis that their growth rates were similar. This observation conflicts with data presented by Sullivan and Coombs (1989), and Kenchington and Augustine (1988), which show significant differences in growth rates between the sexes.

4. Behavioural/physiological characteristics.

Fish behaviour during the spawning season differs between the two areas. On the WCSI, hoki move up off the bottom at dusk and back down again at dawn. These movements can be followed on the echo sounder and target fishing depths alter accordingly. In Cook Strait, this pattern of movement is not apparent. Fish traces on the echo sounder do alter with depth but not in relation to any obvious cycle. Further, the hoki are caught consistently higher in the water column than on the WCSI. While these observations are of interest, they do not necessarily relate to stock differences. More likely, they reflect differences in environmental conditions on the two spawning grounds.

5. Morphology and meristics

No information on morphometric or meristic variation among hoki has been published. A study has just begun to compare the morphology of hoki from different fishing grounds.

6. Tagging

The tagging of hoki has not been attempted in New Zealand. This is because the fish are usually caught at considerable depths and are seldom alive once they reach the surface. Hoki are not commonly caught on hooks although they have been caught by small vessels trolling for tuna on the WCSI. If hoki could be caught in good condition, a large number of fish would have to be tagged to ensure that adequate numbers of fish would be recaptured for analysis of movement patterns.

7. Calcified structures

A study which compared otolith morphology of hoki from around the EEZ (Kuo and Tanaka 1984c) found three different groups which separated into an eastern area (mainly the Chatham Rise), a southern area (mainly the Southern Plateau), and a northwestern area (mainly the WCSI). On the basis of this work, Kuruwa (1985) suggested that there are three subpopulations of hoki, with a high degree of interaction between the southern and northwest stocks.

8. Genetics

A gel electrophoresis study of enzymes in hoki collected from different areas of the EEZ showed no evidence of genetic differences (Smith et al 1981). These investigations were preliminary, however, and the more powerfull mitochondrial DNA technique is currently being investigated (Peter Smith, pers. comm.).

9. Parasitic fauna

There have been no studies on parasite abundance and distribution in New Zealand hoki.

CONCLUSIONS

The strongest indicator that hoki could be regarded as more than one stock for management purposes, lies in the occurence of spawning areas in other parts of the EEZ as well as the WCSI.

Under the single stock hypothesis, we would have to assume that there is rapid mixing among adult hoki from all spawning grounds, and that fish do not necessarily return to the same spawning grounds each year. Thus heavy exploitation of one spawning ground should not lead to a decline in fishing of that area in subsequent years. With such rapid mixing, we should expect similar growth rates and morphological variation among hoki throughout the EEZ. This does not fit the information presented by Kuo & Tanaka (1984) or Kuruwa (1985).

Under the multiple stock hypothesis, some mixing among adults from each spawning ground is anticipated; however, fish would tend to return to the same area to spawn. Thus if heavy exploitation occured on one group, mixing would not be rapid enough to replenish that population by the following season, and could lead to a rapid decline of that fishery. It is assumed, however, that juveniles may mix together on the Chatham Rise, since this is the only known area where large numbers of juvenile hoki have been found.

The information listed above best fits the multiple stock hypothesis and accomodates all the research results so far available. Had all this information been available at the time when Fishstock Areas were first defined, hoki would have been sub–divided. However, if we continue to manage hoki as a single stock, we are in serious danger of over–exploiting the population associated with the West Coast spawning grounds, as it is here where 90% of the catch is taken. If we are to manage hoki as a multiple stock, then careful consideration must be given to defining how many stocks the hoki population could usefully be split into, i.e., how many self–perpetuating systems are there. Other problems which may need to be addressed include determining the proportion of the adult population which is likely to spawn in one year, and ensuring that juvenile fish (particularly on the Chatham Rise) do not become overexploited.

MANAGEMENT IMPLICATIONS

Option 1. No change to current management practice.

It is assumed that vessel size restrictions in Cook Strait supply sufficient restraint on exploitation in that area and that fishing effort will alter from year to year, depending where the best fishing is. A single TAC would therefore remain. The risks are that different parts of the population may be exploited at inappropriate rates, and different production units could be seriously overexploited, particularly if klondiking was introduced in Cook Strait.

Option 2. Sub–divide hoki into separate stock units.

The simplest way of ensuring protection of the largest spawning groups, is to divide the hoki population into two stocks, essentially east–west, on the basis of the distribution of known spawning grounds, and the most likely areas that adults reside in during their dispersed phase (Fig. 6). This is not to say that intermixing between stocks does not occur. It is likely that the juvenile hoki of both stocks occur together on the Chatham Rise. Managing hoki as two separate stocks, therefore, assumes limited mixing among adult fish, but does not address the problem of exploitation of juvenile fish from both stocks.

SUMMARY

Hoki spawn simultaneously and extensively in at least two areas in New Zealand waters. This alone does not tell us how distinct these fish are genetically. However, as the fishery mostly operates during the spawning season it is important to ensure that both spawning areas remain viable fishing grounds. If one area is overfished, it may take many years for that area to regain adequate fish concentrations from new recruits entering the fishery or from natural mixing among the adult population. The hoki fishery should therefore be managed as two stocks to safeguard the two main spawning populations from overfishing. Retention of the present closed areas may provide some protection to the spawning stocks, particularly in Cook Strait. The west coast, however, is far more vulnerable to overfishing as long as the TAC can be taken anywhere in the EEZ.

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Table 1. Reported domestic catch (t) of hoki during June to September of each year (source:FSU data). Areas are domestic fishing return areas.

Cook Strait

	Area 16	Area 17	Total	% of total for CS and WCSI
1984	2.9	3.9	6.8	<1%
1985	53.4	0.1	53.5	1%
1986	64.4	0.5	64.9	1%
1987	59.7	20.6	80.3	1.5%
1988	40.5	1 325.3	1 365.8	31%

WCSI

	Area 33	Area 34	Area 35	Area 36	Total	% of total for CS and WCSI
1984	60.9	2 202.6	4 185.0	267.1	6 715.6	99.9%
1985	913.4	1 855.2	2 982.0	49.9	5 800.5	99%
1986	2 341.2	2 363.3	1 443.8	3.2	6 151.5	99%
1987	1 156.6	820.8	3 389.7	89.8	5 367.1	98.5%
1988	162.5	745.7	2 140.2	12.2	3 060.6	69%

1989 data unavailable at time of writing

Table 2: Reported catch (t) for foreign chartered and foreign licensed vessels only (data source :FSU).

EEZ Management Area	1978–84	%	1985–88	%
B	139	<1	–	–
C	14 053	9	38 011	8
D	29 917	19	8 925	2
E_A	16 254	10	11 068	2
E_B	153	<1	3	<1
E_C	9 468	6	1 477	<1
E_P	5 023	3	1 741	<1
F_E	8 771	5	18 364	4
F_W	18,572	12	4 999	1
G	53 309	34	388 362	<1
H	1 442	1	3 257	<1
Total	157 101		476 207	

(1989 data unavailable at time of writing)

FIG 1. HOKI, UNIT STOCK CONCEPT

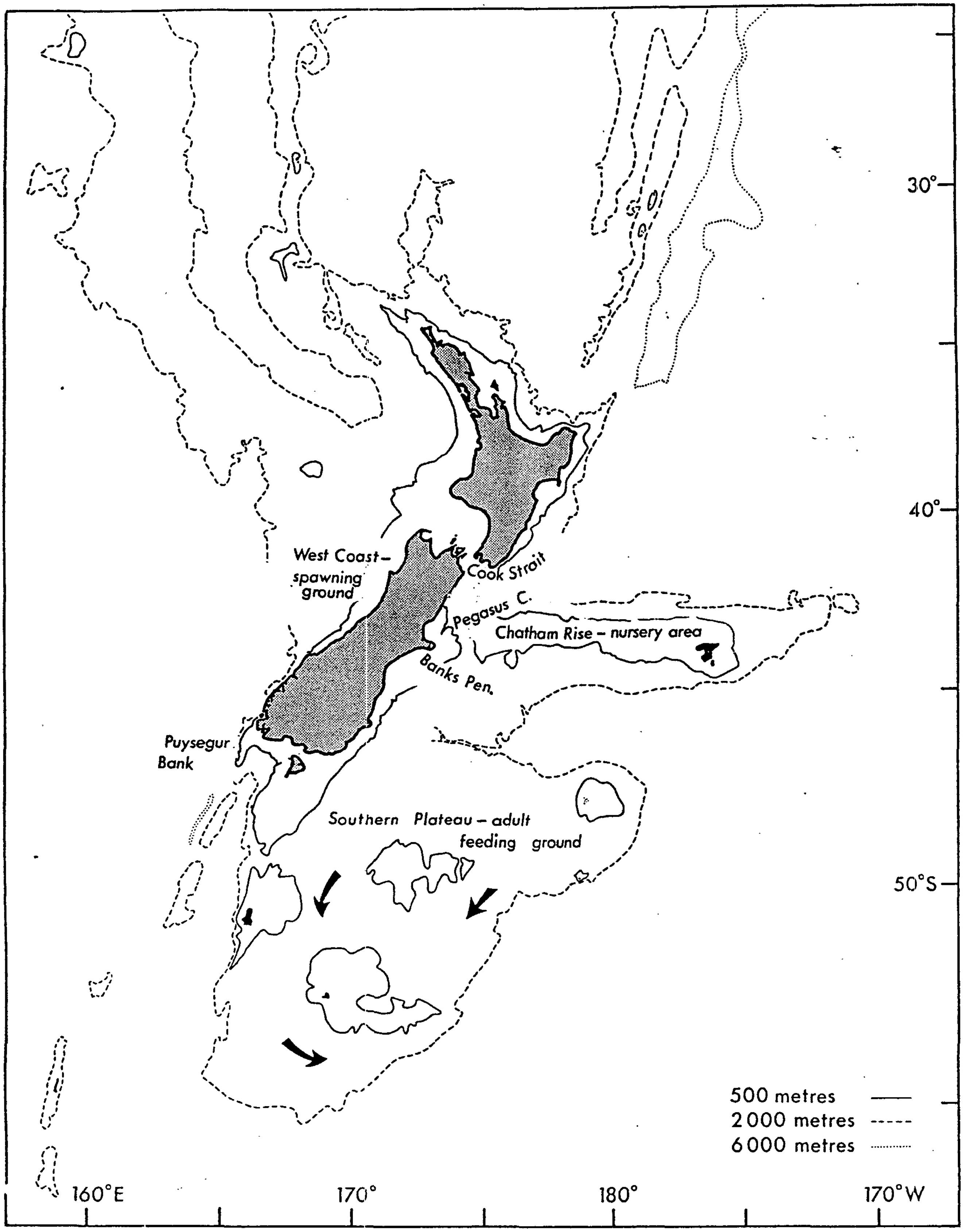


FIG 2. EGG/LARVAE CONCENTRATIONS, SEPT. 1986 (MURDOCH & CHAPMAN, 1989).

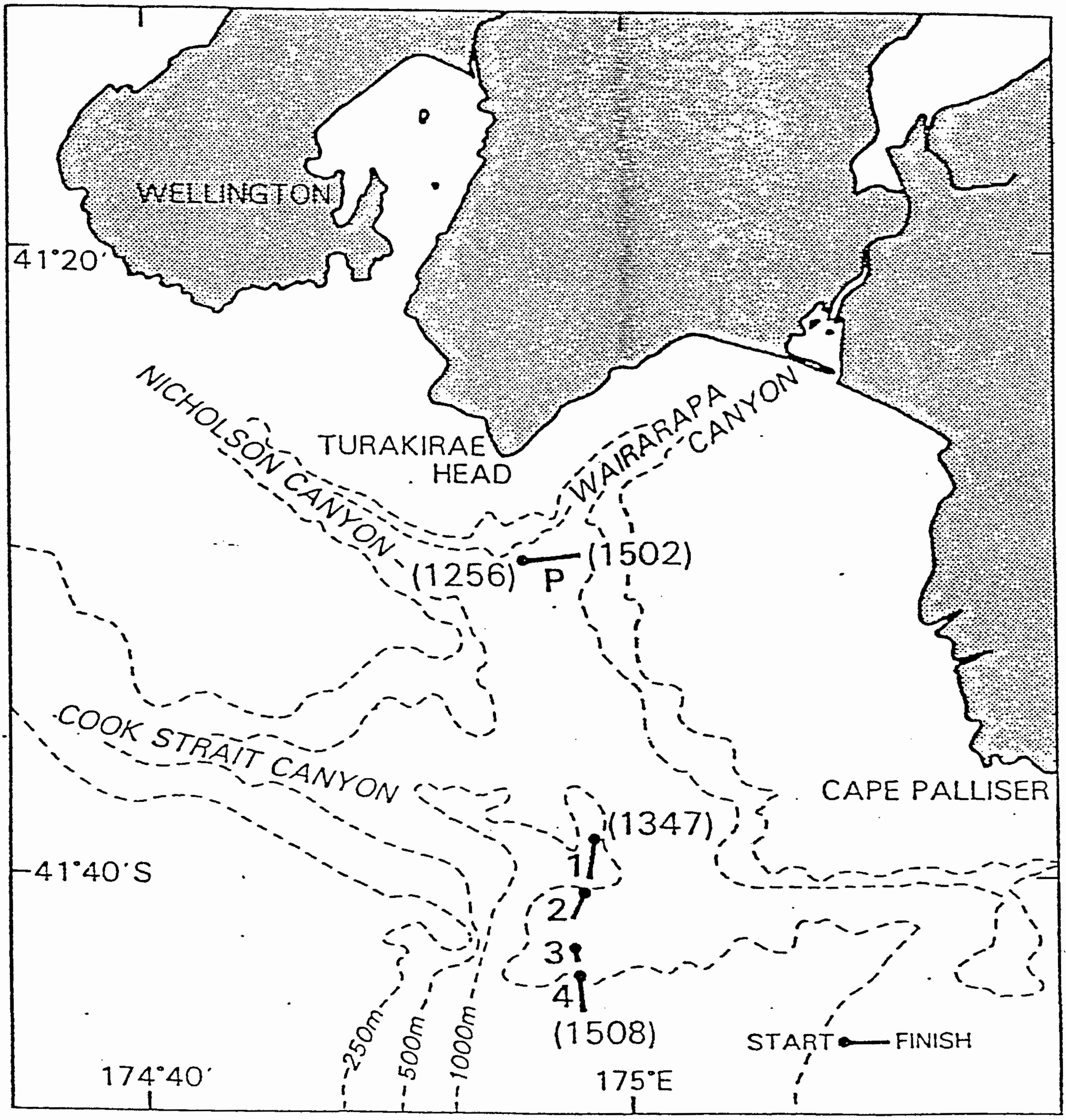
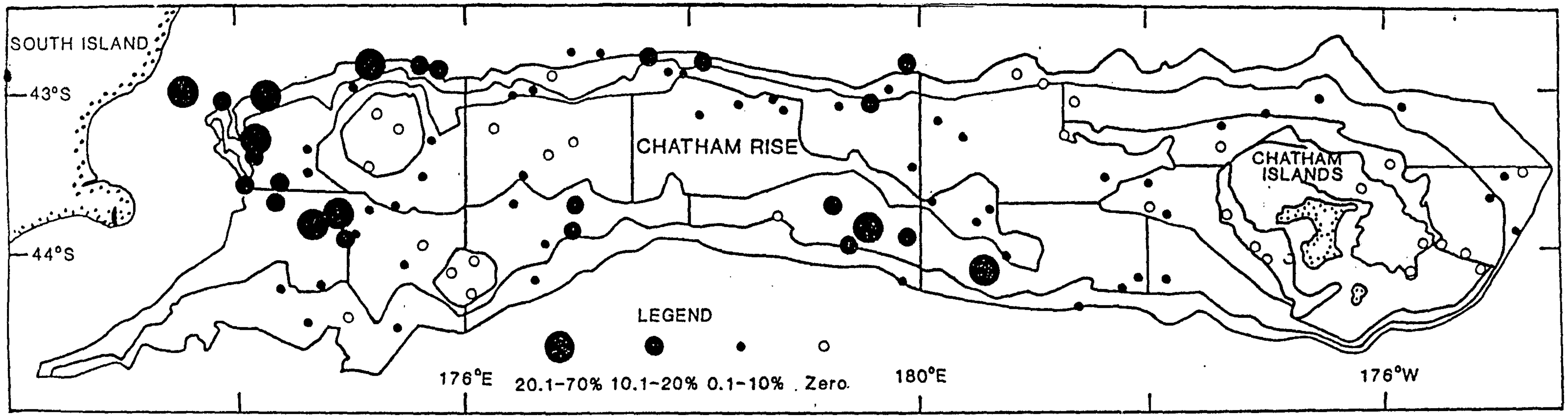


FIG. 3 Distribution of female Hoki with maturing ovaries (ie. eggs visible) expressed as % of catch per tow. Chatham Rise July 1986.



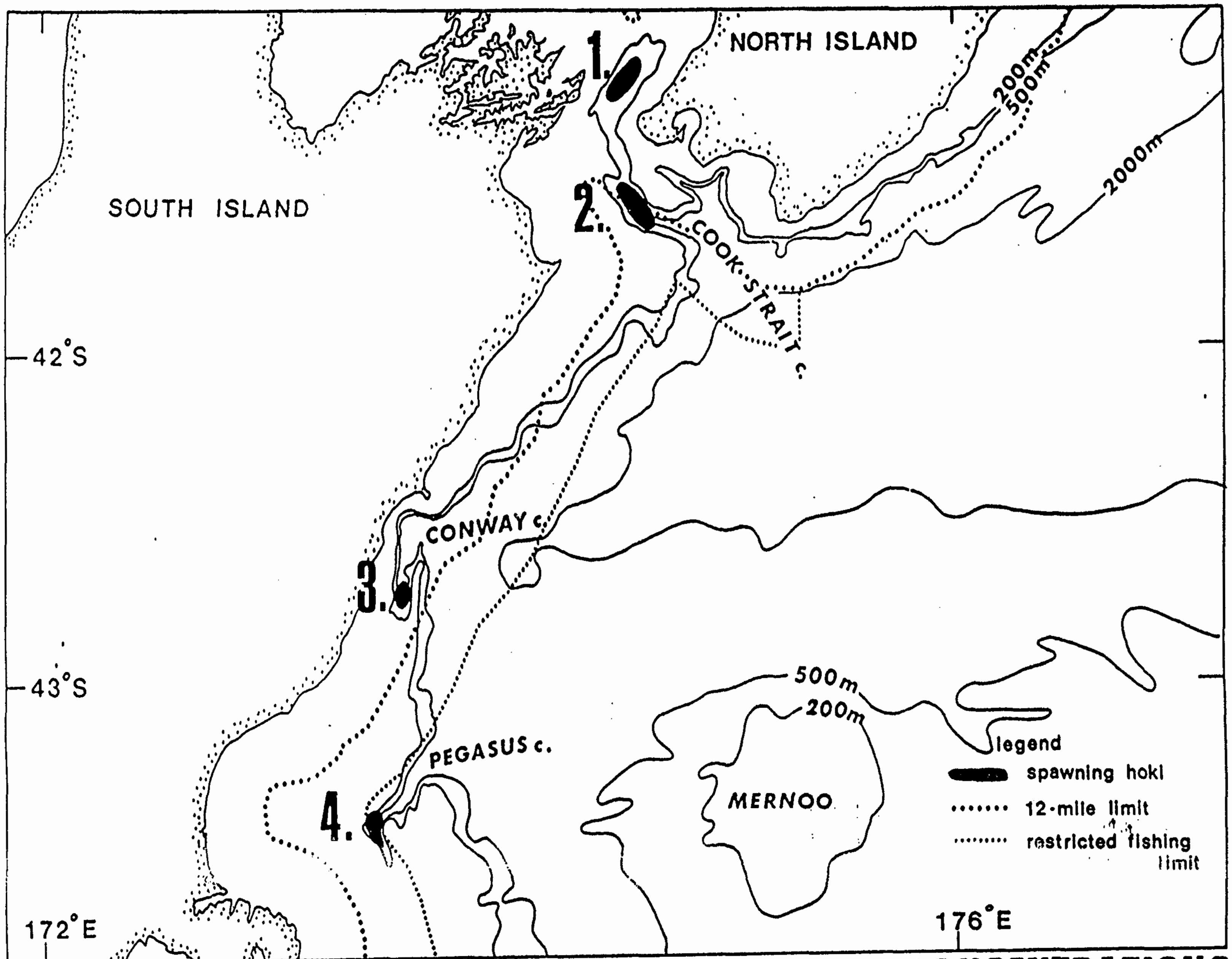
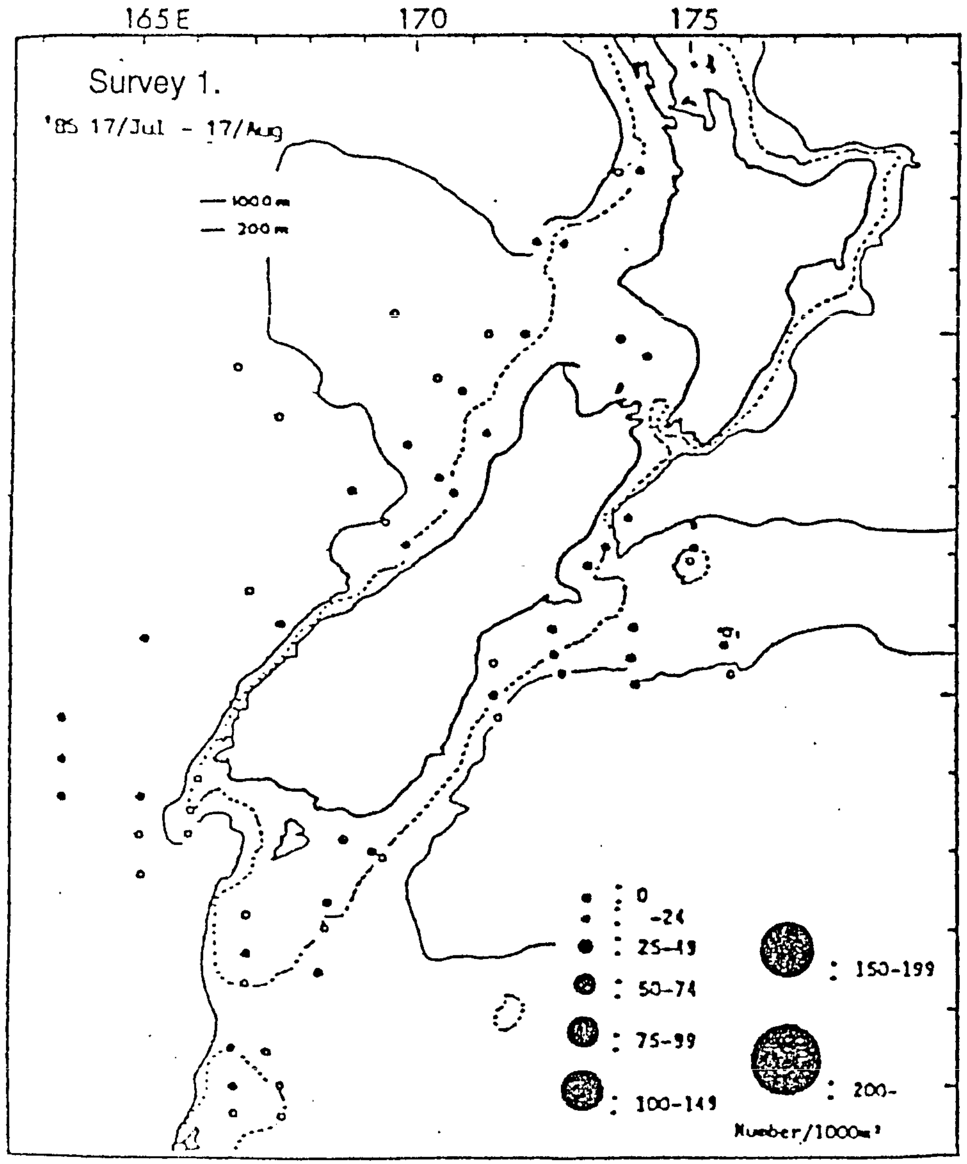


Fig 4. **LOCATION OF NEW-FOUND SPAWNING HOKI CONCENTRATIONS** (16AUG -5 SEP)
(Livinaston & Berben 1987)

Fig.5. Hoki larvae distribution 1985,
1-4mm length
ie. less than 4 days old
(Uozumi 1988).



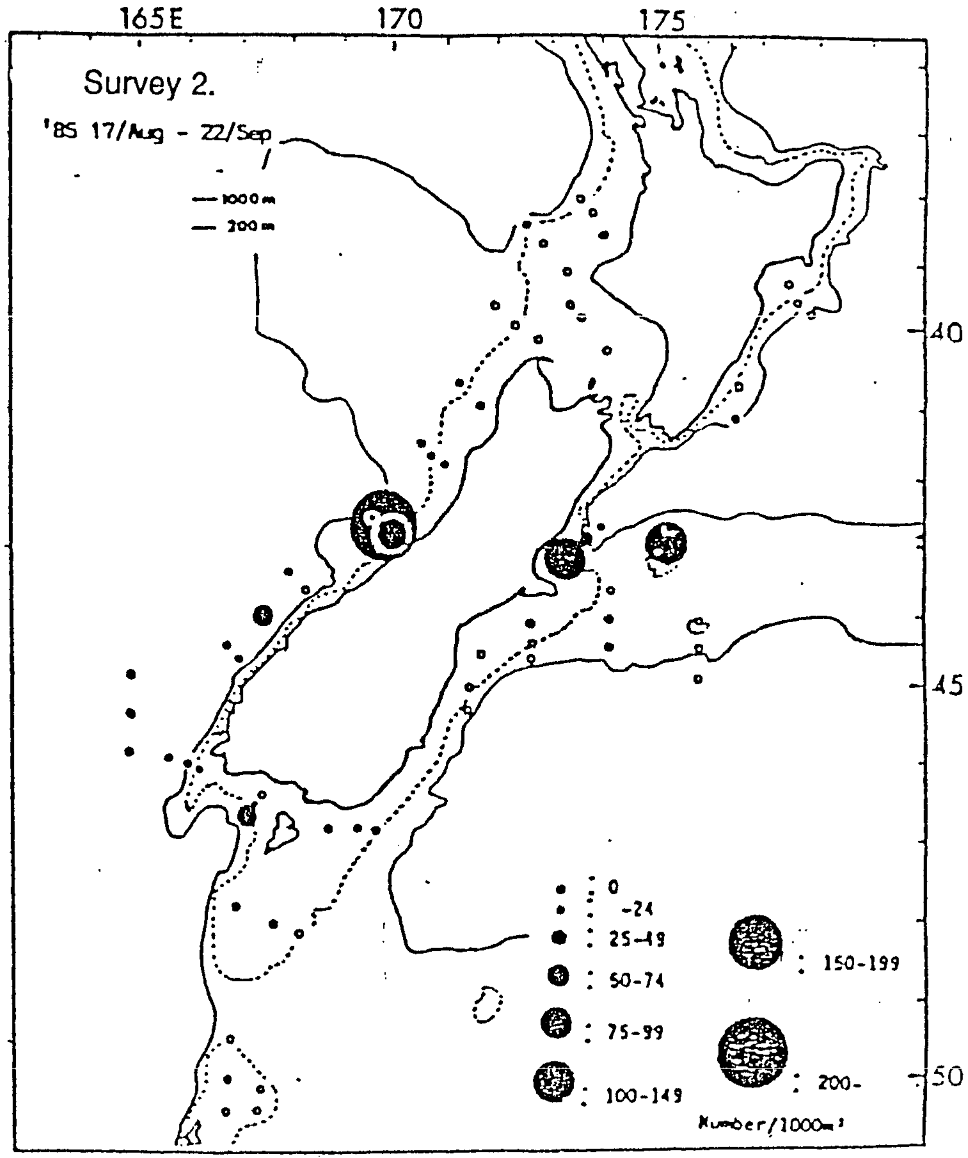


Fig 6. Recommended area split of hoki resource into two stocks.