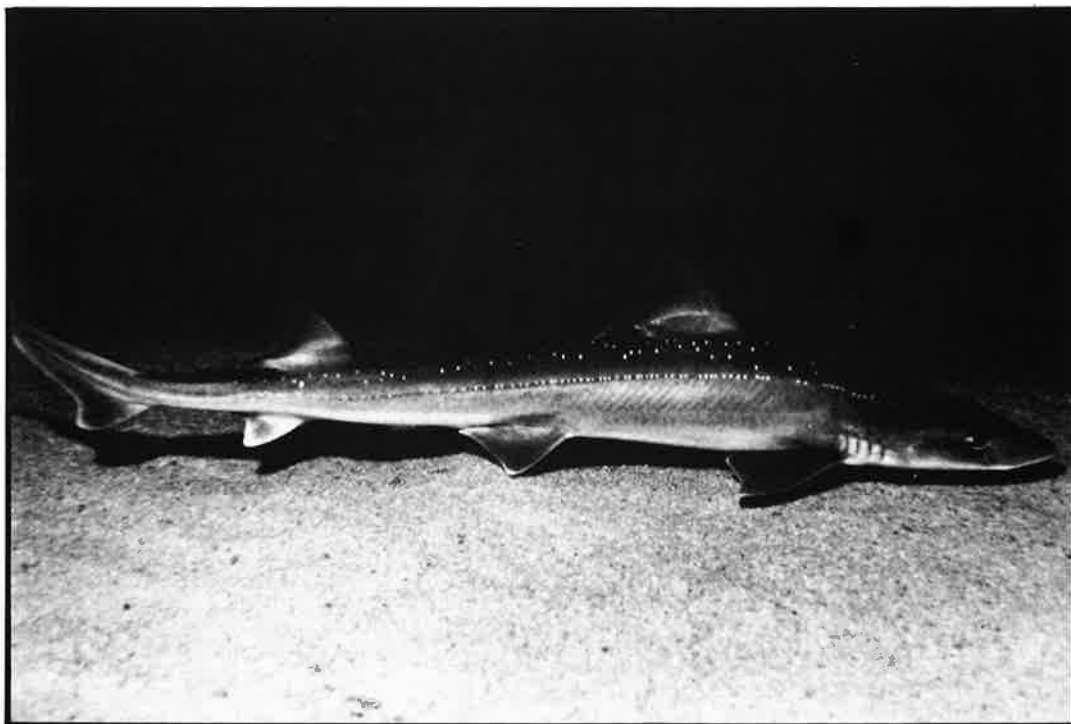


The New Zealand rig fishery: catch statistics and composition, 1974-85

**M. P. Francis
and
D. W. Smith**



**New Zealand Fisheries
Technical Report No. 7**

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MAF Fish

The Leading Edge

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Contents

	<i>Page</i>
Abstract	5
Introduction	5
Fishery statistics	6
Data sources	6
Landings	7
Effort and catch per unit of effort	10
Catch composition	20
Methods	20
Sex and maturity composition	20
Size composition	21
Discussion	27
References	29
Acknowledgments	30
Appendix 1: Sources of catch composition data	30

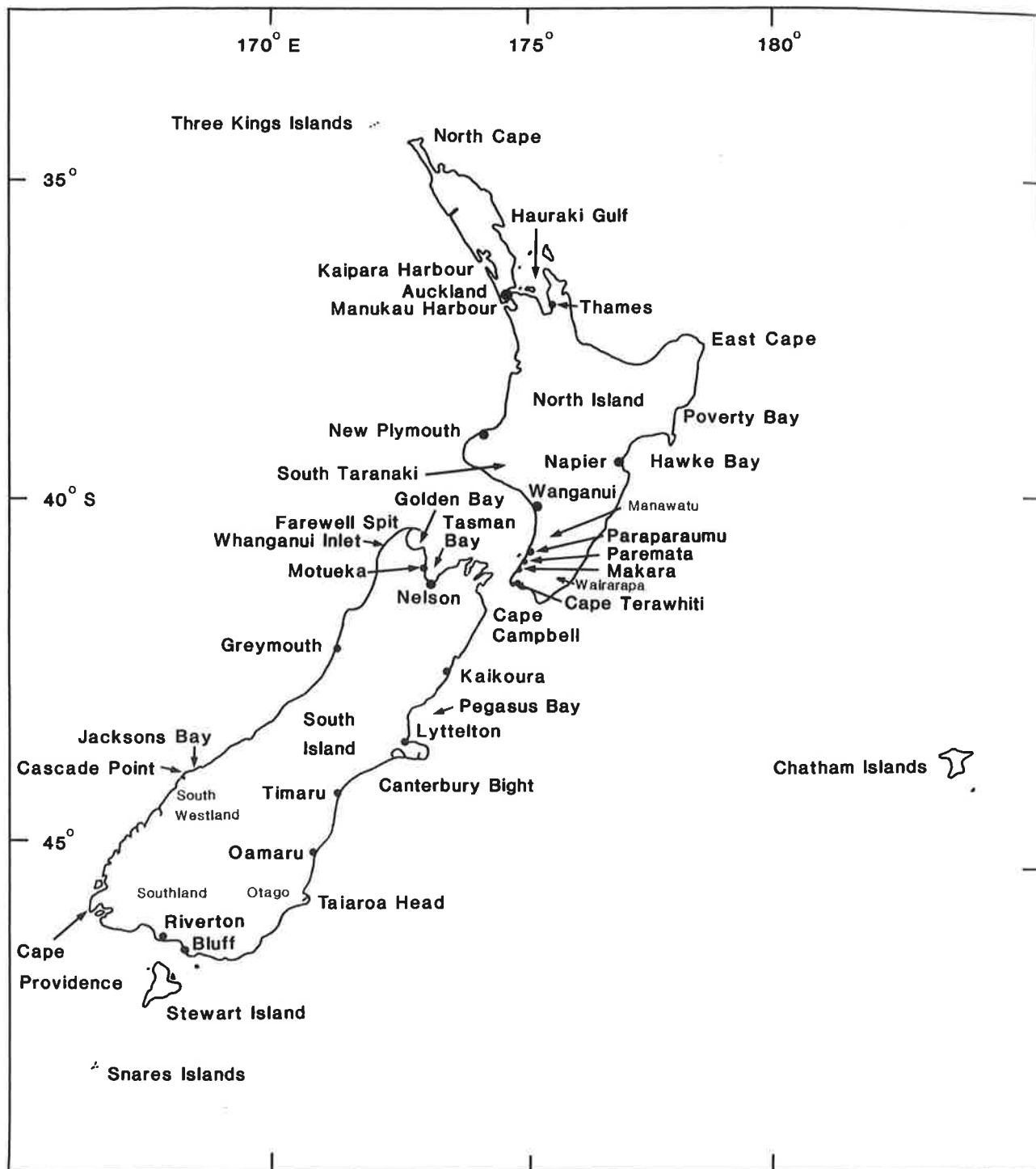


Fig. 1: Places mentioned in the text.

Abstract

Francis, M. P., and Smith, D. W. 1988: The New Zealand rig fishery: catch statistics and composition, 1974–85. *New Zealand Fisheries Technical Report No. 7*. 30 p.

Rig (*Mustelus lenticulatus*) landings increased greatly in the 1970s and fluctuated between 2500 and 3800 t per year from 1976 to 1985. The increase in landings was due to the development of set net fisheries, which now account for about 80% of the landings. The rig fishery is seasonal; peak landings occur in summer, but the timing and shape of the peaks vary among different regions.

Trends in landings from five geographical zones are shown for the seasonal years 1974–75 to 1984–85. Effort trends and two catch per unit of effort (CPUE) indices were calculated for 10 regions within four of the five zones, and the latter have been declining steadily in three of the zones.

Commercial set net catches were sampled at 11 South Island localities to determine sex, maturity, and size composition of the catches. Sex composition varied with locality, month, and depth. The proportion of mature females in catches increased with mesh size, which ranged from 120 to 180 mm. Maturity composition also varied with month and depth in some localities. Most males were mature in samples from commercial nets (mesh size was usually at least 165 mm). In Pegasus Bay more than 50% of females were immature. Size composition varied between months and mesh sizes.

The seasonality and composition of catches suggest that rig have complex, well-defined, and annually consistent behaviour patterns which include migration and segregation by sex and possibly also by size and maturity.

Introduction

Rig (*Mustelus lenticulatus*) are small endemic sharks which are found from the Three Kings Islands to the Snares Islands and around the Kermadec Islands and the Chatham Islands (Fig. 1). The closely related gummy shark (*M. antarcticus*) occurs in southern Australia. Rig are known by many other common names including dogfish, spotted dogfish, gummy shark, pioke, and spotted smoothhound.

Female rig grow to about 140 cm total length (TL) and males to 120 cm. Well-developed young about 30 cm long are born after a gestation period of 10–12 months (Francis and Mace 1980). Parturition and mating occur in spring, and rig aggregate in shallow coastal waters in spring-summer (Francis and Mace 1980, Francis 1988). Growth rates are unknown, but the length-frequency distributions of juveniles suggest

that maturity may be reached in 3–5 years (Francis unpublished data). Rig feed mainly on crustaceans and other benthic invertebrates (King and Clark 1984).

Because many sharks grow slowly and have low fecundity, they are vulnerable to overfishing (Holden 1973, 1974). There are significant commercial fisheries for other *Mustelus* species in Australia, Peru, Argentina, and Italy (see FAO yearbooks of fisheries statistics for 1977–84, even numbers). Only the Australian fishery for *M. antarcticus* has been studied in detail (T. I. Walker pers. comm.).

New Zealand rig landings increased greatly during the 1970s because of increased demand and the introduction of monofilament nylon set nets. More than 2500 t have been landed per year since 1976. Most

rig is exported to Australia. The domestically consumed rig is mainly used in fish and chips or sold as "lemon fish".

Previous studies of New Zealand rig fisheries were made by Francis (1979) at Kaikoura and Massey (1984) at Pegasus Bay. The aims of this study were to investigate historical trends in catch, effort, and catch per unit of effort (CPUE) and to investigate catch composition. Catch per unit of effort was assumed to be proportional to stock abundance and was used to assess the state of the fishery. Information on catch composition helped to determine which components of the rig population were being exploited. The results of this study have been used to provide management advice for the New Zealand rig fishery (Francis 1985, 1986).

This study has concentrated on the years since 1975, when detailed fisheries statistics became available, and on the set net fishery, which has taken most of the rig catch since 1977. The statistics were analysed by five geographical zones:

1. North-east coast North Island (NECNI), North Cape-East Cape;
2. South-east coast North Island (SECNI), East Cape-Cape Terawhiti;
3. East coast South Island (ECSI), Cape Campbell-Cape Providence (including Stewart Island and Snares Islands);
4. West coast South Island (WCSI), Cape Providence-Cape Campbell;
5. West coast North Island (WCNI), Cape Terawhiti-North Cape.

Fishery statistics

Data sources

All catch and effort data in this report were from the monthly returns of commercial fishermen. Summarised data for years up to 1972 were from N.Z. Marine Department annual reports on fisheries for 1946-71 and the N.Z. Ministry of Agriculture and Fisheries (MAF) *Report on Fisheries for 1972*. No data were available for 1973 because landings of rig and school shark (*Galeorhinus galeus*) were added together. Summarised data for 1974-84 were from King (1985, 1986) and King *et al.* (1987). Detailed data for 1974-82 were extracted directly from fishing returns, and detailed data for 1983-85 were from the computer files of the Fisheries Statistics Unit, MAFFish.

The quantity of rig landed may be less than that caught because of poor market demand, loss of fish from nets, and damage to catch by predators, isopods, and decomposition. There is no information on the size of the difference between catch and landings of rig. However, market demand was low until the mid 1970s, and much trawl-caught rig may have been dumped. All values in this report refer to landings rather than to catches.

There are several sources of error in the rig landings statistics, apart from the usual arithmetic errors and possible miscoding of species:

1. Landings were probably underreported by fishermen until 1983 (King 1985, 1986, King *et al.* 1987), and it was not possible to estimate the effect

of this. In December 1983 it became widely known that future catch quotas were likely to be based on past reported landings. Consequently, the amount of fish reported may have increased.

2. Rig are almost always landed in a "trunked" state (i.e., head, fins, guts, and belly flaps are removed). Untrunked rig deteriorate rapidly because of ammoniation of the flesh. Fishermen do not always report the landed state of their rig, and before 1983 any rig not specifically reported as trunked, or headed and gutted, were recorded by MAF as whole. Such landings have not had the appropriate conversion factor applied to give the estimated whole weight, and, therefore, total landings are underestimated by an unknown amount.
3. Before 1980 a set of inaccurate and inconsistent conversion factors was used to convert processed weight to whole weight. Conversion factors ranged from 1.3 for "headed" rig to 3.5 for "dressed", "headed, trimmed, and gutted", and "trunked" rig. The two landed states most often reported by fishermen were "headed and gutted" (conversion factor of 1.4) and "trunked" (3.5). Because a more accurate conversion factor for rig processed in the usual manner is about 2.0, the former would underestimate, and the latter overestimate, whole weight. Therefore, the biases tend to cancel. However, it is impossible to estimate the resultant bias because the proportion of the catch reported in each state is unknown. Since 1980 a conversion factor of 2.0 has been used.

4. Foreign trawlers fished in New Zealand coastal waters in the 1960s and 1970s. Catch data for the Soviet fleet are not available, but the Japanese fleet fished mainly in the WCNI and ECSI zones from 1967 onwards. Their total catches peaked in 1977, just before the declaration of the New Zealand 200 n. mile Exclusive Economic Zone (EEZ) in April 1978. The Japanese reported catching 1628 t of sharks and rays in 1977 (Paul and Robertson 1979), but the species involved are unknown. Before 1977 substantial quantities of rig may have been taken and dumped.

Error sources 1, 2, and 4 have probably resulted in an underestimation of landings before 1983. The effect of error 3 is unknown. Therefore, summarised landings statistics should be interpreted cautiously; only overall trends are likely to be reliable.

Before 1983, information on area of capture was not reliably reported. Therefore, regional analyses up to 1982 were based on the regions of landing as defined by King (1985). However, some adjacent regions were amalgamated if they were spanned by a continuous rig set net fishery:

Hauraki Gulf	Auckland, Thames;
South Taranaki	Wanganui, Manawatu, Paraparaumu, Paremata, Makara;
Golden Bay-	
Tasman Bay	Golden Bay, Motueka, Nelson;
Canterbury Bight	Timaru, Oamaru;
Southland	Bluff, Riverton, Stewart Island.

Because most set net vessels are small and do not fish far from their home ports, the lack of good data for capture area is unlikely to introduce significant errors. Trawlers are not as restricted in their range, and it is likely that fish taken from one zone have been landed into ports within another zone. For example, Nelson trawlers fish four of the zones, and Auckland trawlers fish three.

Landings

Total domestic rig landings for 1946–85 and landings by trawl and Danish seine for 1965–85 are shown in Fig. 2. Reported landings increased greatly during the 1970s and have fluctuated between 2500 and 3800 t per year since 1976. However, trawl landings have declined since 1977.

During the 1960s more than 80% of landings were by trawlers (Fig. 3). Set net fisheries developed during the 1970s after the introduction of cheap effective monofilament nylon nets which could be set from small vessels. There was an influx of new fishermen because of the low capital investment required and the increasing value of rig. Some trawlers were converted to set netting. During 1977–78 set nets became the dominant rig fishing method, and by 1983 they accounted for 80% of the landings.

The rig fishery is strongly seasonal, and most landings are made between October and March (Fig. 4). Examination of monthly CPUE data from some vessels showed that the seasonal trends were due

to changes in rig abundance rather than to changes in fishing effort. This seasonality results from the annual inshore aggregation of rig (Francis and Mace 1980, Francis 1988). Spring-summer peaks in landings are a feature of the major rig fisheries, though the timing of the peaks varies (Fig. 5). The start of the rig season is abrupt and similar each year within a region. The season usually begins in September at Kaikoura; October (occasionally September) at Auckland-Thames, Manukau Harbour, New Plymouth, Wanganui, Golden Bay, Nelson, and Greymouth; and November (occasionally October) at Lyttelton and Timaru.

Landings peaks were usually unimodal (Auckland-Thames, Wanganui, Nelson, Greymouth, Lyttelton, and Timaru) or bimodal (Napier, Manukau Harbour, New Plymouth, and Golden Bay). The peak at Kaikoura has changed from bimodal to unimodal. It is difficult to interpret these patterns without detailed effort data; some of the variability within regions is due to the influence of weather on fishing effort.

Landings peaks at Kaikoura usually occurred 2 months ahead of those at Lyttelton and Timaru, which usually coincided, though Timaru occasionally peaked 1 month later than Lyttelton.

In the 1970s Nelson landings were predominantly trawl landings, many of which may have come from outside the area. However, most Nelson landings have been made recently by set net vessels. Golden Bay landings have always been made mainly by set net vessels. Recent Nelson landings peaks have usually preceded, or coincided with, the first Golden Bay peak. No consistent patterns were observed in landings peaks at Manukau Harbour, New Plymouth, and Wanganui. In all regions rig landings are low from late autumn to early spring.

The following data analyses were only possible from 1974–75, when monthly landings statistics became readily available and, because of the seasonal nature of the rig fishery, were based on seasonal years from 1 July to 30 June.

Seasonal year landings for all New Zealand and for each zone (and average annual landings for 1976–77 to 1984–85) are shown in Fig. 6. The ECSI zone has consistently had the highest landings. Landings from all zones except SECNI declined during the late 1970s and increased again in the early 1980s. Landings from the SECNI zone have declined steadily since 1978–79 and are now less than half the peak landings.

The distributions of landings by statistical areas for 1983–84 and 1984–85 are shown in Fig. 7. The major fisheries are in the inner Hauraki Gulf, along the east coast South Island, Southland, north-west coast South Island, Golden Bay-Tasman Bay, Taranaki, Manukau Harbour, and Kaipara Harbour. Set nets caught 75% or more of the landings in 15 out of 18 areas which produced at least 50 t in 1984–85 (Fig. 8). In the other three areas, which are all in the WCNI zone and are intensively fished, trawlers landed 31–39%. In total, 80% of landings were caught by set net, 18% by trawl.

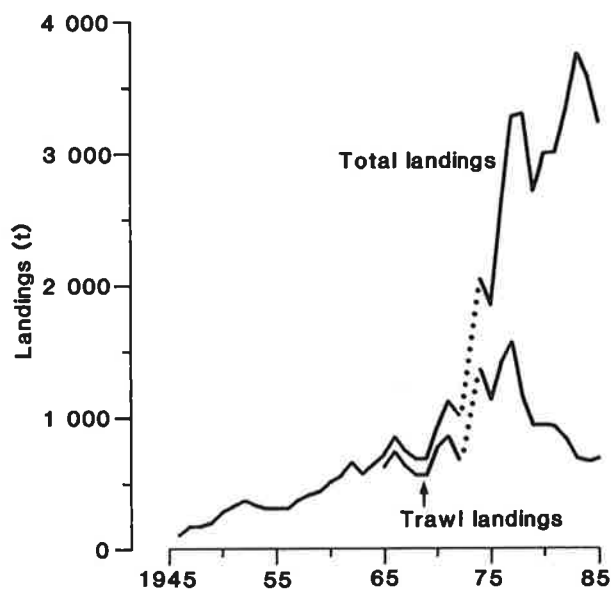


Fig. 2: Total domestic rig landings for calendar years 1946-85, and landings by trawl and Danish seine for calendar years 1965-85. (Data for 1973 were not available.)

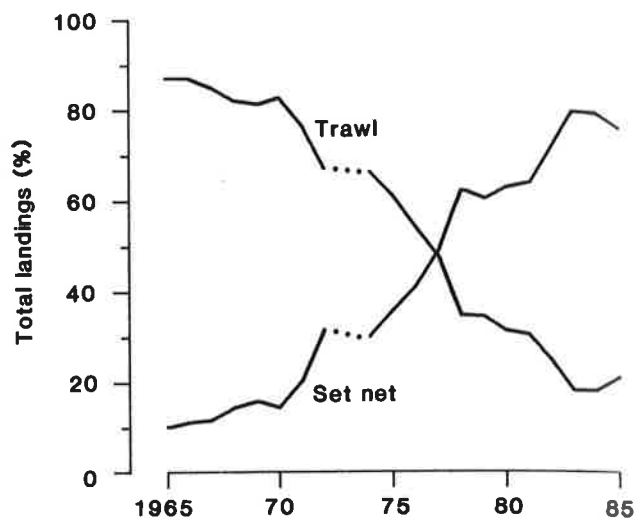


Fig. 3: Percentage of rig landings by trawl (single and pair combined and Danish seine) and by set net for calendar years 1965-85.

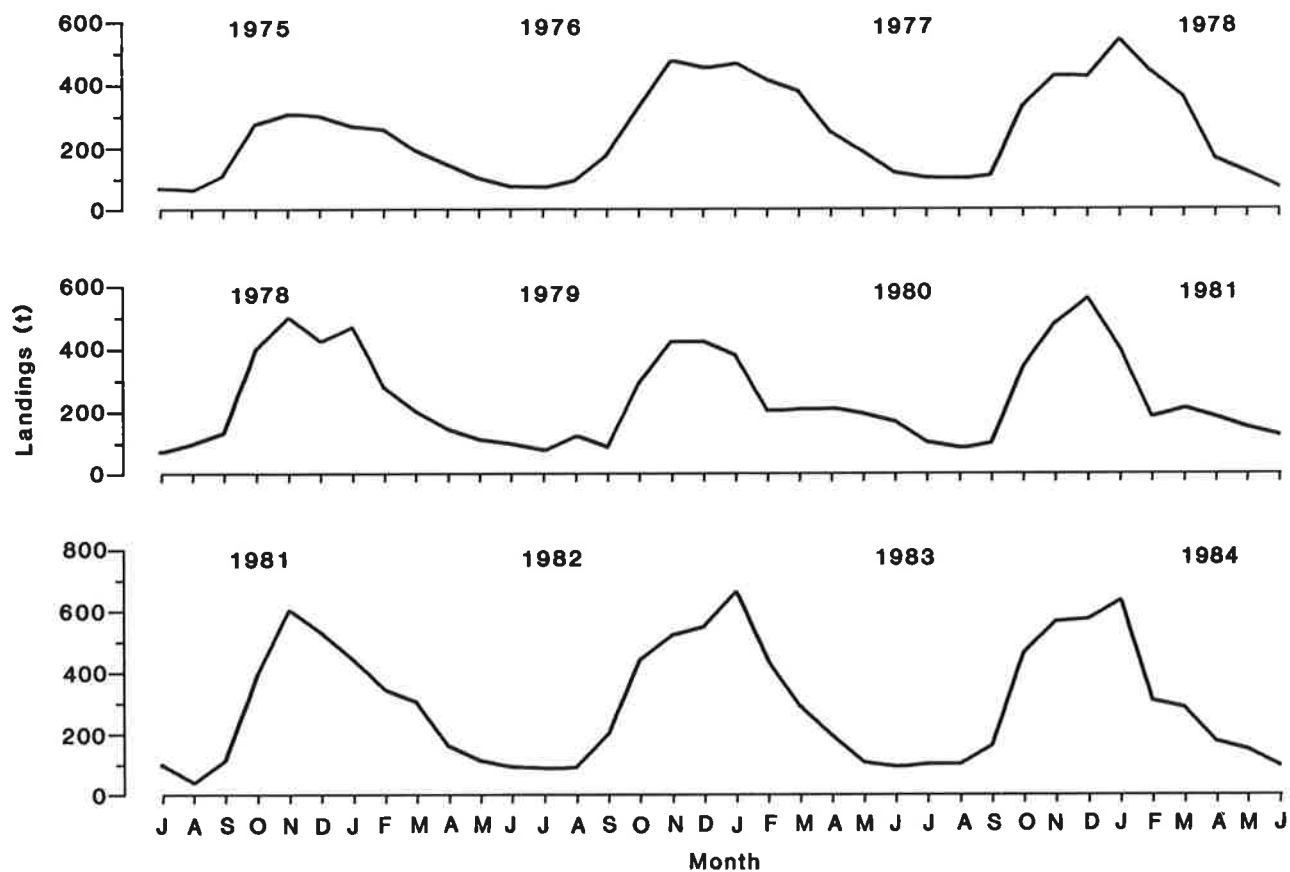


Fig. 4: Monthly rig landings, 1975-84.

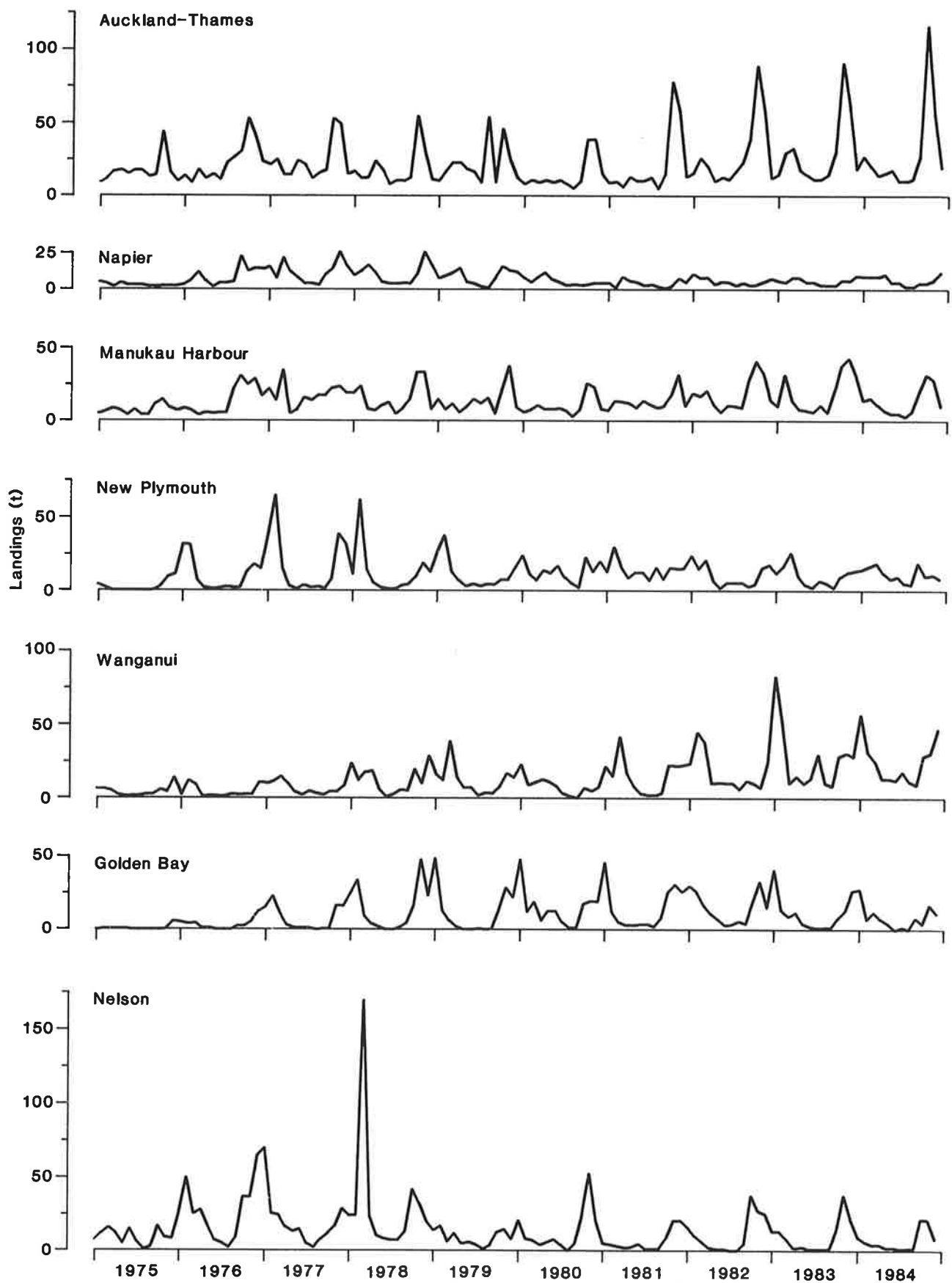


Fig. 5: Monthly rig landings in 11 rig fishery regions, 1975-84.

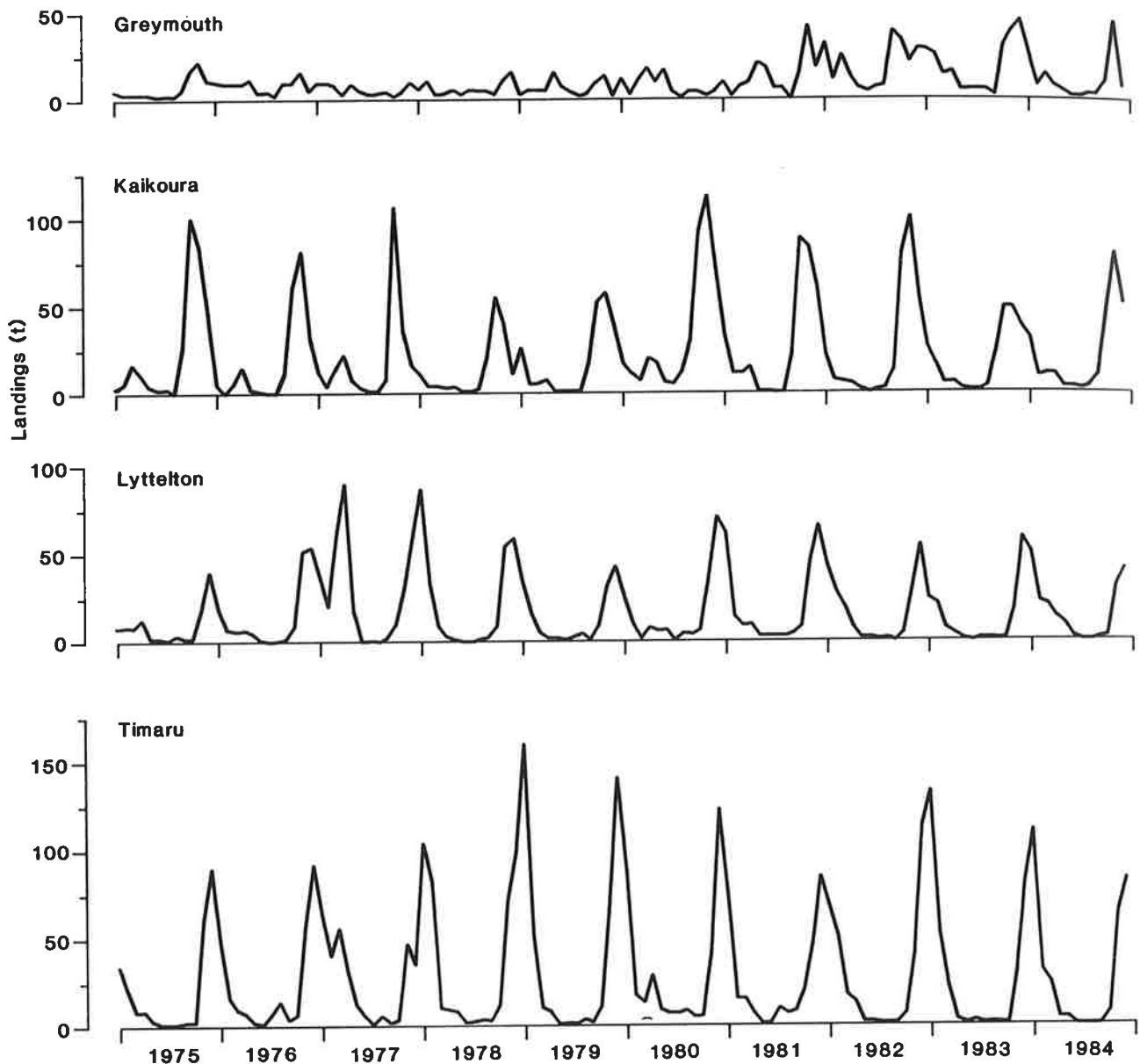


Fig. 5—continued.

Effort and catch per unit of effort

Methods

Catch per unit of effort is proportional to the average density of the fish that are available and vulnerable to the fishing gear (Ricker 1940, Gulland 1969). Because female rig are highly mobile (Francis 1988) they are all assumed to be available to set nets. Males are less mobile, and their stock ranges are less than those of females (Francis 1988). Consequently, their stocks may experience different amounts of fishing effort. Juveniles are not retained by commercially used set nets, and large adults may not penetrate the mesh sufficiently to become wedged (Hamley 1975, Kirkwood and Walker 1986). Therefore, CPUE provides an estimate of the abundance of the catchable stock of rig in the areas fished.

Trends in effort and CPUE were analysed for 10 regions. Only vessels thought to be target fishing for rig were included, and they were identified by the following criteria:

1. Only set net vessels were included. Trawlers have been unable to target fish effectively for rig recently because of small stock sizes.
2. Vessels which used up to 350 m of net per day (averaged over 1 month) were omitted. This excluded most part-time fishermen.
3. Vessels which did not record net length were omitted.
4. Vessels were included only if their catch species mix showed that they were target fishing for rig, or fishing in a manner likely to catch rig if they were present. Fishermen target fishing for flounder (*Rhombosolea* spp., *Pelotretis flavilatus*, and

Peltorhamphus novaezeelandiae), butterflyfish (*Odax pullus*), moki (*Latridopsis ciliaris*), and common warehou (*Seriotelella brama*) generally work in areas where rig are scarce. School shark fishermen, particularly in Southland, often use large mesh (230 mm) nets which do not catch many rig. Vessels with catch mixes of more than 50% of these species in a given month were omitted.

5. Only the peak months of the rig fishing season were included in the analyses. Peaks were determined from the mean monthly CPUE trends in each region. Peak periods ranged from 3 to 6 months:
 - Sep-Dec Hauraki Gulf, Kaipara Harbour, Manukau Harbour, Kaikoura;
 - Oct-Jan Lyttelton;
 - Nov-Jan Southland;
 - Nov-Feb Golden Bay-Tasman Bay, Canterbury Bight;
 - Nov-Apr New Plymouth, South Taranaki.

Because some vessels were omitted, the fishing effort of the selected vessels underestimates the total effort. However, the selected vessels landed most of the rig in 1983–84 and 1984–85 (Table 1), and their effort trends should parallel those of the whole fleet.

The mean net lengths used by the selected fleet for each season and year were calculated as follows:

$$\text{Mean net length (m)} = \frac{\sum_{k=1}^c \sum_{j=1}^b \left(\frac{\sum_{i=1}^a N_{ijk}}{a_{jk}} \right)}{\sum_{k=1}^c b_k}$$

- where N_{ijk} = amount of net used for landing (day) i by vessel j in month k ;
 a_{jk} = number of landings made by vessel j in month k ;
 b_k = number of vessels in month k ;
 c = number of months in rig season.

Effort was calculated by:

$$\text{Effort (metres of net)} = \sum_{k=1}^c \sum_{j=1}^b \sum_{i=1}^a N_{ijk}$$

TABLE 1: Percentage of total landings for selected set net vessels, 1983–84 and 1984–85

Region	1983–84	1984–85
Kaipara Harbour	91	99
Manukau Harbour	99	96
New Plymouth	98	96
South Taranaki	96	99
Hauraki Gulf	71	70
Golden Bay-Tasman Bay	94	95
Kaikoura	79	89
Lyttelton	99	67
Canterbury Bight	86	86
Southland	91	96

Catch per unit of effort was calculated for each selected vessel each month of the fishing season. The distribution of CPUE values within a given month and region was usually positively skewed and had many low and few high values. Therefore, the individual CPUE values were \log_e transformed, and their mean was calculated for each month.

Two different CPUE indices (kilograms per 100 m of net) were calculated:

$$(1) \quad \text{CPUE} = \frac{\sum_{k=1}^c \left(\frac{\sum_{j=1}^b \log_e \left(\frac{\sum_{i=1}^a W_{ijk}}{\sum_{i=1}^a N_{ijk}/100} \right)}{b_k} \right)}{c}$$

$$(2) \quad \text{CPUE} = \frac{\sum_{k=1}^c \sum_{j=1}^b \log_e \left(\frac{\sum_{i=1}^a W_{ijk}}{\sum_{i=1}^a N_{ijk}/100} \right)}{\sum_{k=1}^c b_k}$$

where W_{ijk} = whole weight (kg) of rig in landing i by vessel j in month k .

Index (1) gives equal weighting to all mean monthly CPUEs in each fishing season. Therefore, it should be sensitive to changes in season length as well as to changes in peak height. This could be significant if declining stock size were manifested as reduced abundance during the shoulder months of the season, but not during the peak 1 or 2 months.

Index (2) weights the mean monthly CPUEs by the fishing effort in the relevant month. Because effort is often greatest during the peak 1 or 2 months of the season, this index may not be very sensitive to changes in rig abundance during shoulder months. However, it should be more sensitive to changes in peak height than index (1).

Both indices were calculated for four South Island regions, and differences between the results were negligible. Index (1) was used in this study because it was free of the bias that might result from variable fishing effort.

Catch per unit of effort indices were calculated separately for the whole (selected) fleet and for the top five vessels in any 1 month and region. The top five indices might be expected to reflect increasing skill of the best fishermen and, therefore, not show such a steep decline if stock size were declining. The whole

fleet indices, which include the CPUEs of new and inexperienced fishermen, might be expected to decline faster than stock size.

Regression lines were fitted (by least squares) to the right-hand (downward) slopes of the CPUE graphs where they were significantly different from zero.

Assumptions

The following assumptions were made in the CPUE analysis:

1. The level of reporting of landings by fishermen has remained constant. (This may have been low until 1983 and then increased in 1983–84.)
2. All rig were landed in the trunked state. Errors 2 and 3 (see page 6) were overcome because landings were calculated directly from fishing returns and a conversion factor of 2.0 was used to obtain whole weight.
3. The amount of effort per landing has remained constant. Usually nets are cleared and fish are landed daily. However, bad weather and poor catch rates may lead to nets being left uncleared for at least 2 days. In some regions larger vessels make trips of several days during which nets are lifted and cleared several times. Fishing returns from these vessels usually record only one landing for the whole trip. Where multiple-day sets or multiple-day trips are made, the unit of effort underestimates the true effort. Consequently, CPUE is overestimated. The weather effect has probably been random over the last decade, but the incidence of multiple-day sets due to low catch rates and multiple-day trips made by larger vessels has probably increased. Thus, in recent years, the CPUE index may have increasingly overestimated stock density.
4. Net materials and construction techniques have remained constant. Fishermen continually adjust

and alter their gear to improve its efficiency, especially if catch rates are declining. Mesh size, net material, hanging ratio, and net height may affect set net efficiency (Hamley 1975, von Brandt 1975). Mesh size has declined in some regions as catch rates of larger fish have declined. The opposite trend occurred in Southland, where fishermen used larger mesh when they began to target fish for school shark (their data have been omitted from the CPUE analyses). Net material has generally changed from circular to oval cross-section nylon. The latter is considered by fishermen to be more efficient. A change in hanging ratio produced significant differences in the number of *M. antarcticus* caught in an Australian study (T. I. Walker pers. comm.). Rig are morphologically similar to *M. antarcticus*, and their catch rates would probably also change with changes in hanging ratio. Statistics are not available for any of these parameters.

5. Skill has remained constant. Increasing skill might be expected to result from experience gained in the setting of nets. The validity of this assumption has been tested by the comparison of CPUE indices for the whole fleet and for the top five vessels.
6. Gear competition was negligible. If nets are set at high densities they may physically compete with each other for the same fish. Gear competition might be expected to increase in regions where effort has been increasing. However, vessels also tended to work much greater distances from port in many regions. The overall result is that net density has probably not increased in most regions. Gear competition may have been severe at Kaikoura in the late 1970s, when many fishermen were working in a small area; nets were frequently laid over the top of each other, and this resulted in reduced catching efficiency as well as competition (Francis 1979). Consequently, CPUE may have underestimated stock abundance for the early years



Fig. 6: Seasonal year (1 July to 30 June) rig landings for all New Zealand and for each zone, 1974–75 to 1984–85. Average annual landings (whole weight) for 1976–77 to 1984–85 are in parentheses.

of the Kaikoura fishery. The incidence of gear competition in other regions is unknown.

7. Net saturation was negligible. At high fish densities catches may be physically limited by the number of meshes available. Also, catching efficiency may be reduced if the weight of fish in the net causes it to collapse. High catch rates of rig during the mid to late 1970s may have caused net saturation in many regions. Spiny dogfish (*Squalus acanthias*) may also occur in sufficient numbers to saturate nets, particularly in the ECSI zone. Although the abundance of spiny dogfish may vary annually, the overall stock size has probably not changed over the years of this study, and no systematic bias is likely.

The validity of assumption 1 is unknown, though the rate of reporting may have increased in 1983–84. Assumption 2 is probably valid, and assumption 5 can be tested. Assumption 6 may have been violated in some regions during some years. Assumptions 3, 4, and 7 are probably all violated to some extent. Violation of these assumptions will produce the same bias; the CPUE index will underestimate stock abundance in the early years and overestimate stock abundance in the later years (for 1975–76 to 1984–85). For stocks which are declining in size the slope of the CPUE graphs will underestimate the real rate of decline, and for stocks which are increasing the CPUE graphs will overestimate the real rate of increase.

Results

Trends in effort during the rig season for the selected set net fleet are shown for 10 regions in Fig. 9. They are summarised below:

WCNI (Kaipara Harbour, Manukau Harbour, New Plymouth, South Taranaki)
Mean net length has increased over the last decade at Kaipara Harbour, New Plymouth, and South Taranaki, but not at Manukau Harbour. Mean net length was low (under 1000 m) at Kaipara Harbour and Manukau Harbour. Overall effort has increased recently at Kaipara Harbour, Manukau

Harbour, and South Taranaki. Effort at New Plymouth peaked in 1977–78 and has since fluctuated about a lower level.

NECNI (Hauraki Gulf)
Mean net length and effort have increased by 56 and 155% respectively since 1977–78.

SECNI
No data were available.

WCSI (Golden Bay-Tasman Bay)
Mean net length has increased by 156% since 1975–76. Overall effort peaked in 1978–79 and has since fluctuated about a lower level.

ECSI (Kaikoura, Lyttelton, Canterbury Bight, Southland)
Mean net length has increased by at least 100% in all four regions since 1975–76. Effort has increased at Kaikoura, Canterbury Bight, and Southland, but has remained stable at Lyttelton.

The distributions of net length by vessel, for the month of the 1984–85 season in which the greatest number of vessels were selected, are shown in Fig. 10. All distributions were unimodal, and many had a strong positive skew. However, sample sizes were often small.

Trends in CPUE for the whole (selected) fleet and the top five vessels are shown in Fig. 11 for 10 regions. The top five index for Southland could not be calculated because of insufficient vessels. Regression equations for the significant negative trends and decline rates are given in Table 2.

There is evidence that skill increased in several regions. In four out of five regions where both whole and top five indices showed negative trends the slope of the top five index was less than that of the whole fleet index. At South Taranaki the whole fleet index showed a significant negative decline, whereas the top five index was stable.

A summary of CPUE trends by zone is given below:

WCNI Significant declines in the whole fleet index occurred at Manukau Harbour, New Plymouth, and South Taranaki and in the top five index at New Plymouth.

TABLE 2: Regression equations of CPUE against time for the significant negative trends (see Fig. 11)

Region	Regression equation	r^2 (%)	t^*	% decline per year
Manukau Harbour (W)†	CPUE = 2.08 – 0.098x	44	–2.41‡	9.4
New Plymouth (W)	CPUE = 2.48 – 0.186x	65	–4.23	17.0
New Plymouth (F)	CPUE = 3.14 – 0.138x	68	–4.24	12.9
South Taranaki (W)	CPUE = 3.07 – 0.072x	61	–3.70	6.9
Golden Bay-Tasman Bay (W)	CPUE = 3.48 – 0.144x	56	–3.51	13.4
Golden Bay-Tasman Bay (F)	CPUE = 4.13 – 0.116x	74	–4.91	11.0
Kaikoura (W)	CPUE = 3.41 – 0.170x	91	–9.47	15.6
Kaikoura (F)	CPUE = 3.89 – 0.108x	85	–7.22	10.2
Lyttelton (W)	CPUE = 3.23 – 0.247x	77	–4.96	21.9
Lyttelton (F)	CPUE = 4.13 – 0.278x	84	–6.06	24.3
Canterbury Bight (W)	CPUE = 2.98 – 0.186x	74	–4.22	17.0
Canterbury Bight (F)	CPUE = 3.88 – 0.165x	44	–2.37‡	15.2

* One-tailed t -test of the hypothesis that the slope equals zero with $(n - 2)$ degrees of freedom, where n = number of years.

† W = whole fleet, F = top five vessels.

‡ $p < 0.05$; for all others, $p < 0.005$.

There was an influx of set net fishermen at Kaipara Harbour and Manukau Harbour in the early 1980s. Top five and whole fleet indices diverged greatly at this time, which suggests that changes were occurring in the level of skill in the two fisheries. The CPUE graphs may be interpreted in two ways: first, rig stock size may have been increasing in both regions, but the incoming fishermen were less skilful than local fishermen, and, therefore, the whole fleet CPUE index was stable at Kaipara Harbour, but declined at Manukau Harbour; second, stock size may have been declining, but the incoming fishermen were more skilful than the local fishermen, and, therefore, the downward trends were hidden.

The biases in the CPUE index suggest the second explanation is more likely to be correct. Differences between the Kaipara Harbour and Manukau Harbour whole fleet indices may be due to exploitation of different male stocks in the two regions.

Top five and whole fleet indices also differed at South Taranaki, which suggests that changes in skill may be important. In addition, the incidence of multiple-day trips by some of the larger vessels in this fishery has probably increased recently and resulted in a positive bias in the CPUE index. Because those vessels making multiple-day trips tend to have the highest nominal CPUE in the fleet, this bias is probably greater for the top five index than the whole fleet index.

NECNI Both CPUE indices were relatively constant in the Hauraki Gulf, and, therefore, there is no evidence for a stock decline.

SECNI Set net CPUE indices were calculated for Poverty Bay-Hawke Bay and Hawke Bay-Wairarapa for 1976-82 (Central Fisheries Management Planning Team 1984, Fig. 8.5, and a corrected illustration of these data was given by Francis (1985)). The indices used

were for 8 months of a calendar year (January-April and September-December) rather than a seasonal year; therefore, they are not directly comparable with those calculated in this study. Nevertheless, CPUE declines of 19 and 24% per year for Poverty Bay-Hawke Bay and Hawke Bay-Wairarapa suggest that the stock in the SECNI zone is declining rapidly in size. This in turn suggests that the SECNI and NECNI zones contain different stocks of rig.

WCSI Catch per unit of effort, and presumably stock size, have been declining steadily since 1975-76 at Golden Bay-Tasman Bay. No data were available for the fisheries along the west coast South Island.

ECSI Significant declines in CPUE have occurred at Kaikoura, Lyttelton, and Canterbury Bight. High 1983-84 values at Lyttelton and Canterbury Bight may have been due to increased reporting of rig. Southland CPUE has shown a steady increase and appears to have reached a plateau. Tagging results show that there is substantial mixing of females between Southland and the rest of the ECSI zone. Mixing of males is less obvious, but probably significant (Francis 1988). If the Southland fishery exploits the same stock as the Canterbury Bight, Lyttelton, and Kaikoura fisheries, then a similar decline in CPUE would be expected. The lack of a decline in Southland may be due to exploitation of a partially distinct male stock and/or increasing skill and gear improvements during the development phase of this more recent fishery. However, future declines in CPUE would be expected because of the interaction with other ECSI fisheries.

In the seven regions with significant downward trends in the whole fleet index the 1984-85 CPUE was 18-56% of the maximum CPUE, and in five of these regions it was 33% or less of the maximum.

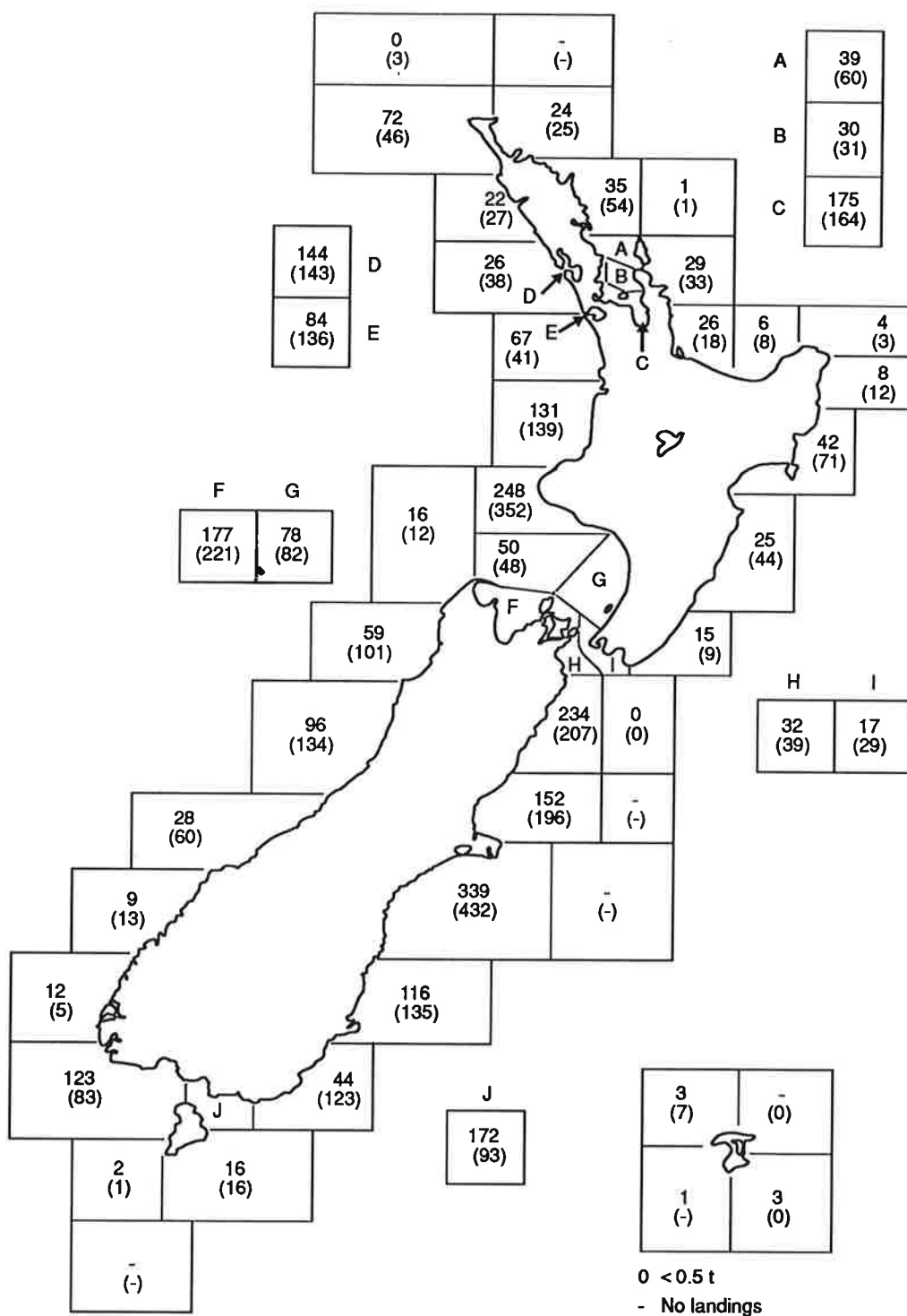


Fig. 7: Distribution of rig landings (t) by statistical area for 1984-85 and 1983-84 (in parentheses) seasonal years (1 July to 30 June).

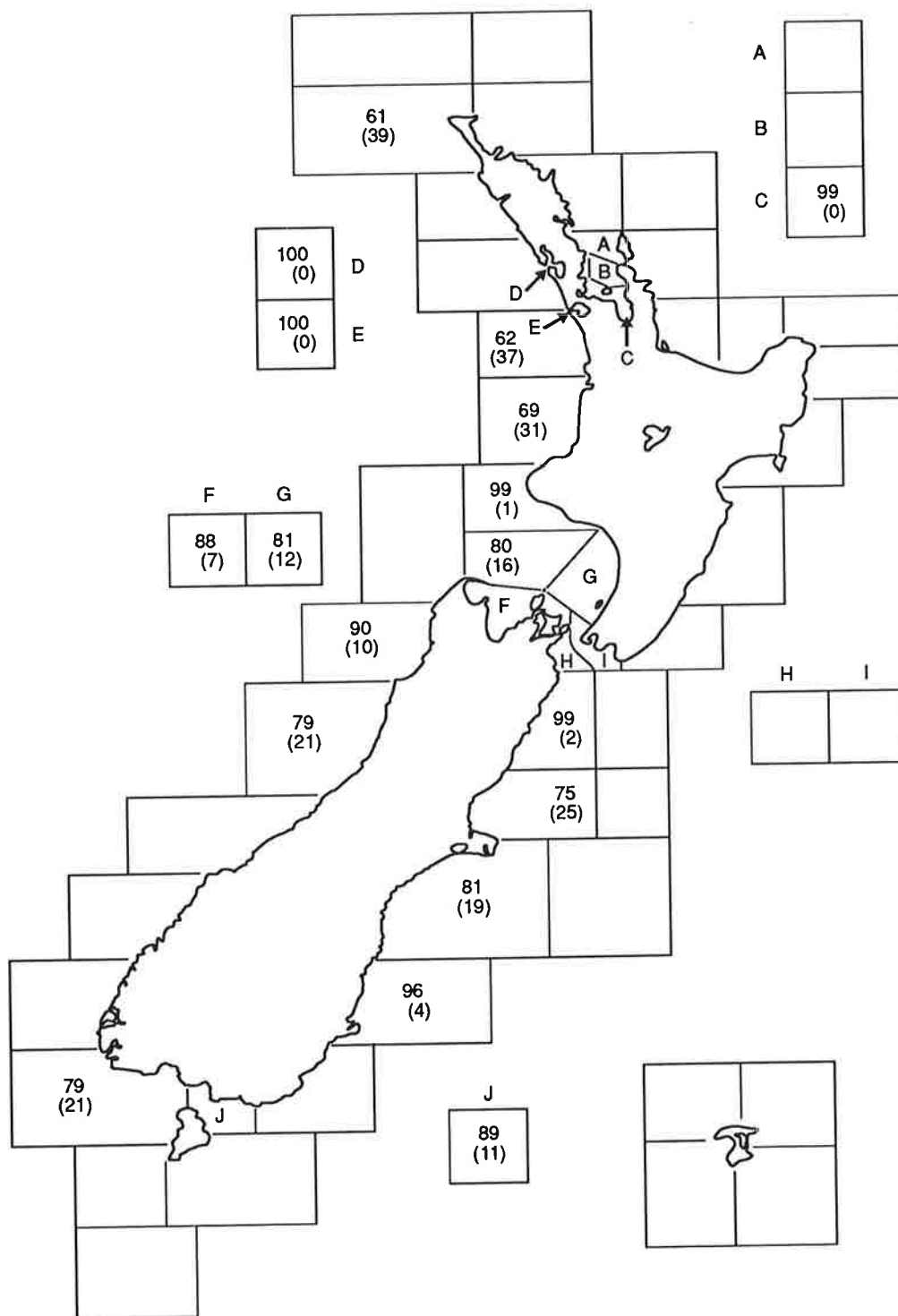


Fig. 8: Percentage of rig landings by set net and by trawl and Danish seine (in parentheses) for areas which landed at least 50 t in the 1984-85 seasonal year (1 July to 30 June). (Area not reported = 161 t (198 t).)

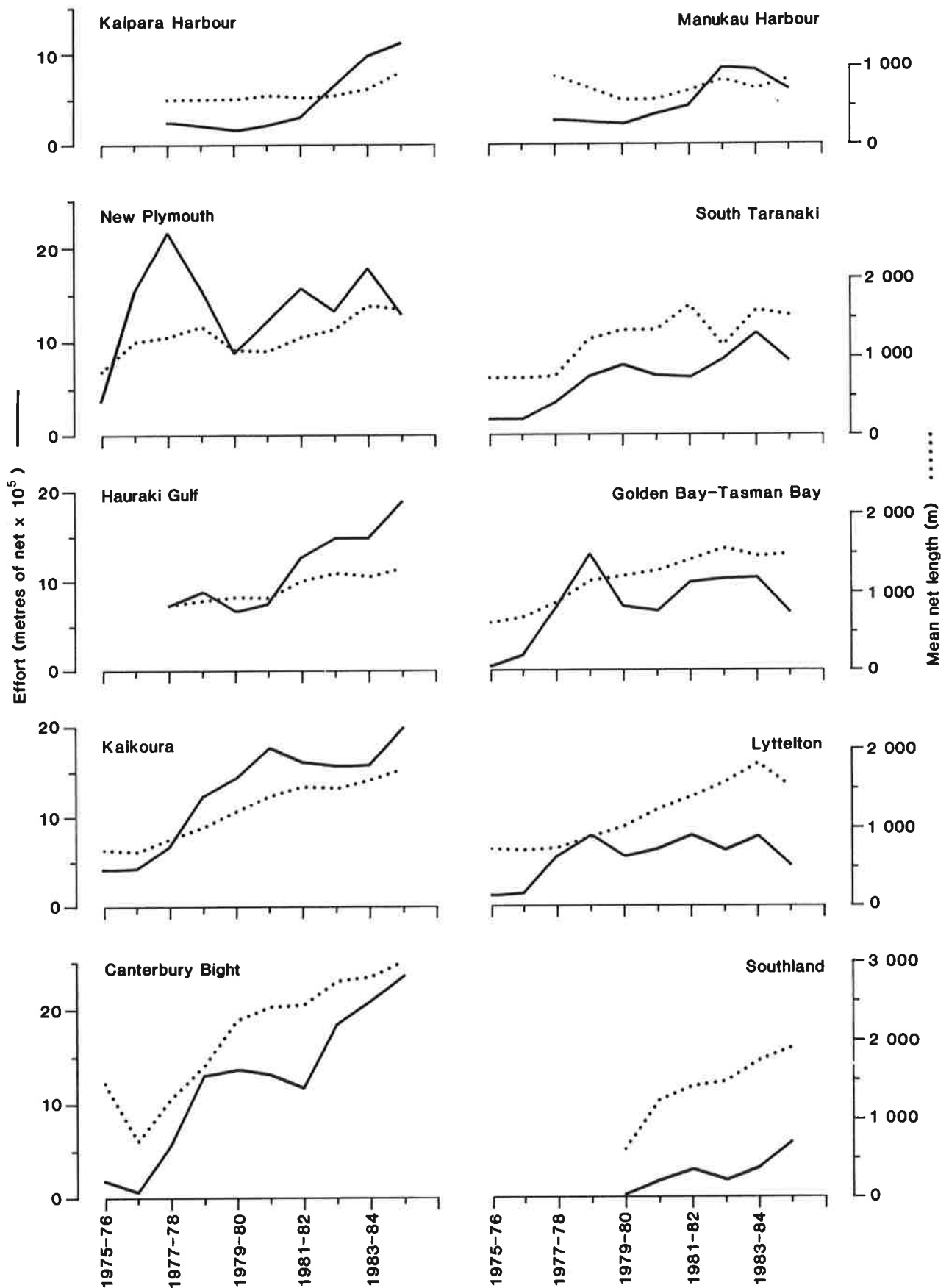


Fig. 9: Trends in set net fishing effort for rig target fisheries in 10 regions, 1975-76 to 1984-85 seasons.

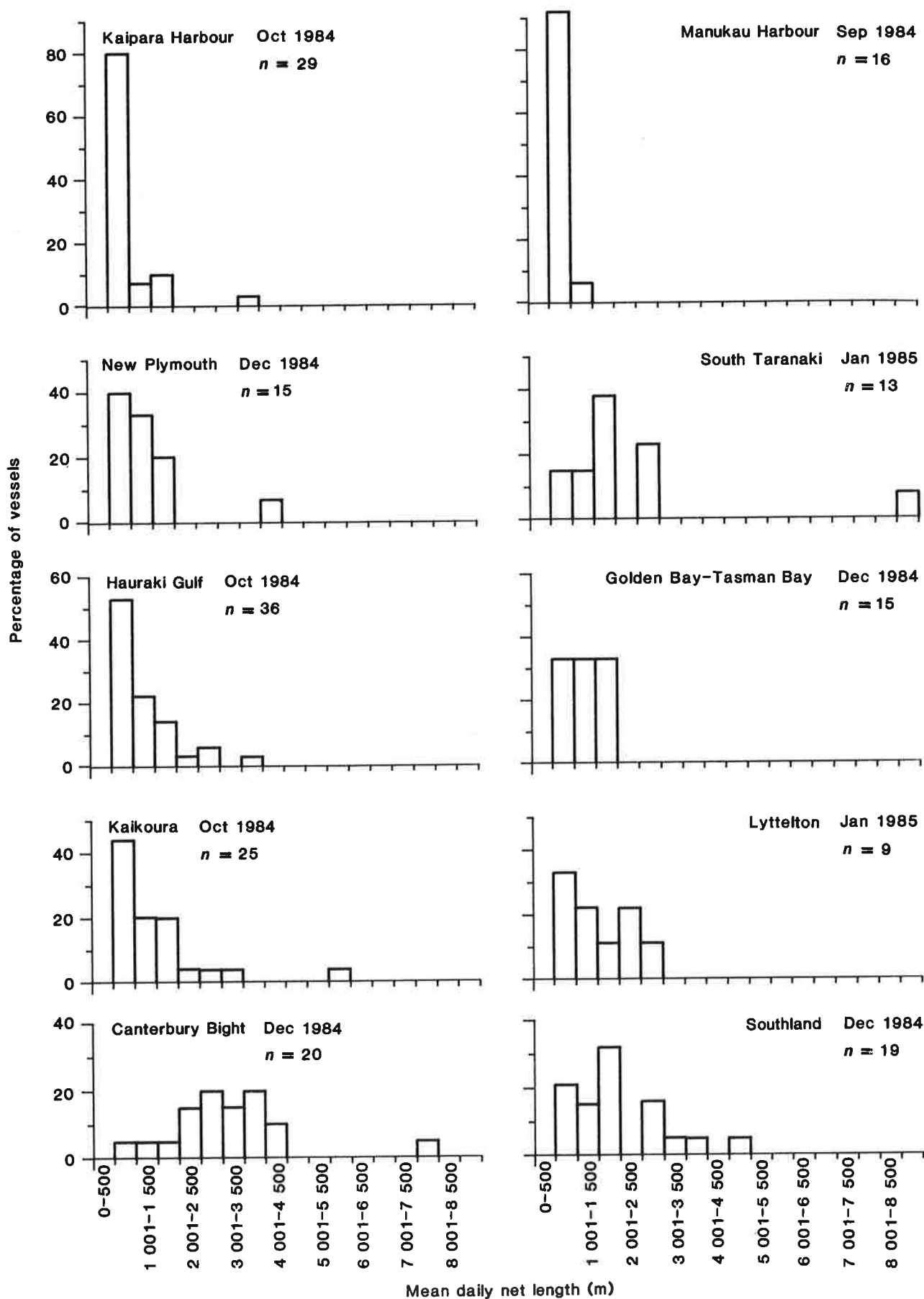


Fig. 10: Distribution of net length by vessel in the peak month of the 1984-85 rig season in 10 regions. (No data were available for the under 500 m net length class.)

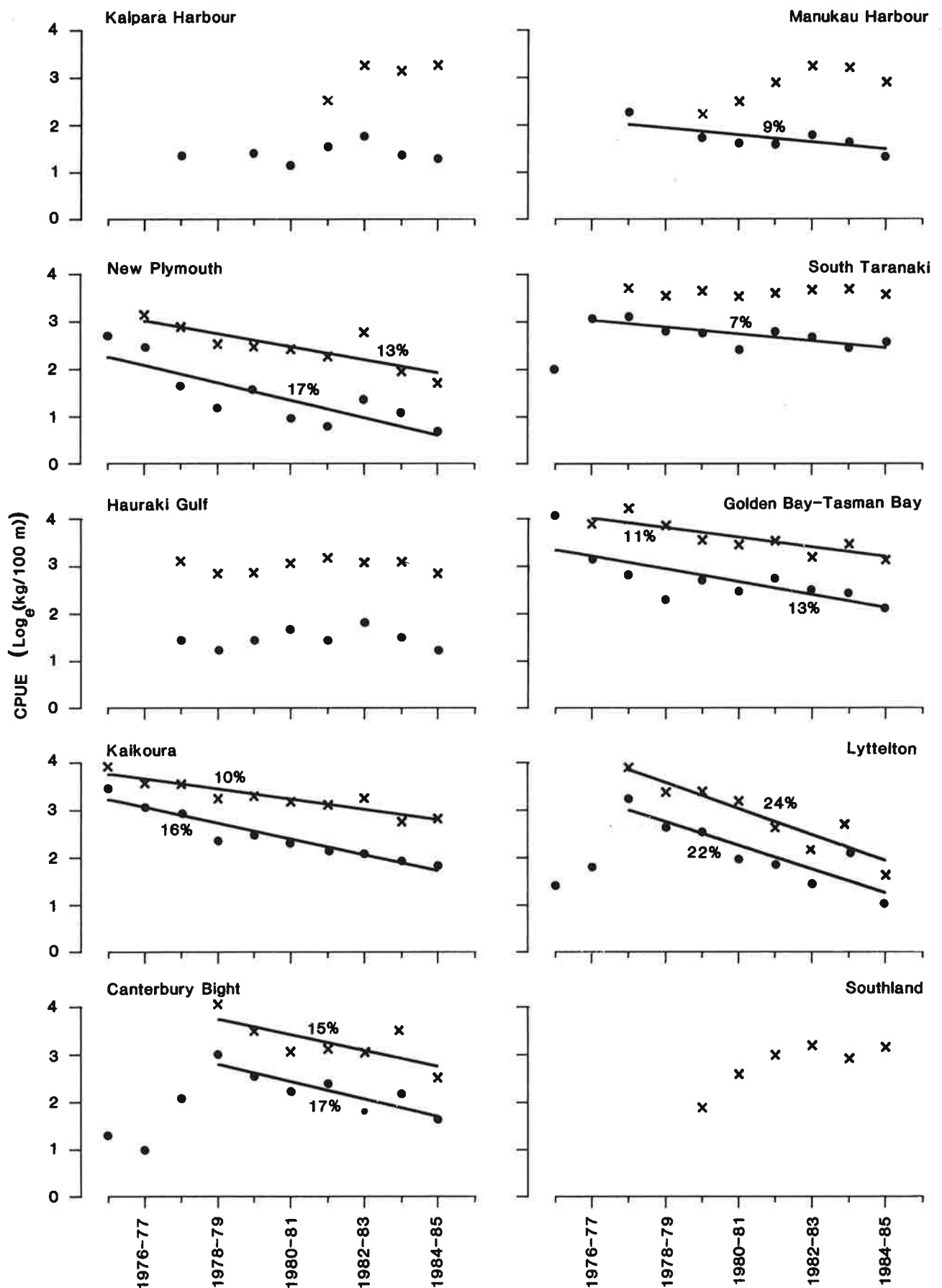


Fig. 11: Trends in CPUE for set net vessels in 10 regions, 1975-76 to 1984-85 rig seasons (x = top five vessels, • = whole fleet). Regression lines are fitted for significant negative trends, and percentages are annual decline rates (see Table 2).

Catch composition

Methods

Commercial set net catches of rig were examined during several research studies at 11 South Island localities between 1977 and 1983. The principal study areas and years and the data sources are given in Appendix 1.

All data presented in this section were collected at sea because rig are usually trawled at sea and it was impossible to obtain information from landed catches. Samples were unreplicated and often small and scattered in time and space. Therefore, differences among samples cannot be assessed statistically, and conclusions based on these samples are tentative.

On each sampling trip the whole rig catch (or a random subsample if the catch was too large) was sexed and measured to the nearest centimetre below total length. In most studies maturity was also assessed. Males were recorded as mature if the claspers were calcified and extended well beyond the posterior edge of the pelvic fins (Francis and Mace 1980). Females were recorded as mature if the ovary contained yolked eggs which were pea-sized or larger and if the nidamental glands and uteri were fully developed. Because assessment of female maturity was only possible by dissection, maturity was not determined for females which were tagged and released during some of the studies. Where maturity status was not recorded, or recorded for only part of the catch, the status of the whole sample was estimated from the length-frequency distributions of the catches. Such samples are identified in the tables and figures. Average sizes at maturity were: ECSI, males 87 cm, females 102 cm; WCSI, males 79 cm, females 85 cm (Francis unpublished data). The Otago females were not measured, but were classed as over or under 95 cm long. Therefore, the proportion of mature females in these samples is less than the proportion over 95 cm.

Sex and maturity composition

Samples were often pooled because of their small sizes. Subjective assessments of the effects of sampling over several days, and of mesh size, on the sex and maturity compositions of samples were made for some sample sets.

Comparisons were made of samples taken on consecutive days (Table 3). For each set of samples, mesh size was constant and fishing depths were similar. Sex ratios were very similar within each sample set. For those with adequate sample sizes, the proportions of males which were mature were also similar, but the proportions of females varied in some sets. These results suggest that female rig segregate according to state of maturity. However, small sample sizes may have produced the observed differences.

Samples were also compared for different mesh sizes (Table 4). The variability of sex ratios within sample sets was low, which suggests that mesh size has little effect on sex ratio. However, the proportions of mature rig within some sample sets did vary; the percentage of mature males increased with mesh size in one of the three sets for which data were available, but there was no appreciable difference in the others. The percentage of females which were mature increased with mesh size in the January 1980 Farewell Spit samples over the mesh size range 120 to 180 mm. This trend was also apparent in the February 1983 Pegasus Bay samples, but not the December 1982 Kaikoura samples.

Set nets are size-selective (Hamley 1975), and a selective effect has been reported for *M. antarcticus* (Kirkwood and Walker 1986). Because rig maturity is size-dependent (Francis and Mace 1980), the proportion of mature fish should increase with increasing mesh size. However, rig segregate by size and sex (Graham 1956, McKenzie 1960, this study);

TABLE 3: Composition of set net catches sampled on consecutive days

Locality	Date	Mesh size (mm)	Depth (m)	Sample size	% female	No. of males staged	% males mature	No. of females measured	% females mature*
Kaikoura	28/10/82	165-180	60-90	43	98	1	-†	42	81
	29/10/82	165-180	60-90	48	98	1	-	47	94
	30/10/82	165-180	120-210	20	95	1	-	19	79
Timaru	1/11/82	180	110	136	25	102	97	34	74
	2/11/82	180	110	368	34	244	90	124	44
Timaru	6/12/82	165	37	268	6	252	95	16	6
	7/12/82	165	35	28	14	24	92	4	-
Pegasus Bay‡	27/01/83	180		24	75	6	-	18	44
	28/01/83	180		101	73	27	63	74	23
Whanganui Inlet	15/11/83	165	42	141	1	139	100	2	-
	16/11/83	165	53	49	6	46	100	3	-

* Kaikoura and Timaru, percentage of females over 102 cm.

† Sample size was too small for analysis.

‡ No depth data were recorded at Pegasus Bay.

therefore, catch composition will also be influenced by the composition of the rig schools available to the nets.

Seasonal trends in sex ratios are shown for four areas in Fig. 12. Only data from mesh sizes in the range 160 to 180 mm were included. Data were pooled into monthly intervals.

At Kaikoura females dominated most samples, though the percentage of females declined in February and November-December 1978. The percentage of females in Pegasus Bay increased during the season in 1979-80 and 1982-83.

There were large differences in the sex ratios of Otago rig catches. Data were collected from Taiaroa Head in 27-35 m for 23 November to 17 December 1982 and then from East Otago in 183 m for 18 December 1982 to 12 March 1983. The change in sex composition was abrupt and coincided with the shift in fishing ground. At Taiaroa Head males dominated the catches, which on 16-17 December comprised 7% females ($n = 191$), whereas at East Otago the catches on 18-19 December comprised 99% females ($n = 374$). Therefore, the differences were probably due to locality and/or depth.

Sex ratios also differed with depth at Golden Bay-Tasman Bay. In depths over 25 m females constituted less than 40% of the samples during October-December. Only females were caught in the shallow waters of Farewell Spit during January-March. Males dominated all samples from Canterbury Bight and the WCSI zone, except for one sample from Cascade Point in South Westland (Table 5).

Seasonal trends in female maturity composition are shown in Fig. 13. Data were separated by mesh size because of the possible effect on the proportion of mature fish caught. Most females caught at Kaikoura were mature (over 102 cm TL), and the lowest percentage maturities were observed during December-March. This mid-season dip coincided with the decline

in the percentage of females in the samples (see Fig. 12). Mature females at Pegasus Bay and Canterbury Bight usually constituted less than 50% of the samples. Clear seasonal trends occurred in the two Pegasus Bay samples, though they were opposite in direction; in 1979-80 the percentage of mature females increased during the season, whereas in 1982-83 it decreased. At Otago the percentage of large females (over 95 cm) was very low in the shallow Taiaroa Head samples and very high in the deep East Otago samples. Golden Bay shallow water (under 10 m) samples were almost exclusively made up of mature (over 85 cm) females.

Seasonal trends in male maturity composition are shown in Fig. 14. In all regions most males were mature.

Size composition

The length-frequency distributions of male rig sampled from two consecutive sets of the same nets at Oamaru on 1-2 November 1982 are shown in Fig. 15. The two distributions had the same variances ($F_{243,101} = 1.01$), but significantly different means (analysis of variance, $F_{1,344} = 10.83$, $p < 0.005$). However, the difference between the means was only 1.9 cm, which is probably biologically insignificant.

Male and female length-frequency distributions of samples taken from 180 and 165 mm mesh nets set by four vessels during the 1982-83 season at Pegasus Bay are shown in Figs. 16 and 17. Variances for the 180 mm data were heterogeneous for both sexes (Bartlett's test: males, $X^2_3 = 24.11$, $p < 0.01$; females, $X^2_3 = 52.3$, $p < 0.01$). The greatest variance exceeded the least by a factor of 3.3 for males and 7.1 for females. Transformation did not homogenise the variances. A Kruskal-Wallis test showed that there was significant variability of mean lengths among the male samples ($H_3 = 31.02$, $p < 0.01$), but not among the female samples ($H_4 = 5.70$, $p > 0.2$). The significant differences among the male samples were probably due

TABLE 4: Composition of set net catches sampled from different mesh sizes

Locality	Date	Mesh size (mm)	Depth (m)	Sample size	% female	No. of males staged	% males mature*	No. of females measured	% females mature†
Kaikoura	11/12/82	165	70	51	78	11	—‡	40	30
	11/12/82	180	70	41	73	11	—	30	30
Pegasus Bay§	17/12/82	165		120	20	96	69	24	29
	20/12/82	180		55	15	47	91	8	—
Pegasus Bay	22/02/83	165		21	86	3	—	18	6
	22/02/83	180		63	90	6	—	57	72
Tasman Bay	Oct-Dec 79	120-140	25-40	51	10	46	93	5	—
		160-180	25-40	55	16	46	100	9	—
Farewell Spit	16-25/01/80	120	< 10	82	100	0	—	82	41
		140	< 10	52	100	0	—	52	62
		160	< 10	36	100	0	—	36	92
		180	< 10	69	100	0	—	69	99
Whanganui Inlet	15-16/11/83	165	42-53	190	3	185	100	5	—
	16/11/83	180	49	71	3	69	99	2	—

* Tasman Bay, percentage of males over 79 cm.

† Kaikoura, percentage of females over 102 cm; Farewell Spit, percentage of females over 85 cm.

‡ Sample size was too small for analysis.

§ No depth data were recorded at Pegasus Bay in 1982 or 1983.

to the presence of two distinct length modes in the population. Both modes were also present in the 165 mm mesh samples. However, samples from different vessels were mixed, and it is possible that the length-frequency distributions were influenced by different gear parameters (e.g., nylon gauge and cross-sectional shape or hanging ratio).

The significant differences in the size composition of catches of males taken at 1- to 4-week intervals suggest that conclusions about the effect of mesh size on catch composition should only be based on samples taken from nets which are set simultaneously.

When all the 180 mm Pegasus Bay male samples were pooled, and all female samples pooled, unimodal length-frequency distributions were obtained (Fig. 18). Variances of the male and female lengths were

significantly different ($F_{280,267} = 1.37, 0.02 < p < 0.05$). The female variance was almost twice the male variance.

Nets with mesh sizes 120, 140, 160, and 180 mm were set simultaneously in Golden Bay-Tasman Bay between September 1979 and January 1980. Length-frequency distributions by sex are shown in Fig. 19. For each mesh size the female variance in length was greater than the male variance (the differences were statistically significant for 120, 140, and 160 mm samples). For both sexes the mean size increased significantly with mesh size (Kruskal-Wallis test: males, $H_3 = 22.22, p < 0.01$; females, $H_3 = 78.93, p < 0.01$). Female length-frequency distributions were multi-modal for 120 and 140 mm mesh sizes, which suggested that several year classes were present in the samples.

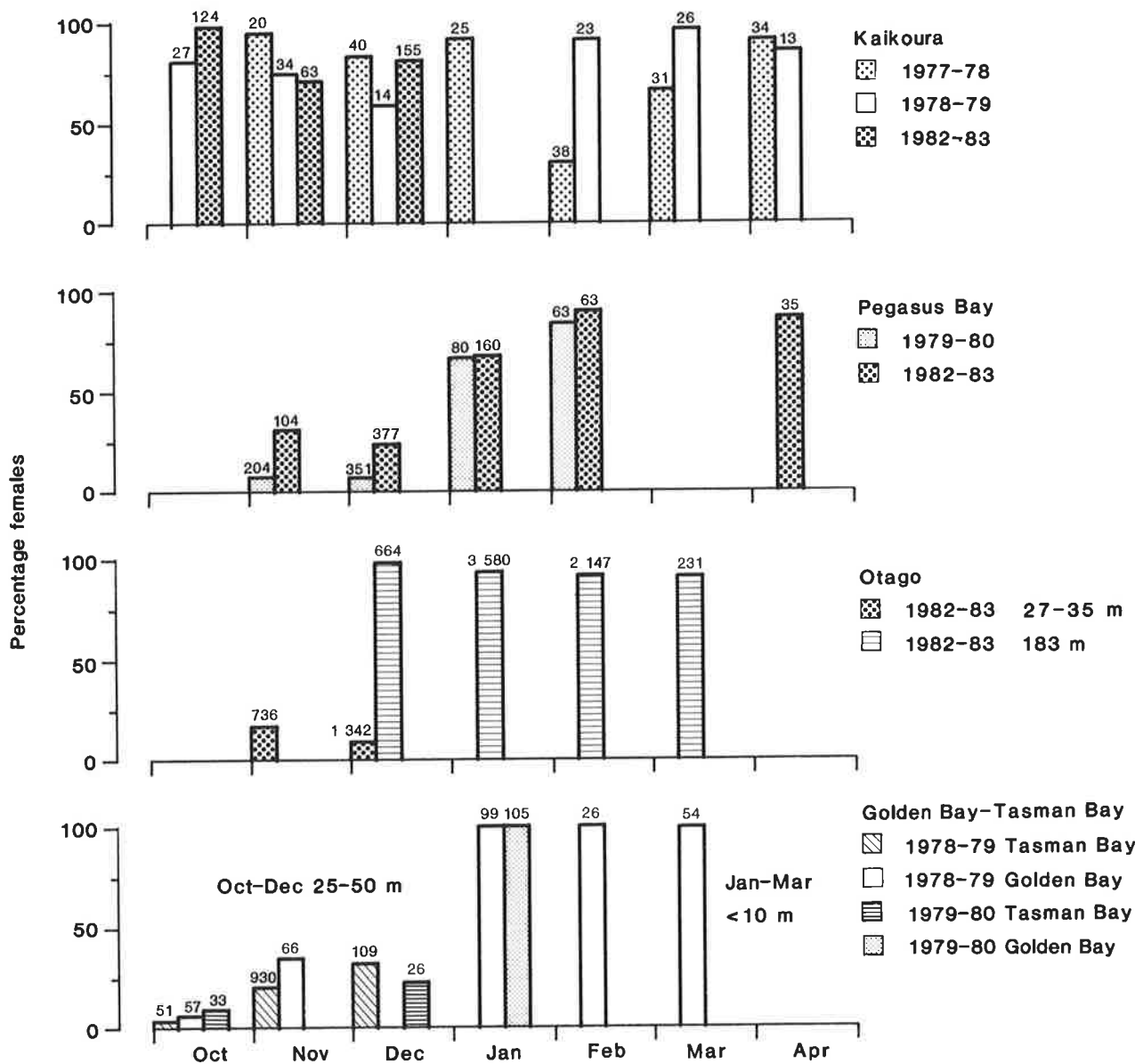


Fig. 12: Seasonal trends in the sex ratio of set net catch samples for 160-180 mm mesh sizes combined. (Numbers are sample sizes.)

TABLE 5: Seasonal analysis of composition of some set net catches

Locality	Date	Mesh size (mm)	Depth (m)	Sample size	% female	No. of males staged	% males mature	No. of females measured	% females mature*
Canterbury Bight									
Oamaru	Nov 82	180	110	504	31	346	92	158	50
Timaru	Dec 82	165	36	296	7	276	95	20	5
	Dec 83	165	15	60	40	36	81	24	42
West coast South Island									
Cascade Point	Dec 82	180	62	117	86	16	94	63	56
Jacksons Bay	Mar 83	180	90	74	23	57	100	12	33
Karamea	Feb 83	165	15-42	67	39	41	98	26	39
Whanganui Inlet	Feb 83	165	51	143	13	125	97	18	33
	Nov 83	165	42-53	190	3	185	100	5	-†
	Nov 83	180	49	71	3	69	99	2	-

* Oamaru, Timaru, Cascade Point, and Jacksons Bay, percentage of females over 102 cm; Karamea and Whanganui Inlet, percentage of females over 85 cm.

† Sample size was too small for analysis.

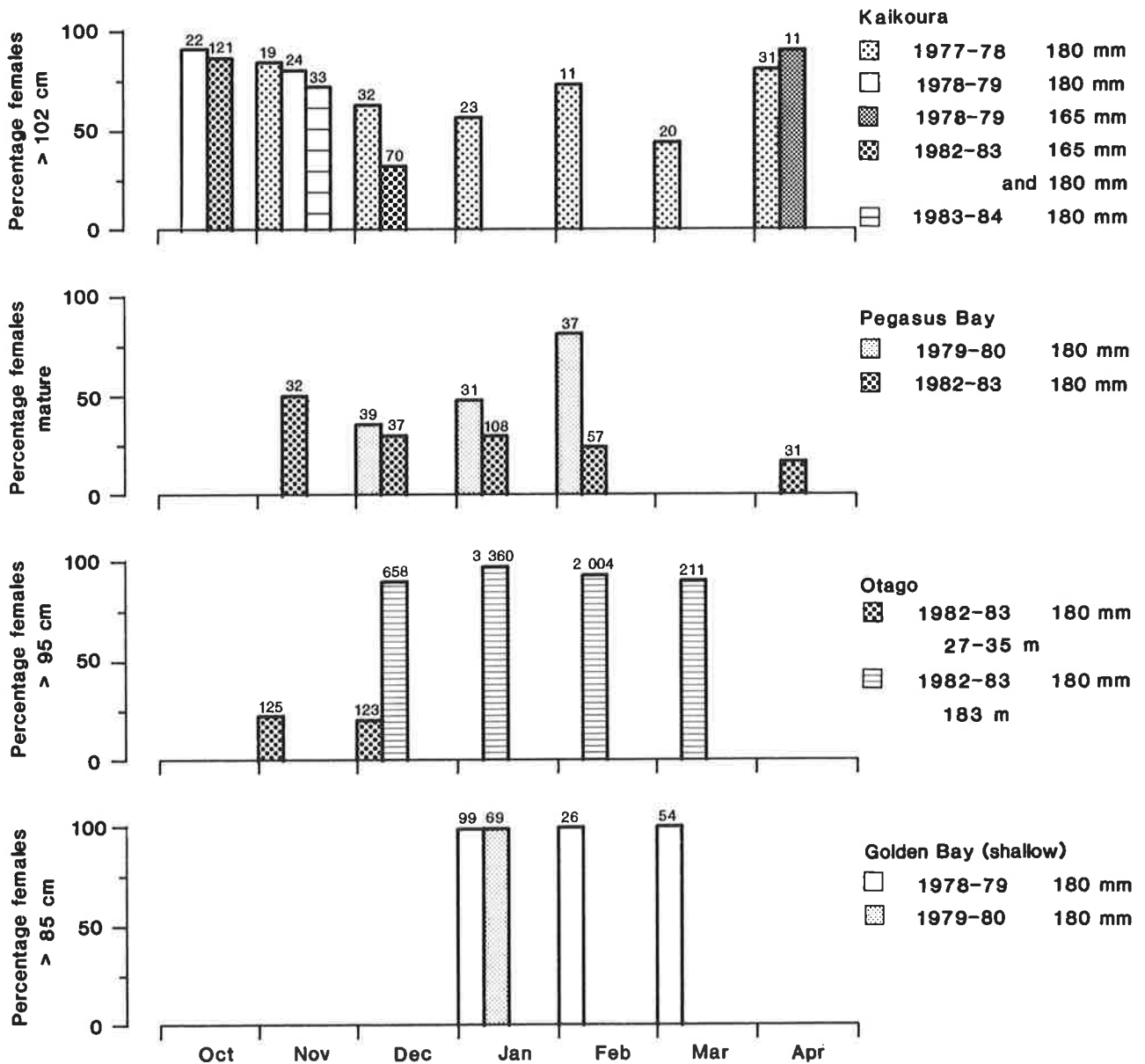


Fig. 13: Seasonal trends in the proportions of females which were mature (or longer than the average length at maturity). (Numbers are sample sizes.)

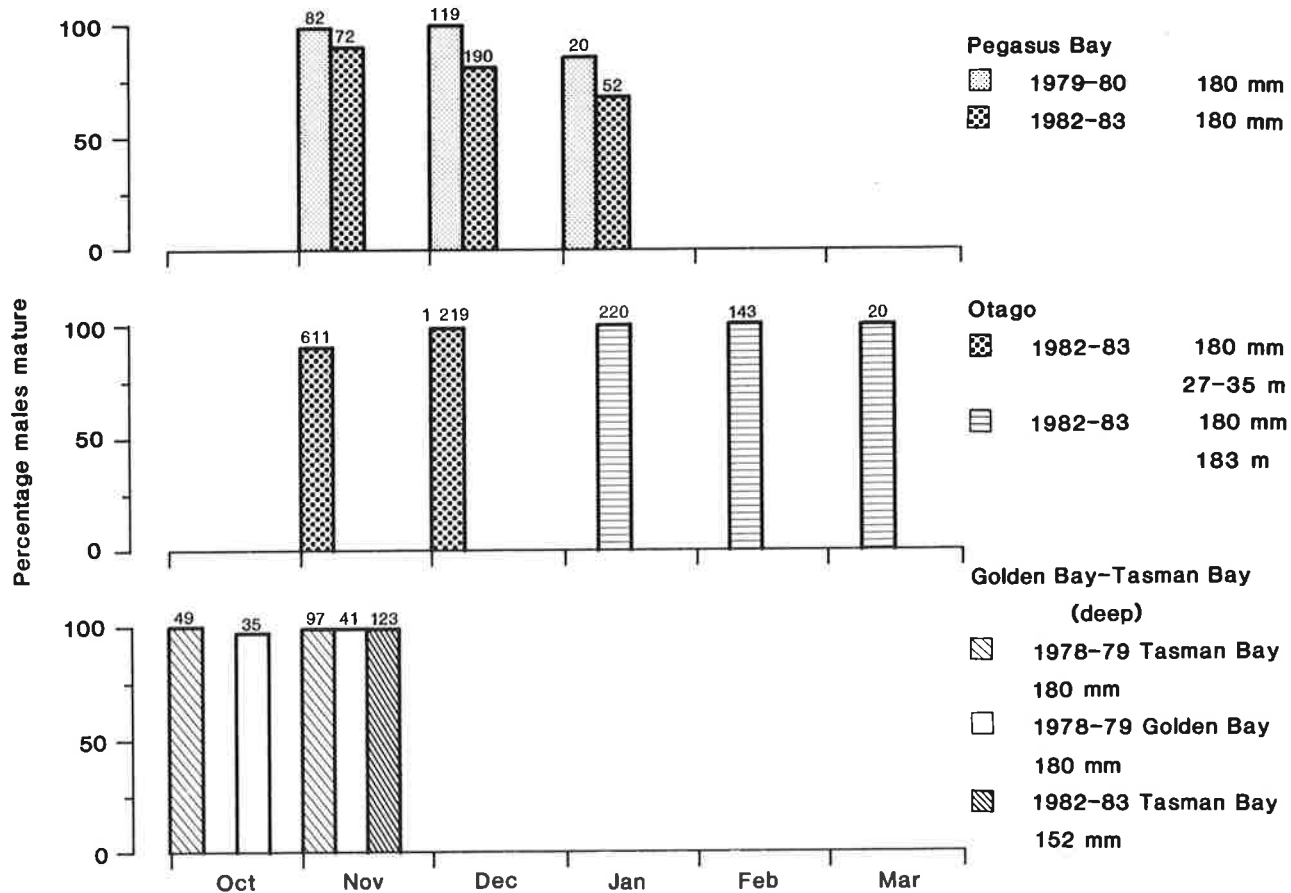


Fig. 14: Seasonal trends in the proportions of males which were mature. (Numbers are sample sizes.)

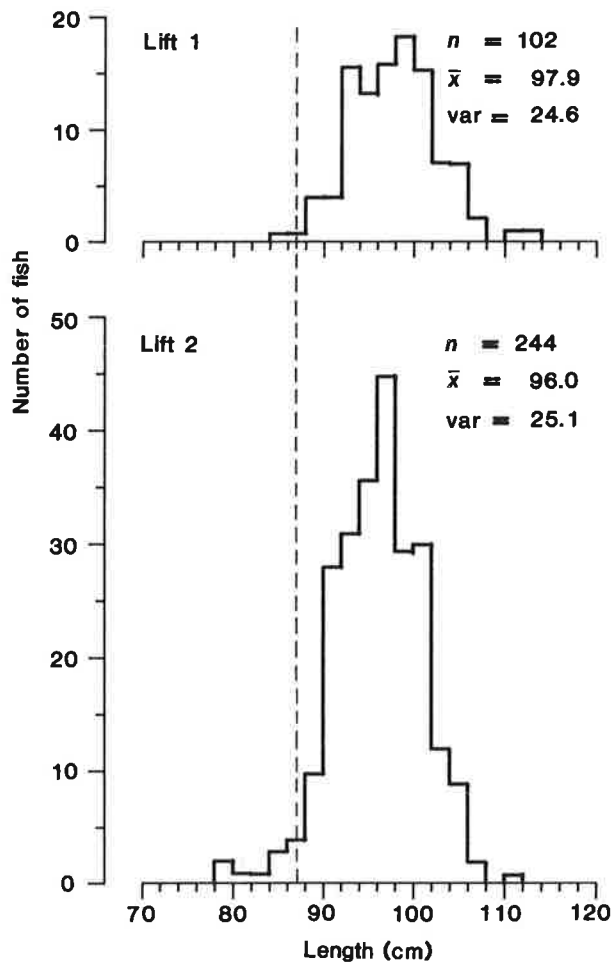


Fig. 15: Length-frequency distributions of male rig from two consecutive lifts of the same 180 mm mesh nets set off Oamaru, 1-2 November 1982. (Dashed vertical line shows average length at maturity.)

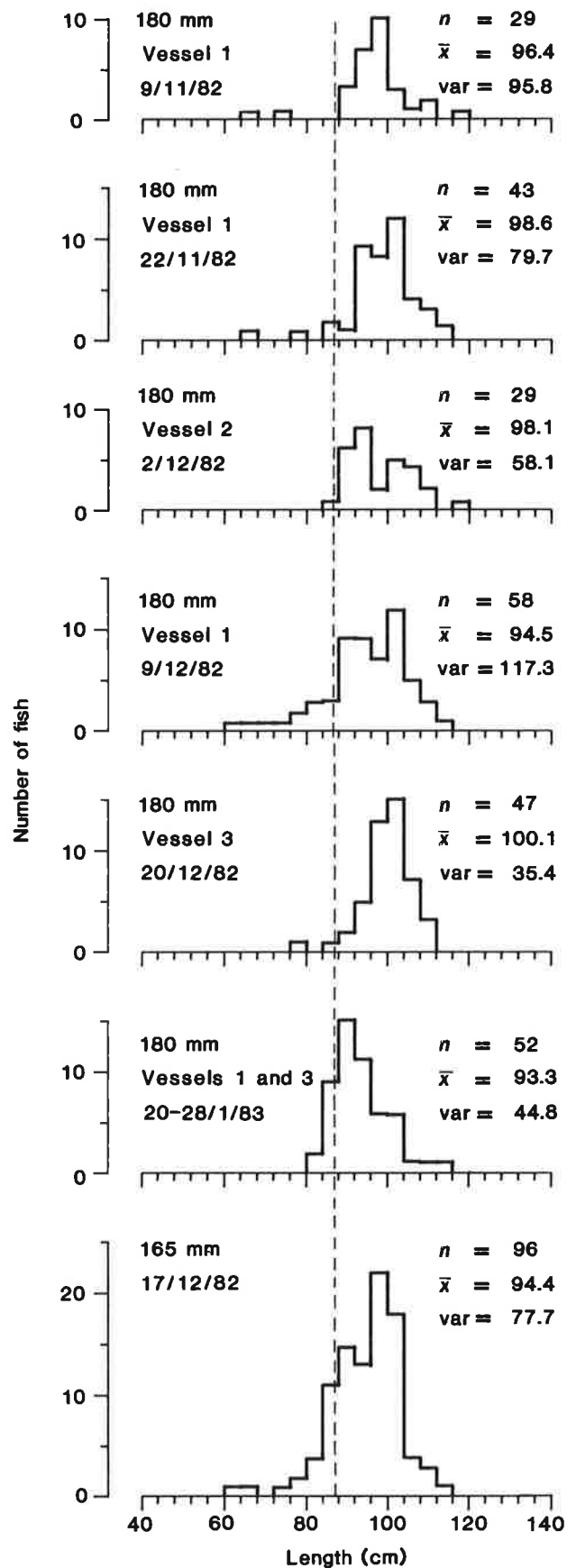


Fig. 16: Length-frequency distributions of male rig from 180 mm mesh set net catches and from one 165 mm mesh catch at Pegasus Bay, 1982-83 season. Catches were sampled from several vessels. (Dashed vertical line shows average length at maturity.) (B. R. Massey unpublished data.)

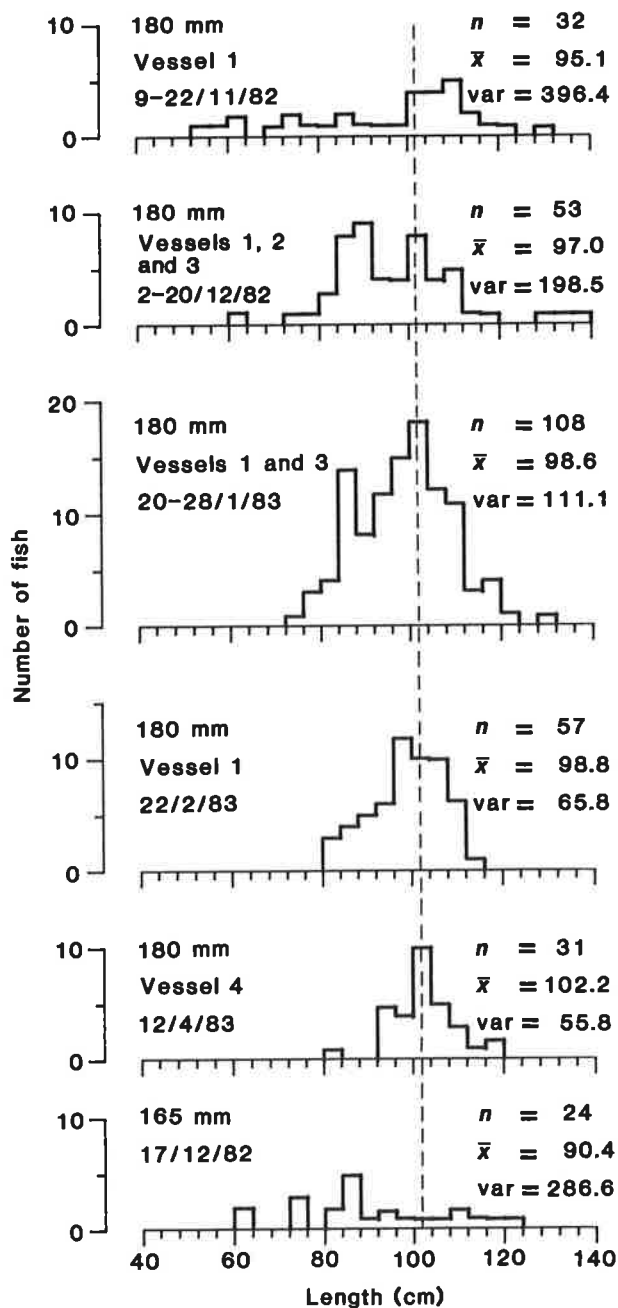


Fig. 17: Length-frequency distributions of female rig from 180 mm mesh set net catches and from one 165 mm mesh catch at Pegasus Bay, 1982-83 season. Catches were sampled from several vessels. (Dashed vertical line shows average length at maturity.) (B. R. Massey unpublished data.)

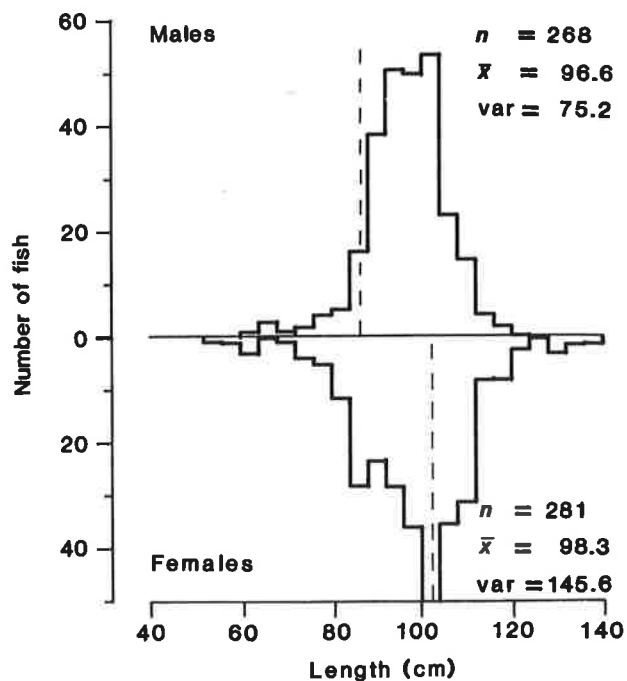


Fig. 18: Length-frequency distributions of male and female rig from 180 mm mesh set net catches at Pegasus Bay, 1982-83 season. (Dashed vertical lines show average lengths at maturity.) (Modified from Massey (1984).)

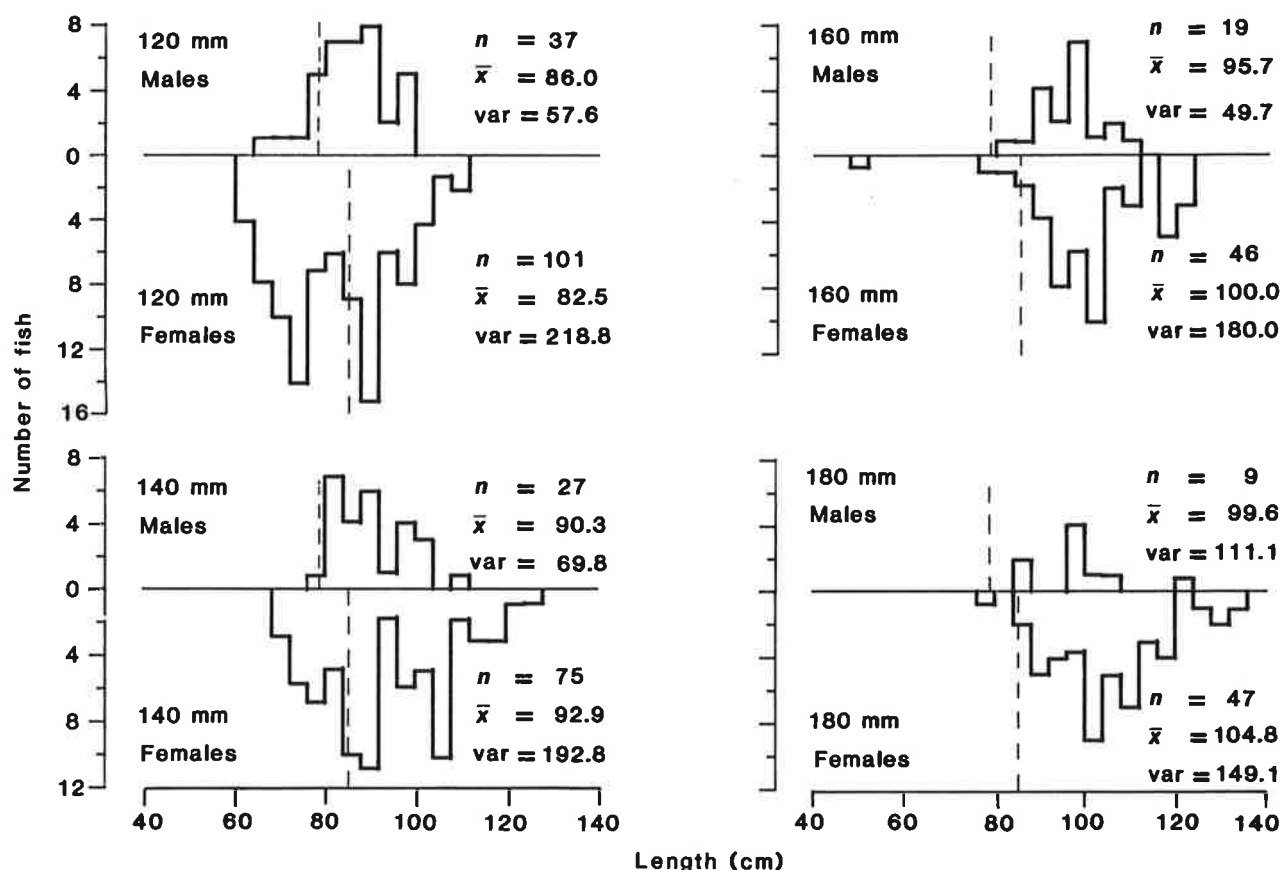


Fig. 19: Length-frequency distributions of male and female rig sampled from various mesh sizes at Golden Bay-Tasman Bay, September 1979-January 1980. (Dashed vertical lines show average lengths at maturity.) (J. T. Mace unpublished data.)

Discussion

Catch per unit of effort analyses suggest that rig stocks have declined in size in many parts of New Zealand. Biases in the CPUE indices mean that the true decline rates are probably greater than those shown in Fig. 11. Because annual exploitation rates of more than 20% have been estimated from tagging experiments in the ECSI and WCSI zones (Francis unpublished data), the declines are probably due to high fishing mortality. The same conclusion may be valid for the WCNI and SECNI zones, though estimates of exploitation rates are unavailable for these.

Although there is no evidence of a decline in stock size in the NECNI zone, fishing effort in the Hauraki Gulf has increased sharply in the last 5 years and landings have doubled to 500 t. Such high yields may prove unsustainable.

Cushing (1971, 1973) showed that the ability of fish species to maintain stable populations in the face of environmental variability or human exploitation is related to fecundity. Low-fecundity species are more susceptible to population fluctuations (both man-induced and natural) because of the effect of population size changes on recruitment. Female rig produce an average of 11 young per year (Francis and Mace 1980). Rig have presumably evolved density-dependent mechanisms to compensate for natural population declines. These mechanisms may include decreased juvenile natural mortality rate, increased growth rate (which would lead to earlier maturity and a greater age-specific fecundity), and changes in reproductive output (Wood *et al.* 1979). However, heavy fishing of rig stocks may lead to a decline in reproductive capacity. Fecundity increases exponentially with female length (Francis and Mace 1980);

therefore, if set nets selectively catch the larger females, the average fecundity of females remaining in the population could drop rapidly. Samples representative of the population would be necessary to determine whether the mean size of females has declined.

If CPUE is an accurate indicator of stock size, rig populations have been reduced to below one-third of their initial sizes in several areas. Density-dependent compensation may not be adequate to maintain recruitment after such large changes.

The southern Australian fishery for *M. antarcticus* is the only other *Mustelus* fishery for which CPUE data are available. Between 1974 and 1983 CPUE declined to 42% of the initial level. This decline in CPUE, the large proportion of the commercial catch under the average age at maturity, and the decline in average size of both males and females suggest that this fishery is being overexploited (T. I. Walker pers. comm.).

Rig landings are strongly seasonal, though the timing and shape of landings peaks vary among regions. Sex and maturity compositions of catch samples varied considerably with season, depth, and locality. Nevertheless, the patterns appear to be fairly stable from year to year (though not for the female maturity composition of Pegasus Bay samples). These facts suggest that rig have consistent, well-defined, and complex behaviour patterns which involve migration and segregation by sex and possibly by maturity and size. Rig tagging around southern New Zealand has confirmed this (Francis 1988). Despite the low number of catches sampled, several general statements about rig movements and aggregations can be made from the results of this study.

At Kaikoura mature females dominated catches throughout the season, but there was a decline in the proportion of females, and in the proportion of females that were mature, during the middle of the season. Because this dip coincided with a decline in landings it was probably due to emigration of mature females rather than to immigration of males. The composition of the second seasonal peak (February-April) is unknown, because it did not occur during the years in which late-season samples were obtained (1977-78 and 1978-79). The disappearance of the second Kaikoura landings peak in recent years may be a result of a decline in rig stock size, a shift of fishing effort towards tarakihi (*Nemadactylus macropterus*), or a combination of both.

At Pegasus Bay the proportion of females in samples increased sharply in January-February, when Lyttelton landings were declining. The landings peak is apparently dominated by mature males which begin to emigrate in January.

At Otago mature males dominated the shallow Taiaroa Head samples. The few females which were present were mostly immature. Mature females

dominated the deep East Otago samples. Because no shallow samples were obtained after December and no deep samples before December, it was impossible to determine whether seasonal changes had occurred.

At Golden Bay-Tasman Bay mature males predominated in deep (over 25 m) water during October-December, whereas mature females predominated in shallow (under 10 m) water (mainly on the banks inside Farewell Spit) during January-March. The first Golden Bay peak corresponds with the fishery for males in deep water at Golden Bay and Tasman Bay, and the second peak corresponds with the shallow water fishery for females.

Length-frequency distributions of samples showed that the size composition of catches varied significantly during the season at Pegasus Bay. This may have been due to changes in the size composition of the school being fished, movement of different schools through the fishing grounds, or sampling errors which were not detected because of a lack of replication. If a wide range of size classes of rig were available to the nets, mesh size would also influence the size composition of catches.

Segregation by size and sex is a common feature of shark populations (Springer 1967) and has been reported for *M. higmani* (Springer and Lowe 1963) and *M. antarcticus* (T. I. Walker pers. comm.). Segregation by sex is also a feature of New Zealand rig populations, but segregation by size has not been demonstrated in this study.

The variances of the female length-frequency distributions always exceeded those of the male distributions. This occurs because females show greater girth variance than males at any given length (J. T. Mace pers. comm.) and, for the larger mesh sizes, because females grow bigger than males.

For length-frequency samples to be representative of the rig population size composition, they must be collected over the full season from a variety of areas in the range of the population and from a range of mesh sizes. Furthermore, samples should be taken from several randomly selected vessels in each locality to allow for the possibility that gear parameters (such as net hanging ratio) may affect catch composition. Rig samples measured during this study are unlikely to be representative of the population size composition. However, the results illustrate some of the sampling difficulties and give a general indication of catch composition in several areas.

Sampling at sea is time consuming and may result in very small sample sizes, especially when stock sizes are low. Larger, more representative samples of landed fish could be obtained by the use of a partial length measurement and the development of a means by which processed fish could be sexed. Routine collection of mesh size data from the set net fleet is desirable because of the influence of mesh size on size composition.

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Appendix 1

Sources of catch composition data

Study area	Year	Source
Kaikoura	1977-79	Study of set net fishery and rig biology (Francis 1979).
Golden Bay-Tasman Bay	1978-80	Study of rig fishery and biology, and set net selectivity (J. T. Mace pers. comm.).
Tasman Bay	1978	Analysis of rig catch composition (G. Squires pers. comm.).
Pegasus Bay	1979-80	Catch sampling by MAF (Massey 1984).
Pegasus Bay	1982-83	Study of rig fishery and biology (Massey 1984).
South Island	1982-84	Study of rig fishery and biology (Francis and Smith unpublished data).
Otago	1982-83	Analysis of rig catch composition (M. Chaplin pers. comm.).
West coast South Island	1983	Catch sampling between Whanganui Inlet and Jacksons Bay (M. Bradstock pers. comm.).

