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in New Zealand waters**

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## **EXECUTIVE SUMMARY**

**Horn, P.L. (2005). A review of the stock structure of ling (*Genypterus blacodes*) in New Zealand waters.**

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This report examines all currently available sources of data that may provide information on the structure of ling stocks in New Zealand waters. Information was available from published studies of genetics and morphology, from trends in catches, and from life history characteristics. The life history data (i.e., growth parameters, size and age at maturity, location and timing of spawning, estimates of recruitment strength) were found to be the most useful, and enabled five distinct stocks to be identified. They correspond with the five stocks defined in recent years for assessment: Chatham Rise, Campbell Plateau (including the Stewart-Snares shelf and Puysegur Bank), Bounty Plateau, Cook Strait, and west coast South Island. There is currently no information available that allows inferences about the stock structure of ling around the North Island (excluding Cook Strait).

It is unlikely that any of the defined stocks are genetically distinct; indeed, mixing between them at the egg, larval, and adult stages appears inevitable. However, because it is believed that most of the fish in each stock spend a sufficiently large proportion of their lives geographically separated from those in other areas, management and assessment assuming five major stocks is logical.

It is recommended that an analysis of life history characteristics be the first step in any future ling stock discrimination study. Genetic and morphological analyses appear to have relatively poor resolving power for ling. Tagging studies and analyses of otolith microchemistry have not been trialled for ling, but are likely to add little to the current picture and would be very expensive. Studies of natural parasite 'tags' may be useful.

## 1. INTRODUCTION

This document reports the results of Ministry of Fisheries Project LIN2004/01, Objective 3, to review the stock structure of ling from available data sources.

It has been standard practice to subdivide New Zealand's commercial marine fishes into stocks or management units which exhibit various degrees of isolation. There is no universal definition of a 'stock', although most definitions include spatial and temporal isolation, and, often, reproductive isolation. Ling fisheries are managed as eight administrative Fishstocks (Figure 1), although five of these (LIN 3, 4, 5, 6, and 7) currently produce about 93% of landings (Horn 2005). The most recent review of ling stock structure (Horn & Cordue 1996) indicated that there are at least four major biological stocks of ling in New Zealand waters: the Chatham Rise, the Campbell Plateau (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Plateau, and the west coast of the South Island (WCSD).

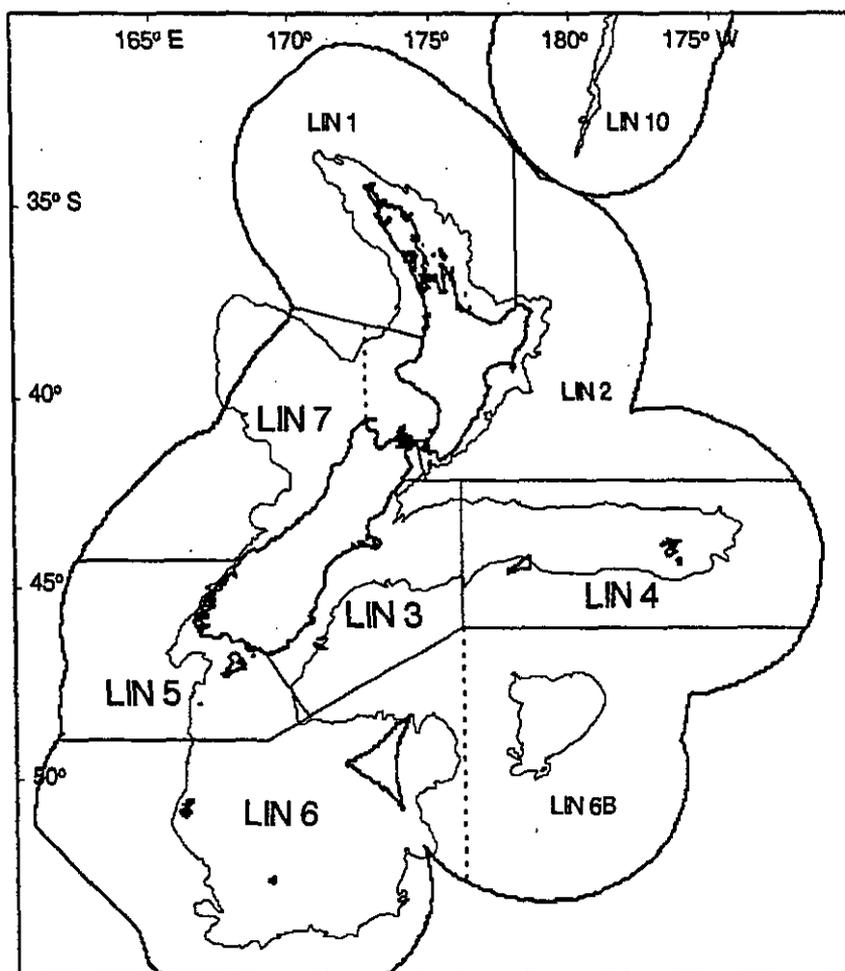


Figure 1: Areas of administrative fishstocks for ling (Fishstocks LIN 1, 2, 3, 4, 5, 6, 7, and 10). The 1000 m isobath is also shown. The boundaries used to separate the assessed stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the Cook Strait section, are shown as broken lines.

In the stock assessment process, at least five biological stocks of ling are recognised in New Zealand waters, defined as follows: Chatham Rise (LIN 3 and LIN 4), Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176° E), Bounty Plateau (LIN 6 east of 176° E), west coast South Island (LIN 7 west of Cape Farewell), and Cook Strait (those parts of

LIN 2 and LIN 7 making up statistical areas 16 and 17 in Cook Strait) (Figure 1). These stocks are referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively. However, the stock affinity of ling in Cook Strait and around the North Island is unknown.

Since the review by Horn & Cordue (1996) a large volume of data has been collected which may allow further discrimination of stocks, particularly in relation to the stock affinity of ling in Cook Strait. This review examines all available data that may provide information about stock structure, i.e., genetic analyses, meristic and morphometric studies, life history characters (i.e., growth rates, size and age at maturity, timing and position of spawning grounds, and estimated population year class strength distributions). Some categories of data are examined entirely by literature review. Other categories comprising raw numerical or descriptive data are actively analysed for areal trends.

## 2. LITERATURE REVIEW

### 2.1 Genetics

The distribution of alleles in two polymorphic enzymes from 395 ling liver tissue samples was examined by Smith (1979). Samples from five areas (northeast North Island, Cook Strait, WCSI, Canterbury Bight, Pukaki Rise) were analysed. One enzyme (phosphoglucosmutase) exhibited no apparent differences in allele frequency throughout the sampling range. The other (glucosephosphate isomerase) exhibited no statistical differences in allele frequency in all the between-location pairwise comparisons ( $P = 0.49$  across all samples), but differences were indicated ( $P < 0.10$ ) when the Pukaki Rise sample was compared with the grouped data from the four northern locations. The probability of a difference increased when the Canterbury Bight data were removed from the combined group. Hence, Smith (1979) concluded that the Pukaki Rise ling were from a stock separate to that providing all the other samples, and that the two stocks were separated by the Subtropical Convergence. The Canterbury Bight sample, being close to the Subtropical Convergence, was proposed as a possible area of stock mixing.

In an expansion of the 1979 study, Smith & Francis (1982) analysed the glucosephosphate isomerase allele frequency from a greater range of samples, both spatially and temporally. Despite the large number of fish analysed ( $n = 1743$ ), there was no overall allelic heterogeneity ( $P = 0.26$  across all samples). However, after pooling regional samples and considering hydrological conditions, Smith & Francis (1982) suggested that there were two, and possibly three, ling stocks. A mainland stock incorporated ling around North Island and the 'inshore' areas around South Island as far south as the Snares Islands. A southern stock occurred on the northern section of the Campbell Plateau (i.e., Pukaki Rise and Auckland Islands), and a possible third discrete stock was present around Campbell Island. The Chatham Rise was proposed as an area of mixing between the mainland and southern stocks.

Comparisons of partial sequences of mitochondrial DNA (mtDNA) were used to examine the taxonomic relationships between ling (*Genypterus* spp.) from New Zealand, Australia, and South Africa (Smith & Paulin 2003). The pink or mottled ling, *Genypterus blacodes*, from New Zealand and Australian waters was shown to be a separate species from both the rockling, *G. tigerinus*, from Australia, and the kingclip, *G. capensis*, from South Africa. A fourth species, the banded ling, *G. microstomus*, based on a few generally small specimens from New Zealand and Australia, was not able to be distinguished from *G. blacodes*, even though the analysed fish included small individuals (under 50 cm TL) from the Bay of Plenty and Chatham Rise, and both small and large individuals from the Campbell Plateau. It was concluded that *G. microstomus* is a junior synonym of *G. blacodes*. Genetic differences between *G. blacodes* from New Zealand and Tasmania were small (only 5 out of 575

nucleotides differed). Differences were greater between *G. blacodes* and *G. tigerinus* (28 differences), and greater still between *G. blacodes* and *G. capensis* (31 differences).

The conclusions of Smith & Paulin (2003) were very similar to those of Daley et al. (2000) and Ward et al. (2001), who analysed microsatellite DNA and mtDNA to determine if the orange and pink morphs of *Genypterus blacodes* were genetically distinct, and to examine the genetic difference between *G. blacodes*, *G. tigerinus*, and *G. capensis*. They concluded that the orange and pink morphs are probably the juvenile and adult forms, respectively, of a single species. Similar colour variation is also apparent in New Zealand ling samples. However, in contrast to Smith & Paulin (2003), Daley et al. (2000) concluded that *G. blacodes* from Australia and *G. capensis* from South Africa are more closely related to each other than either was to *G. tigerinus* from Australia.

The New Zealand *Genypterus blacodes* specimens collected by Smith & Paulin (2003) were from three locations (Bay of Plenty, Chatham Rise, and the Campbell Plateau), and were tested at two regions of the mtDNA: the cytochrome *b* and control region. There was no evidence for any geographical structure from cytochrome *b* sequence variation. However, an analysis of molecular variation among the control region haplotypes indicated significant pairwise variation between the Campbell Plateau samples and both the Bay of Plenty and Chatham Rise samples. This result is indicative of 'northern' and 'southern' ling stocks. There was a greater significant difference in control region haplotype frequencies between the New Zealand and Tasmanian populations, indicating that the tested *G. blacodes* populations from New Zealand are more closely related to each other than to *G. blacodes* from Tasmania. An analysis of allozyme variation and microsatellite DNA in *G. blacodes* off southeastern Australia found no significant differences between ling from five sample locations (Ward & Reilly 2001, Ward et al. 2001), so the null hypothesis of a single ling stock off Australia could not be rejected.

Genetic studies of New Zealand ling have not been extensive. No samples from the Bounty Plateau have been analysed in any study. The allelic differences described by Smith (1979) and Smith & Francis (1982) provide only weak evidence for multiple ling stocks around New Zealand, tentatively indicating a mainland and a southern stock. MtDNA control region haplotypes indicate northern and southern stocks (Smith & Paulin 2003).

## 2.2 Morphometrics and Meristics

Colman (1995) analysed the morphometrics of heads and otoliths of ling from south of about 41° S. He partitioned the sample area into relatively small sections, and while this allowed comparisons between fish from different parts of a major geological feature (e.g., the Chatham Rise comprised one coastal and four offshore areas) it did result in small sample sizes in some cells. Only data from fish with total lengths in the range 70–100 cm were used in the analyses. Based on the morphometrics of otoliths collected from 1976 to 1979, there were two distinct groups of ling: northern (comprising Chatham Rise, Canterbury, and WCSI) and southern (comprising all the Campbell Plateau, Puysegur, and Snares). Male fish from Otago fitted best in the southern group, but females were more aligned with the northern group. No otoliths from the Bounty Plateau were analysed. Based on head measurements from ling collected from 1989 to 1992, there was again a clear north-south split, with Otago fish being more clearly aligned with the southern group. Generally, fish from the northern areas had longer heads, narrower interorbital widths, and thinner otoliths than southern fish. A small sample of seven male fish from the Bounty Plateau could be interpreted as being distinct from both the northern and southern groups.

Colman (1995) concluded that there were at least two, more or less separate, stocks. The northern stock comprised fish from WCSI, Canterbury coast, and Chatham Rise. The southern

stock comprised fish off the Otago and Southland coasts, and the entire Campbell Plateau, although it was suggested that Otago was an area of mixing between the northern and southern stocks. Ling on the Bounty Plateau were tentatively postulated to derive from another separate stock.

Daley et al. (2000) examined meristic and morphometric characters (most being the same as those examined by Colman 1995) in samples of *Genypterus blacodes* from Australian waters. They found that some meristic characters (e.g., counts of vertebrae, gill rakers, and pyloric caecae) exhibited little variation between areas, while others (e.g., fin ray counts) showed broad ranges with no clear modes. Hence, Daley et al. (2000) concluded that meristics could not refute the hypothesis of a single ling stock in Australian waters. Morphometric characters were also unable to identify any regional differences. The authors noted that the morphometric analysis was confounded by a limited success in compensating for regional differences in mean fish size, highlighting the need to obtain fish of similar size for morphometric or otolith shape studies.

Meristics and morphometrics were also used as part of a study to test whether more than one species of *Genypterus* occurred in New Zealand waters (Smith & Paulin 2003). This investigation examined small (total length 57 cm and under) ling from northern (Bay of Plenty and Chatham Rise) and southern (Campbell Plateau) waters off New Zealand, and also from Australian waters off Tasmania and Victoria. The counts and measurements had similar ranges to those produced by Daley et al. (2000). There were no significant differences between northern and southern New Zealand ling in any of the characters. There were differences in scale counts between New Zealand and Tasmanian ling, but comparable counts from Victorian fish overlapped both regions. Several of the meristic characters overlapped published ranges for other *Genypterus* species. Hence, Smith & Paulin (2003) concluded that meristics and morphometrics are of limited use for the intraspecific identification of populations, or even the identification of *Genypterus* species.

Different colour morphs of ling (i.e., the brown, orange, and pink morphs) are clearly not population-specific (Daley et al. 2000, Ward et al. 2001), but are related to fish size and habitat. Smaller and shallower ling tend to be darker (i.e. brown or orange, rather than pink).

### **2.3 Growth rates**

As part of an analysis to determine ling growth parameters, Horn (1993) aged ling from four areas around southern New Zealand, i.e., WCSI, Chatham Rise, Campbell Plateau, and Bounty Plateau. Growth rates clearly differed between sexes (females grew faster than males), and it was also apparent that growth differed between areas. By comparing von Bertalanffy  $k$  values and estimated mean length at age 25, Horn (1993) concluded that there were three groups of ling on the basis of growth characteristics: WCSI ling grew the fastest, Campbell Plateau fish grew the slowest, and ling from the Chatham Rise and Bounty Plateau were intermediate.

### **2.4 Population size-structure**

Horn (1993) noted that ling length-frequency histograms from four areas around southern New Zealand (WCSI, Chatham Rise, Campbell Plateau, and Bounty Plateau) were different. The differences correlated with the growth rate data (large fish were common off WCSI but rare on the Campbell Plateau), but it was acknowledged that some of the differences would have resulted from different fishing gear selectivities. Subsequent publications have also demonstrated different length-frequency distributions between the areas noted above, and

between different gear types in the same area (e.g., Horn et al. 2000, Horn 2002, Horn & Dunn 2003).

## 2.5 CPUE analyses

Series of standardised catch per unit of effort (CPUE) from commercial line fisheries targeting ling have been produced annually for some years, and are used as indices of relative abundance in stock assessment modelling (i.e., it is assumed that a standard unit of fishing effort will catch an amount of fish proportional to their abundance at the time). Hence, any differences between areas in CPUE trends over time may be indicative of stock differences. The most recent CPUE update presented series from fisheries on the Chatham Rise, Campbell Plateau (including Puysegur), Bounty Plateau, WCSI, and Cook Strait (Horn in press). There were doubts about the reliability of the WCSI and Cook Strait series (Horn in press). However, the Chatham, Campbell, and Bounty series are believed to accurately index the abundance of ling vulnerable to the line fishery on those grounds, and are presented in Figure 2. It appears likely that ling at Campbell have declined only slightly since 1991, but that stock abundance in the Chatham and Bounty areas declined by about half since the development of the line fisheries in those areas in the early 1990s. Hence, these data indicate a stock differentiation between Campbell ling and those on both the Chatham Rise and Bounty Plateau. However, it could also be argued that the difference between the Campbell and the other two series is solely the two relatively low values at Campbell in 1991 and 1992.

An analysis of CPUE in the target line fishery for ling in LIN 1 indicated that two ling stocks might be present in the area, i.e., east Northland and Bay of Plenty (Horn in press). The apparent decline in CPUE was quite marked in the Northland fishery, whereas there was little change in the Bay of Plenty indices. There was also a marked geographical discontinuity in landings and catch rates between the two areas, providing further evidence for a stock boundary. However, the CPUE analysis was compromised by having relatively few data points in some years.

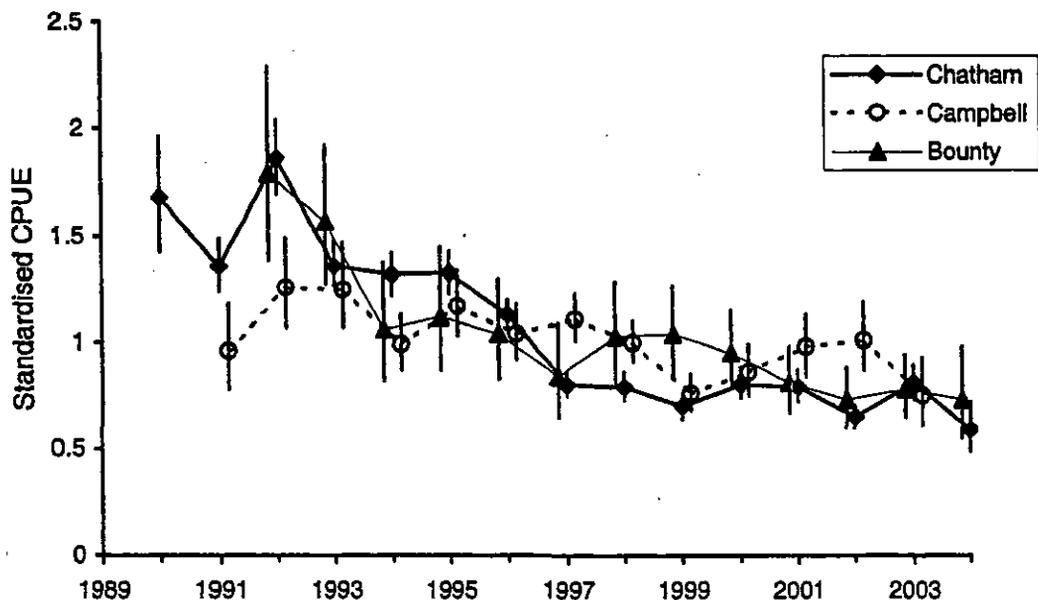


Figure 2: Estimated indices of relative abundance (with 95% confidence intervals) from standardised CPUE analyses of target longline fisheries for ling on the Chatham Rise, Campbell Plateau, and Bounty Plateau. Note that there is no Campbell index for 2004.

## 2.6 Parasites

Parasites have been useful in stock discrimination studies of some fish species (Lester 1990). Checklists of parasites recorded from ling are available (e.g., Sardella et al. 1998, Hine et al. 2000), but while some of these are known to occur at a reasonably high prevalence and be easily detected, no stock discrimination studies using parasites have been reported for *Genypterus blacodes* in New Zealand waters. Studies of South Atlantic *G. blacodes* parasites have indicated some potential for stock discrimination. Parasitism of ling by the anisakid nematode *Hysterothylacium aduncum* increased from north to south between Uruguayan and Patagonian waters (Navone et al. 1998), and differences in the prevalence of the parasitic copepod *Sphyrion laevigatum* on *G. blacodes* from different areas around the Falkland Islands may infer a degree of stock separation (Brickle et al. 2003).

## 2.7 Biochemical analyses

An analysis of mercury levels in the flesh of ling indicated significant differences between areas, i.e., levels were low off the Canterbury coast and on the southern Campbell Plateau, high around Auckland Islands, and intermediate off WCSI and Puysegur (van den Broek et al. 1981). However, this analysis did not take the age of the fish into account, and it is considered likely that mercury concentrations are generally related to age rather than length. A later analysis was completed, this time standardising on age, and reporting estimated concentrations of mercury in 14-year-old male and female ling from various areas (Timperley & Tracey 1997). There was a clear areal difference in concentrations, with ling from the Chatham Rise ( $n = 200$ , mean Hg =  $360 \mu\text{g.kg}^{-1}$ ) having about half the mercury of those on the Campbell Plateau ( $n = 304$ , mean Hg =  $635 \mu\text{g.kg}^{-1}$ ). Levels for WCSI ling ( $n = 33$ , mean Hg =  $664 \mu\text{g.kg}^{-1}$ ) were similar to those from Campbell, although the sample size was small. Interestingly, mercury levels in ling from the Auckland Islands were the highest of all the Campbell sub-areas, as found in the original study.

Measurements of other heavy metal concentrations (i.e., cadmium, copper, zinc, lead) are available from ling sampled off the Canterbury coast and on the Campbell Plateau (Fenaughty et al. 1988). None of the elements exhibited significant between-area differences.

## 3. ANALYSES

### 3.1 Spawning biology

Two aspects of spawning biology are examined below: the timing and position of spawning fish, and maturity ogives by area.

#### 3.1.1 Time and place of spawning

To determine the timing and position of spawning, ling gonad stage data were derived from three sources: the research *trawl* database, the scientific observer *obs\_lfs* database, and the SeaFIC *logbook* database. Catch date, catch position, and sex were extracted from each database for all ling staged with 'running ripe' gonads, i.e., stage 5 in the *trawl* database, and stage 4 in the two other databases. The *obs\_lfs* database contains stage data for females only. Data were grouped by month and plotted by sex (Figures 3 and 4). The danger of using these data to infer spawning seasons is that all areas were not fished or sampled in all months. For example, sampling of the ling habitat around the North Island is very sparse, and sampling off WCSI is confined virtually to the hoki spawning season from June to September. However,

the Chatham Rise, Campbell Plateau, and Bounty Plateau are well sampled throughout the year.

Spawning fish of both sexes were recorded in all months (Figures 3 and 4). However, some clear areal and temporal trends are apparent as follows.

**WCSI:** Spawning females are recorded off the northwest coast of the South Island from July to September. Spawning males are common only in August (but this is the only month providing abundant WCSI trawl survey data; no male *obs\_lfs* or *logbook* data are available from this area). The start of the spawning season in July is well defined (there is abundant *obs\_lfs* data from June), but the season could extend after September, as few data are available from any source beyond the end of that month.

**Cook Strait:** Spawning males and females are relatively abundant from June to September. Additional data from onshore processing shed sampling also indicates that ling in Cook Strait are spawning from June to September (unpublished data from the *market* database). Few data are available from this area in other months, so the spawning season could start earlier and extend later than is proposed here.

**Chatham Rise:** Spawning females are abundant from July to November. The available data indicate that spawning could start and finish about a month earlier on the eastern Rise than it does on the western Rise. Running ripe males are also abundant on the Chatham Rise from July, but in contrast to the females, they are also recorded in December and January from trawl surveys. The apparent spawning of males in these last two months could be a result of residual milt still being present, and extruding, after the main spawning season has concluded. There are two apparent areas of relatively intensive spawning; one to the west of the Chatham Islands, and the other to the east of Mernoo Bank. Target longlining for ling can occur in all months across the entire Rise (Horn 2001), so the gap between the two spawning areas is not likely to be an artefact of fishing activity. The proposed spawning season for the Chatham Rise is from July to November.

**Puysegur Bank and Solander Corridor:** Spawning females are abundant from October to December (but are also present in August and September), and males are abundant from October to December. A September–December spawning season is proposed.

**Campbell Plateau:** There is an indication that spawning can occur over much of the Campbell Plateau from October to December. Spawning fish on the main Campbell Plateau are sparse, but spawning fish of both sexes have been consistently encountered in the trough between the Stewart-Snares shelf and Auckland Islands during the December trawl survey series. An October–December spawning season is proposed, and spawning is clearly more concentrated near the margins of the Stewart-Snares shelf rather than on the Campbell Plateau itself.

**Bounty Plateau:** Spawning males and females are abundant from October to February. Spawning females are also relatively abundant in September. A September–February spawning season is proposed.

**East Coast North Island:** Spawning females (but no spawning males) were recorded south of Cape Kidnappers on a longline trip in May.

Additional published information reports a pre-spawning aggregation of ling just north of North Cape at the beginning of October (Roberts 1987). No running-ripe fish were recorded, but some of the females had large ovaries containing more than 50% hyaline eggs. There are also anecdotal reports of running-ripe female ling being captured during commercial line fishing in the Bay of Plenty. The target line fisheries for ling off the north and east coasts of

North Island produce peak landings from July to October (Horn 2001), and peak CPUE in August–September (Horn in press). In other ling longline fisheries, landings and catch rate peaks coincide with the spawning seasons proposed above, so this could also be the case for the North Island fisheries.

Spawning season data are summarised in Table 1.

**Table 1: Estimated spawning seasons, by area, for ling. Question marks denote uncertainty in either the start or end month of the season.**

Area	Spawning season	
	Start	End
Northland	July?	October?
Bay of Plenty	July?	October?
Northern Wairarapa coast	May?	October?
West coast South Island	July	September?
Cook Strait	June?	September?
Chatham Rise	July	November
Puysegur/Solander	September	December
Campbell Plateau	October	December
Bounty Plateau	September	February

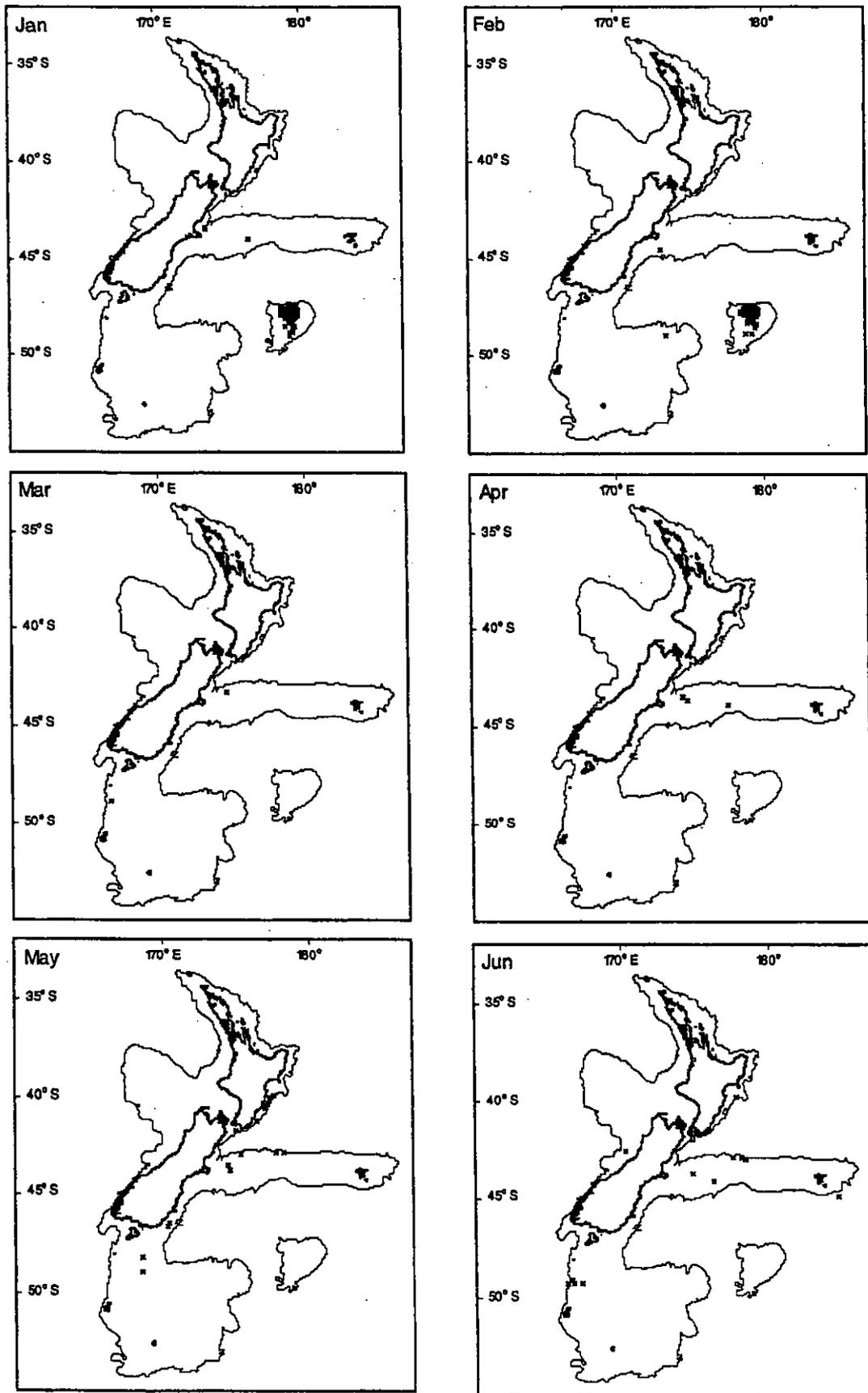


Figure 3: Positions (x) of trawl tows or longline sets capturing at least one running ripe female ling, by month. The 1000 m isobath is also shown.

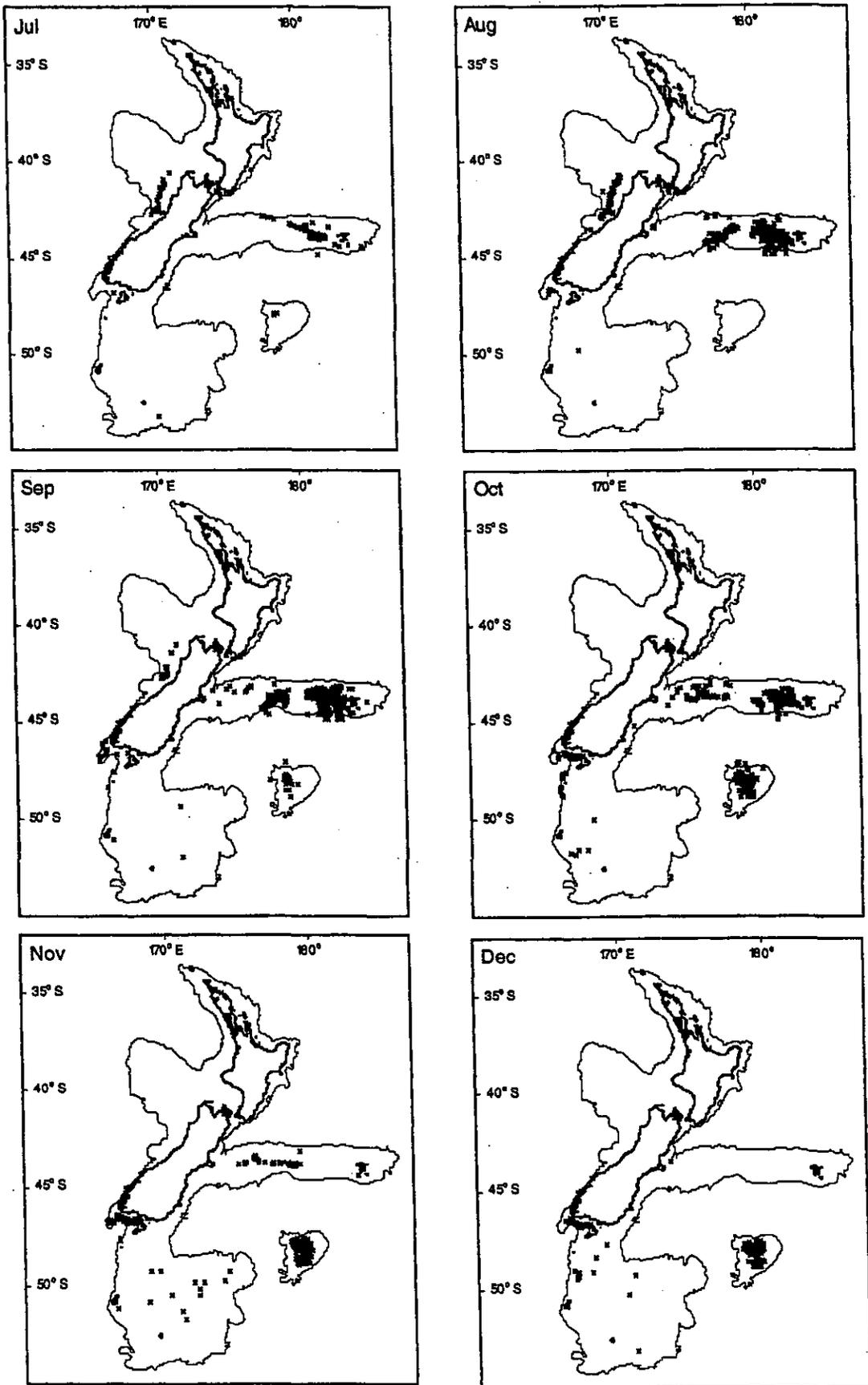


Figure 3 continued.

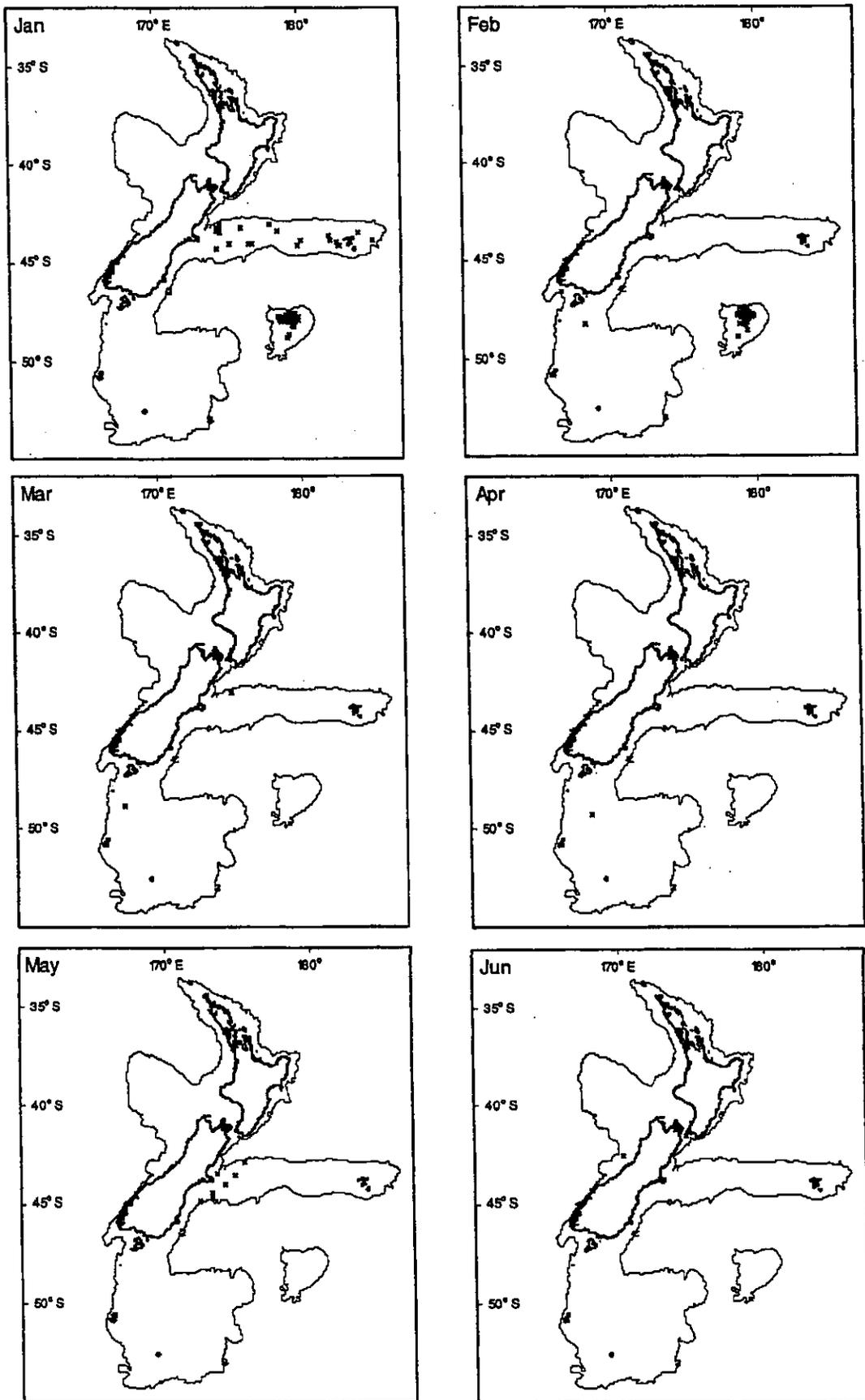


Figure 4: Positions (x) of trawl tows or longline sets capturing at least one running ripe male ling, by month. The 1000 m isobath is also shown.

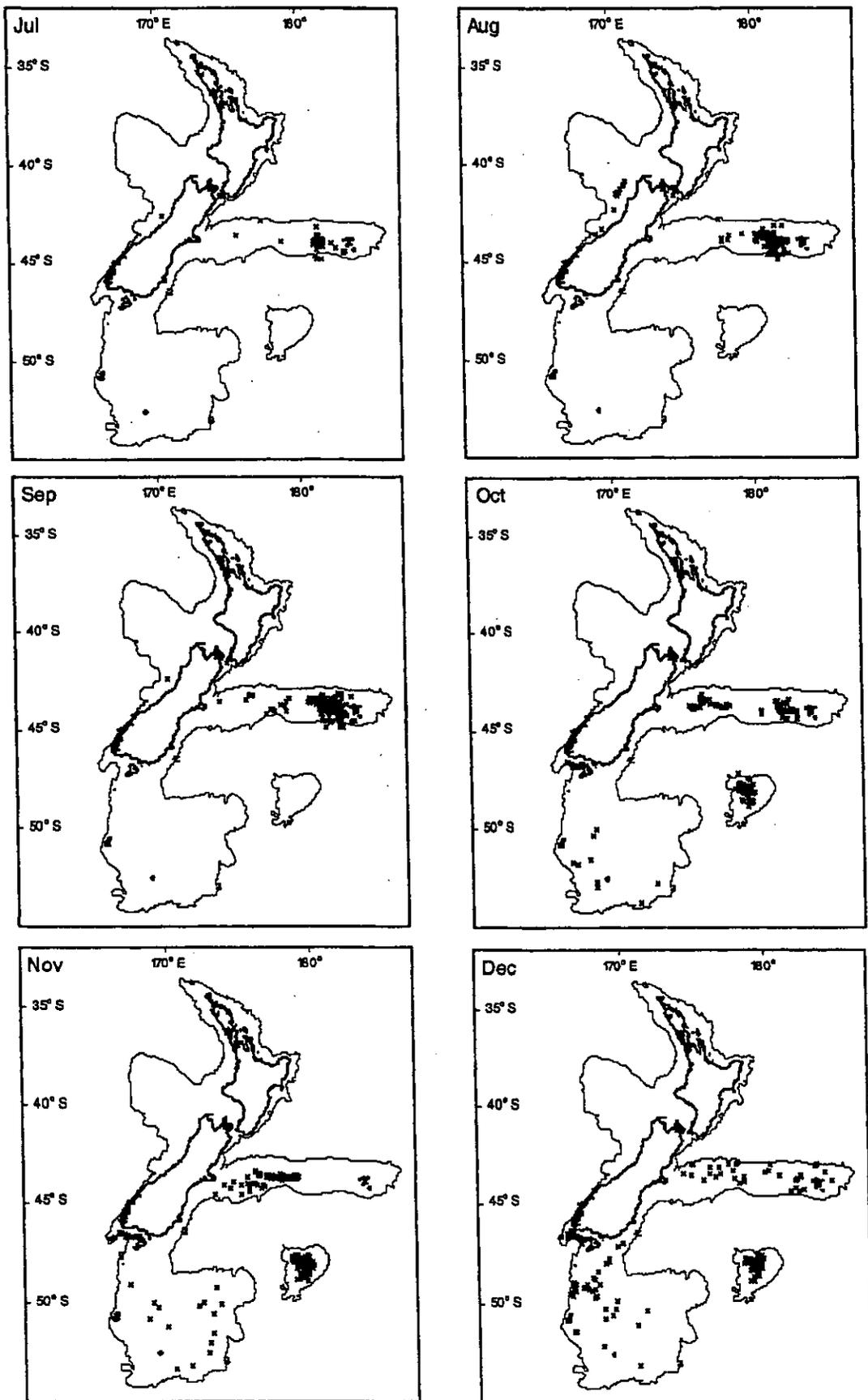


Figure 4 continued.

### 3.1.2 Maturity ogives

Size-based and (where possible) age-based maturity ogives were estimated for ling from various areas. Initial analyses split the Chatham Rise into eastern and western sectors (at longitude 180°), and the Campbell area into Puysegur (including the Solander Corridor) and the Campbell Plateau (including the southeastern Stewart-Snares shelf). Data to determine the ogives were derived from three sources: the research survey *trawl* database, the scientific observer *obs\_lfs* database, and the catch sampling *market* database. The *obs\_lfs* database contains gonad stage data for females only, and the *market* database contains gonad stage data for male and female ling from four years of catch sampling in Cook Strait. Length, sex, and maturity stage of ling were extracted from all the databases, and, where available, age and gonadosomatic index (GSI, gonad weight divided by body weight) were obtained from the research databases.

Five stages of development are recognised in the *obs\_lfs* and *market* databases, and seven stages in the research *trawl* database (Table 2). Stages 1 and 2 (immature and resting) in *trawl* are combined in *obs\_lfs* and *market* stage 1, and stages 5 and 6 (running ripe and partly spent) are combined as *obs\_lfs* and *market* stage 4. Consequently, in *obs\_lfs* and *market*, stage 1 includes all immature and some previously mature (but resting) fish.

Table 2: Descriptions of gonad stages used for ling gonads (male and female) in the *obs\_lfs*, *market*, and *trawl* databases.

<i>obs_lfs</i> and <i>market</i>		<i>trawl</i>	
Stage	Description	Stage	Description
1.	Immature or resting	1.	Immature
2.	Maturing	2.	Resting
3.	Ripe	3.	Maturing
4.	Running ripe	4.	Ripe
5.	Spent	5.	Running ripe
		6.	Partially spent
		7.	Spent

Maturity was initially classified in the following ways.

#### 1. *obs\_lfs* and *market* data

Stage 1 fish were classified as immature, and stages 2–5 fish were classified as mature. Extracted data were from the spawning season in a particular area only, with seasons defined as in Table 1 (e.g., for WCSI ling, only data from June to September were analysed).

#### 2. *trawl* data, exclude stage 2

Stage 2 fish in the *trawl* database include large individuals resting but capable of spawning, and small fish that have yet to spawn. Stage 2 fish constitute a high proportion of the sample, and classifying all of them as mature or all as immature markedly alters the ogive (Dunn et al. in press). So stage 2 fish from *trawl* surveys were ignored. Stage 1 fish were defined as immature, and stages 3–7 were defined as mature.

#### 3. *trawl* data, GSI method

This method attempts to use some of the information from the many fish classified as stage 2. Stage 1 fish were classified as immature, and stages 3–7 were classified as mature. Stage 2 fish (resting or approaching first maturity) were classified as immature or mature

depending on the GSI index. GSIs for individual fish were rounded to three decimal places, binned, and summarised as frequency plots, by maturity stage and sex, for three seasons in two areas (Figure 5). Sufficient data were available only from the Chatham and Campbell areas. There are large overlaps between gonad stages in the GSI range, but, in general, mean GSI increases with increasing gonad stage. It is also apparent that GSIs tend to be higher on the Campbell Plateau than on the Chatham Rise; it is not possible to determine whether this is a true between-area biological effect, or a function of sampling different parts of the spawning cycle in the two areas. On each of the plots in Figure 5, a visual search identified a GSI cut-off that excluded most of the stage 1 fish and included most of the stage 3 fish. For the Chatham Rise, that was between the 0.001 and 0.002 bins for males, and between the 0.005 and 0.006 bins for females. For the Campbell Plateau, they were between the 0.002 and 0.003 bins for males, and between the 0.007 and 0.008 bins for females. It was considered desirable to use a single GSI, by sex, for ling from all areas. Consequently, male stage 2 fish were classified as immature if their GSI was 0.0025 or lower, and female stage 2 fish were classified as immature if their GSI was 0.0075 or lower. All other stage 2 fish were classified as mature.

Data from all months were extracted from the *trawl* database. However, much of the available information was from outside the defined spawning seasons (e.g., virtually all the Chatham Rise data derived from the post-spawning months of December to February). Consequently, data were classified as deriving from the spawning, pre-spawning, or post-spawning season. For each of the sets of data described above, the number of mature ling as a percentage of the total number of ling was calculated for each length or age class for both males and females (Figures 6 and 7). For sets with abundant data, the calculated percentages are presented as jagged line plots using all lengths for which there were at least three data points. Some sets contained few data, generally with fewer than three data points per length, but were considered useful; they are presented as sets of crosses (x). The plots of percentage maturity (Figures 6 and 7) provide a rather confusing and unexpected picture.

First, there can be marked differences in ogives derived using the 'exclude stage 2' and 'gsi' methods. Ogives tend to be lower using the 'gsi' method, particularly so for Chatham Rise females (Figure 6a), but this trend is apparent in all comparisons except for Campbell Plateau females (Figures 6a and 7a). In the discussion above of the GSI 'cutoff' between mature and immature fish, it was noted that GSIs tend to be higher on the Campbell Plateau than the Chatham Rise. Because of the relatively large number of stage 2 fish in the *trawl* samples, the selection of GSI cutoff can markedly influence the ogive position. Consequently, it was concluded that the 'gsi' ogives are probably less reliable than the 'exclude stage 2' ogives, as the latter are based solely on a macroscopic examination of the gonads, while the difference in GSIs between pre-mature and post-mature fish could vary between seasons and/or grounds.

Second, there can be marked differences in the maturity ogives derived from *obs\_lfs* and *trawl* data collected in the same part of the reproductive cycle (e.g., WCSI females, Figure 6b). Fish classified as 'mature' in the *trawl* and *obs\_lfs* databases are identical (see Table 2). However, 'immature' in *obs\_lfs* comprise truly immature fish plus some resting fish that have previously spawned, while 'immature' in *trawl* includes only truly immature fish because the stage 2 category has separately classified all the resting fish. Consequently, if the same sample of fish was staged by both the *obs\_lfs* and *trawl* methods, the resulting *trawl* ogive would be above the *obs\_lfs* ogive because the total number of fish at any length class will tend to be higher in the *obs\_lfs* sample (because resting fish have not been excluded), while the number of mature fish will be the same under both methods. This explains the differences between ogives derived in the same area and season from *trawl* and *obs\_lfs* data (Figure 6a). Logically, the ogives derived from *trawl* data are likely to be more accurate because they are use only truly immature and truly mature fish.

Third, there are differences in ogives derived from *trawl* data in different parts of the reproductive cycle in the Campbell–Puysegur area (e.g., Puysegur males, Figure 7a). If there were to be between-season differences in the *trawl* data, it would be expected that spawning season ogives would tend to be higher and further to the left than pre- or post-season ogives, because the greatest proportion of mature fish should be present in the spawning season. Puysegur male and female ogives behave in this way, but Campbell female ogives (and, to a much lesser extent, Campbell male ogives) behave in a contrary manner (Figures 6a and 7a). Such a pattern of ogive trends would occur if the Campbell–Puysegur region holds a single stock of ling, and the fish are dispersed in the non-spawning season but congregated in the main spawning grounds (i.e., Puysegur) during the spawning season. During the spawning season, most of the fish in Puysegur would be mature (even many of the smaller ones), and many of the fish in Campbell would be immature or resting (even many of the large ones). Consequently, it is concluded that the best ogives for the Campbell–Puysegur region will be derived by combining trawl survey data from the two areas and seasons.

In summary, final ogives of proportion mature by length were derived using only data from *trawl* and excluding all fish classified as stage 2 (Figure 8). Data from the Campbell Plateau and Puysegur areas in both the spawning and pre-spawning season were combined for the reasons described above. Data from the eastern and western Chatham Rise were also combined because there were no apparent areal differences in the male ogives (Figure 7a), and very few data on mature female fish from the eastern Rise (Figure 6a). Sufficient *trawl* data from WCSI were available to fit reasonably reliable ogives. Ogives for ling from the Bounty Plateau, Cook Strait, and northern North Island can only be roughly estimated from the few available data shown in Figures 6b and 7b.

Ogives were fitted using the logistic model

$$P(x) = 1/(1 + \exp(-\log_e(19)*(x-\mu)/(2*sd)))$$

where  $x$  is length (or age),  $\mu$  is the length (or age) at which 50% of fish are mature, and  $\mu+(2*sd)$  is the length (or age) at which 95% of fish are mature. Bootstrapped 95% confidence intervals for  $\mu$  and  $sd$  were calculated from 1000 simulations.

There are significant differences between the lengths at 50% maturity ( $L_{50}$ ) for males from the Campbell Plateau, Chatham Rise, and WCSI (Table 3). The curves fit the raw male data well, but fits to the raw female data are less convincing (see Figure 8) resulting in wider confidence bounds around both the  $\mu$  and  $sd$  parameters. The curve fitted to the Campbell female data is clearly biased by the relatively large number of fish longer than about 90 cm that have been classified as being stage 1. The 'true' ogive should probably be steeper and have an  $L_{50}$  of about 82 cm. There is a significant difference between the  $L_{50}$  values for female ling from the Chatham Rise and WCSI (Table 3).

Ogives of proportion mature by age could be derived only for the Chatham Rise and Campbell Plateau areas, as these were the only areas where aged and staged fish from trawl surveys were available (Figure 9). As in the length-at-maturity analyses, all fish classified as stage 2 were excluded. The curves for both sexes and areas fit the raw data well. There are significant differences between the ages at 50% maturity ( $A_{50}$ ) for both sexes from the Campbell Plateau and Chatham Rise (Table 3).

Based on the maturity ogives, there are distinct differences between ling populations from the Campbell Plateau, Chatham Rise, and WCSI. The sparse information available indicates that northern North Island ling have a higher  $L_{50}$  value than the three main southern populations.

**Table 3: Parameters of the logistic model fitted to the proportions mature at length (cm) and age (years), by sex and area, for the Campbell Plateau, Chatham Rise, and WCSI. Bootstrapped 95% confidence intervals are in parentheses. Likely bounds for the length at which 50% of fish are mature (i.e.,  $\mu$ ) derived by eye from Figures 6b and 7b are listed for the Bounty Plateau, Cook Strait, and the northern North Island.**

Sex	Ogive	Area	$\mu$ (cm)		sd	
Male	By length	Campbell	67.90	(67.51–68.26)	5.44	(5.16–5.72)
		Chatham	72.05	(71.58–72.58)	8.26	(7.87–8.66)
		WCSI	70.36	(68.46–71.94)	5.39	(4.33–6.39)
		Bounty	70–85			
		Cook Strait	65–85			
		North Island	85–100			
Female	By length	Campbell	86.15	(85.46–86.87)	11.83	(11.08–12.63)
		Chatham	96.55	(94.91–98.45)	9.19	(8.06–10.26)
		WCSI	87.36	(84.48–90.03)	8.95	(6.89–10.78)
		Bounty	70–90			
		Cook Strait	75–95			
		North Island	90–110			
Sex	Ogive	Area	$\mu$ (years)		sd	
Male	By age	Campbell	6.69	(6.56–6.83)	1.04	(0.91–1.15)
		Chatham	8.07	(7.91–8.25)	1.67	(1.52–1.81)
Female	By age	Campbell	8.85	(8.61–9.11)	1.01	(0.81–1.18)
		Chatham	11.91	(11.38–12.38)	1.71	(1.41–1.97)

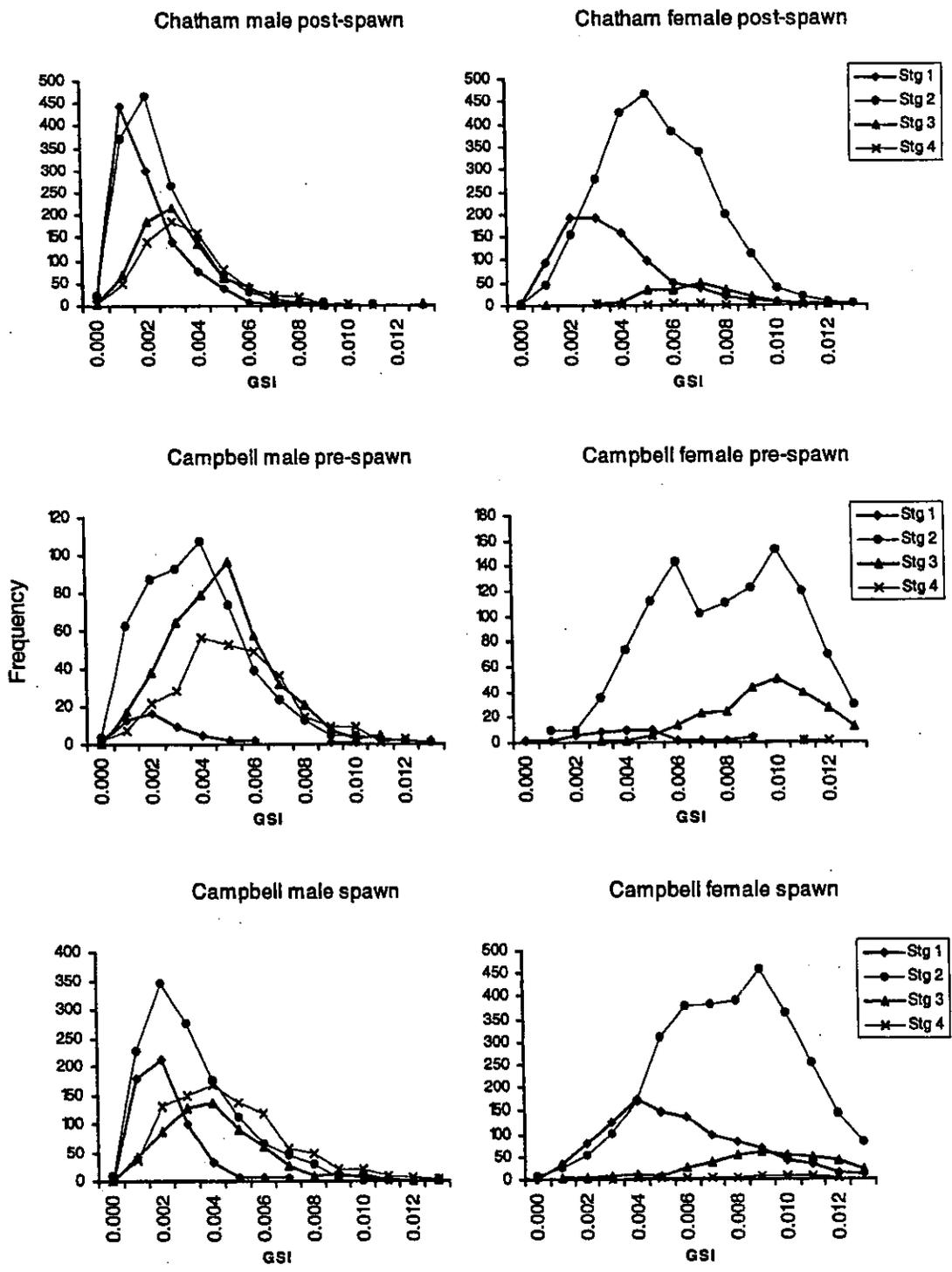


Figure 5: Frequency plots of GSIs by gonad stage, from the *trawl* database. Data are available from the Chatham Rise in the post-spawning season (December-February), and from the Campbell and Puysegur area in the pre-spawning (February-August) and spawning (September-December) seasons.

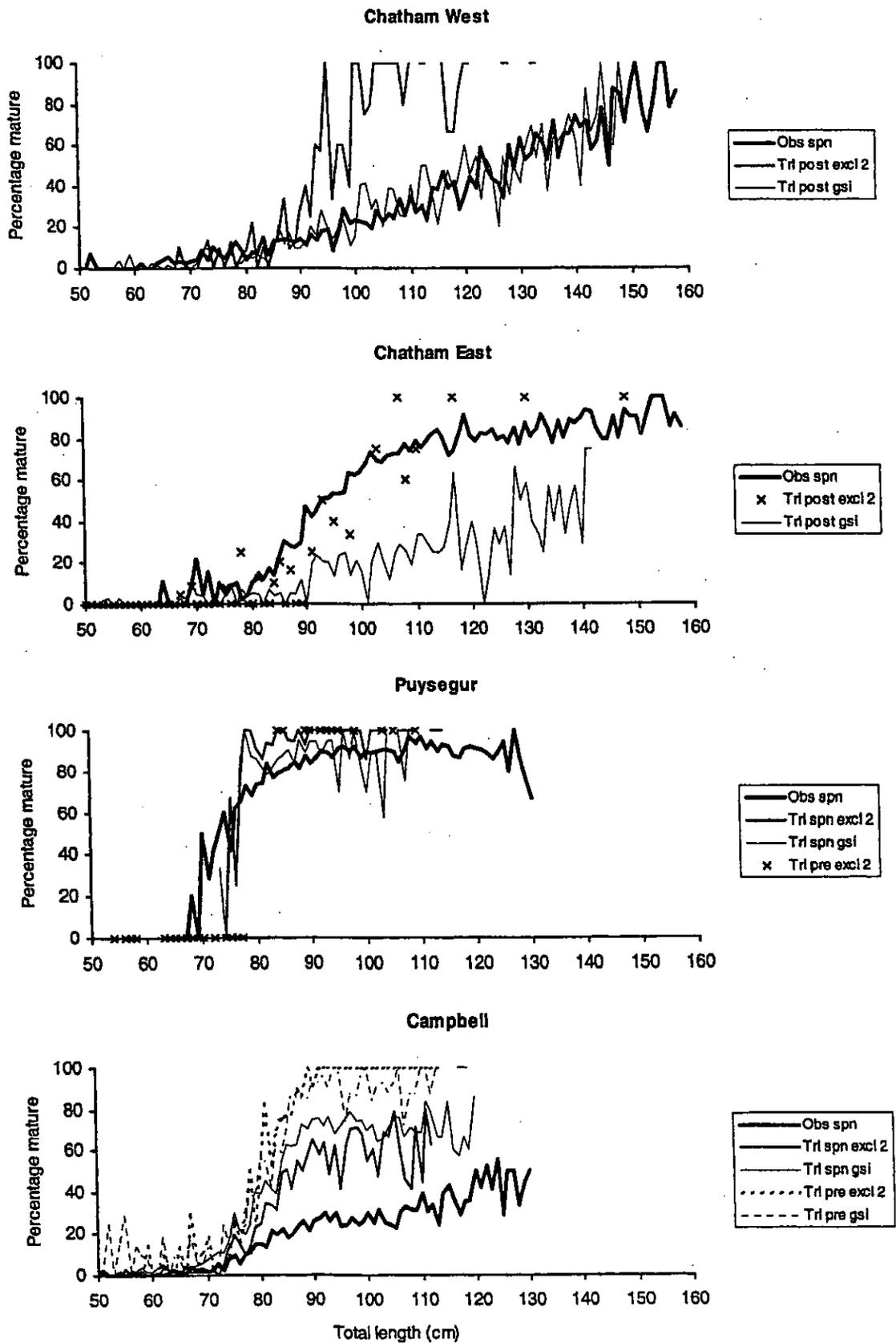


Figure 6a: Maturity-at-length data for female ling, by area. Obs, *obs\_lfs* database; Trl, *trawl* database; spn, spawning season; post, post-spawning season; pre, pre-spawning season; excl 2, excluding all stage 2 data; gsi, including stage 2 fish based on GSL.

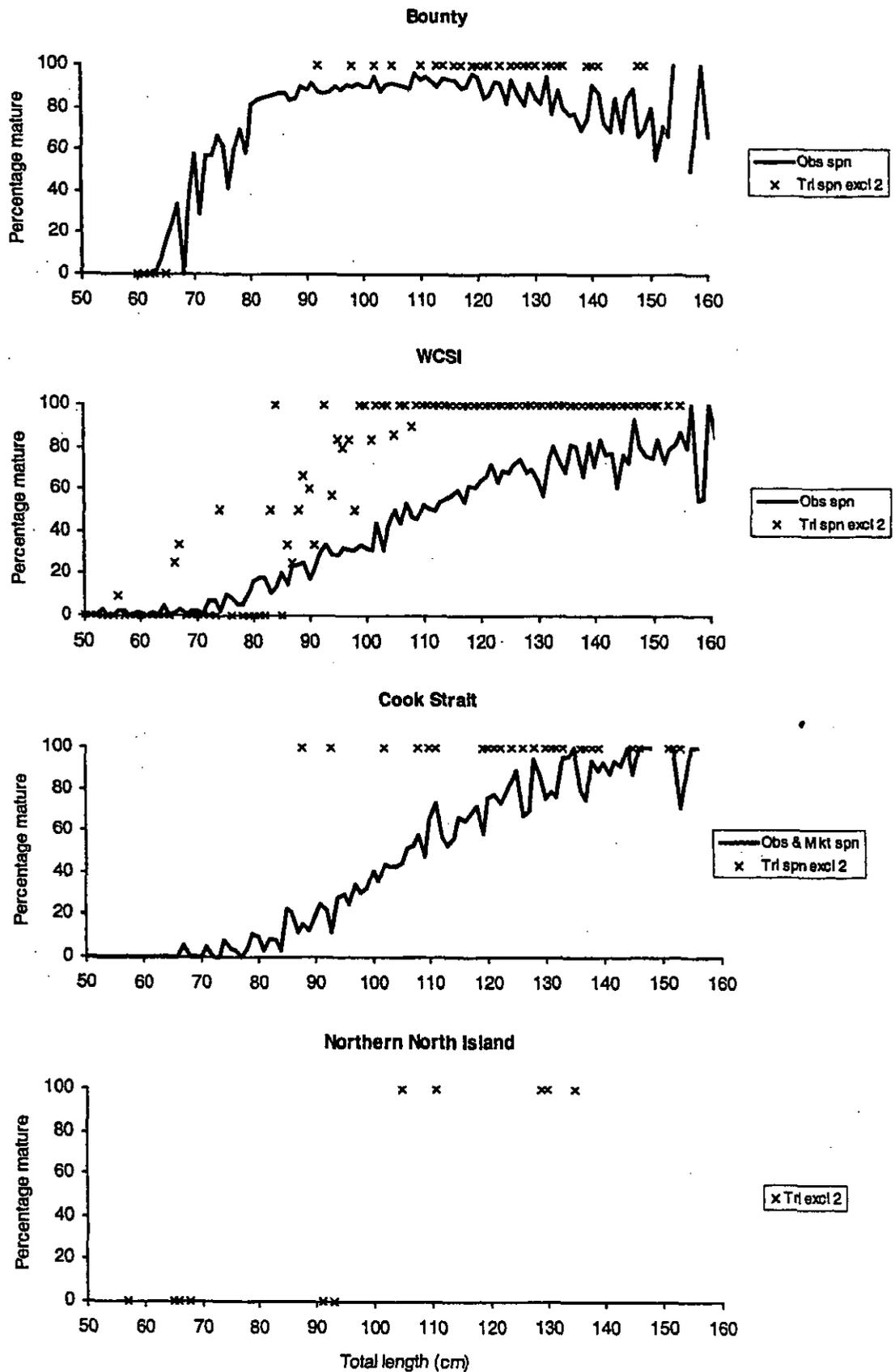


Figure 6b: Maturity-at-length data for female ling, by area. Obs, *obs\_lfs* database; Trl, *trawl* database; Mkt, *market* database; spn, spawning season; excl 2, excluding all stage 2 data.

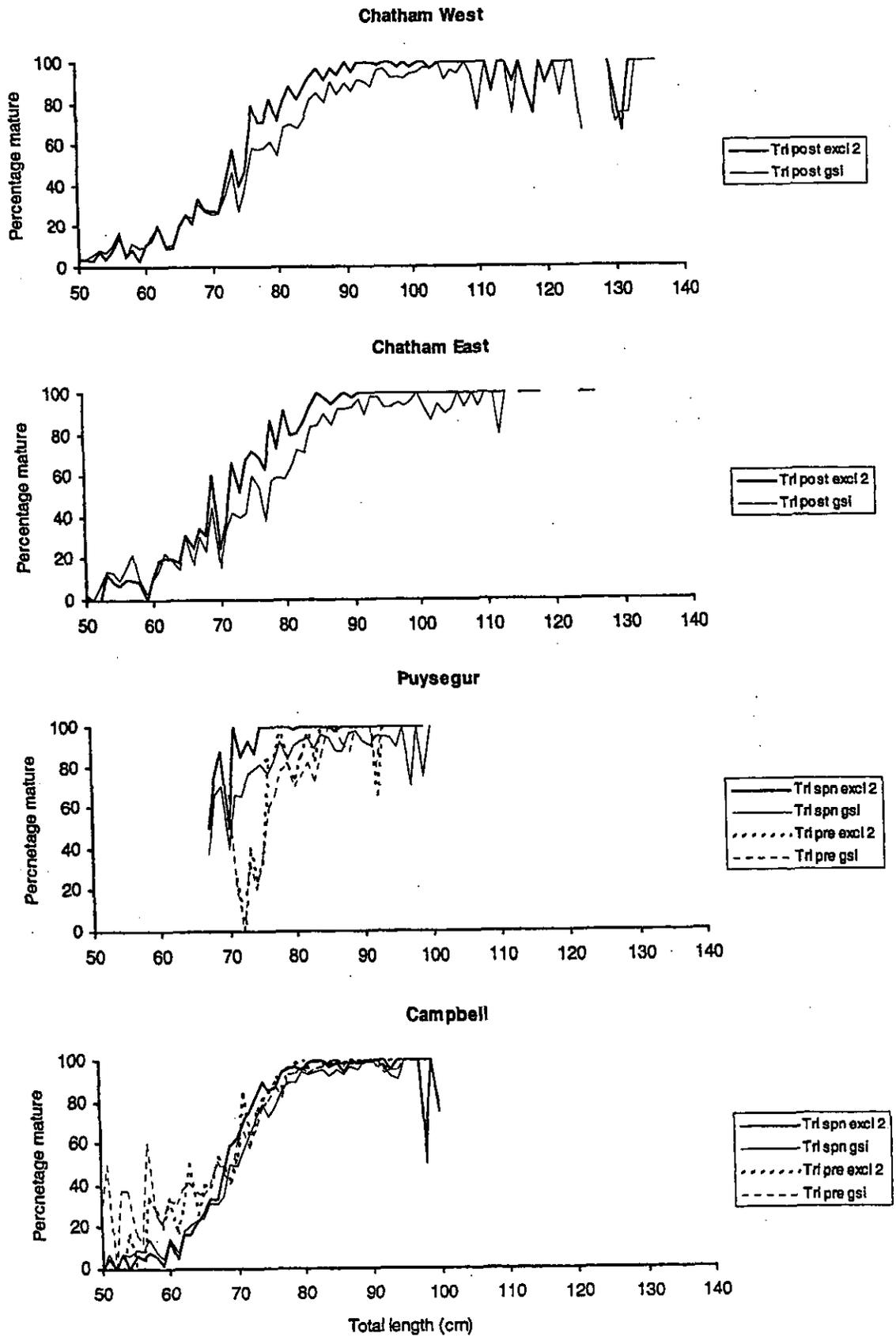


Figure 7a: Maturity-at-length data for male ling, by area. Trl, trawl database; spn, spawning season; post, post-spawning season; pre, pre-spawning season; excl 2, excluding all stage 2 data; gsi, including stage 2 fish based on GSI.

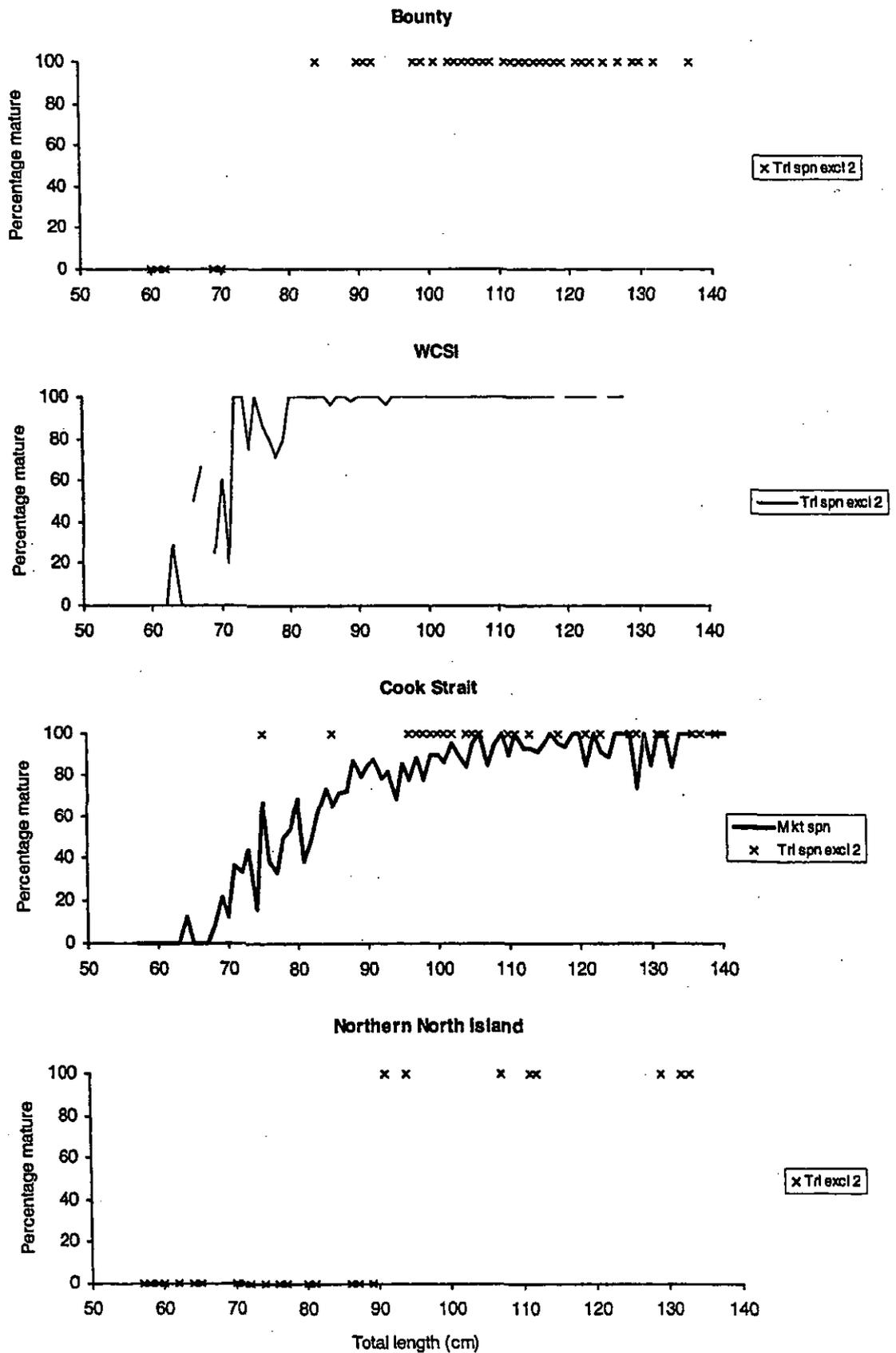


Figure 7b: Maturity-at-length data for male ling, by area. Trl, trawl database; Mkt, market database; spn, spawning season; excl 2, excluding all stage 2 data.

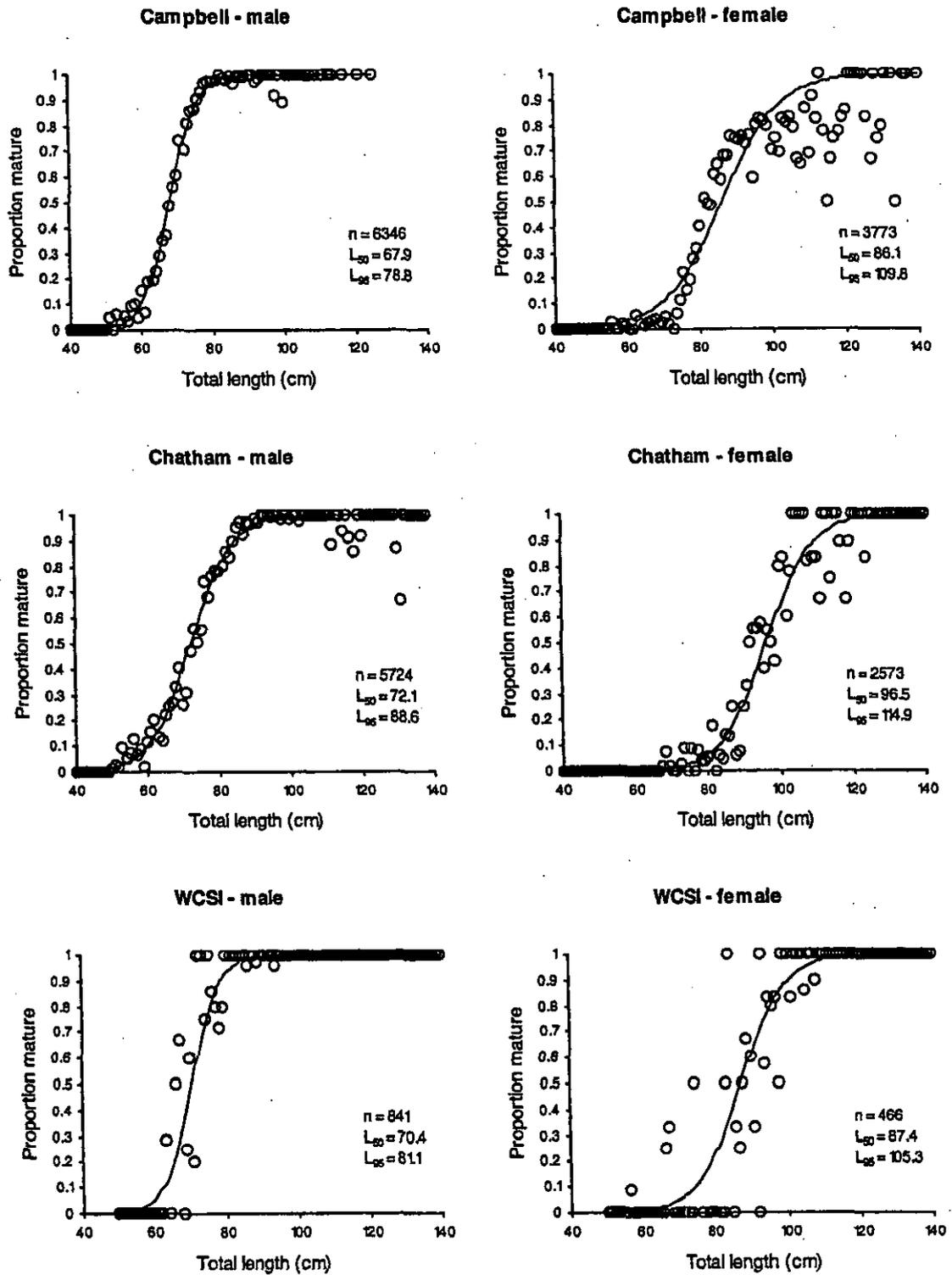


Figure 8: Logistic ogives fitted to proportion mature-at-length data for ling, by sex, sampled in trawl surveys of the Campbell Plateau, Chatham Rise, and WCSI. n, number of observations;  $L_x$ , length at which x proportion of fish are mature.

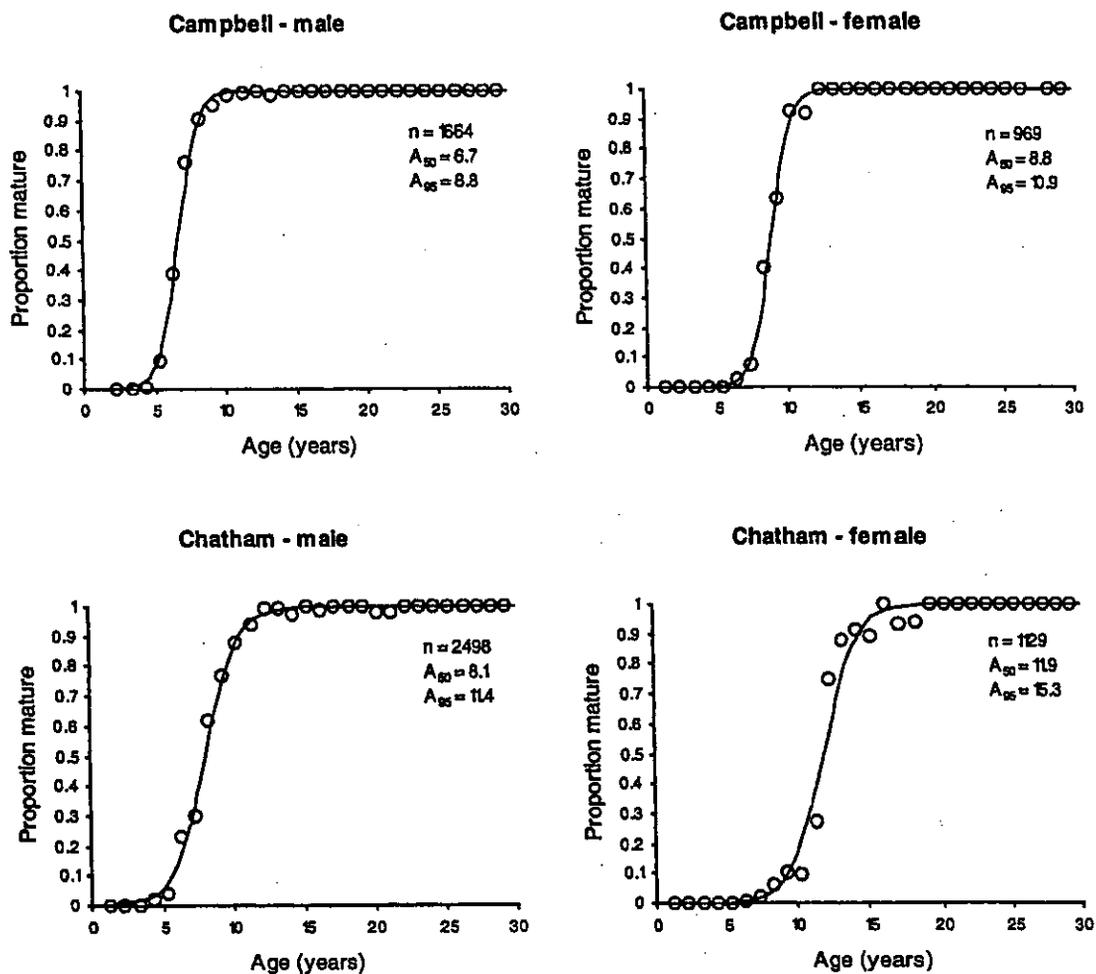


Figure 9: Logistic ogives fitted to proportion mature-at-age data for ling, by sex, sampled in trawl surveys of the Campbell Plateau and Chatham Rise.  $n$ , number of observations;  $A_x$ , age at which  $x$  proportion of fish are mature.

### 3.2 Age and growth

Two aspects of the age and growth of ling are examined below: a comparison of growth parameters between areas, and a comparison of maximum ages between areas.

#### 3.2.1 Comparison of growth parameters

Large quantities of age-length data are available for ling from around the South Island. The data were grouped by sex and area, with the areas being Chatham Rise, Bounty Plateau, Campbell Plateau (including Puysegur Bank), WCSI, and Cook Strait. Pairwise comparisons of the data sets were then conducted using age-standardised randomisation tests (A. Dunn, NIWA, pers. comm.). Von Bertalanffy curves were fitted to the two compared sets separately, and to the combined data, using the maximum likelihood method of Kimura (1980). The randomisation test determines whether the residual sum of squares (RSS) of the separate models is significantly less than the RSS of the combined model. If it is, then a significant between-area difference in the growth curves is indicated. For all pairwise comparisons, data from each area were trimmed to ensure that each data set had a minimum of five (but usually many more) points in each age class. Only within-sex comparisons were made; Horn (1993) showed that growth rates differed significantly between sexes.

Results of the pairwise randomisation tests are listed in Table 4, and the fitted curves are presented in Figure 10. All comparisons were highly significant, indicating significant differences in the growth characteristics of ling from all five areas tested. There is a clear differentiation between areas in the fitted growth curves for male ling (Figure 10). The visual differentiation of the fitted female growth curves is less clear. As for the males, growth is fastest in Cook Strait and off WCSI, and slowest on Campbell Plateau. However, the curves for Chatham Rise and Bounty Plateau females are quite similar, and, in contrast to males, Chatham females over 20 years old are, on average, longer than Bounty females of the same age. So although all within-sex comparisons are significantly different, there are some slight areal differences in the trends between sexes.

**Table 4: Results of randomisation tests between same-sex age-length data from paired areas. *n*, number of age-length data points by area and sex.**

	Area	<i>n</i>	Male				
			Chatham	Campbell	Bounty	WCSI	Cook Str
			5203	4374	451	2887	1080
Female	Chatham	5377	-	$P=0$	$P=0$	$P=0$	$P=0$
	Campbell	6315	$P=0$	-	$P=0$	$P=0$	$P=0$
	Bounty	651	$P=0$	$P=0$	-	$P=0$	$P=0$
	WCSI	2892	$P=0$	$P=0$	$P=0$	-	$P=0$
	Cook Strait	1087	$P=0$	$P=0$	$P=0$	$P=0$	-

It was surprising that all the paired tests were so highly significant, e.g., the Chatham-Bounty female comparison had a probability of zero of similar growth despite the apparent visual similarity of the fitted curves. It was considered likely that the large sample sizes enabled the powerful test results. To test this hypothesis, the Chatham and Bounty female data sets were reduced in size by randomly removing 75% of the points from each. The comparison was then re-run, and this time the randomisation test indicated no significant difference between the areas ( $p = 0.108$ ).

Four additional comparisons were conducted. Age-length data from the Puysegur Bank and Solander Corridor section of the Campbell sample were compared with the remainder of the

Campbell Plateau data, because it was known that most of the Puysegur data were from spawning fish, and most of the Campbell Plateau data were not (Figure 11A). The within-sex comparisons were both highly significantly different (randomisation test,  $p = 0$  for both tests). Also, age-length data from the Chatham Rise obtained from the longline fishery were compared with data from Chatham fish caught by trawl (commercial, and research survey) to test for differences between fishing methods (Figure 11B). Randomisation tests indicated highly significant differences ( $p = 0.003$  for females,  $p = 0$  for males).

The Campbell vs Puysegur comparison (Figure 11A) indicated that, on average, younger fish were likely to be 3–4 cm longer, and older fish likely to be 2–3 cm longer, at Puysegur Bank relative to the Campbell Plateau. Because many of the Puysegur samples were taken during the spawning season (i.e., from the target longline fishery and the summer research survey series), some of the difference is possibly because larger fish in the younger age classes are more likely to be mature (and, hence, spawning) than smaller fish of the same age class. Also, Puysegur is close to the west coast South Island, and any ling that migrate from the west coast would tend to inflate the mean length-at-age of fish occurring at Puysegur. Hence, the Puysegur curves could be higher than the Campbell curves (particularly at the young ages) even if the fish from both areas constitute a single population.

In contrast, the Chatham curves (Figure 11B) are similar between methods at the younger ages (under 15 years), but diverge with increasing age such that line-caught fish are, on average, 3–5 cm longer at age than trawl-caught fish. This is simply a function of the line fishery selectivity; larger fish, and proportionately more of them, are taken by the line fishery, compared to the trawl fishery. Hence, the Chatham longline curves would be expected to be higher than the trawl curves, particularly at the older ages.

Because it has been suggested that the Chatham Rise and Canterbury-Otago coast could be an area of stock mixing (Smith & Francis 1982, Colman 1995), age data from the Chatham Rise were analysed in more detail. Only data from the series of trawl surveys in January were used; this ensured a constant selectivity over all samples, and a sampling period unlikely to be influenced by any spawning aggregation behaviour. Data were divided into four groups (northeast, southeast, northwest, and southwest) by divisions at latitude  $43^{\circ} 30' S$  and longitude  $180^{\circ}$ . Results of the pairwise comparisons are listed in Table 5, and the fitted curves are shown in Figure 12. All but one of the comparisons (i.e., males, southeast vs southwest) indicated a significant difference in growth rates between areas. There were some consistent trends between sexes. Growth was fastest in the northern sectors, particularly the northwest, and slowest in the southwest. However, it is clear from a comparison of Figures 10 and 12 that the variation in growth between sectors on the Chatham Rise is still much less than the variation between the areas of the five postulated stocks. The implications that the between-sector variation in growth on the Chatham Rise has on the stock structure hypothesis is discussed in more detail below.

**Table 5: Results of randomisation tests between same-sex age-length data from paired areas on the Chatham Rise.  $n$ , number of age-length data points by area and sex.**

	Area	$n$	Male			
			Northeast	Southeast	Northwest	Southwest
			481	1136	917	1433
Female	Northeast	624	-	$P = 0$	$P = 0$	$P = 0$
	Southeast	850	$P = 0.003$	-	$P = 0$	$P = 0.422$
	Northwest	1185	$P = 0.030$	$P = 0$	-	$P = 0$
	Southwest	1258	$P = 0$	$P = 0.037$	$P = 0$	-

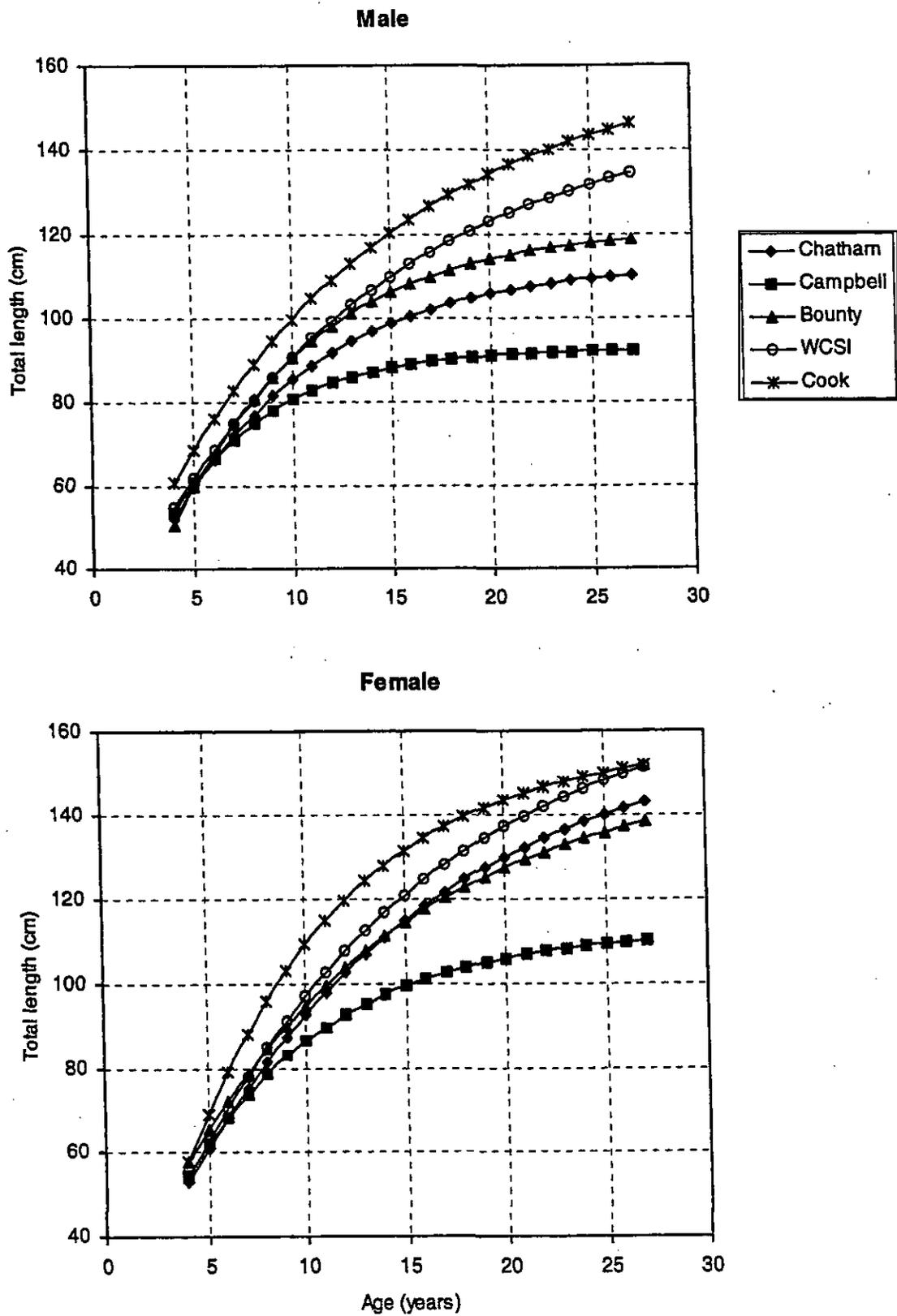


Figure 10: Von Bertalanffy curves fitted separately by sex to age-length data (age range 4–27 years) from five areas.

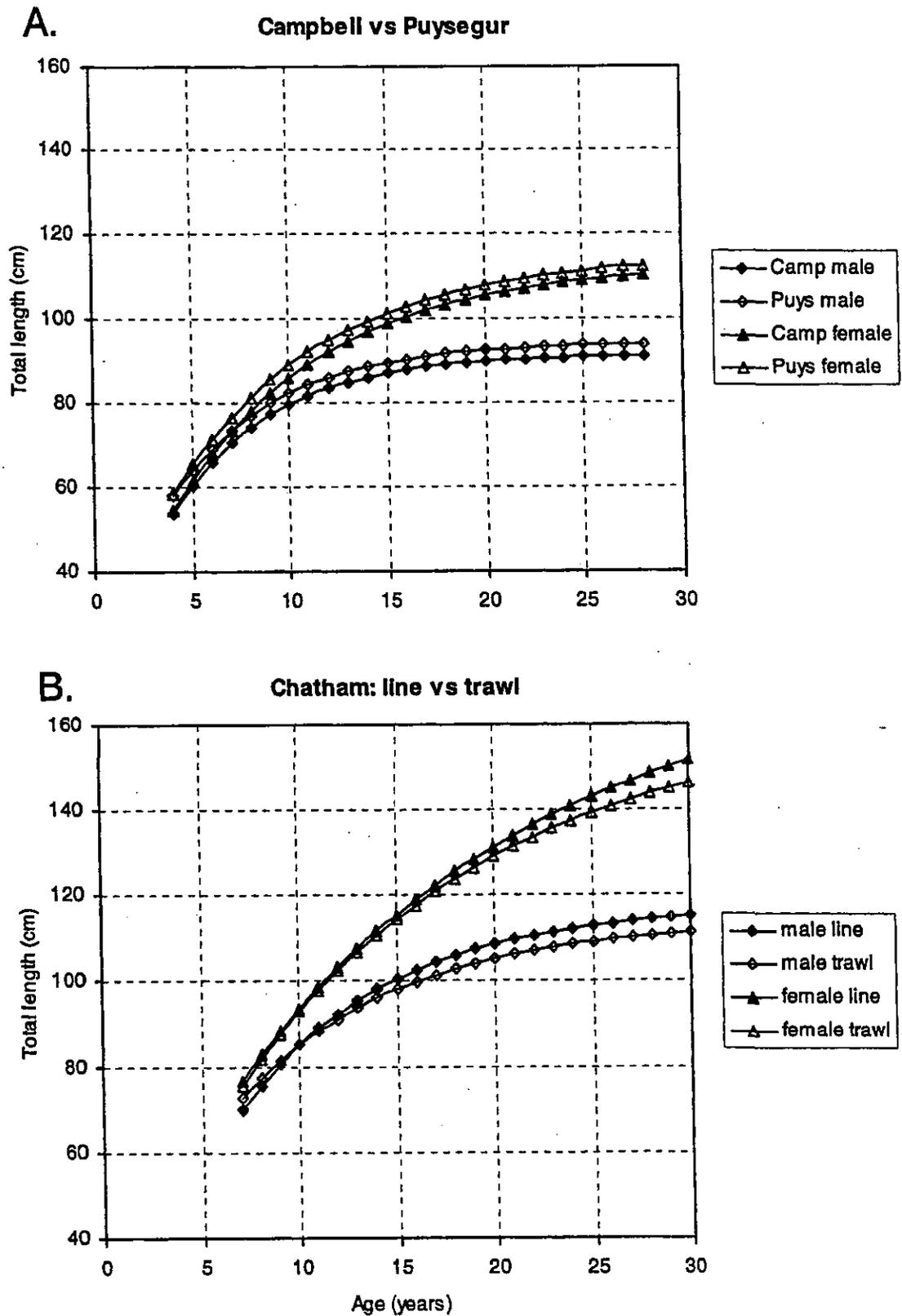
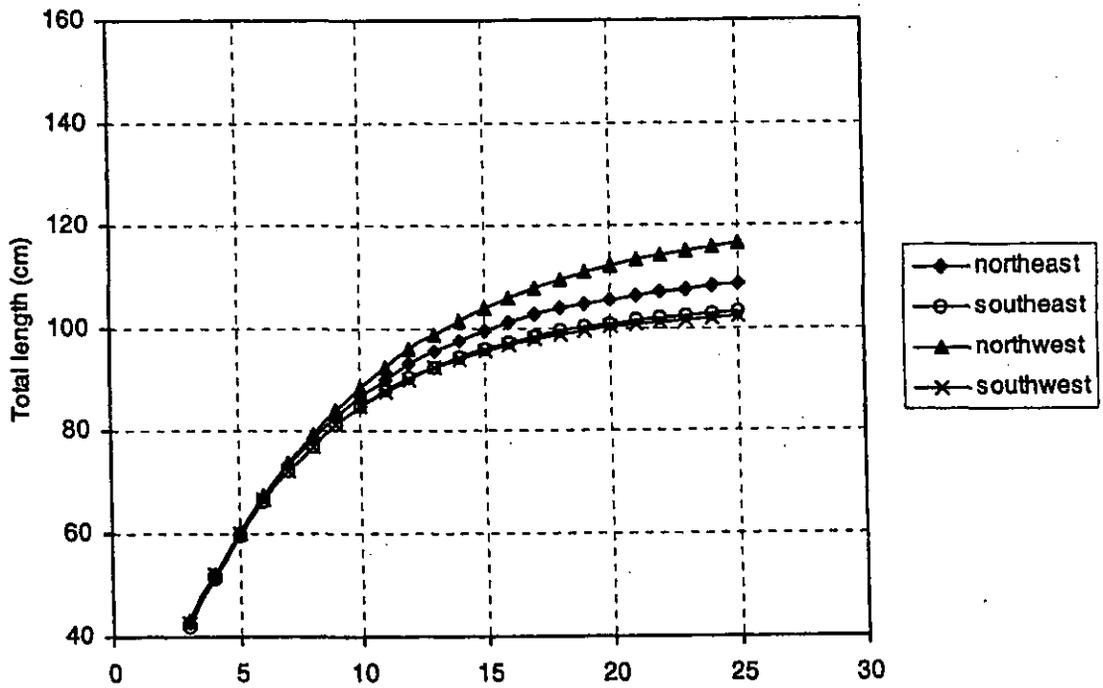


Figure 11: Von Bertalanffy curves fitted by sex to A.) age-length data from the Campbell Plateau and Puysegur Bank areas separately (age range 4–28 years), and to B.) age-length data from the Chatham Rise line-caught and trawl-caught catch separately (age range 7–30 years).

### Chatham survey: male



### Chatham survey: female

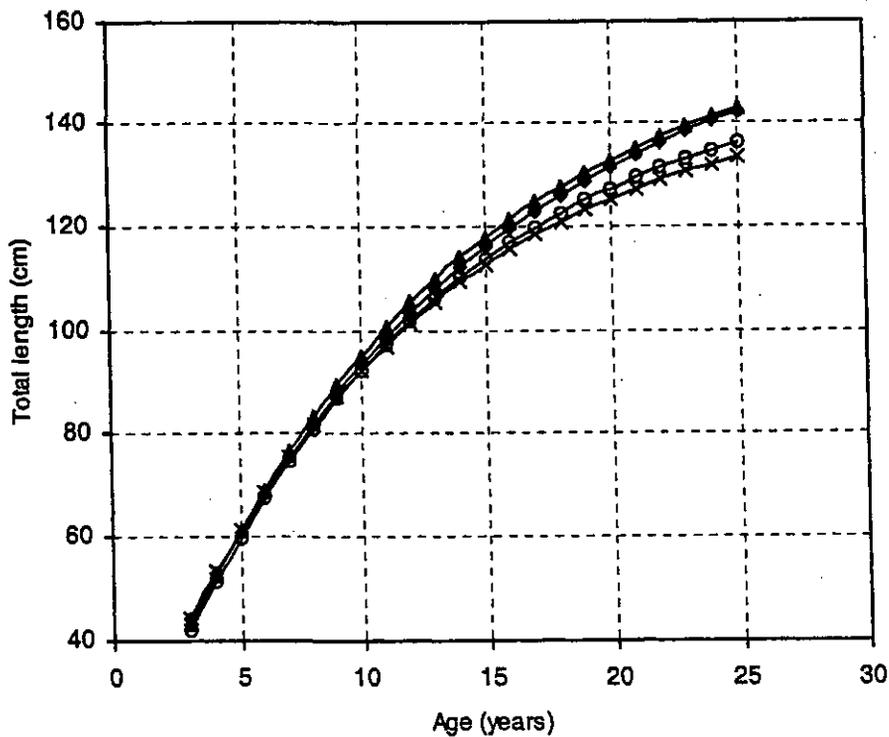


Figure 12: Von Bertalanffy curves fitted separately by sex to age-length data from the northeast, southeast, northwest, and southwest sectors of the Chatham Rise (age range 3–25 years). All data are derived from the series of January trawl surveys.

Clearly, the randomisation test is quite powerful, particularly with large sample sizes. The Chatham Rise fishing method comparison showed that differences in fishing selectivity can result in the indication of significantly different growth characteristics in what is probably a single population. If different fishing methods are used to exploit the same stock, but in different areas, growth data from the two fisheries could lead to an erroneous conclusion of two stocks being present. The Campbell area comparison indicated significant differences that are likely related to behaviour within a single stock, i.e., fish that move to the spawning grounds are, on average, larger at age than those that are yet to mature. The possibility that statistically significant differences in growth curves may not be indicative of stock differentiation has been demonstrated.

### 3.2.2 Maximum age

Maximum age is another character that can be used to describe stock dynamics, and, therefore, be used as a stock differentiation indicator. Maximum age by itself can be misleading; the oldest ling aged from the Chatham Rise (and, indeed, from any New Zealand sample) was 46 years old, with the second oldest fish from that area being 39 years. Hence, a minimum age reached by a defined percentile of the oldest fish is generally reported (Begg et al. 1999). The minimum age reached by the oldest 5% of fish in any sample is reported here. For any sample this 'maximum age' can be influenced by:

- the selectivity of the method used to obtain the sample, e.g., a longline fishery will catch fewer young fish than a trawl survey, generally resulting in a higher maximum age in the former sample,
- the exploitation level on the stock, i.e., a more heavily exploited stock may have fewer older fish than a lightly exploited stock,
- the levels of recruitment, i.e., strong recruitment tends to lower the maximum age, and
- whether or not the aged fish have been selected randomly from the catch.

Calculated catch-at-age distributions, which had been scaled to represent the population vulnerable to the trawl in the survey area, or the total catch from a particular commercial fishery, are already available. Consequently, maximum ages were determined for each catch-at-age distribution, by sex, and are presented, by fishing method, in Figure 13.

The maximum ages of the available samples add little to the interpretation of ling stock structure. Based on linear regressions to the available points there are clear trends of reductions in maximum age over time in the three trawl survey series (Chatham summer, Campbell summer, and Campbell autumn), but no apparent differences between the two areas (Figure 13). Similar age reductions over time are apparent in the Chatham, WCSI, and Cook Strait commercial trawl fisheries, but, in contrast, maximum age in the Campbell trawl fishery has remained quite flat for both sexes. Maximum ages in the Puysegur, Campbell, and Chatham longline fisheries have remained relatively constant at about 24 years for males and 22 years for females, but the time series for all these fisheries are short with no data before 1998. Only the Bounty longline fishery stands out as being different, with the maximum age for males being about 31 years.

In summary, maximum age appears to have declined over time in all the main fished areas. The only clear between-area distinction separates Bounty Plateau males from those on the Chatham Rise and Campbell Plateau.

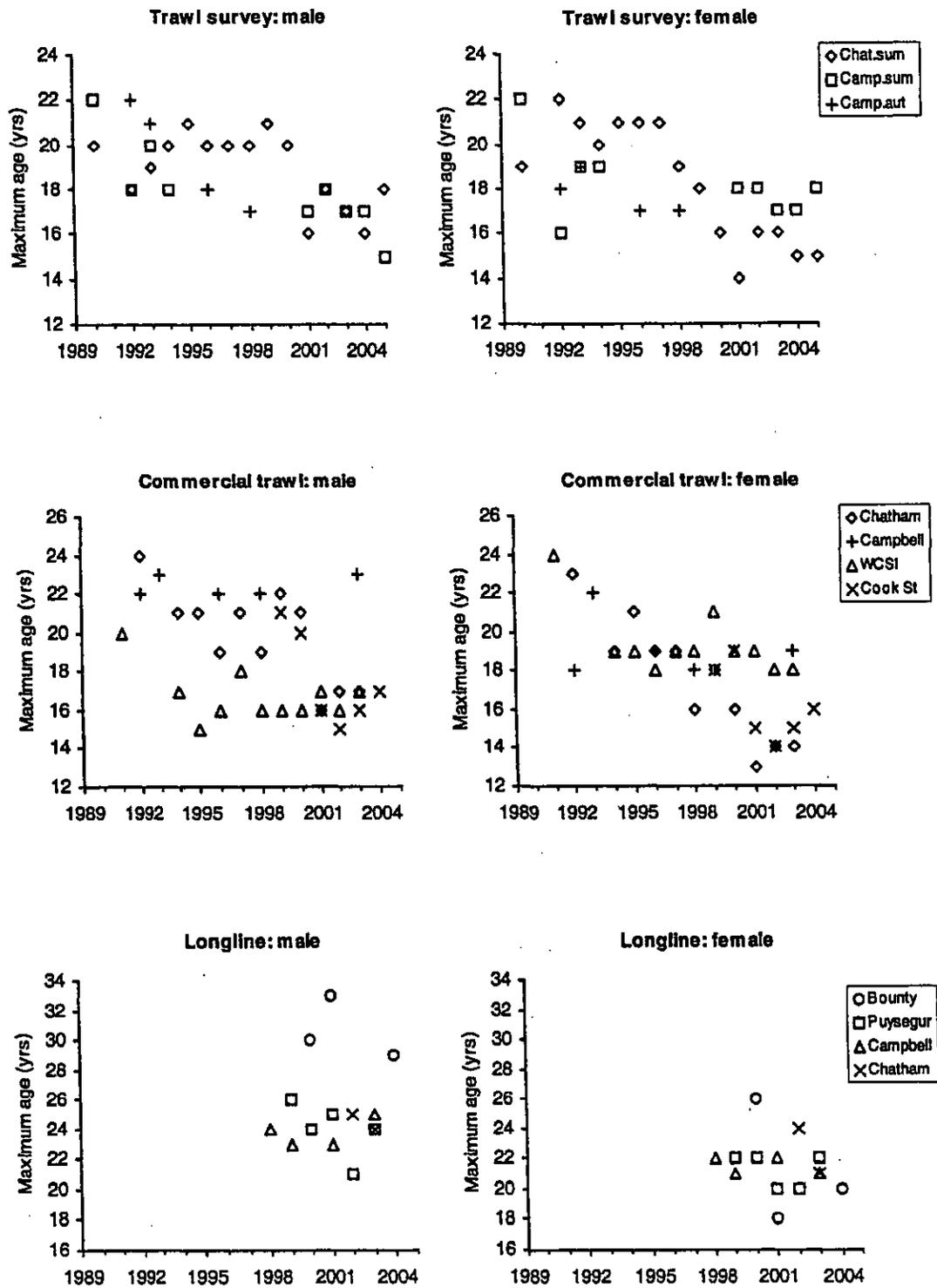


Figure 13: Minimum ages reached by the oldest 5% of fish in samples derived from trawl surveys, and commercial trawl and longline fisheries, by sex, area, and year.

### 3.3 Estimated year class strengths

Estimated year class strengths (YCS) have been produced previously as outputs of stock modelling using the CASAL software (Bull et al. 2004). The estimates are derived from series of catch-at-age data from trawl surveys and commercial fisheries, after the application of selectivity ogives relevant to the particular survey or fishery. Not all the five postulated 'biological' stocks are assessed each year, so up-to-date estimates of YCS are not available for them all. However, Horn & Dunn (2003) presented YCS estimates for the five stocks from MPD model runs (Figure 14). More recent estimates are available for the LIN 3&4, LIN 5&6, and LIN 7WC stocks (Horn 2004, 2005), but they are little different to those presented here.

Clearly there are some marked differences between areas in YCS estimates (Figure 14). On the Chatham Rise (LIN 3&4), two periods of relatively strong recruitment (the mid-late 1970 and 1990s) are separated by a relatively long period of below average year classes. On the Campbell Plateau (LIN 5&6), was very variable from the early-mid 1970s until the mid 1980s, and then relatively poor until the early-mid 1990s. Recruitment on the Bounty Plateau (LIN 6B) is probably the most variable of any of the grounds, and is characterised by a few years of strong (sometimes very strong) recruitment in between years of virtual recruitment failure. The WCSI (LIN 7WC) population exhibits the least variable recruitment series, with no periods of consistently strong or weak year classes being apparent. In the Cook Strait (LIN 7CK), recruitment appears quite variable, but was based on only three samples of age data. However, the YCS patterns apparent for that area do not mirror recruitment in any of the other four areas.

Patterns of year class strengths are clearly different in each of the five areas currently assessed separately, providing further support that they should be treated as distinct biological stocks.

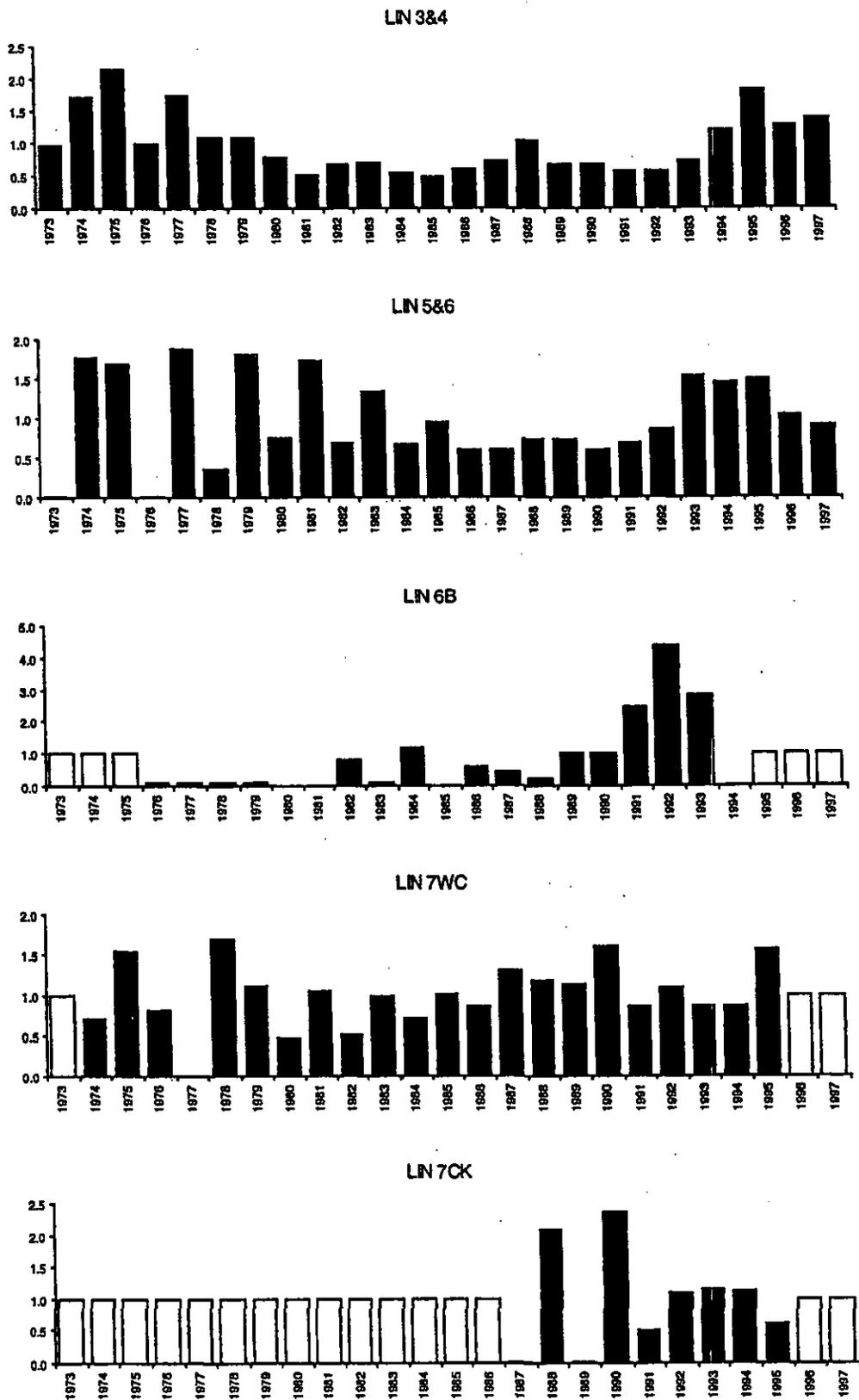


Figure 14: Estimated year class strengths, by stock, from MPD model runs. Year class strengths in these plots that were not estimated are assumed to be 1 and are indicated by unfilled bars.

#### 4. DISCUSSION

Fish stock assessment involves the estimation of certain population and fishery parameters to better manage a 'unit stock'. Hence, an understanding of stock structure is necessary to apply appropriate management strategies in fisheries where multiple stocks are differentially exploited. A practical definition of a 'unit stock' has been widely debated. Following a recent symposium on stock identification, Waldman (2005) suggested that the most robust definition, yet one still sufficiently specific to be useful, had been given by Ihssen et al. (1981), who proposed that a stock is "an intraspecific group of randomly mating individuals with temporal or spatial integrity". Many techniques are now available to discriminate between stocks, and some can even be used to estimate proportions in mixed stocks. However, the strongest inferences on stock structure are drawn from a suite of complementary techniques that cover multiple aspects of the biology of a fish species (Begg & Waldman 1999).

The aim of this report is to examine all currently available sources of data that may provide information on the structure of ling stocks in New Zealand waters. Stock boundaries are postulated, areas of uncertainly identified, and ways to clarify these uncertainties proposed. The likely applicability of stock discrimination methods as yet untried on ling is considered.

No tagging of ling has been conducted. While the species can be easily targeted, tagging would be practically difficult owing to likely physiological damage to the fish when they are retrieved from depths. 'In situ' tagging (e.g., using detachable hook tags (Horn 2003)) could probably be used with some success on this species. However, because ling are widespread, tagging to determine stock structure would need to be conducted at a large number of localities to ensure representative marking of the stocks. Such a study would be prohibitively expensive and is not recommended for ling.

Parasite 'tags' can also be used to distinguish fish stocks. The species composition and abundance of parasites may differ between fish stocks for a variety of reasons (Begg & Waldman 1999). Studies involve the examination of a large number of host individuals for a small number of selected parasite species. The characteristics of the ideal tag parasite have been described in detail (e.g., MacKenzie & Abauza 1998); it should be a relatively abundant, long-lived, easily detected species, with relatively constant levels of infection between years. Ideally, the age of the host should also be available for the analysis as the abundance of some parasites is age-dependent. Ling are known to harbour some types of parasites that have frequently been used in stock discrimination studies (e.g., larval anisakid nematodes, parasitic copepods). Such a study has not been conducted on ling, but could be worthy of further consideration.

Analyses of otolith microchemistry have shown that the trace elements incorporated in the structure can be related to the chemical composition of the water bodies inhabited by the fish. Hence, stocks in different water masses may be distinguished by the chemical 'signatures' in the otoliths if the environmental signal is pronounced. However, the results can be difficult to interpret because chemical deposition in otoliths can also be influenced by physiological, genetic, temporal, and environmental effects (Begg & Waldman 1999). This technique probably has limited applications for ling stock discrimination. As shown above, ling spawning occurs over an extended period and in widespread locations (even within a presumed stock), hence otolith core chemical signatures are likely to be quite variable within and between years. Adult ling in some areas are also likely to be exposed, in different years, to water masses with different chemical compositions because of the varying position of the sub-tropical convergence. Consequently, analyses of ling otolith microchemistry are not currently recommended as a method likely to enhance the understanding of stock structure.

Age-standardised estimates of mercury levels in ling flesh were indicative of at least two stocks, i.e., Chatham fish were distinct from ling in the WCSI and Campbell areas (Timperley & Tracey 1997). Fish stock discrimination studies based on biochemical analyses of flesh samples are very rare (e.g., Dutil et al. 1985), and the technique has not been considered in recent reviews of stock identification methods (e.g., Cadrin et al. 2005).

Genetic differences between groups of fish provide a basis for determining the degree of reproductive isolation between these groups. An examination of some enzymes indicated that there was no significant allelic heterogeneity, although a north-south split of ling stocks at the Subtropical Convergence Zone was postulated (Smith 1979, Smith & Francis 1982). A later analysis of molecular variation in the mtDNA control region found significant variation between Campbell Plateau and both Bay of Plenty and Chatham Rise samples, providing further support for 'northern' and 'southern' ling stocks (Smith & Paulin 2003). It was noted that ling populations were characterised by a high level of genetic diversity; high genetic diversity is a usual prerequisite for stock identification studies. The likelihood of adult migration or larval dispersal between areas is unknown, but even low levels could quickly blur any significant genetic differences. There are few major barriers to adult migration. Ling prefer depths of 200 to 700 m (Anderson et al. 1998), and the only significant constrictions of the continental shelf in this depth range are off Fiordland and Kaikoura. However, the Bounty Plateau is separated from mainland New Zealand by depths in excess of 1100 m. Larval dispersal between areas is also highly probable. Although the eggs of *Genypterus blacodes* are undescribed (Furlani 1998), those of the closely related *G. capensis* are pelagic (Brownell 1979). The time spent by eggs and larvae in the pelagic environment is also unknown. However, the general westward drift of currents around New Zealand enhances the likelihood that eggs and larvae could be transported from WCSI to the Campbell Plateau or Cook Strait, and from the Campbell Plateau to the Chatham Rise or Bounty Plateau. In conclusion, it is suggested that additional genetic analyses are unlikely to further clarify the stock structure question.

Morphometric and meristic investigations of New Zealand ling have produced ambivalent results. Colman (1995) detected a north-south split based on morphometric characteristics, with Campbell and Puysegur ling being distinct from those from off WCSI and the Chatham Rise. Bounty Plateau ling were tentatively postulated to constitute a third stock. In contrast, Smith & Paulin (2003) could detect no differences between ling from the Bay of Plenty, Chatham Rise, or Campbell Plateau; they concluded that most characters appeared to be either far too variable, or not variable enough, to be useful as population discriminators. However, Colman (1995) tested many fish and focussed on stock discrimination, whereas Smith & Paulin (2003) tested fewer fish and focussed on species discrimination in the *Genypterus* genus. Daley et al. (2000) analysed Australian ling using most of the characters examined by Colman (1995) and concluded that morphometrics and meristics were of little use for stock discrimination of that species. Consequently, although it appears likely that there are some stock-related differences in ling morphology within New Zealand waters, no further morphological analyses of ling are recommended here.

Catch data have provided indications of multiple ling stocks in New Zealand waters. Analyses of commercial longline CPUE show an apparent distinction in relative abundance trends between Campbell ling and ling from the Chatham Rise and Bounty Plateau. Distinctions are also apparent between all the five assessed 'stocks' (i.e., Campbell, Chatham, Bounty, WCSI, Cook Strait) based on estimated year class strengths. Moderate to large volumes of catch-at-age data are incorporated in the estimates for each of the areas, and all the areas exhibit different trends. However, it should be noted that while this information indicates differences between the five areas, it does not rule out the possibility of further stock divisions within an area (e.g., could the Chatham Rise actually hold two distinct ling stocks?). It is possible to estimate patterns of year class strengths for 'sub-areas' like the western Chatham Rise. However, this would require considerable work to recalculate catch-at-age distributions and

relative abundance series, develop catch histories for the sub-areas, and re-run the assessment models; it is not considered further here.

Data relating to life history characteristics constitutes the bulk of the information presented in this document, and also provides the strongest evidence for multiple ling stocks in New Zealand waters. There are significant differences in growth parameters between all the five assessed 'stocks' (Campbell, Chatham, Bounty, WCSI, Cook Strait). There are also relatively distinct spawning grounds in all these areas, and some marked differences in the timing of spawning between some areas. Differences in age and length at 50% maturity are also apparent. However, while it appears that ling from these five areas should logically be treated as separate stocks, at least for assessments, it is still possible that there are further stock divisions within some of these areas. There appear to be two relatively distinct spawning areas on the Chatham Rise (one west of the Chatham Islands, the other east of Mernoo Bank, see Figures 3 and 4), and significant differences in growth parameters between sub-areas of the Rise. The Campbell area also holds two relatively distinct spawning grounds, i.e., the area from Puysegur Bank to the Solander Corridor, and the area from the southeastern Snares shelf to the Auckland Islands. It is considered likely that the Campbell area is home to a single ling stock, based on information from trawl survey series conducted in summer and autumn (O'Driscoll & Bagley 2001). During the summer, when ling are spawning, catch rates were high in the two spawning areas, and relatively low on the eastern Campbell Plateau. In autumn, some months after spawning has finished, catch rates are relatively constant over all the survey area. This is indicative of a single stock, with spawning fish tending to move northwest to the spawning grounds, and later disperse over the whole area outside the spawning season. The differences in the maturity ogives from the Puysegur and Campbell areas (Section 3.1.2) are also best explained by there being a single biological stock in the Campbell-Puysegur area.

The life history parameters presented above are indicators of phenotypic stock differences only; they do not provide evidence of genetic isolation between stocks. The differences could be genetically or environmentally driven, although the relative lack of apparent genetic differentiation suggests environment as the most likely driver. However, irrespective of the cause they do provide a basis for the continuation of separate assessments for ling from the five areas (i.e., Campbell, Chatham, Bounty, WCSI, Cook Strait). Some mixing between these stocks appears inevitable; the likelihood of egg and larval transport has been discussed above. Genetic (Smith 1979) and morphometric (Colman 1995) studies both tentatively indicated an area of stock mixing along the coast between Banks Peninsula and Otago. The current analysis shows that the Chatham Rise sector with the slowest ling growth is the southwest (i.e., the area adjacent to the slow-growing Campbell stock), and is perhaps indicative of mixing between slow-growing and fast-growing fish.

The current analysis has examined a broad spectrum of complementary techniques in an attempt to define the stock structure of ling in New Zealand waters. Five distinct stocks have been identified; they correspond with the five stocks defined in recent years for assessment purposes (i.e., Chatham Rise, Campbell Plateau including the Stewart-Snares shelf and Puysegur Bank, Bounty Plateau, Cook Strait, and WCSI). These areas account for about 95% of the annual ling catch (Horn 2001).

There is essentially no information from which to infer the stock structure of ling around the North Island (excluding Cook Strait). Spawning fish have been recorded south of Cape Kidnappers in May, and spawning is also believed to occur in the Bay of Plenty and near North Cape. Peak landings from longline fisheries targeting ling off the east and north North Island occur from July to October (Horn 2001); as for other longline fisheries it is likely that these peaks are associated with spawning aggregations. Hierarchical analyses of mtDNA control region showed significant differences between the Campbell Plateau and the Chatham Rise, but non-significant differences between Chatham Rise and Bay of Plenty (Smith &

Paulin 2003). No life history parameters (and very little biological data of any form) are available for North Island ling. Begg (2005) recommends that life history parameters should be the first data examined in any stock identification study, and they certainly appear to have proven very useful in the current analysis. Hence, it is recommended that any stock structure investigations of northern ling initially follow this path.

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