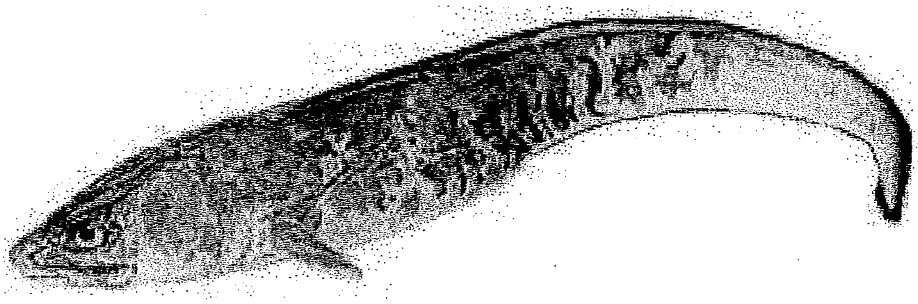
97/115

Report of the Workshop on pink ling in the South East Fishery

for the South East Fishery Assessment Group

Robin Thomson
(CSIRO)



AFMA Boardroom
Canberra
29 February 2000

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

CSIRO MARINE RESEARCH

Introduction

A workshop was held in December 1998 to review the information available for pink ling (*Genypterus blacodes*) in the South East Fishery (SEF). Progress has been made since then towards understanding the stock structure of ling and towards stock assessment. Additional fishery data have been collected through the AFMA log book scheme and the Independent Scientific Monitoring Program (ISMP). The purpose of the 2000 workshop was to review progress since the 1998 workshop and to seek comments from industry and researchers on this work; to discuss the means by which industry information could be incorporated into analyses; and to examine hypotheses that might explain the trends that have been observed in the data, particularly the CPUE and catch-at-age data. The workshop agenda and list of participants are shown in Appendices 1 and 2.

The SEF divisions identified by Klaer and Tilzey (1994) are used. The 'east' fishery is defined as that in zones 10, 20 and 30 and the 'west' fishery as that in zones 40, 50 and 60.

Stock structure

The meeting discussed the importance of stock structure information to the stock assessment process. If an assessment is conducted for an area in which two populations are found but a single stock is assumed, the results of the assessment reflect some average of the status of the two populations. If harvest levels are based on a combined assessment but for operational reasons the harvest level differs between the two populations, unintentional overharvesting can occur. If a population is divided (unintentionally) into two, the results of assessments will be unnecessarily imprecise as the data set for each putative stock will be smaller than that for the actual population. Therefore, population structure and the dispersal of juvenile ling should be understood if the data are to be correctly interpreted.

Bob Ward presented the results of a recent study into the stock structure of pink ling using genetics and Ross Daley presented the results of a morphometric and meresitic study (see Appendix 3). A relatively small amount of mixing between stocks would prevent genetic differences being found. Conversely, environmental differences between areas could lead to differences being found when morphometric and meristic methods are used. Therefore these two studies compliment each another in that one is extremely conservative (i.e. unlikely to reject the hypothesis of a single stock) and the other sensitive to differences (i.e. likely to reject this assumption even if it is true). Bob Ward and Ross Daley concluded that neither the genetic nor morphometric evidence allow the hypothesis of a single stock to be rejected. The data are consistent with mixing between regions, although the extent of this mixing is unknown.

Pink ling from eastern Tasmania, western Tasmania, eastern Victoria, western Victoria, and New South Wales were examined to evaluate stock structure. Genetic data were gathered for three variable allozyme loci and nine variable microsatellite loci. Seven meristic characters (dorsal-fin ray, anal-fin ray, precaudal vertebrae, caudal vertebrae, dorsal pyloric caecae and ventral pyloric caecae counts) were examined. Proportional head and body measurements, and measures of otolith size, were also made.

Shallow water orange morphs and deep water pink morphs were shown to be the same species. There was no significant genetic or meristic differentiation among regions. There were indications of regional differences in otolith measurements, but it proved difficult to disentangle these from the confounding effect of fish size. There were some differences in relative head and jaw lengths between some regions, but these are more likely to be artefacts arising from distortion during storage and freezing than true stock differences.

Dave Smith suggested that future comparisons of otoliths from fish from different areas compare the otoliths of fish of the same age, rather than of the same length. He also suggested that Fourier shape analysis be used. However, Andre Punt pointed out that the results of these studies are difficult to interpret and that future studies may not add to our understanding of ling stock structure. Future work in this area could include the use of tagging studies using break-away tags, or trapping in shallow water. The location and timing of spawning might also be examined. It was noted that Barry Bruce is currently evaluating larval dispersion for pink ling.

Integrated Scientific Monitoring Program (ISMP) data

Ian Knuckey presented length frequency data collected by the ISMP during 1999 and compared the results with those for previous years (Appendix 5). The data were summarised by gear type (trawl, mesh, line and trap) and by area (east: zones 10, 20 and 30 and west: zones 40, 50 and 60). Ling caught by trawlers in the east generally ranged between 40 to 80 cm with a broad mode around 55 to 65 cm. In contrast, trawl caught ling in the west generally ranged between 50 to 105 cm with a mode between 65 and 75 cm. Overall, ling caught by non-trawl methods were larger than those caught by trawling. Fish caught by mesh nets and demersal longlines covered a broad size range (60-115 cm; mode around 80 cm).

Ageing data prepared by the Central Ageing Facility were based on trawl catches in the east and west. Although ling may reach 20 years old, most fish caught in the west ranged between two and six years of age (mode of three or four). In the east, most fish ranged between one and six years of age with a mode at ages two or three. No clear trends were apparent in either the size or age structure of the landed catches over the last five years. This might be indicative of extremely individual variable growth or alternatively of a wide spawning period.

On-board monitoring revealed that there was negligible discarding of ling during 1999 by any of the fishing methods. There has been some discarding of fish of less than 45cm. However, discarding rates have never been high (< 7%) during the monitoring period (1993-1999).

Preliminary results from covered codend experiments were presented. Trawl gear with a 90 mm double braided codend was used and the gear selectivity for pink ling calculated. Gear selectivity is the probability that a fish that enters a trawl net will be retained within that net. Gear selectivity increased from zero retention around 35 cm to full retention around 50 cm with the size at 50% retention at about 43 cm (Figure 1). This was compared with the vulnerability function estimated as part of the stock assessment model. Vulnerability is the probability that a fish of a given length will be caught by the trawl fishery. It is thus a function of the gear selectivity and the probability that the fish will be in the area at the time that the gear is used (availability). It was noted that there was a large disparity between the gear selectivity and vulnerability of fish in roughly the 40 – 55 cm range (Figure 1). The model indicates that vulnerability drops off for fish larger than approximately 75cm. Anthony Jubb suggested that this might be due to the ability of large fish to outswim the net and also their tendency to occupy rocky areas where trawlers cannot operate.

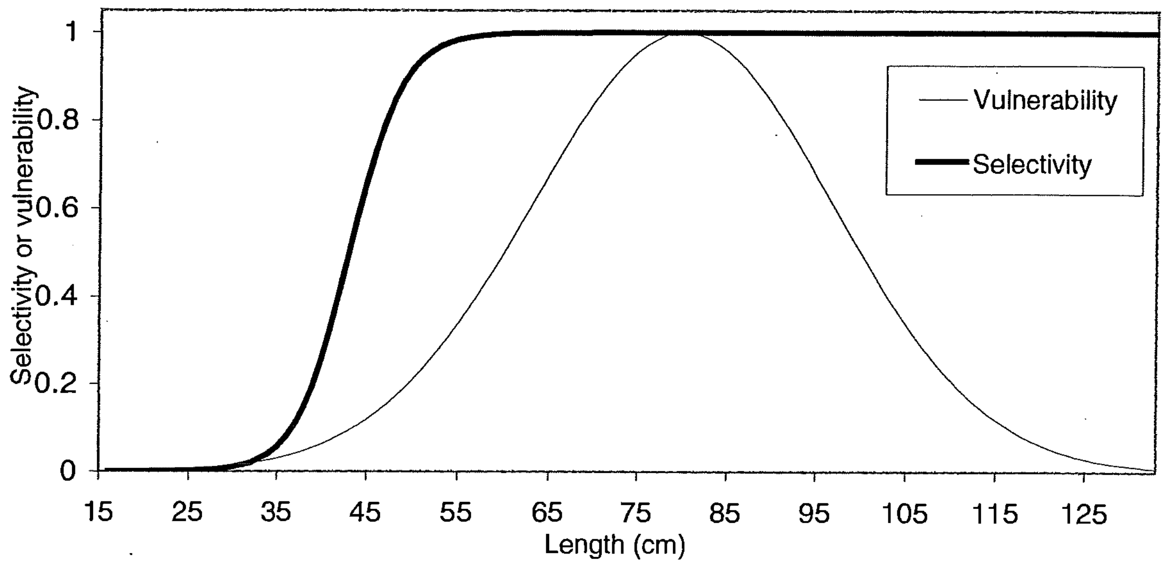


Figure 1. Gear selectivity for commercial trawl gear calculated using a covered cod-end experiment ("Selectivity") and vulnerability (a function of selectivity and availability) of fish to this gear calculated using an age-structured stock assessment model ("Vulnerability").

The length-frequency data used in the stock assessment model were aggregated after catch weighting with respect to zone and month (see Appendix 5). There was considerable discussion regarding the need to consider factors such as depth, season, species targeted and mesh size when aggregating the length frequency data. Information on targeting is available in the SEF1 logbook data, however, it has long been recognised that this field cannot be used reliably.

Standardization of CPUE

Kate Hodgson presented the results of an analysis completed with Malcolm Haddon (Appendix 6). Catch per unit effort (CPUE) data were standardised by fitting a General Linear Model following log transformation. The analysis of all catch-effort records provides no indication of downward trends in abundance. In the west there appears to have been a steady increase in catch rate since 1992. In the east catch rates appear to have remained fairly stable or increased slightly since 1986 with two significant highs in 1990 and 1995.

The results based on all records were compared with those based on only records with catches of >30kg, and with results based on only records for dominant vessels in the fishery. This was an attempt to focus on targeted fishing and major fishers. The results of these restricted analyses differed little from those of the analyses based on the complete data set; the only change being that removal of small catches resulted in considerably and consistently higher catch rates in the east.

Trends in catch rate in the east were examined for two depth strata delineated at 200 m depth. In the 'shallow' fishery there is an apparent decline in CPUE, except for the period between 1992 and 1995, which had relatively high standardized catch rates. The 'deep' fishery displays a stable or slightly increasing CPUE over time. However, the validity of the results of these analysis is questionable because (i) 200m may not reflect any natural boundary and because (ii) catch positions are known to have been falsified during the period of the 'OCS loophole' (particularly during 1993 and 1994).

Andre Punt pointed out that a fishery in its early stages, as this one is, ought to show a decreasing CPUE as the biomass is lowered from the unfished level. Yet ling CPUE is stable to slightly increasing. This implies that factors, other than ling abundance, that could not be included in the standardisation may be influencing the trend in CPUE.

In a multi-species fishery such as the SEF the catch rates of some species will be influenced by changes in the availability of other species. For example 1999 was a good year for the blue grenadier fishery and this might have increased ling catches. Jeremy Prince pointed out that the fishery has shifted towards catching ling and that this would result in a consequent increase in ling catch rates. Market demand also influences targeting practices. The availability of quota is an important factor as fishers are often able to avoid catching species for which they do not have quota. The nature of the fishery changed in 1992 following the introduction of ITQs. Fishers concentrated on taking a more mixed bag, leading to increased numbers of small catches of pink ling.

Increased vessel efficiency (vessel power), such as the introduction of colour echo-sounders, would maintain the CPUE at a higher level than would otherwise be the case.

Andre Punt suggested that interactions between the year and other factors be investigated. Significant interactions would indicate, for example, different trends in CPUE in different depths or zones. Anthony Jubb suggested that the CPUE analysis consider only the 10 vessels that have caught the most ling over the time period considered. Fishers landing more than 30t in the west or 20t east might be considered dedicated ling fishers.

Mr Tilzey suggested that the data for 1992 be excluded due to their known poor quality. It was also pointed out that the catches recorded in shallow state waters off the NSW coast during 1993-1995 are probably mis-reported due to the 'OCS' loophole; they were probably taken in deeper Commonwealth managed waters. Some catches attributed to trawlers may actually have been taken using Danish seine gear. The comparison of CPUE in deep and shallow waters on the east coast is therefore probably not meaningful.

Preliminary stock assessment

Robin Thomson presented an initial stock assessment for pink ling (Appendix 7). An Integrated Analysis assessment approach was used (similar to those used for blue grenadier, eastern gemfish, school whiting and blue warehou). The model assumed two commercial sub-fisheries and also made allowance for research catches taken by the Kapala in 1976 and 1996. Discards were modelled but as the discarding rate is so low these did not contribute much to the model fit. The data used to estimate the values for the parameters of the model were landings, discard rate, standardised CPUE, and catch-at-age and –length. The base case model assumed a single ling stock.

The standardised CPUE and the catch-at-age and –length data give different signals and the model is unable to reconcile these differences. The output of the model is strongly dependant on the relative weights given to each data source. An increase in recruitment strength in recent years might explain both data sources. However, there is no evidence in the age and length data to support such an increase.

The effect of changing the proportion of the TAC that is allocated to the non-trawl fishery was examined by projecting the base case stock assessment model forward 20 years assuming a fixed TAC; fixed proportion of the TAC caught by the non-trawl fleet; and no change in the vulnerability patterns of the trawl and non-trawl sub-fisheries. If the vulnerability patterns estimated by the model are correct the model indicates the non-trawl: trawl split of the TAC does not greatly influence the results.

The current model is clearly unable to explain the observed data and its qualitative results therefore cannot be used at present to provide the basis for comparing the trade-off achieved by different levels of future TAC. Future work on this assessment will need to take into account factors that might explain the conflicting signals coming from the CPUE and age and length data. Various hypotheses were discussed that might explain the observed data were discussed. It may be that ling productivity has increased over recent years. This could result from their feeding on offal discarded from fishing vessels or due to reduced competition with other species (such as deep sea dogfish). This could result in increased recruitment (although this is not supported by evidence form the ISMP), or decreased mortality rates, or faster individual growth. The individual growth hypothesis can be examined using ALK data. Ling may move into the trawl grounds in search of offal, thus keeping ling catch rates high.

Changes in the behaviour of the fishery could have distorted the CPUE or the age and length data. Jeremy Prince pointed out that since the introduction of ITQs fishers have begun to exploit a wider depth range in search of a mixed bag. As discussed previously, the influence of changes in the abundance of other species, e.g. gemfish, also impacts on the CPUE. He stated that ling have become a major part of the fishery since 1992.

Further work that might be undertaken was discussed:

a) Consideration of the possibility was discussed that ling might be cannibalistic. Stomach content data would indicate whether or not this is the case.
b) Examination of ALK data to determine whether or not individual ling growth rates have changed with time.
c) Further dis-aggregation of the catch-at-age and -length data may be required. The annual age and length data used in the model were catch weighted according to zone. Other groupings that might be considered include season and depth.
d) The early age and length data may not be as reliable as the more recent data and it appears that much of the decreasing trend observed in the data results from use of these early data. These need to be re-examined. Andre Punt suggested that the model be run with very little of the data and then with more and more in order to assess the influence of each piece of data. Length and age samples could also be weighted in the model according to their sample sizes. The influence of early data on the model results should be assessed. Retrospective analysis should also be completed.
e) In response to a comment from Horst Fisher, it was agreed that discards will be set to zero for the non-trawl sub-fishery.

General viewpoints

Dave Guillot and Horst Fisher stated that the mean size of ling being caught out of Lakes Entrance has decreased. The fishery caught only roughly 75% of the TAC in 1999. Horst Fisher reminded the workshop of the collapse of kingklip (a closely related species) in South Africa. Others, particularly those who fish in the west disagreed. For example, Bert Tober feels that fish in the west are larger than they were 15 years ago. Anthony Jubb stated that ling catches off Bermagui are better than they were because there are fewer boats now; those that remain are spending more time at sea. He also noted that the different sizes of ling caught on the east and west coasts may be due to the different mesh sizes used – 90mm in the east and 100mm in the west.

John Sealy stated that catches of ling off Portland, using the same grounds, have increased as the TAC has increased. He pointed out that ling have been targeted in recent years because of the decline in blue grenadier but that this might reverse in the next few years as two large year classes of blue grenadier become available to the fishery. Last year's ling catch was not good but this may have been due to warmer water.

Ling Assessment Group and Future work

It was widely felt that the workshops of this nature are useful fora for discussion, and that there is no need at present for the formation of another assessment group. It was agreed that a progress report detailing attempts to resolve the technical difficulties discussed at the workshop should be presented to the SEFAG plenary in June 2000. It will then be decided how to advance stock assessment of ling and whether or not to provide the assessment results to the TAC sub-committee.

Reference

Klaer, N.J. and Tilzey, R.D.J. 1994. The multispecies structure of the fishery. In: The South East Fishery (Tilzey, R.D.J. Ed). Bureau of Resource Sciences.

Acknowledgements

The FRDC are thanked for funding the workshop (through projects granted to CSIRO). AFMA provided the venue and AFMA staff, in particular Ingrid Holliday, were very helpful in facilitating the workshop. Speakers at the workshop, Ross Daley, Bob Ward, Ian Knuckey, and Kate Hodgson are thanked for their contributions, which included providing sections of text summarising their talks that were incorporated into this report. Andre Punt, Xi He and Tony Smith are thanked for constructive comments on the format of the workshop as well as comments on an earlier draft of this report.

Appendix 1

AGENDA

Ling Workshop
29 February 2000
Canberra

Chair: Xi He

10:10am	Introduction and workshop objectives (Xi He)
10:20am	Stock structure of ling - recent genetic investigation (Bob Ward)
10:30am	Stock structure of ling - recent morphometric investigation (Ross Daley)
10:50am	Discussion of stock structure
11:10am	*morning tea*
11:30am	ISMP data (Ian Knuckey)
12:00pm	SEF1 data and biological parameters (Robin Thomson)
12:00pm	Discussion of data
12:30pm	*Lunch*
1:00pm	Analysis of CPUE information (Kate Hodgson)
1:25pm	Discussion of CPUE analysis
1:45pm	Presentation of ling stock assessment and several hypotheses that may explain the data (Robin Thomson)
2:10pm	Discussion of modelling approach
3:00pm	*afternoon tea*
3:20pm	Discussion of hypotheses
4:40pm	Is there a need for a Ling Assessment Group? Discussion
5:00pm	End

Appendix 2

Participants

Pascale Baelde	University of Canberra
Peter Cui	CSIRO
Ross Daley	CSIRO
Horst Fisher	Industry
Chris Grieve	AFMA
David Guillot	Industry
Xi He	CSIRO
Kate Hodgson	TAFI
Anthony Jubb	Industry
Ian Knuckey	MAFRI, CAF
Rocky Lagana	Industry
James Larcombe	BRS
Locky Marshall	Industry
Michael Miriklis	Industry
Jeff Moore	AFMA
Ryan Murphy	AFMA
Brad Norman	AFMA
Jeremy Prince	Biospherics
Joe Puglisi	Industry
Andre Punt	CSIRO
John Sealy	Industry
David Smith	MAFRI
Tony Smith	CSIRO
Miriana Sporcic	AMC
Robin Thomson	CSIRO
Richard Tilzey	BRS
Bert Tober	Industry
Bob Ward	CSIRO

Appendix 3

Stock delineation of pink ling (*Genypterus blacodes*) in Australian waters using genetic and morphometric techniques

R.K. Daley and R.D. Ward

Stock delineation of the pink ling (*Genypterus blacodes*) in Australian waters using genetic and morphometric techniques

R. K. Daley
R. D. Ward

CSIRO MARINE RESEARCH

Pink ling (*Genypterus blacodes*) was the third most commercially important species in the South East Fishery (SEF) in 1997, having increased in value to AU$5.6 million. Total landings for that year were 1980 tonnes, the fifth highest in the fishery. With increased consumer acceptance, demand and price, there are pressures to expand the fishery, particularly in western waters. The fishery is managed by the Australian Fisheries Management Authority who have highlighted concerns that need to be addressed before any changes to the total allowable catch are made. Two key needs are to resolve species composition and stock structure issues.

Two species of ling are currently known from Australian waters: a minor commercial species, the estuarine rock ling (*G. tigerinus*); and the SEF quota species, the pink ling, which occurs more widely on the continental shelf and upper slope. The pink ling has two colour forms: a shallow water orange morph and a deeper water pink morph. It has been suggested that these might represent separate species.

The fishery is currently managed as a single unit stock, which implies that increased fishing pressure in one area would affect biomass in other areas. However, industry has noted differences in catchability and size composition between different fishing grounds, which could indicate more than one stock.

A multi-disciplinary study was undertaken by CSIRO Marine Research (CMR) using several genetic and morphological approaches to examine both species and stock composition. The genetic techniques included allozyme and microsatellite analysis, and mitochondrial DNA sequencing. The morphological studies included meristics (counts of fin rays, vertebrae and pyloric caecae), proportional head and body measurements, and measures of otolith size. The study has linkages to other CMR studies focussing on ling stock assessment and life history.

No evidence was found from any of the techniques to indicate that the pink and orange morphs are different species. They may be safely regarded as different forms of the same species. On the other hand, all of the genetic and some of the non-genetic techniques were able to distinguish between pink ling and rock ling. The pink ling, rock ling and the South African kingklip (*G. capensis*) were distinguishable by the one genetic technique applied to these three species, mitochondrial DNA sequencing. Pink ling from Australia and New Zealand are considered to be the same species.

Pink ling from eastern Tasmania, western Tasmania, eastern Victoria, western Victoria, and New South Wales were examined to evaluate stock structure. Genetic data were gathered for three variable allozyme loci and nine variable microsatellite loci. Meristics and shape measurements as listed above were also made. During the initial part of the study, there were some indications of more than one stock. However, once material from all regions had been examined, neither the genetic nor the non-genetic evidence refuted the working hypothesis of a single stock.

Specimens obtained from western regions did tend to have wider and thicker otoliths than those from eastern regions. However, these otolith dimensions also varied with fish size, an effect that could not be entirely eliminated by statistical methods. Fish from the west were mostly larger than those from the east, and it was not possible to confidently distinguish between the effects of size, intraspecific variation, and regional differences on otolith shape.

None of the seven meristic characters examined (dorsal-fin rays, anal-fin rays, pectoral-fin rays, precaudal vertebrae, caudal vertebrae, dorsal pyloric caecae and ventral pyloric caecae counts) differed significantly between regions in overall comparisons.

The average relative head and jaw lengths of ling from both NSW and western Tasmania were shorter than those from other regions. However these differences are more likely to be associated with errors associated with distortion and freezing during storage than to true stock differences.

In conclusion, the genetic evidence indicates sufficient mixing to eliminate regional differences in the genes examined. There was little evidence for regional differences in morphology, and what evidence there was could not unambiguously discriminate between single and multiple stocks. We therefore conclude that neither the genetic nor morphological data allow us to reject the one stock hypothesis.

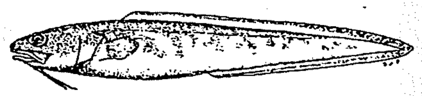
Appendix 4

Pink ling data collected by the Integrated Scientific Monitoring Program

I.A. Knuckey

Integrated Scientific Monitoring Program

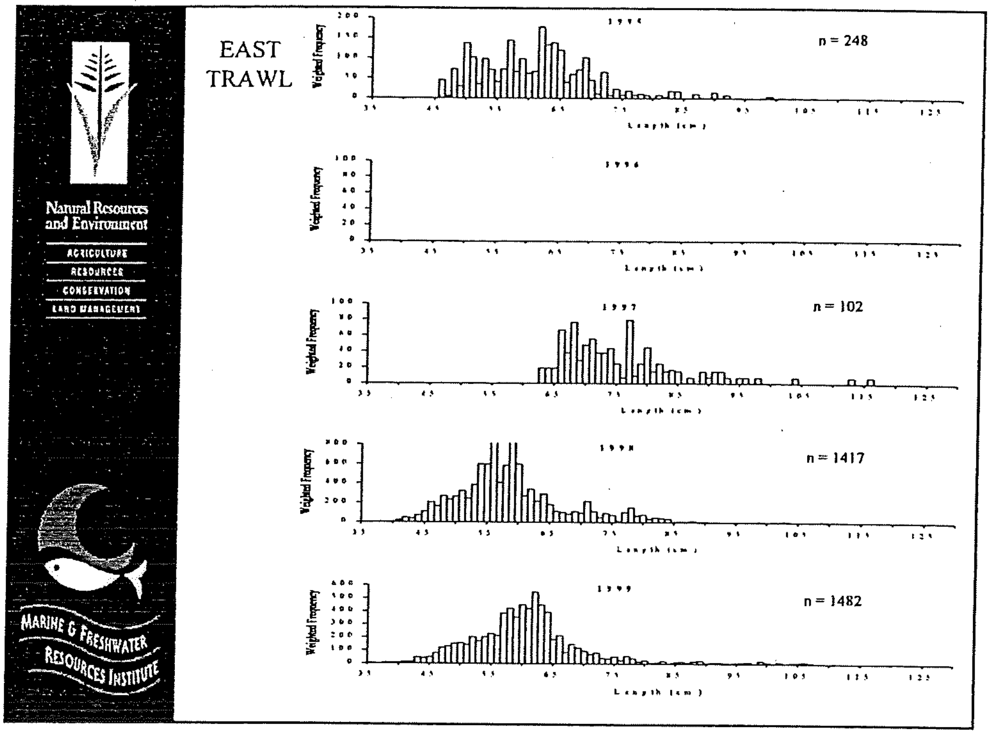
Data Summary for Ling Workshop



by
Ian Knuckey

Outline

- Port based length frequency
  - Trawl (East/West)
- Onboard length frequency
  - Retained / discarded
- Age distribution
- Comparison of gears
- Preliminary results of trawl selectivity


EAST
TRAWL
n = 248
n = 102
n = 1417
n = 1482
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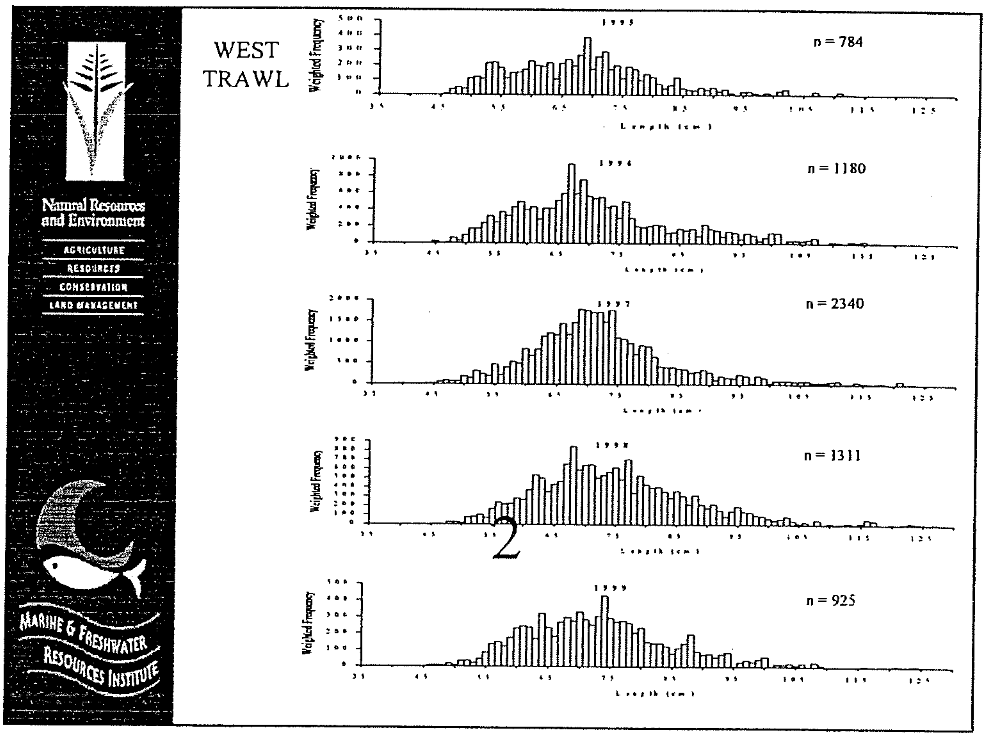
LAND MANAGEMENT
MARINE & FRESHWATER
RESOURCES INSTITUTE


WEST
TRAWL
n = 784
n = 1180
n = 2340
n = 1311
2
n = 925
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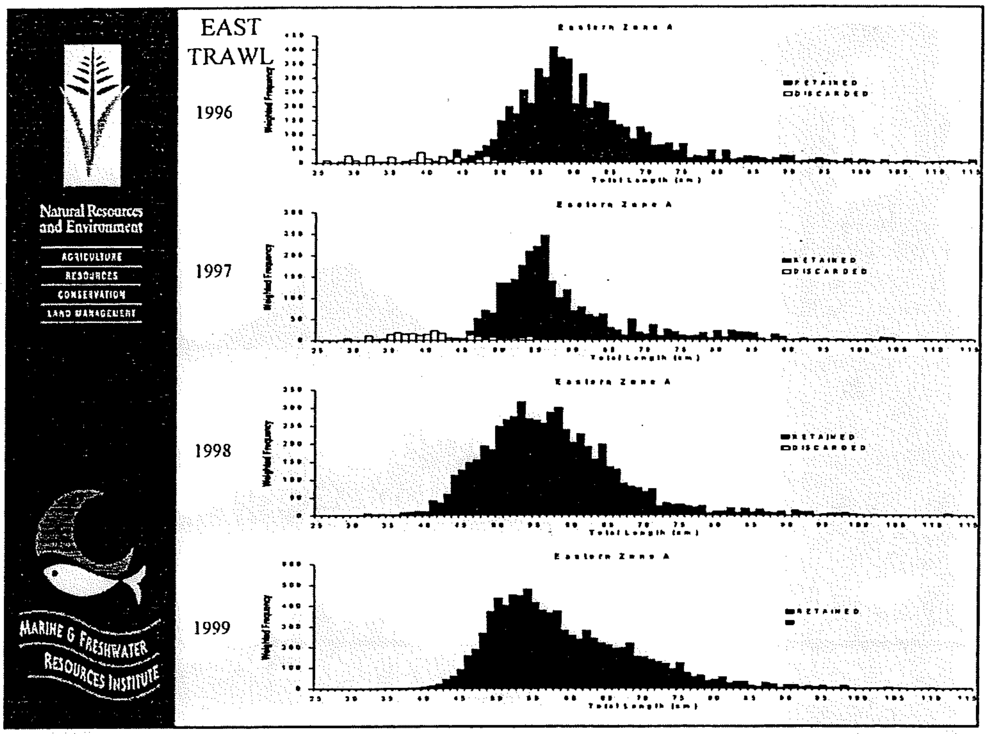
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LAND MANAGEMENT
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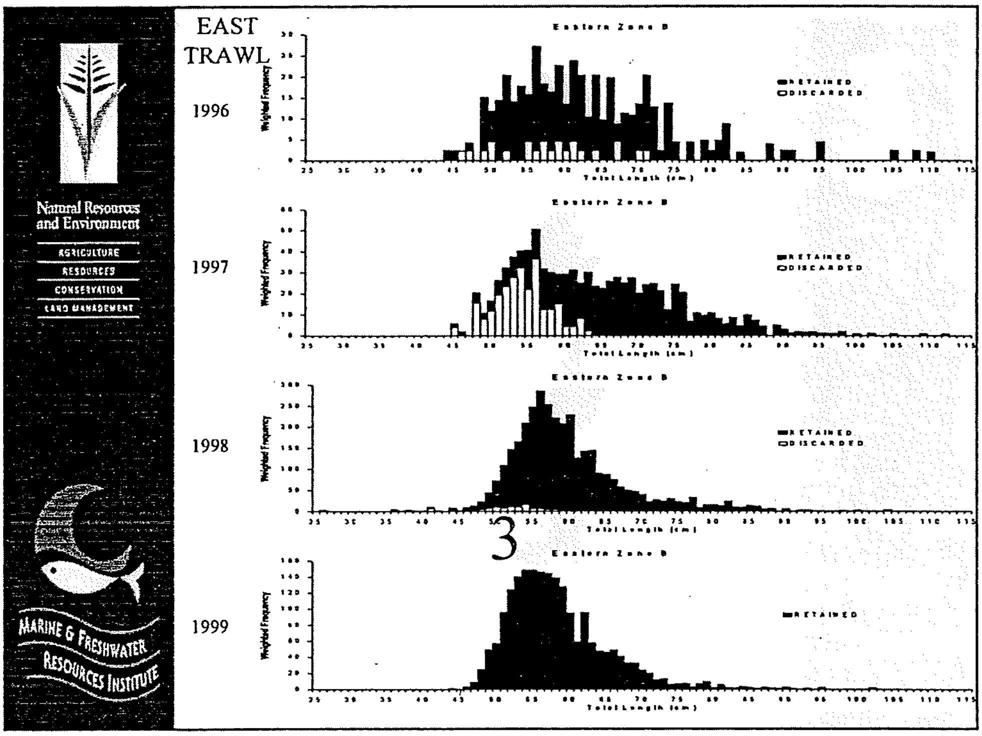
EAST TRAWL
1996
1997
1998
1999
Eastern Zone A
Weighted Frequency
Total Length (cm)
RETAINED
DISCARDED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EAST TRAWL
1996
1997
1998
1999
Eastern Zone B
Weighted Frequency
Total Length (cm)
RETAINED
DISCARDED
3

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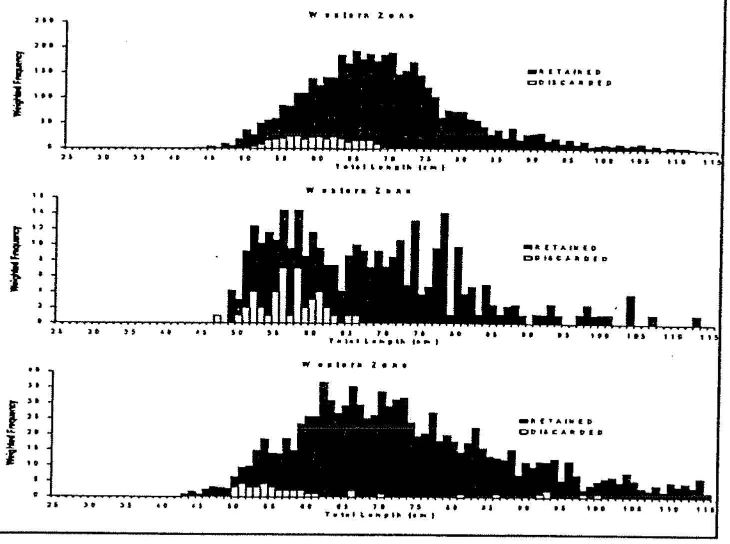
WEST
TRAWL

1996

1997

1998

1999



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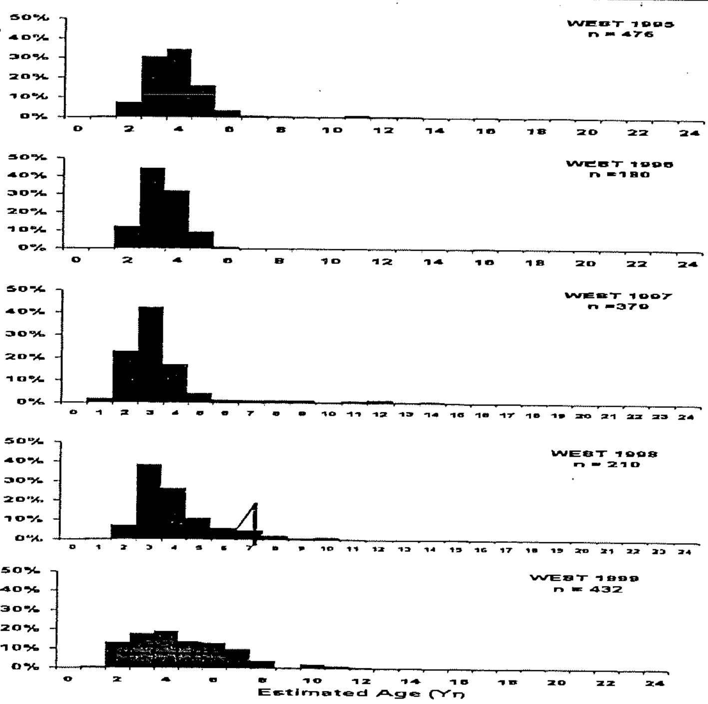
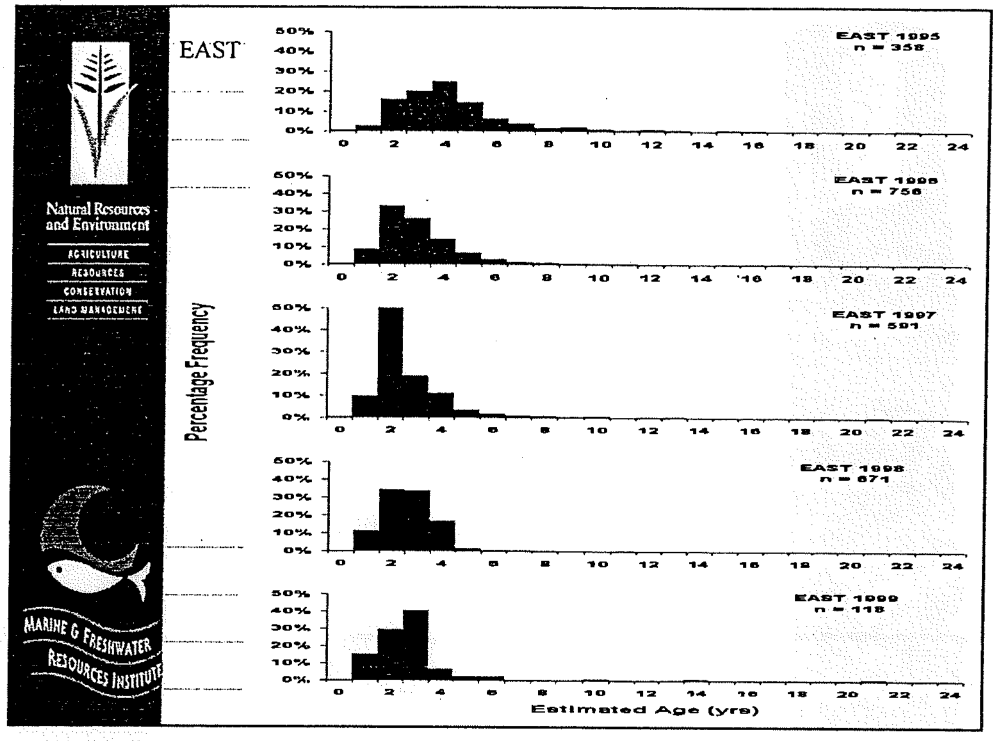
WEST





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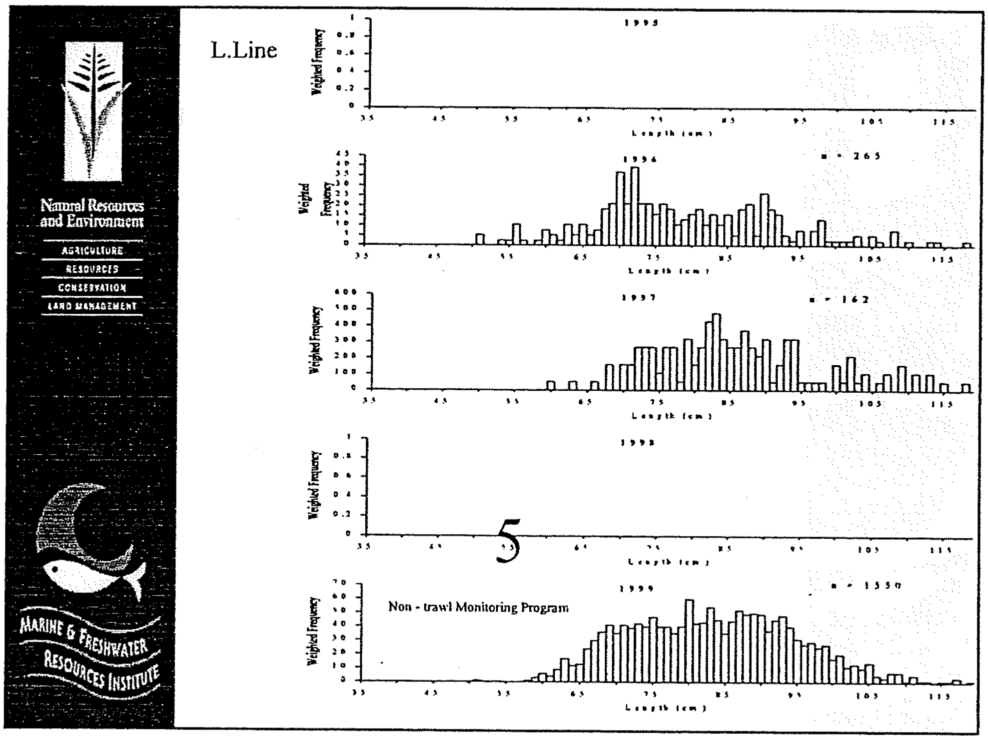
EAST
Percentage Frequency
EAST 1995 n = 358
EAST 1996 n = 756
EAST 1997 n = 591
EAST 1998 n = 671
EAST 1999 n = 118
Estimated Age (yrs)



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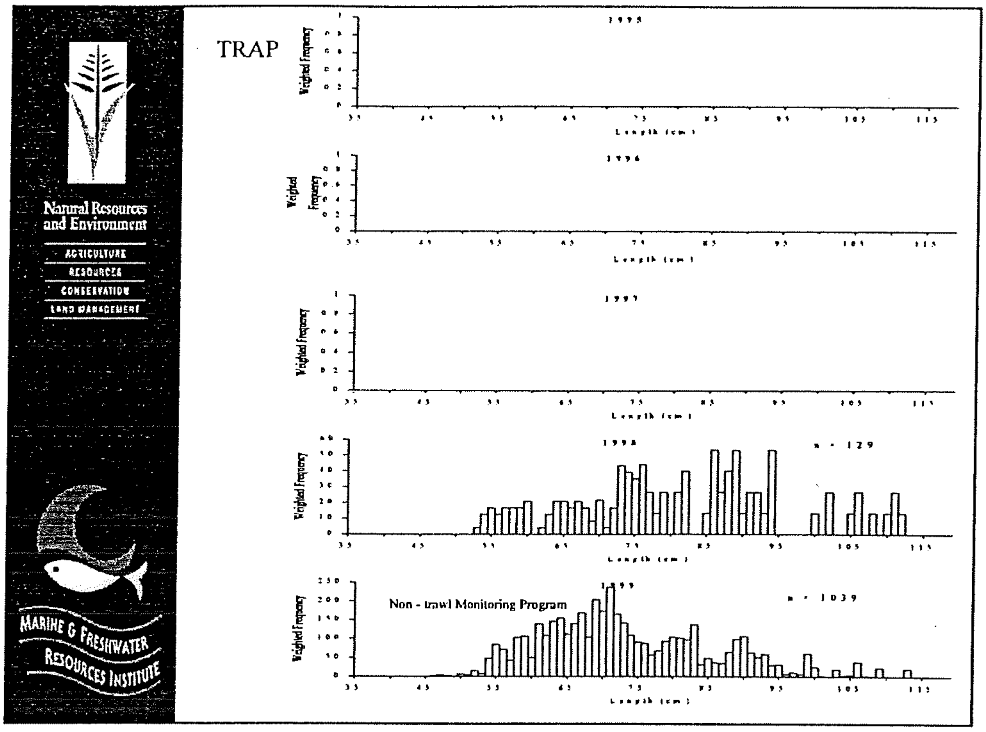
L.Line
Weighted Frequency
Length (cm)
Non - trawl Monitoring Program


TRAP
Natural Resources and Environment
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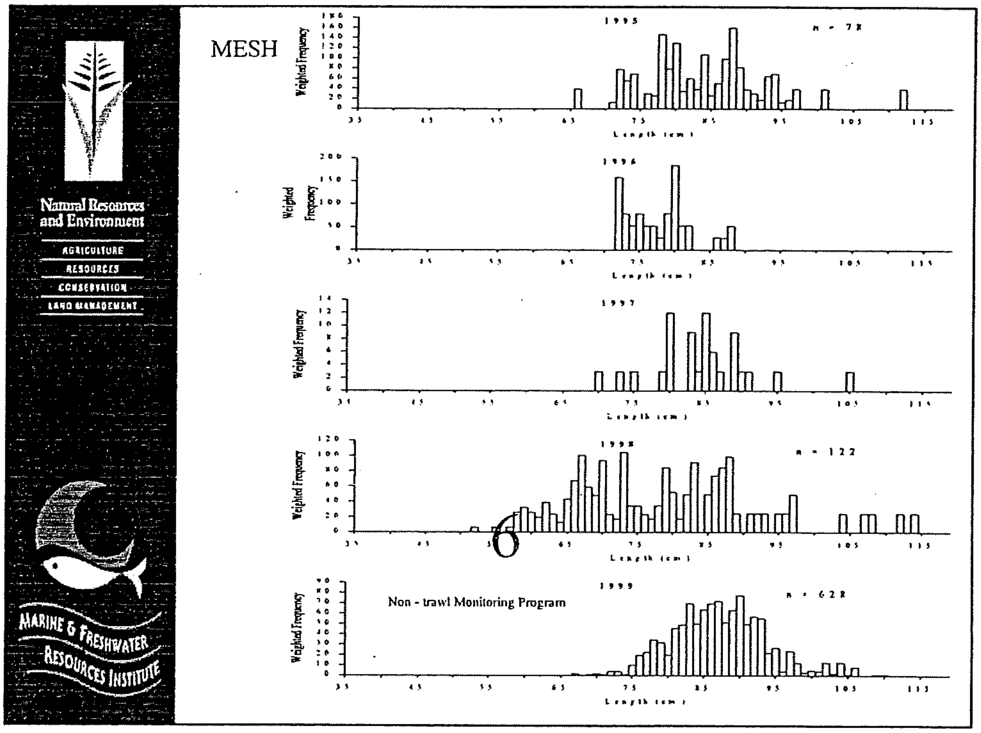
Weighted Frequency
Length (cm)
1995
1996
1997
1998
n = 129
1999
Non - trawl Monitoring Program
n = 1039


MESH
Natural Resources and Environment
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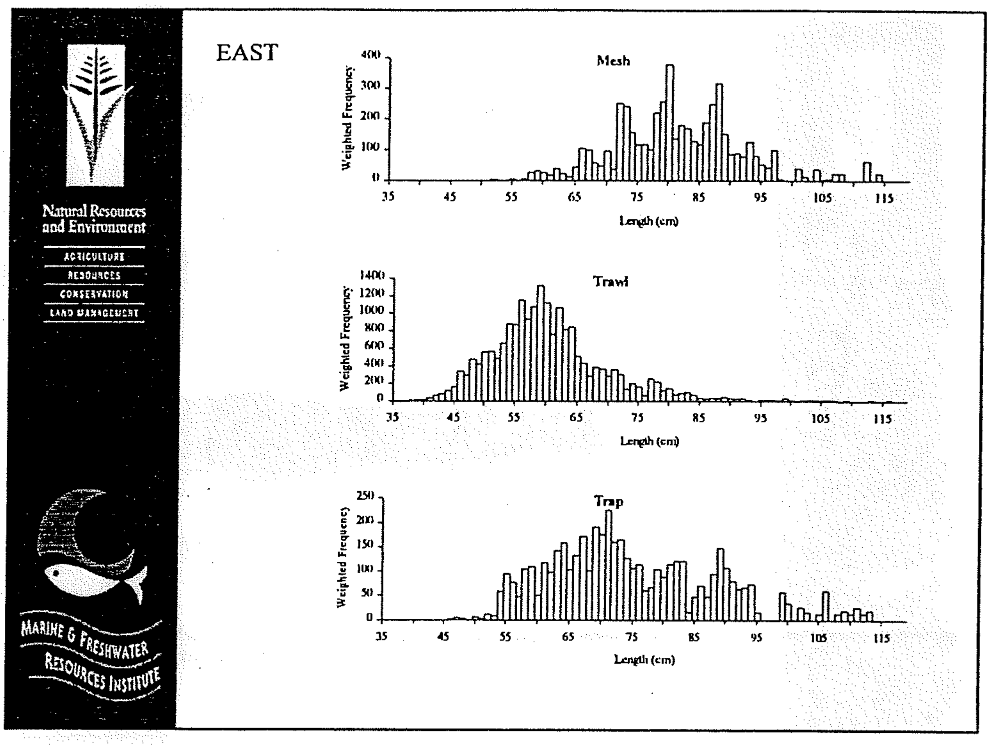
RESOURCES
CONSERVATION
LAND MANAGEMENT
MARINE & FRESHWATER RESOURCES INSTITUTE
Weighted Frequency
Length (cm)
1995
n = 78
1996
1997
1998
n = 122
1999
Non - trawl Monitoring Program
n = 628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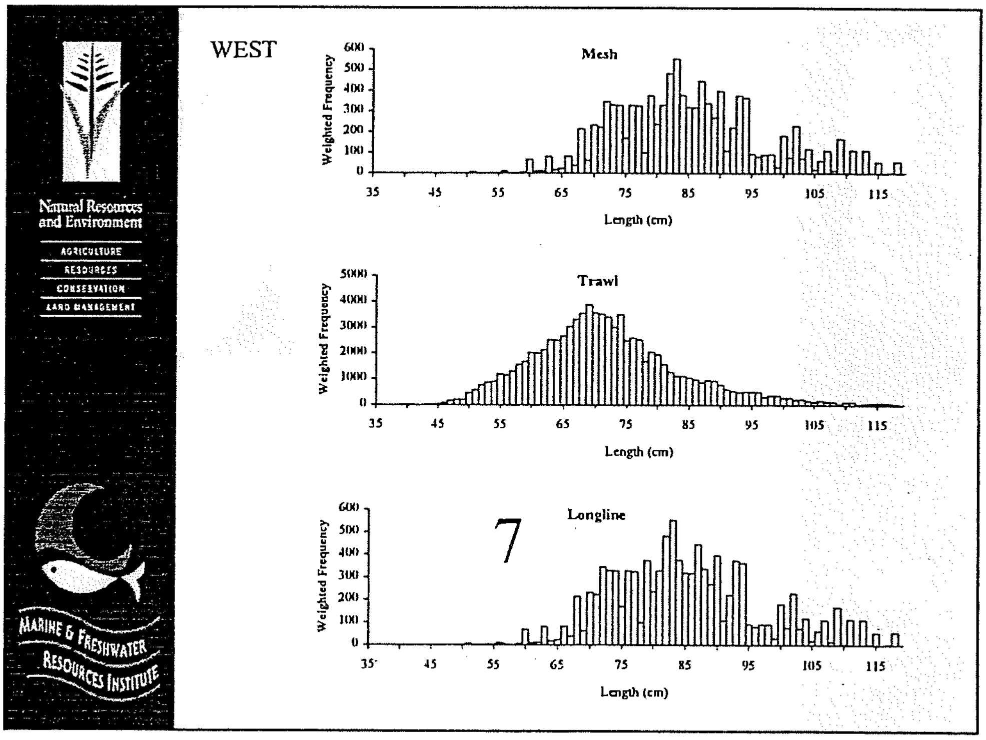
MARINE & FRESHWATER RESOURCES INSTITUTE
EAST
Mesh
Weighted Frequency
Length (cm)
Trawl
Weighted Frequency
Length (cm)
Trap
Weighted Frequency
Length (cm)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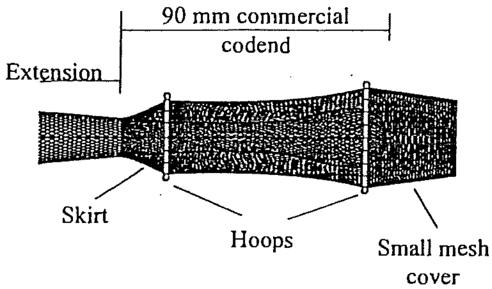
WEST
Mesh
Weighted Frequency
Length (cm)
Trawl
Weighted Frequency
Length (cm)
Longline
7
Weighted Frequency
Length (cm)

Selectivity trials

- Progress
  - → Two codend covers constructed & tested

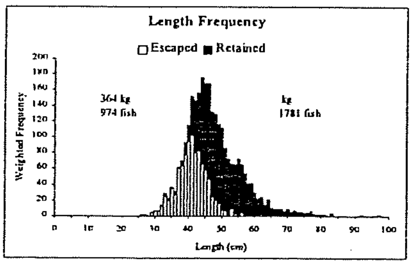


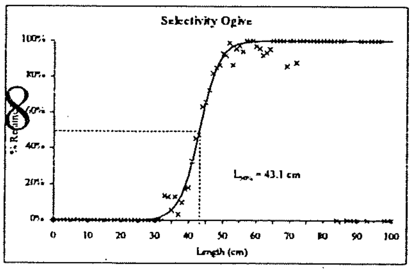
A small mesh cover was placed around the outside of the codend to retain the species passing through the 90 mm mesh.

Selectivity trials

- Trawl

Pink ling

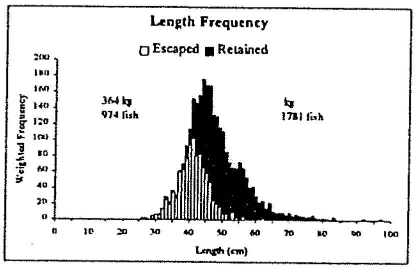




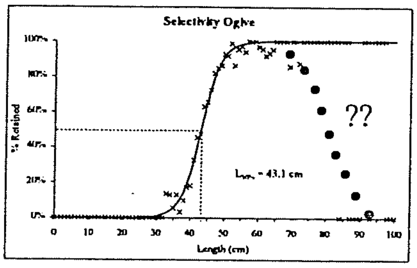
Selectivity trials

- Trawl

Pink ling



Missing larger ling ??



Appendix 5

Summary of fishery and survey data for pink ling (*Genypterus blacodes*) in the South East Fishery

D. Furlani *et al*

Summary of fishery and survey data for pink ling (*Genypterus blacodes*) in the South East Fishery

Report to
South East Fisheries Assessment Group (SEFAG)

February 2000

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Robin Thomson
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Introduction

A workshop funded by the AFMA and organised by Richard Tilzey of BRS, was held in Canberra in December 1998. The aim of the workshop was to review available data, identify sources for obtaining outstanding data, and to discuss a stock assessment framework for pink ling (*Genypterus blacodes*) in the South East Fishery. This report summarises those data and compiles them into ready-to-use formats for stock assessment models, the structure of which will be discussed at the February 2000 ling workshop in Canberra.

An initial stock assessment model was proposed as an age-structured population model subject to two sub-fisheries: trawl and non-trawl. Separate East and West trawl sub-fisheries are also considered, defined as East (zones 10-30) and West (zones 40-60) (Figure 1). The model uses the following data: composition of catch and discard at age and length; annual time series of total catches and discards; relative abundance indexes (catch per unit effort); and relevant population parameters (such as growth and length-weight relationships).

Data for pink ling are held by several organisations across Australia. It is possible that relevant data exist that are not included in this report. For this reason, the data used, particularly the age- and length-composition datasets, are described as clearly as possible.

Data Sources and Methods

Data sources include: (1) the South East Fishery (SEF) logbook data managed by the AFMA; (2) the Independent Scientific Monitoring Program (ISMP) data together with its predecessor, the SMP, collected and maintained by the MAFRI, (3) various surveys (Kapala NSW FRI, Tasmania DPIF, and CSIRO surveys); (4) the Central Ageing Facility (CAF), and (5) comparison with other *Genypterus* stocks. A summary of the available data sets is given (Table 1).

Fishery data

Length composition of the catch data are given in Table 2. Sexes are combined in these data. Additional data are still being compiled for 1993-4 and earlier years (Ian Knuckey). Where an ALK exists for the same sector (East or West), and year, as a length composition data set, that ALK has been used to convert the length dataset into an age composition dataset (Table 3).

Where more than one length composition dataset exists within a particular year, zone and gear type, these have been catch weighted and combined.

Age composition of the catch data was provided in the form of age-length keys (ALK's) (Table 1). The samples from which these were derived were collected on-board commercial or research vessels or by sampling at ports. Gear type is not always given, but more than 90% of these samples were collected using otter trawl gear (S Morison *pers comm*). The problem of length classes for which no fish were aged was dealt with by assigning the calculated von Bertalanffy age to fish from this length category. Data is available separately for males and females but these data have been combined for this report.

Discard data have been obtained for 1992-1999. These were collected by on-board sampling in all zones (ISMP). Available data include age-composition and length-frequency (Table 4a and 4b). Discard ratios (Table 5) were obtained from otter trawl catches only, but in the absence of discard ratio data for other gears, these ratios have been applied to nontrawl catches also.

Total catch and effort data for the trawl fishery for the period 1985 to 1998 is stored on an Access database at CSIRO. It has been down-loaded from the AFZ logbook database which is stored at BRS, and maintained and managed by AFMA. No local editing has been performed on this data. Nominal catch per unit effort (CPUE) in $kg.hr^{-1}$ has been calculated by taking the geometric mean of the CPUE for individual records. Data from the East and West sector are presented separately.

General Linear Modelling (GLM) was used (M. Haddon 1999) to standardise the CPUE for East and West sectors separately, and for all areas combined (Table 5). For the GLM analysis, East was taken to be zones 10, 20 and 30, and West to be zones 40, 50 and 60 (Haddon 1999). Only vessels with more than three years of catch records, and only shots which yielded 30kg or more of ling were used. Further work, using other species caught as a factor in the GLM, is being considered.

Population parameters
Four species of *Genypterus* occur in the southern hemisphere:. *G. blacodes, G. capensis, G. microstomus* and *G. tigerinus.*

G. blacodes occurs in south-west Australia (WA to NSW, and Tasmania) and also in New Zealand. It is found on the continental shelf and slope from 20-900 m depth. *G. capensis* occurs in southern Africa, and like *G. blacodes*, is fished commercially. *G. microstomus* occurs in small numbers in New Zealand only, and *G. tigerinus* on shallow reefs down to 60 m in Australia only. Neither species is fished commercially, and as such, little is known of their biology. Withell and Wankowski (1986) comment that, though morphologically similar, *Genypterus blacodes and G. capensis* differ in maximum age and growth rate. As such, growth parameters for *G capensis* can not be substituted for *G. blacodes.*

Length and weight data were used to estimate the parameters of a length-weight relationship of the form:

$$W = aL^b \qquad (1)$$

by non-linear regression. This was done by finding the values of the a and b parameters that minimised the sum of the squared differences between the observed weights and those predicted by Equation 1.

Data are divided into two categories. The first category (gear unspecified) relates to catches taken with an unspecified gear type, however it is known that roughly 95% of the gear used was commercial (~90% being otter trawl), with the remaining 5% being research gear (Table 1). Sample size in early years is comparatively small. The second category (gear specified) relates to data where gear type is given. This is predominantly otter trawl ("Trawl"), but also includes longline, trap, and gillnet ("Non-trawl") (Table 2).Data from East and West sectors were treated separately, and together. Data for males and females were treated separately at first, and were later combined (Table 6).

Growth parameters for pink ling are available from the literature for both Australia and New Zealand. Australian parameters currently exist for the East sector only, while New Zealand parameters cover a range of areas. In all cases, the von Bertalanffy growth curve has been used. Age and length data from all ALK's currently available (Table 1) were combined, and a von Bertalanffy curve fitted to these using the sum of squares method (Table 7). Data for age 0's were excluded.

Total mortality rate was calculated using catch curve analysis for each year in which age composition data were available (Table 8).

Results

Fishery data
Length composition data are presented as percentage catch-at-length (Table 2) (Figure 2). The length-class is defined as including fish of length (X-0.0cm) to (X-0.9cm), where X is the designated length class, i.e. lengths are rounded down to the next whole cm.

Age composition of catch from 1979 to 1997 are presented as percentage catch-at-age (Table 3) (Figure 3). Where the age composition was derived from an ALK, sample numbers are those of the applied ALK.

Discard data collected by the ISMP (I. Knuckey) are shown in Table 4a and 4b.

Total catch and effort by sector and year, are presented in Table 5 and Figure 5, along with standardised CPUE from GLM analysis (Figures 6a and 6b). These data apply to vessels using otter trawl and Danish seine gear only, and are based on South East Trawl fishery logbook data.

Population parameters
For *G. blacodes*, life history information is minimal. Although larvae have been described, limited documentation is available for spawning sites. Larvae have been caught in shelf and slope waters off NSW from July to September, and off Sydney in coastal waters from April to August (Gray 1995;

Neira, Miskiewicz and Trnski 1998). GSI data for Tasmania and Western Bass Strait gives maximum values generally between August and November, with the highest mean value occurring in late winter/spring (September) (Smith 1992, Lyle and Ford 1993, Jordan 1997).

Maximum length, weight and age in this dataset are 124 cm TL, 1323gm at 117 cm for females, and 850gm at 108cm for males; and 28 years. Size at maturity for females is given as 72cm (Lyle and Ford 1993), 60cm (Smith and Tilzey 1995), and 65cm (Jordan 1997). Egg surveys have not been undertaken for this species.

Length and weight relationships were fitted for sexes separately. Sufficient differences were not found in the results, therefore sexes were combined. Length-weight relationships from the literature exist for the Western Bass Strait trawl fishery (Smith et al 1995), and for trawl catches throughout the ling fishery (East and West sectors combined, Lyle and Ford 1993) for specified years (Table 6).

Growth parameters for pink ling in Australian waters have been calculated from East sector catches only, using data from the 1970's, 1980's, and 1990's (Table 7). New Zealand parameters (Horn 1993) are given for sexes separately, for samples taken between 1986 and 1993, over a range of four discrete areas south of latitude 40 (Chatham Rise, Bounty Platform, Southern Plateau, and the South Island north-west coast) (Table 7). As yet, growth parameters have not been calculated using the Australian West sector data. These are available in smaller datasets for 1982-89. The von Bertalanffy growth parameters are given in Table 7.

Total mortality values have been calculated from the catch-at-age information. It should be noted that the regressions are highly dependent on the age range used, which were selected visually from plots of the data. For years were data allowed, mortality values are given (Table 8).

Discussion

The modelling work is progressing using an Integrated Analysis approach.

The data shown in Tables 2 to 4, together with Total Catch and Discard Ratios, will be used in the stock assessment model. The model uses the standardised CPUE's for the East and West trawl fisheries (Haddon 1999), and for both areas combined.

The length-weight (Table 6) and growth (Table 7) parameters fitted using the data presented here fall within the range of published values and will be used in the stock assessment model.

The only non-trawl data available to the authors are the length compositions shown in Table 2 and Total Landings data. CPUE and discard data are required for this sector of the fishery.

List of abbreviations used

AFMA	Australian Fisheries Management Authority
AFZ	Australian Fishing Zone
ALK	Age Length Key
BRS	Bureau of Resource Sciences
CAF	Central Ageing Facility (Vic)
CPUE	Catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPIF	Department of Primary Industry and Fisheries
FRI	Fisheries Research Institute (NSW)
GLM	General Linear Modelling
GSI	Gonado Somatic Index
ISMP	Integrated Scientific Monitoring Program
MAFRI	Marine and Freshwater Resources Institute
SEF	South East Fishery
SEFAG	South East Fishery Assessment Group
SMP	Scientific Monitoring Program
WBS	Western Bass Strait

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Table and Figure captions

Table 1. Data type and source of all data currently available to the authors, relating to pink ling catches in the South East Fishery from 1979-1999.

Table 2 Length composition of the catch of pink ling in the South East Fishery, for all years, sectors and gear types for which data are available. Where more than one length composition exists for a year and zone, these have been combined. "All" indicates that data from the East and West sectors are combined. Shown as percentage caught-at-length.

Table 3 Percentage age composition data for pink ling in the South East Fishery. These are produced by applying an ALK to a length composition dataset. Standard deviation of the log length is shown for each age class. "*n*" values are those of the applied ALK.

Table 4a Length composition of discards measured during the SMP/ISMP.

Table 4b Age composition of discards measured during the SMP/ISMP.

Table 5 Total catch for otter trawl for both East and West sectors, and nontrawl for sectors combined. Figures are not yet available for 1999. Discard ratios (%) are given where available.

Table 6. Pink ling length-weight relationships from specified data-sets 1979-1996 ($W=aL^b$).

Table 7 Growth parameters (von Bertalanffy) for Australian and New Zealand ling data, taken from the literature.

Table 8 Estimates of total mortality for East and West sectors calculated using a catch-curve analysis (Butterworth et al, 1989).

Figure 1 South East Fishery area showing designated zones within the East and West sectors.

Figure 2 Percentage length composition of the South East Fishery pink ling catch, for all years, sectors and gear types where data are available. (From Table 2.)

Figure 3 Percentage age composition data for pink ling in the South East Fishery. (Following Table 3.)

Figure 4a Percentage length composition of discards from the South East Fishery pink ling catch, for all years, sectors and gear types where data are available. (Following Table 4a.)

Figure 4b Percentage age composition of discards from the South East Fishery pink ling catch, for all years, sectors and gear types where data are available. (Following Table 4b.)

Figure 5. Total catch of pink ling from the South East Fishery by trawl gear (East and West sectors), and nontrawl gear (sectors combined), 1986 to 1998. Trawl catches from the SEF logbook records. (Presented in Table 5.)

Figure 6a. Standardised CPUE for the eastern fishery (zones 10, 20, and 30) for all records with reported catches greater than 30 kg and for vessels which have been in the fishery for more than two years. "Geo. Mean" is simply the analysis of the geometric mean CPUE for each year. "Standardised" CPUE was : Ln(Catch-Effort) = Constant + Year + Month + Depth + Vessel + Depth x Month. The final term is an interaction term suggesting that the depth distribution of the fishery varies with season (Haddon 1999).

Figure 6b. Standardised CPUE for the western fishery (zones 40, 50, and 60) for all records with reported catches greater than 30 kg and for vessels which have been in the fishery for more than two years. "Geo. Mean" is simply the analysis of the geometric mean CPUE for each year. "Standardised " CPUE was : Ln(Catch-Effort) = Constant + Year + Month + Zone + Depth + Vessel (Haddon 1999).

Table 1. Data type and source of all data currently available to the authors, relating to pink ling catches in the South East Fishery from 1979-1997.

Year	Collected from	Source
Length composition of catch; gear unspecified		
1987-88	port sampling	SMP, I. Knuckey
1987-88	port sampling	SMP, I. Knuckey
1996	port sampling	ISMP, I. Knuckey
1997	port sampling	ISMP, I. Knuckey
Length composition of catch; gear specified (see Table 2)		
1977	Kapala - East	NSW FRI, K. Graham
1979	Kapala - East	NSW FRI, K. Graham
1982-85	Tasmania - East	SMP, I. Knuckey
1982-85	Tasmania - West	SMP, I. Knuckey
1992	zone 20	SMP, I. Knuckey
1995	zone 20	SMP, I. Knuckey
1996	zones 10-50	ISMP, I. Knuckey
1997	Kapala - East	NSW FRI, K. Graham
1997	zones 10-50	ISMP, I. Knuckey
1998	zones 10-20, 40	ISMP, I. Knuckey
Age composition of catch (ALK's) ~90% known to be otter trawl		
1979	Kapala, NSW - East	CAF; NSW FRI
1994	EBS - East	CAF, A. Morison
1994	NSW - East	CAF, A. Morison
1995	EBS - East	CAF, A. Morison
1995	NSW - East	CAF, A. Morison
1996	NSW - East	CAF, A. Morison
1997	NSW - East	CAF, A. Morison
1997	WBS - West	CAF, A. Morison
1996	SEF96 – East & West combined	CAF, A. Morison
1997	SEF97 – East & West combined	CAF, A. Morison
1998	EBS and NSW	CAF, I. Knuckey
1999	EBS and NSW	CAF, I. Knuckey
Discard information		
1998	On-board sampling (zone 10-60)	ISMP, I. Knuckey
Total catch and effort		
1985-98	AFZ logbook, BRS database	BRS, J. Larcombe
Length and weight; Gear unspecified		
1982-85	Tasmania –East	TAFI J. Lyle
1982-85	Tasmania –West	TAFI J. Lyle
1987-89	research (zone 20)	Withell & Wankowski (1989)
1993-96	research (zone 10-20)	SEF CSIRO
Length and weight; Gear specified		
1992-98	zone 10-50	SMP/ISMP, I. Knuckey

Table 2. Length composition of South East Fishery pink ling catch, for all years, sectors and gear types for which data are available. Where more than one length composition exists for a year and zone, these have been combined. "All" indicates that data from East and West sectors are combined. Shown as percentage caught-at-length.

Year	Sector	Source	Gear	*n*	Length-class percentages within individual sectors 16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1977	East	Kapala	Research	1848										0.11					0.11			0.05		
1979	East	Kapala	Research	2568																				0.04
1997	East	Kapala	Research	2655																0.04	0.04			
1992	East	SMP	Trawl	54																				
1994	East	SMP	Trawl	-																				
1995	East	SMP	Trawl	248																				
1996	East	ISMP	Trawl	-																	0.01	0.00		0.02
1997	East	ISMP	Trawl	-																			0.00	
1998	East	ISMP	Trawl	1417																				
1979	West	SMP	Trawl	114																				
1980	West	SMP	Trawl	86																				
1981	West	SMP	Trawl	602																			0.05	0.16
1982	West	SMP	Trawl	120																				
1992	West	SMP	Trawl	399																				
1995	West	SMP	Trawl	784																				
1996	West	SMP	Trawl	1180																				
1997	West	ISMP	Trawl	2340																				
1998	West	ISMP	Trawl	1311																				
1979	All	SMP	Trawl	114																				
1980	All	SMP	Trawl	86																				
1981	All	SMP	Trawl	602																			0.05	0.16
1982	All	SMP	Trawl	120																				
1992	All	SMP	Trawl	453																				
1994	All	SMP	Trawl	-																				
1996	All	SMP	Trawl	1032																	0.01	0.00		0.01
1997	All	SMP	Trawl	-																			0.00	
1998	All	SMP	Trawl	2728																				
1995	All	SMP	Nontrawl	78																				
1996	All	ISMP	Nontrawl	322																				
1997	All	ISMP	Nontrawl	178																				
1998	All	ISMP	Nontrawl	251																				
1999	East	ISMP	Trawl	1413																				0.02
1999	West	ISMP	Trawl	853																				
1999	All	ISMP	Trawl	2266																				0.01

Table 2. Length composition of South East Fishery pink ling catch, for all years, sectors and gear types for which data are available. Where more than one exists for a year and zone, these have been combined. "All" indicates that data from East and West sectors are combined. Shown as percentage caught-at-length.

Length-class percentages within individual year, sector and gear type																									
36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
0.16	0.11	0.11		0.11	0.22		0.22	0.11	0.22	0.54	0.43	0.43	0.59	0.86	0.81	1.19	1.51	2.00	1.35	2.43	1.84	1.78	2.00	2.27	2.64
		0.12	0.04	0.23	0.12	0.23	0.23	0.31	0.90	0.78	0.82	1.09	1.40	1.95	2.57	2.77	2.77	2.88	4.09	3.58	4.09	3.08	3.27	2.69	2.84
0.08		0.11	0.04	0.11	0.41	0.45	0.90	0.75	1.39	1.32	1.66	2.11	3.24	4.14	3.50	4.37	4.11	5.27	6.03	5.57	5.46	4.93	4.52	4.41	3.54
																	3.70	3.70	3.70	1.85	1.85		9.26	5.56	7.41
	0.06				0.01	0.75	0.52	0.61	1.22	1.35	1.38	2.56	3.04	3.48	2.39	5.77	4.02	2.82	10.79	7.27	4.84	5.80	6.39	7.11	3.39
										2.10	0.15	2.86	1.40	6.30	4.50	1.55	4.11	3.10	1.70	2.86	6.21	2.95	4.11	2.55	2.99
0.02	0.02	0.05	0.01	0.09	0.11	0.16	0.26	0.55	0.48	1.01	1.00	2.26	2.10	3.61	3.60	3.90	4.95	5.38	5.30	5.05	4.75	4.93	5.83	4.41	4.44
0.00	0.00	0.01	0.01	0.10	0.13	0.07	0.25	0.40	1.03	1.25	1.66	3.03	3.75	5.02	5.76	6.57	6.62	6.27	7.45	5.66	4.78	4.00	3.80	3.78	2.23
		0.10	0.16	0.22	0.65	1.17	1.20	1.54	2.36	2.68	2.60	3.30	3.18	3.33	3.30	2.78	4.24	4.57	5.17	5.26	4.05	5.15	4.57	3.58	2.59
													1.40		1.40	1.40			2.26	4.94	3.22	0.43	4.31	3.78	2.49
															2.32	1.21	1.21	1.11	2.32	5.86	3.53	2.43	3.53	4.54	6.96
0.05	0.11			0.16	0.31	0.05		0.26		0.16	0.58	0.38	0.21	0.87	1.36	1.36	0.40	2.61	1.58	1.57	2.13	1.93	2.18	0.68	2.99
														0.78	0.78			2.42	0.86	2.42	0.78	1.57		3.28	0.86
							0.27	0.22			0.22		1.23	2.30	0.92	2.64	1.94	2.31	1.64	4.06	2.32	5.44	2.15	2.36	3.52
										0.11	0.53	0.65	0.60	1.52	1.75	1.53	3.29	3.40	2.71	1.68	2.44	2.12	2.79	3.81	3.42
									0.08		0.05	0.44	0.25	0.68	1.14	1.24	1.62	2.43	1.88	2.93	2.04	3.10	3.44	2.45	2.79
				0.03				0.05	0.01	0.18	0.26	0.20	0.17	0.64	0.30	0.92	0.72	0.52	1.20	0.36	0.99	1.39	1.17	1.95	1.52
										0.05		0.04	0.04	0.08	0.41	0.34	0.52	0.25	0.66	1.23	0.99	1.38	1.76	1.27	1.92
													1.40		1.40	1.40			2.26	4.94	3.22	0.43	4.31	3.78	2.49
															2.32	1.21	1.21	1.11	2.32	5.86	3.53	2.43	3.53	4.54	6.96
0.05	0.11			0.16	0.31	0.05		0.26		0.16	0.58	0.38	0.21	0.87	1.36	1.36	0.40	2.61	1.58	1.57	2.13	1.93	2.18	0.68	2.99
														0.78	0.78			2.42	0.86	2.42	0.78	1.57		3.28	0.86
							0.25	0.20			0.20		1.13	2.12	0.84	2.44	2.08	2.42	1.79	3.89	2.28	5.02	2.69	2.60	3.81
	0.06				0.01	0.75	0.52	0.61	1.22	1.35	1.38	2.56	3.04	3.48	2.39	5.77	4.02	2.82	10.79	7.27	4.84	5.80	6.39	7.11	3.39
0.01	0.01	0.03	0.01	0.06	0.07	0.09	0.15	0.33	0.32	0.60	0.61	1.52	1.34	2.41	2.60	2.82	3.59	4.17	3.91	4.18	3.64	4.19	4.86	3.61	3.77
0.00	0.00	0.00	0.00	0.05	0.04	0.02	0.07	0.16	0.32	0.49	0.67	1.04	1.23	1.94	1.92	2.59	2.47	2.23	3.05	1.93	2.12	2.16	1.95	2.49	1.73
		0.05	0.08	0.10	0.31	0.56	0.57	0.73	1.12	1.30	1.24	1.59	1.54	1.63	1.79	1.50	2.29	2.31	2.81	3.15	2.45	3.17	3.09	2.37	2.24
															0.46			0.23	0.23	0.93	0.23		0.23	0.70	0.46
																								0.65	
																0.40	0.40	1.20	1.99	1.20	1.99	3.19	3.59	3.59	1.20
0.08		0.06	0.27	0.21	0.70	0.68	1.57	1.58	1.96	3.10	3.80	3.64	4.10	5.23	4.44	5.88	6.05	5.03	4.12	3.87	4.22	3.71	3.01	3.17	2.74
										0.07	0.10	0.05	0.17	0.07	0.20	0.36	0.07	0.56	1.41	0.82	1.33	1.01	2.06	2.31	2.47
0.05		0.04	0.17	0.14	0.45	0.44	1.02	1.02	1.27	2.03	2.50	2.38	2.71	3.41	2.94	3.94	3.94	3.46	3.17	2.80	3.20	2.76	2.68	2.87	2.64

Table 2. Length composition of South East Fishery pink ling catch, for all years, sectors and gear types for which data are available. Where more than one exists for a year and zone, these have been combined. "All" indicates that data from East and West sectors are combined. Shown as percentage caught-at-length.

Length-class percentages within individual year, sector and gear type																									
62	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**
2.32	2.00	2.43	0.86	2.54	2.43	2.21	1.84	2.32	1.73	1.67	2.16	1.84	2.05	1.57	1.67	1.78	1.40	0.97	1.40	1.24	1.19	1.03	1.13	1.13	0.97
1.91	2.34	1.99	1.48	2.34	1.48	1.79	1.56	1.52	0.86	1.71	1.71	1.01	1.48	1.56	1.05	1.40	1.40	1.01	1.17	1.60	1.13	1.01	0.90	1.21	1.32
4.14	2.49	2.71	2.49	2.19	1.66	1.85	1.77	1.51	1.06	1.28	0.90	0.68	0.75	0.49	0.45	0.53	0.26	0.68	0.19	0.11	0.34	0.23	0.15	0.23	0.15
3.70	3.70	1.85	5.56		1.85	5.56	1.85	7.41			3.70		1.85		3.70	3.70		1.85	1.85	1.85		1.85	1.85	1.85	
0.96	4.40	3.43	2.32	0.49	1.54	1.02	1.20	0.49	1.86	0.90			1.39	0.90	0.55		0.90		0.11			0.06		0.11	
8.04	5.38	6.04	5.39	1.72	2.36	3.16	4.55	2.10	0.53	2.91	0.37	1.11	0.39	0.93	0.39	0.53	0.39	0.05	0.39	0.18	0.88	0.83			0.53
2.97	3.39	2.85	2.88	1.97	2.62	1.68	1.96	1.39	1.46	1.49	1.20	1.00	0.96	0.71	0.55	0.91	0.39	0.47	0.34	0.40	0.26	0.52	0.35	0.24	0.43
1.92	1.64	1.75	2.47	1.26	1.66	2.03	0.99	0.98	1.36	1.29	0.99	0.95	0.74	0.61	0.49	0.62	0.43	0.32	0.59	0.27	0.43	0.10	0.10	0.19	0.22
3.37	1.89	2.31	2.46	1.51	1.66	1.31	1.32	0.72	1.37	0.69	1.01	1.42	0.71	0.48	0.95	0.93	0.74	0.69	1.13	1.15	1.07	0.57	0.38	0.55	0.16
5.18	4.01			4.12	2.61	4.67	5.21	3.58	3.03	3.03	2.80	2.13	3.27		0.85	1.94	2.49		5.30		2.49	2.49	3.27	1.40	1.09
2.32	3.32	4.64	1.21	2.32	1.21		3.43	3.43	2.22	4.64	5.96	2.43	3.32		2.32	2.32	4.75		1.21		2.43	1.21	1.11	2.43	1.11
2.27	4.85	2.75	2.89	2.95	1.81	1.65	1.46	4.14	2.83	3.24	1.61	3.99	1.44	2.87	2.80	1.44	1.70	2.32	2.75	1.84	2.32	2.47	2.02	2.16	1.44
2.50	3.13	3.28	4.22	2.35	5.00	2.35	2.58	0.86	3.43	3.36	5.15	3.28	1.72	3.21	1.72	1.72	3.28	4.29	1.72	1.64	3.43	3.28		1.72	2.50
1.46	2.71	3.81	4.75	4.16	2.48	3.06	3.46	2.92	3.11	3.38	2.45	3.62	1.98	2.13	3.80	1.92	2.37	1.71	2.19	0.77		1.40	0.22	0.48	0.74
3.10	3.93	1.65	3.27	4.13	2.62	3.90	6.22	2.25	3.52	4.05	2.82	2.64	1.19	2.66	2.34	1.53	2.05	1.68	1.33	0.76	0.90	1.71	0.71	0.43	0.51
1.47	2.91	2.60	3.32	3.92	5.83	3.98	4.51	3.51	3.62	3.12	2.54	2.39	1.77	2.96	1.85	1.09	1.14	1.08	1.42	1.29	0.76	0.76	0.91	0.88	1.09
2.23	3.06	3.18	3.05	3.83	3.10	4.09	4.99	4.75	5.11	5.40	4.22	5.67	3.37	3.47	2.74	2.02	2.99	2.72	1.81	1.26	1.26	1.30	1.10	1.10	0.76
3.13	2.33	2.19	2.51	2.65	3.48	4.12	3.70	3.59	3.54	2.93	3.68	2.81	3.66	2.86	3.74	1.89	2.57	3.37	2.09	2.61	2.26	1.71	2.52	1.66	1.65
5.18	4.01			4.12	2.61	4.67	5.21	3.58	3.03	3.03	2.80	2.13	3.27		0.85	1.94	2.49		5.30		2.49	2.49	3.27	1.40	1.09
2.32	3.32	4.64	1.21	2.32	1.21		3.43	3.43	2.22	4.64	5.96	2.43	3.32		2.32	2.32	4.75		1.21		2.43	1.21	1.11	2.43	1.11
2.27	4.85	2.75	2.89	2.95	1.81	1.65	1.46	4.14	2.83	3.24	1.61	3.99	1.44	2.87	2.80	1.44	1.70	2.32	2.75	1.84	2.32	2.47	2.02	2.16	1.44
2.50	3.13	3.28	4.22	2.35	5.00	2.35	2.58	0.86	3.43	3.36	5.15	3.28	1.72	3.21	1.72	1.72	3.28	4.29	1.72	1.64	3.43	3.28		1.72	2.50
1.64	2.79	3.66	4.81	3.84	2.43	3.25	3.33	3.26	2.87	3.12	2.55	3.34	1.97	1.97	3.79	2.05	2.19	1.72	2.17	0.86		1.44	0.34	0.58	0.69
0.96	4.40	3.43	2.32	0.49	1.54	1.02	1.20	0.49	1.86	0.90			1.39	0.90	0.55		0.90		0.11			0.06		0.11	
2.35	3.20	2.75	3.06	2.76	3.93	2.62	3.00	2.25	2.34	2.15	1.75	1.56	1.29	1.63	1.08	0.98	0.70	0.72	0.78	0.76	0.46	0.62	0.58	0.50	0.70
2.14	2.64	2.76	2.88	3.07	2.67	3.48	3.80	3.63	4.00	4.18	3.26	4.27	2.59	2.62	2.07	1.61	2.23	2.01	1.45	0.96	1.01	0.95	0.81	0.83	0.60
3.24	2.12	2.25	2.49	2.11	2.61	2.78	2.57	2.22	2.51	1.87	2.41	2.15	2.26	1.72	2.41	1.43	1.70	2.10	1.64	1.92	1.69	1.17	1.50	1.13	0.94
				2.31					0.76	4.61	3.33	4.09		1.78	1.52	8.70	4.61	7.67	2.04	3.56	2.27	6.36	1.52	3.03	5.87
0.23	0.93	0.46	0.93	0.46	0.70	1.62	1.86	3.26	1.86	10.60	5.32	4.35	4.94	4.60	3.93	2.18	4.80	9.50	4.11	3.35	1.57	0.93	1.40	1.95	2.79
	0.65			0.65		1.96		1.98	1.96	3.27	3.29	3.27	1.33	3.27	3.27	0.65	3.95	2.04	3.27	5.24	5.95	3.95	3.35	3.31	4.60
2.79	1.99	2.79	3.98	4.38	4.78	3.19	2.39	3.59	1.20	1.99	4.78	2.79	2.39	2.39	1.20	1.20	2.39	1.20	1.20	1.99	1.59		1.20	2.79	2.39
2.49	3.48	2.02	1.31	1.41	0.98	1.11	1.43	0.77	0.89	0.79	0.73	0.92	1.08	0.38	0.63	0.63	0.72	0.59	0.21	0.26	0.48	0.19	0.40	0.31	0.25
3.00	2.07	3.28	2.72	2.42	3.09	3.67	3.76	4.29	3.73	3.84	4.22	5.81	4.22	3.15	3.19	3.15	2.89	2.69	1.76	2.03	1.48	1.57	1.07	0.63	1.92
2.67	2.98	2.47	1.81	1.77	1.73	2.01	2.25	2.01	1.89	1.87	1.96	2.64	2.18	1.36	1.53	1.52	1.49	1.33	0.75	0.88	0.83	0.68	0.64	0.43	0.84

Table 2. Length composition of South East Fishery pink ling catch, for all years, sectors and gear types for which data are available. Where more than one exists for a year and zone, these have been combined. "All" indicates that data from East and West sectors are combined. Shown as percentage caught-at-length.

Length-class percentages within individual year, sector and gear type																									
88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113
1.35	0.76	1.35	1.84	1.46	1.67	1.35	1.08	1.67	1.13	1.35	0.81	1.51	1.35	1.08	0.81	0.76	0.81	0.76	0.65	1.03	0.65	0.76	0.86	0.81	0.59
1.01	0.78	0.82	0.82	0.97	1.29	0.70	1.01	1.21	1.17	0.90	0.43	0.90	0.78	0.58	0.58	0.78	0.31	0.62	0.31	0.31	0.39	0.31	0.31	0.23	0.23
0.11	0.11	0.15	0.08	0.04	0.08	0.26	0.23	0.08	0.08	0.08	0.04	0.19	0.04	0.04	0.08	0.11	0.04	0.04			0.04	0.11	0.04		0.04
1.85	1.85	1.85													1.85										
	0.90	0.27						0.20				0.06		0.10	0.10						0.10	0.09			
0.05		0.59		0.39		0.05				0.05	0.15		0.05		0.05								0.05		
0.38	0.11	0.12	0.16	0.22	0.13	0.19	0.06	0.12	0.12	0.09	0.06	0.04	0.09	0.09	0.05	0.04	0.07	0.04			0.01	0.02	0.02	0.01	0.02
0.16	0.25	0.17	0.22	0.13	0.04	0.12	0.14	0.18	0.01	0.10	0.02	0.09	0.03	0.03	0.06	0.08	0.05	0.01	0.03			0.03			0.02
0.27	0.19	0.16		0.13			0.17	0.06	0.07		0.10		0.11		0.23					0.06	0.10				
	2.49		2.49	1.09			1.09		1.09			1.09													
4.54					1.11																				
0.40	2.13	1.77	2.63	1.09	2.00	0.32	0.85	0.59	0.32	0.24	0.16	0.45	0.16		0.35							0.32			
1.64	3.43	0.86	1.72	1.72		1.72			0.86	0.86		1.72													
0.01	0.27	0.27	0.75	0.91		0.27			0.54	0.01			0.48	0.48	0.48				0.48				0.48		
0.57	0.41	0.65	0.44	0.64	0.15		0.41	0.42	0.15	0.07	0.21	0.04	0.48	0.46			0.02		0.18				0.37	0.05	
0.64	1.41	1.06	0.95	0.50	1.03	0.68	0.32	0.97	0.60	0.25	0.49	0.71	0.82		0.18	0.26	0.18	0.34	0.42			0.14	0.03		0.23
0.85	0.88	0.84	0.22	0.57	0.33	0.43	0.63	0.56	0.03	0.60	0.28	0.05	0.22	0.24	0.19	0.16	0.21	0.16	0.10	0.07	0.08	0.16	0.25	0.01	0.04
1.89	1.13	1.14	1.50	1.04	0.89	1.16	0.95	0.70	0.76	0.34	0.56	0.35	0.28	0.24	0.42	0.44	0.10	0.28		0.23		0.16		0.05	0.23
	2.49		2.49	1.09			1.09		1.09			1.09													
4.54					1.11																				
0.40	2.13	1.77	2.63	1.09	2.00	0.32	0.85	0.59	0.32	0.24	0.16	0.45	0.16		0.35							0.32			
1.64	3.43	0.86	1.72	1.72		1.72			0.86	0.86		1.72													
0.15	0.39	0.39	0.69	0.84		0.25			0.50	0.01			0.45	0.44	0.58				0.44				0.44		
	0.90	0.27						0.20				0.06		0.10	0.10						0.10	0.09			
0.49	0.64	0.50	0.48	0.33	0.50	0.39	0.17	0.47	0.31	0.15	0.24	0.31	0.38	0.05	0.10	0.13	0.12	0.16	0.17		0.01	0.07	0.02	0.01	0.11
0.65	0.69	0.64	0.22	0.44	0.25	0.34	0.49	0.44	0.03	0.46	0.20	0.07	0.16	0.18	0.15	0.14	0.16	0.11	0.08	0.05	0.06	0.12	0.18	0.01	0.04
1.12	0.68	0.67	0.79	0.61	0.47	0.61	0.58	0.40	0.43	0.18	0.34	0.19	0.20	0.13	0.33	0.23	0.05	0.15		0.15	0.05	0.09		0.03	0.12
9.45	4.84	2.27	1.78	1.02	3.82	4.09	0.76	1.02	2.31				2.31											2.31	
4.17	0.48	2.51	1.64	1.49	0.48	0.23	0.87		1.13	1.16	0.23	0.23	0.23	0.23	0.46		0.46	0.23		0.70		0.23			0.23
3.27	2.67	3.95	0.67	1.96	3.93	3.93	0.67	0.65	0.65	0.65		1.96	0.65	2.62	0.65	1.31	0.02	0.65	1.31		1.96		1.31		1.31
2.79	1.99	0.40	1.20	1.20	0.80	1.59	0.40	0.40	0.80			0.40		0.80		0.40	0.40	0.80	0.40	0.80		0.40	0.80	0.80	
0.19	0.32	0.05	0.15	0.21	0.05	0.22	0.05	0.10	0.05		0.09	0.08	0.10	0.18	0.10	0.05	0.10	0.09	0.05						
1.89	1.07	1.18	1.02	0.74	0.33	0.68		0.49	0.28	0.51	0.65	0.51		0.27	0.14	0.14	0.22	0.29		0.49	0.22				
0.79	0.58	0.45	0.45	0.40	0.14	0.38	0.03	0.24	0.13	0.18	0.29	0.23	0.07	0.21	0.12	0.08	0.14	0.16	0.03	0.17	0.08				

Table 2. Length composition of South East Fishery pink ling catch, for all years, sectors and gear types for which data are available. Where more than one exists for a year and zone, these have been combined. "All" indicates that data from East and West sectors are combined. Shown as percentage caught-at-length.

Length-class percentages within individual year, sector and gear type																			
114	**115**	**116**	**117**	**118**	**119**	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**127**	**128**	**129**	**130**	**131**	**132**	**133**
0.49	0.38	0.59	0.16	0.43	0.27	0.27		0.22	0.22	0.05	0.11	0.22		0.05	0.05	0.05	0.05	0.11	
0.31	0.23	0.12	0.12	0.20	0.12	0.12	0.04	0.04	0.12	0.04									
				0.04	0.04	0.08													
			0.07			0.03									0.02				
		0.02	0.01													0.01		0.01	
				0.06															
		0.16																	
														0.01				0.01	0.01
0.12	0.28		0.14																
0.17	0.09	0.05	0.04	0.09			0.26		0.02										
	0.23	0.13	0.18			0.05		0.07	0.11	0.07	0.07		0.07						
		0.16																	
														0.01				0.01	0.01
0.05	0.11		0.10			0.02									0.01				
0.12	0.06	0.04	0.03	0.06			0.18		0.01							0.00		0.00	
	0.12	0.07	0.09	0.03		0.03		0.04	0.06	0.04	0.04		0.04						
0.23				0.23															
	0.65			0.65															
0.40														0.40		0.40			
0.05			0.05																
		0.05					0.07			0.05									
0.04		0.02	0.04				0.02			0.02									

Table 3. Percentage age composition data for pink ling in the South East Fishery. These are produced by applying an ALK to a length composition dataset. "*n* " values are those of the applied ALK.

				Age-class percentages within individual samples																	
Year	**Sector**	**Gear**	***n*=**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1979	Kapala	Research	399	0.35	2.72	27.92	23.96	14.03	9.95	6.80	2.76	1.87	2.25	1.44	0.65	0.50	0.44	0.27	0.79	0.83	0.04
1997	Kapala	Research	114	9.53	51.04	24.49	9.66	2.04	0.76	0.43	0.42	0.19	0.13	0.24	0.24	0.01	0.04	0.11	0.02	0.06	0.00
1994	East	Trawl	237	2.06	32.16	46.70	10.00	3.25	2.83	1.01	0.06	0.11	0.90	0.27	0.00	0.00	0.00	0.00	0.20	0.00	0.00
1995	East	Trawl	315	2.10	22.04	24.92	28.77	13.29	3.37	2.40	0.39	1.12	0.38	0.49	0.24	0.00	0.00	0.00	0.20	0.00	0.00
1996	East	Trawl	756	6.21	42.15	30.86	13.24	3.86	1.50	0.47	0.63	0.13	0.13	0.17	0.04	0.02	0.06	0.01	0.02	0.03	0.00
1997	East	Trawl	591	10.24	64.39	13.78	6.80	2.00	0.92	0.32	0.46	0.03	0.15	0.17	0.05	0.00	0.00	0.00	0.18	0.00	0.00
1998	East	Trawl	671	12.62	32.08	28.92	16.65	3.48	1.86	0.59	1.78	0.71	0.00	0.34	0.13	0.00	0.17	0.00	0.00	0.00	0.00
1995	West	Trawl	477	0.00	2.96	14.69	36.86	25.10	8.02	2.08	2.73	0.39	1.19	1.96	0.83	0.48	0.41	0.00	0.27	0.00	0.00
1996	West	Trawl	138	0.08	13.07	30.06	19.88	14.33	2.93	2.49	2.43	1.97	2.06	2.01	1.53	0.68	0.32	0.00	1.22	0.60	0.00
1997	West	Trawl	379	1.29	8.23	26.65	27.23	15.69	5.13	5.43	1.54	2.42	0.11	1.04	1.09	0.61	0.89	0.16	0.42	0.05	0.00
1998	West	Trawl	210	0.15	5.32	30.26	24.80	13.89	6.06	4.62	2.79	0.70	2.35	1.67	0.00	1.16	0.00	0.28	0.70	0.76	0.00
1979	All	Trawl	114	0.00	0.70	19.50	27.49	22.64	16.49	7.13	2.30	1.79	0.86	0.00	0.16	0.16	0.00	0.16	0.27	0.36	0.00
1994	All	Trawl	484	0.49	21.65	42.34	21.85	7.87	2.80	1.05	0.00	0.11	0.55	0.85	0.00	0.00	0.06	0.00	0.00	0.00	0.00
1995	All	Trawl	792	0.00	7.60	20.81	32.27	20.47	6.17	3.84	1.78	1.46	1.03	1.22	0.72	0.60	0.29	0.02	0.33	0.00	0.00
1996	All	Trawl	1005	4.21	30.21	30.18	19.05	7.42	3.24	1.16	1.34	0.57	0.46	0.37	0.05	0.07	0.17	0.02	0.13	0.06	0.00
1997	All	Trawl	970	3.69	25.77	27.56	24.10	7.68	3.16	1.64	1.19	0.89	0.57	0.80	0.70	0.18	0.28	0.14	0.11	0.02	0.00
1998	All	Trawl	881	6.03	18.00	28.01	23.93	9.39	4.35	2.70	2.03	0.41	1.33	1.01	0.00	0.00	0.00	0.14	0.00	0.00	0.00
1995	All	Nontrawl	792	0.00	0.00	1.11	8.42	10.20	15.04	11.38	8.55	8.81	6.85	7.40	9.18	5.32	0.76	0.00	1.33	0.00	0.00
1996	All	Nontrawl	1005	0.14	3.35	13.17	30.85	25.83	12.16	4.02	4.29	0.51	0.24	1.40	0.39	0.23	0.87	0.00	0.39	0.08	0.00
1997	All	Nontrawl	970	0.00	1.04	9.46	23.97	17.08	8.48	7.07	3.93	5.70	1.33	6.35	4.53	0.65	1.20	1.31	0.55	0.65	0.00
1998	All	Nontrawl	881	0.39	9.58	27.20	26.75	12.33	6.68	3.63	2.22	0.60	1.46	1.99	0.00	0.00	0.00	0.40	0.00	0.00	0.00
1999	East	Trawl		22.13	43.00	22.83	2.10	1.46	2.22	0.85	2.52	0.31	0.76	0.05	0.25	0.22	0.19	0.00	0.10	0.05	0.00
1999	West	Trawl		0.26	6.78	16.41	25.49	18.30	14.39	8.68	3.30	0.33	2.01	0.94	0.65	0.06	0.29	0.00	0.29	0.24	0.09
1999	All	Trawl		12.33	27.57	23.39	12.96	7.98	6.54	3.92	2.01	0.12	1.11	0.47	0.31	0.03	0.23	0.00	0.11	0.09	0.07

Table 3. Percentage age composition data for pink ling in the South East Fishery. These are produced by applying an ALK to a length composition dataset. "*n*" values are those of the applied ALK.

Age-class percentages within individual samples									
19	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
0.02	0.16	0.02	0.00	0.00	0.00	0.00	0.00	0.00	2.22
0.08	0.00	0.06	0.00	0.00	0.00	0.02	0.00	0.00	0.38
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.14
0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.27
0.10	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.34
0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.56
0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60
0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00	3.85
0.60	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	1.39
0.34	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.00	3.59
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15
0.00	0.00	0.00	0.00	0.05	0.00	0.44	0.00	0.00	0.74
0.45	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.04
0.18	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	2.15
1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.61
0.00	0.00	0.00	0.00	0.23	0.00	0.46	0.00	0.00	1.39
0.65	0.00	0.65	0.00	0.00	0.00	0.13	0.00	0.00	5.26
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.77
0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.85
0.21	0.17	0.25	0.21	0.00	0.24	0.00	0.00	0.00	0.39
0.13	0.10	0.11	0.12	0.00	0.09	0.00	0.00	0.00	0.21

Table 4a. Length composition of discards measured during the ISMP.

					Length-class percentages within individual samples																		
Year	**Sector**	**Source**	**Gear**	*n* =	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
1993	East	SMP	Trawl	5													62.72					12.89	
1994	East	SMP	Trawl	857						0.60				0.20	1.97	0.41	0.41	2.09	1.10	26.60	0.20	3.76	0.61
1995	East	SMP	Trawl	135															10.54			10.54	
1996	East	ISMP	Trawl	310											2.05		1.38	8.31	3.02		5.24	1.15	0.62
1997	East	ISMP	Trawl	242		1.77					0.12							1.57	0.06		3.21	0.31	1.07
1998	East	ISMP	Trawl	479											3.08		0.45			1.79			0.90
1992	West	SMP	Trawl	141																			
1993	West	SMP	Trawl	695																			
1994	West	SMP	Trawl	1290							0.01	0.01			0.01		0.00	0.01	0.01	0.01	0.02	0.01	0.02
1995	West	SMP	Trawl	4430																0.00		0.00	
1996	West	ISMP	Trawl	1516																			
1997	West	ISMP	Trawl	363																			
1998	West	ISMP	Trawl	329																			
1992	All	ISMP	Trawl	142																			
1993	All	ISMP	Trawl	700													8.88					1.83	
1994	All	ISMP	Trawl	2147						0.41	0.00	0.00		0.14	1.35	0.28	0.28	1.43	0.75	18.21	0.14	2.58	0.42
1995	All	ISMP	Trawl	4565															1.55	0.00		1.55	
1996	All	ISMP	Trawl	1826											0.90		0.61	3.64	1.32		2.30	0.50	0.27
1997	All	ISMP	Trawl	605		1.59					0.11							1.42	0.05		2.90	0.28	0.97
1998	All	ISMP	Trawl	808											2.51		0.36			1.46			0.73

Table 4a. Length composition of discards measured during the ISMP.

Length-class percentages within individual samples

35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
							23.97		0.42																
0.30	0.41	1.16	2.44	0.68	3.52	0.41	4.10	3.62	0.16	0.07	0.33	0.09	0.46	0.77	1.33	3.29	1.11	1.73	2.12	2.24	1.13	1.23	1.26	1.47	1.84
	6.09	3.83	1.01	1.42	0.35	14.60	1.04	10.91	3.11	1.04	1.38	2.07	2.07	3.11	2.42	2.42	0.69	1.38	0.69	0.69	1.04		1.38	1.04	1.04
4.63		1.20	1.89	7.62	3.55		5.71	0.71	3.75	0.56	0.97	2.39	4.70	2.29	2.07	2.60	1.24	2.86	1.85	2.16	2.22	2.45	1.65	2.59	2.93
5.07	6.76	5.14	5.78	4.71	5.44	8.71	6.98	1.65	2.04	0.36	5.30	2.73	1.18	4.13	2.44	2.69	3.74	3.83	6.25	2.04	2.67	0.47	0.47	0.57	0.22
1.34	4.71	2.24	4.42	3.42	2.97	6.16	1.91		0.45		0.73	2.09	2.93	5.02	7.11	5.12	7.74	7.21	12.13	4.39	4.39	2.93	2.93		1.46
																						0.71			
						0.02	0.02		0.05	0.07	0.02	0.22	0.04	0.18	0.10	0.02	0.16		0.32	0.48	0.48	0.32	1.12	0.16	0.72
0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.08	0.08	0.30	0.84	0.75	1.18	1.77	2.15	2.54	2.46	2.80	2.59	3.70	3.08	3.41	3.20	4.07
		0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.04	0.04	0.14	0.22	0.57	0.89	1.15	1.55	1.78	2.38	2.35	2.84	3.21	3.01	3.49	3.60	3.61
	0.00			0.00		0.00		0.06	0.03	0.03	0.13	0.25	0.54	0.73	0.93	1.28	1.84	2.71	2.72	3.76	3.44	4.30	4.03	4.08	4.00
								0.00		0.00	0.02		0.00	0.38	0.89	1.27	2.52	5.02	5.77	6.26	7.48	7.61	5.60	6.97	7.22
									0.13			2.38			2.51	4.64	9.15	4.51	2.26	9.02	15.79	2.26	15.79	4.51	6.77
					20.20																	0.57			
						0.02	3.41		0.11	0.06	0.02	0.18	0.03	0.15	0.08	0.02	0.14		0.28	0.42	0.42	0.27	0.96	0.14	0.62
0.21	0.28	0.80	1.67	0.47	2.42	0.28	2.81	2.48	0.14	0.07	0.32	0.33	0.55	0.90	1.47	2.93	1.56	1.96	2.33	2.35	1.94	1.82	1.94	2.02	2.54
	0.90	0.57	0.15	0.21	0.06	2.16	0.15	1.61	0.49	0.19	0.32	0.49	0.79	1.22	1.33	1.68	1.62	2.24	2.11	2.52	2.89	2.57	3.18	3.22	3.23
2.03		0.53	0.83	3.34	1.55		2.50	0.35	1.66	0.26	0.50	1.19	2.37	1.41	1.43	1.86	1.58	2.78	2.34	3.06	2.91	3.48	2.99	3.43	3.54
4.57	6.09	4.63	5.21	4.25	4.90	7.85	6.29	1.49	1.84	0.33	4.78	2.46	1.07	3.76	2.29	2.55	3.62	3.95	6.20	2.45	3.15	1.17	0.97	1.20	0.91
1.09	3.84	1.82	3.60	2.78	2.42	5.02	1.56		0.39		0.60	2.15	2.38	4.09	6.26	5.03	8.00	6.71	10.30	5.25	6.50	2.80	5.31	0.84	2.45

Table 4a. Length composition of discards measured during the ISMP.

Length-class percentages within individual samples																									
61	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**
1.40	1.83	1.80	2.17	1.37	1.81	1.04	0.74	0.92	1.17	0.81	1.35	0.81	0.47	0.54	0.48	0.78	0.55	0.34	0.51	0.30	0.50	0.27	0.20	0.21	0.17
1.38	1.04	0.35	1.04	1.73	0.69	1.04	1.04	1.04		0.69		0.69			0.69		0.69	0.69	0.35	0.35			0.35		
2.30	0.94	1.85	0.94	0.57	0.71	0.59	0.29	0.57	0.79	0.65	0.43	0.86	0.43			0.29	0.29	0.14				0.14	0.14		
0.09	0.37	0.05																							
0.71	0.71		1.42	0.71			2.84	2.84	2.84	2.84	2.13	2.84	4.96	2.13	3.55	2.84	1.42	4.96	2.84	2.84	2.84	7.09	4.26	5.67	4.26
0.64	0.32	1.12	0.48	1.37	1.12	0.48	1.53	1.67	1.85	1.76	2.88	2.02	4.41	3.13	3.37	5.05	6.75	3.44	3.37	3.86	4.65	5.07	2.89	2.49	2.40
3.96	3.32	2.68	2.49	2.73	2.82	2.79	2.38	2.77	2.69	3.06	2.05	3.36	2.97	2.23	1.92	2.36	1.61	1.02	0.79	0.71	0.87	0.96	0.62	0.78	0.68
3.44	3.06	3.43	3.04	2.95	3.46	3.16	3.44	3.29	2.87	3.01	2.34	2.26	2.49	2.06	1.91	1.76	1.79	1.42	1.85	1.71	1.38	0.86	1.03	0.79	1.11
3.83	3.97	4.24	4.74	4.22	3.67	3.39	3.26	3.53	3.00	2.55	2.13	1.76	1.85	1.58	1.23	1.25	1.14	0.67	0.89	1.22	0.94	1.06	0.58	1.15	0.78
5.97	7.23	6.22	3.98	4.99	5.11	5.23	2.74	1.00	0.50																
9.02	4.51	2.26		2.26	2.26																				
0.57	0.57		1.13	0.57			2.26	2.26	2.26	2.26	1.70	2.26	3.96	1.70	2.83	2.26	1.13	3.96	2.26	2.26	2.26	5.66	3.40	4.53	3.40
0.55	0.28	0.96	0.42	1.17	0.96	0.42	1.31	1.44	1.59	1.51	2.47	1.74	3.79	2.69	2.89	4.33	5.79	2.95	2.89	3.31	3.99	4.35	2.48	2.14	2.06
2.21	2.30	2.08	2.27	1.80	2.13	1.59	1.26	1.50	1.65	1.52	1.57	1.61	1.26	1.08	0.94	1.28	0.89	0.56	0.60	0.43	0.62	0.49	0.33	0.39	0.33
3.14	2.76	2.97	2.74	2.77	3.05	2.85	3.08	2.95	2.45	2.67	2.00	2.03	2.12	1.76	1.73	1.50	1.63	1.31	1.62	1.51	1.18	0.73	0.93	0.67	0.95
3.16	2.64	3.20	3.08	2.62	2.37	2.16	1.96	2.24	2.04	1.72	1.39	1.37	1.23	0.89	0.69	0.83	0.76	0.44	0.50	0.69	0.53	0.66	0.39	0.65	0.44
0.67	1.05	0.66	0.39	0.49	0.50	0.52	0.27	0.10	0.05																
1.67	0.84	0.42		0.42	0.42																				

Table 4a. Length composition of discards measured during the ISMP.

Length-class percentages within individual samples																									
87	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**	**111**	**112**
0.23	0.23	0.13	0.16	0.17	0.17	0.07	0.07	0.07	0.10	0.01		0.11	0.07	0.07	0.13	0.07		0.07	0.07	0.07			0.07		0.01
	0.35																								
		0.14	0.14	0.14				0.14														0.14			
3.55	4.26	3.55	2.13	0.71	2.13	3.55		1.42	1.42	0.71	0.71	0.71	0.71	0.71	0.71		2.13								
2.17	1.77	1.44	3.05	1.85	1.61	0.56	0.96	0.96	0.80	1.69	1.29	1.05	0.48	1.12	1.20	0.16	0.64	0.80	0.40	0.32	0.16	0.72	0.16		
1.33	0.83	0.32	0.53	0.36	0.41	0.47	1.46	0.32	1.03	0.07	0.58	0.61	0.51		0.25	0.33	0.21	0.11		0.03	0.07		0.07	0.07	0.07
0.77	0.71	0.46	0.63	0.55	0.38	0.69	0.48	0.28	0.47	0.45	0.29	0.42	0.28	0.17	0.26	0.30	0.26	0.25	0.16	0.15	0.10	0.08	0.16	0.06	0.09
0.34	0.55	0.33	0.13	0.60	0.36	0.44	0.24	0.10	0.19	0.44	0.26	0.30	0.11	0.13	0.13	0.23	0.28	0.13	0.11	0.15	0.05	0.05	0.27	0.11	0.11
2.83	3.40	2.83	1.70	0.57	1.70	2.83		1.13	1.13	0.57	0.57	0.57	0.57	0.57	0.57		1.70								
1.86	1.52	1.24	2.62	1.59	1.38	0.48	0.83	0.83	0.69	1.45	1.10	0.90	0.42	0.96	1.03	0.14	0.55	0.69	0.34	0.28	0.14	0.62	0.14		
0.58	0.42	0.19	0.28	0.23	0.25	0.19	0.50	0.15	0.39	0.03	0.18	0.27	0.21	0.05	0.17	0.15	0.07	0.08	0.05	0.05	0.02		0.07	0.02	0.03
0.66	0.66	0.39	0.54	0.47	0.33	0.58	0.41	0.24	0.40	0.38	0.24	0.36	0.24	0.15	0.23	0.26	0.23	0.21	0.14	0.13	0.08	0.07	0.14	0.05	0.07
0.19	0.31	0.25	0.13	0.40	0.20	0.25	0.13	0.12	0.10	0.25	0.15	0.17	0.06	0.07	0.08	0.13	0.16	0.07	0.06	0.09	0.03	0.09	0.15	0.06	0.06

Table 4a. Length composition of discards measured during the ISMP.

Length-class percentages within individual samples																				
113	**114**	**115**	**116**	**117**	**118**	**119**	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**127**	**128**	**129**	**130**	**131**	**132**	**133**
	0.07	0.07																		
																0.71				
0.24	0.48		0.16	0.32		0.16	0.16	0.16	0.16		0.16									
	0.07					0.07														
0.13	0.06		0.03			0.02			0.04											
	0.05	0.05	0.05		0.13	0.05							0.05							
																0.57				
0.21	0.42		0.14	0.28		0.14	0.14	0.14	0.14		0.14									
	0.07	0.05				0.02														
0.11	0.05		0.03			0.02			0.03											
	0.03	0.03	0.03		0.07	0.03							0.03							

Table 4b. Age composition of discards measured during the ISMP. "*n* " values are those of the applied ALK.

Year	Sector	Source	Gear	*n* =	Age-class percentages within individual samples																
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1994	East	SMP	Trawl	237	25.77	38.01	15.77	8.05	4.61	2.36	1.68	0.68	0.40	0.36	0.33	0.24	0.07	0.07	0.00	0.10	0.00
1995	East	SMP	Trawl	315	56.72	13.86	8.28	12.65	3.63	1.48	1.46	0.33	0.78	0.15	0.22	0.44	0.00	0.00	0.00	0.00	0.00
1996	East	SMP	Trawl	756	38.48	36.90	16.48	5.98	1.09	0.38	0.13	0.08	0.06	0.00	0.07	0.00	0.00	0.18	0.00	0.00	0.00
1997	East	SMP	Trawl	591	56.18	42.90	0.88	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	East	SMP	Trawl	671	27.05	49.09	19.49	4.26	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	West	SMP	Trawl	484	0.48	10.83	29.06	23.34	14.81	5.75	3.74	0.36	3.28	2.83	2.10	1.08	0.00	0.52	0.26	0.18	0.07
1995	West	SMP	Trawl	477	0.00	3.20	14.13	36.23	22.72	7.81	2.18	2.61	0.57	1.15	2.99	1.64	1.26	0.28	0.00	0.35	0.00
1996	West	SMP	Trawl	138	0.25	17.26	36.66	22.03	9.25	2.35	2.11	2.80	1.12	0.88	0.72	0.80	0.24	0.10	0.00	0.44	0.44
1997	West	SMP	Trawl	379	3.44	34.12	49.06	12.46	0.82	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	West	SMP	Trawl	210	0.65	14.88	56.26	27.38	0.38	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	All	ISMP	Trawl	484	17.34	28.82	20.00	13.90	8.93	3.36	1.97	0.22	1.52	1.30	0.92	0.46	0.00	0.21	0.13	0.11	0.00
1995	All	ISMP	Trawl	792	1.72	7.43	21.56	28.50	17.23	6.58	4.11	2.33	1.63	1.18	1.87	1.44	1.39	0.25	0.22	0.30	0.00
1996	All	ISMP	Trawl	1005	18.49	27.00	26.65	16.33	5.53	2.17	0.62	0.86	0.33	0.32	0.31	0.05	0.16	0.13	0.06	0.08	0.09
1997	All	ISMP	Trawl	970	50.61	41.43	6.89	0.99	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	All	ISMP	Trawl	881	22.07	44.07	26.16	7.49	0.16	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4b. Age composition of discards measured during the ISMP.

Age-class percentages within individual samples										
18	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.74
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69
0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.62
0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	2.25
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59
0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08
0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.16	0.00	0.00	0.62
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Total catch for otter trawl for both East and West sectors, and nontrawl for sectors combined. Figures are not yet available for 1999. Discard ratios (%) are given where available.

Total catch (otter trawl), nontrawl catch (Danish seine) and discard ratios (otter trawl)							
	Trawl (kg)			**Nontrawl**	**Trawl discard ratio (%)**		
Year	**East**	**West**	**All**	**All**	**East**	**West**	**All**
1977	108130	41870	150000				
1978	144170	55830	200000				
1979	144170	55830	200000				
1980	216250	83750	300000				
1981	288340	111660	400000				
1982	252300	97700	350000				
1983	324380	125620	450000				
1984	549280	212720	762000	11000			
1985	490170	189830	680000	54000			
1986	488010	188990	677000	86000			
1987	604070	233930	838000	88000			
1988	516850	200150	717000	103000			
1989	547840	212160	760000	115000			
1990	481520	186480	668000	82000			
1991	529820	205180	735000	82000			
1992	472150	182850	655000	274000			
1993	746800	289200	1036000	615000	0.22		0.18
1994	754720	292280	1047000	496000	0.92	0.01	0.66
1995	1016390	393610	1410000	415000	1.46	0.345	1.06
1996	1044500	404500	1449000	591000	2.16	16.381	6.11
1997	1265800	490200	1756000	224000	8.22	4.133	6.85
1998	1219670	472330	1692000	202000	1.12	1.825	1.41

Table 6. Pink ling length-weight relationships from specified data-sets 1979-1996 ($W=aL^b$).

Sector	Year	Sex	*n*=	a (g.cm^{-1})	b	Source
All	1979-87	all	560	1.17E-03	2.736	Lyle and Ford 1993
All	1979-87	males	259	5.23E-03	3.004	Lyle and Ford 1993
All	1979-87	females	195	5.10E-03	2.495	Lyle and Ford 1993
West	1987-89	all	1167	2.80E-03	3.15	Smith et al 1995
West	1987-89	males	500	2.80E-03	3.15	Smith et al 1995
West	1987-89	females	574	3.20E-03	3.12	Smith et al 1995
East	1982-96	all	1397	1.93E-03	3.153	This paper
West	1982-85	all	371	2.78E-03	3.157	This paper
All	1982-96	all	1768	2.93E-03	3.139	This paper

Table 7. Growth parameters (von Bertalanffy) for Australian and New Zealand ling data, taken from the literature.

Year	Sex	Linf (cm)	K (yr^{-1})	t0 (yr)	Source
1970's	Females	126	0.151	-0.791	Morison et al 1999
1970's	Males	112.5	0.167	-0.769	Morison et al 1999
1980's	Combined	134.9	0.096	-1.39	Withell & Wankowski 1989
1990's	Females	117.8	0.14	-2.19	Morison et al 1999
1990's	Males	96.2	0.198	-1.83	Morison et al 1999
1986-93	Females	160.1	0.076	-1.05	CR, Horn 1993
1986-93	Females	158.4	0.079	-0.7	BP, Horn 1993
1986-93	Females	125.7	0.113	-0.67	SP, Horn 1993
1986-93	Females	165.9	0.09	0.22	SI, Horn 1993
1986-93	Males	119	0.108	-1.24	CR, Horn 1993
1986-93	Males	123.2	0.128	0.28	BP, Horn 1993
1986-93	Males	95.1	0.194	0.16	SP, Horn 1993
1986-93	Males	146.1	0.087	-0.13	SI, Horn 1993
1979-97	Combined	99.9	0.186	-1.88	This paper (ALK's)

Table 8 Estimates of total mortality for East and West sectors calculated using a catch-curve analysis (following Butterworth et al, 1989).

Sector	Year							
	1979	**1983**	**1984**	**1985**	**1987**	**1994**	**1996**	**1997**
East	0.3373	0.0783	0.082	0.1455	-	0.4306	0.4936	0.3813
West	-	0.2657	0.2434	0.2158	0.2073	-	-	-
All								

Figure 1. South East Fishery area showing designated zones within the East and West sectors.

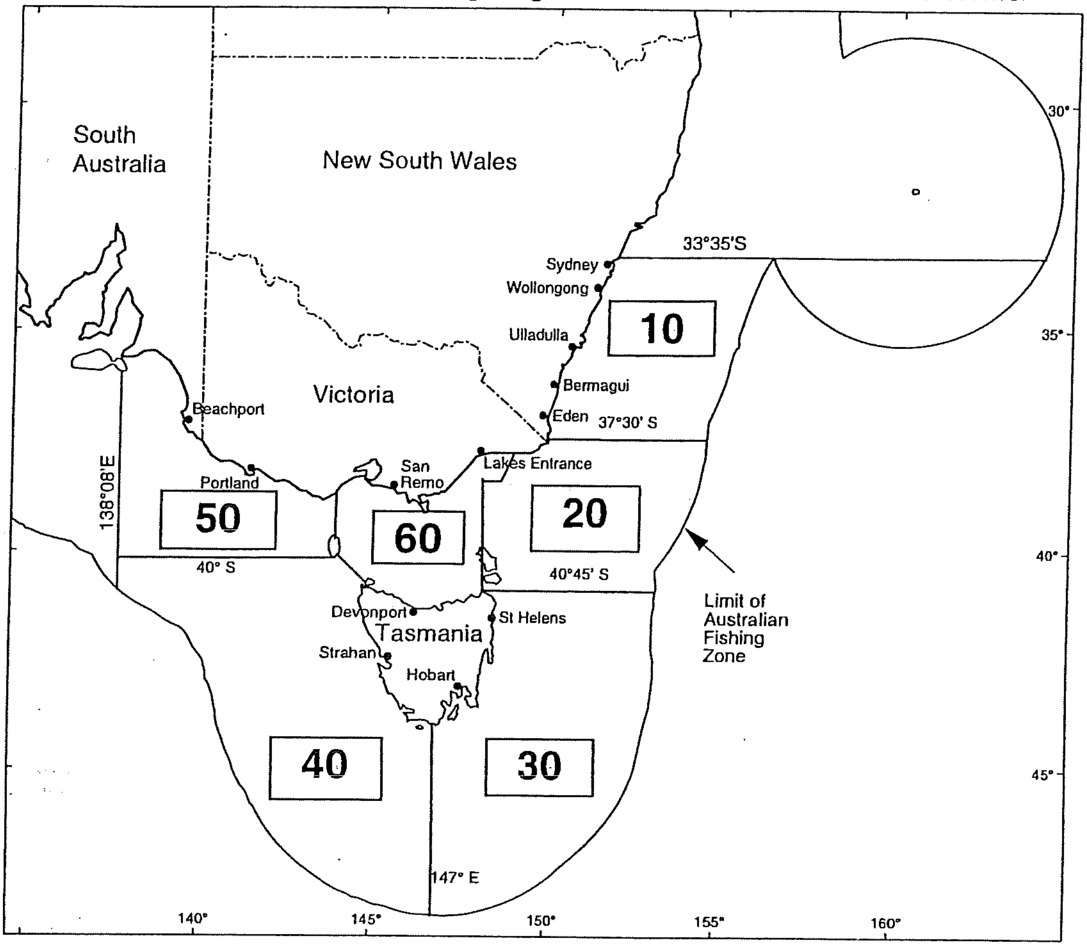


Figure 2. Percentage length composition of the South East Fishery pink ling catch, for all years, sectors and gear types where data are available. (From Table 2.)

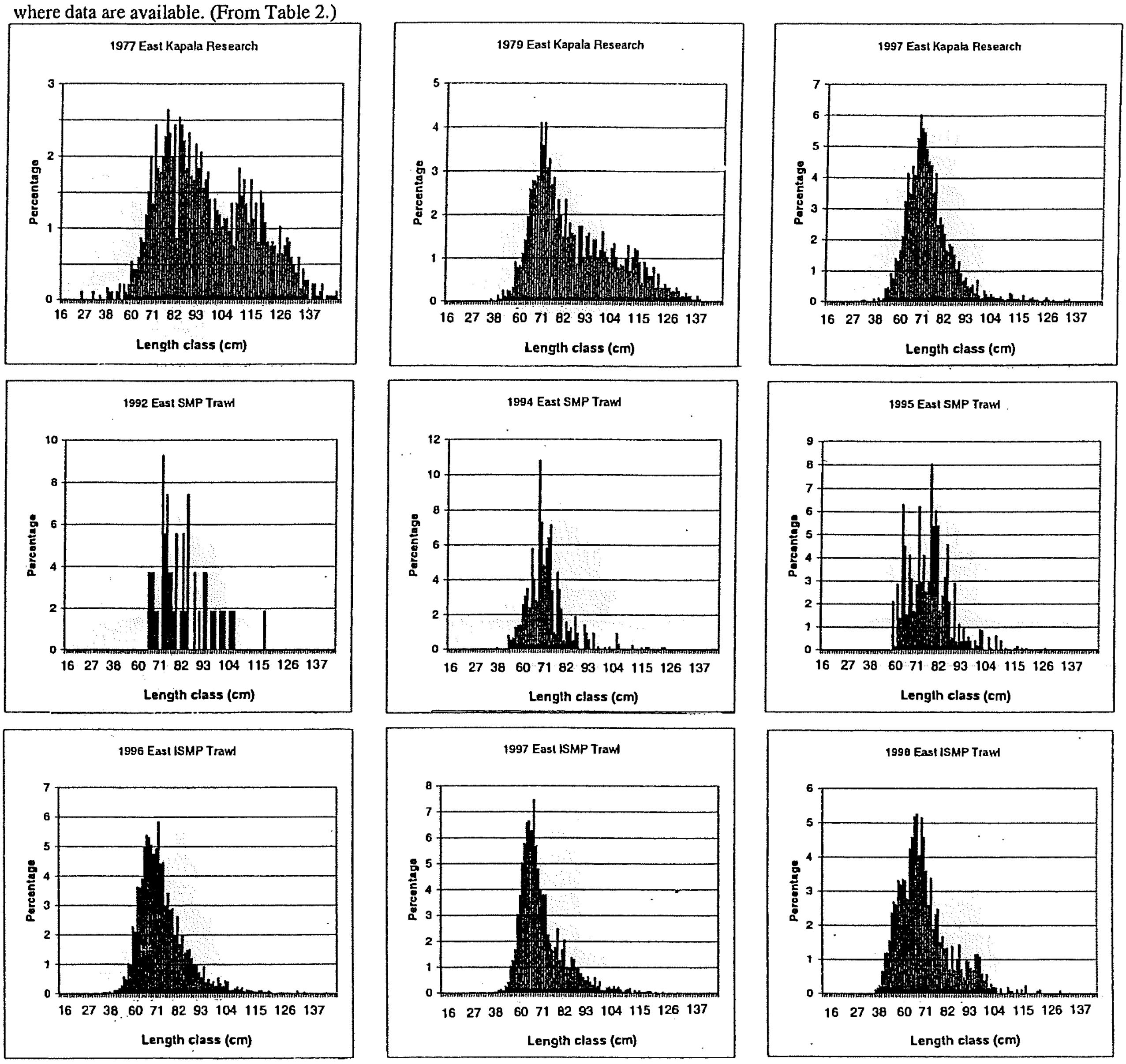


Figure 2 continued

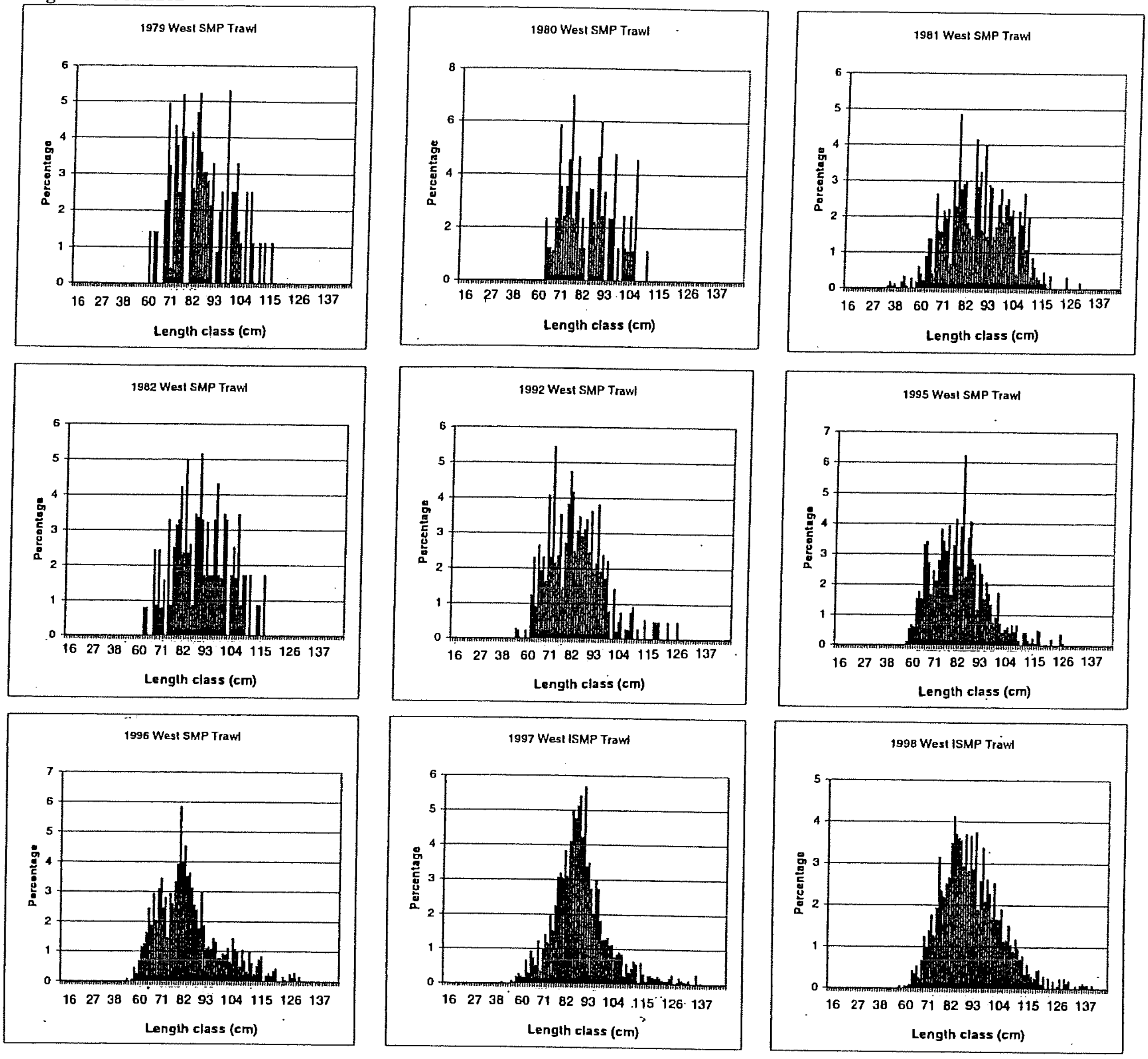


Figure 2 continued

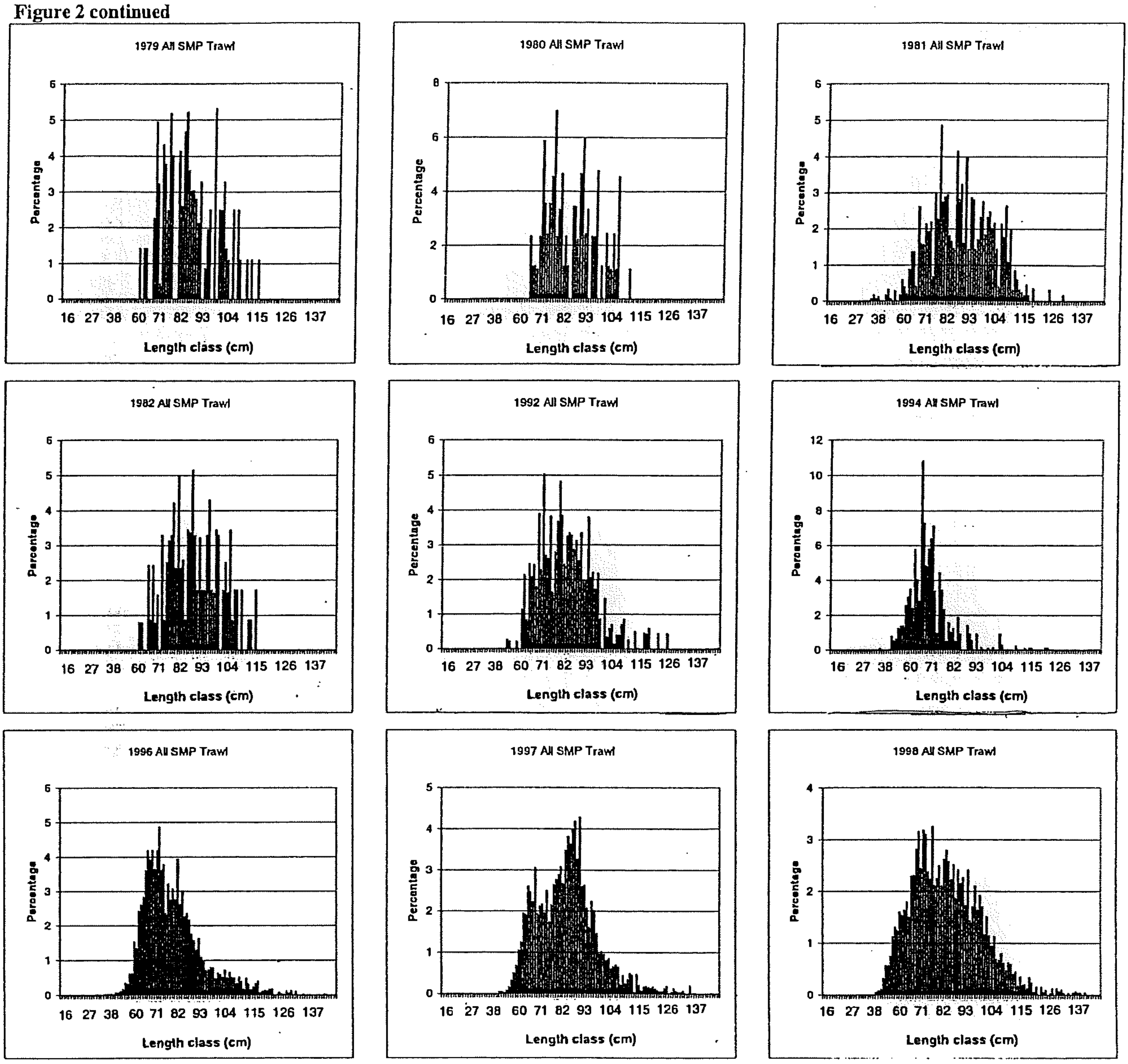


Figure 2 continued

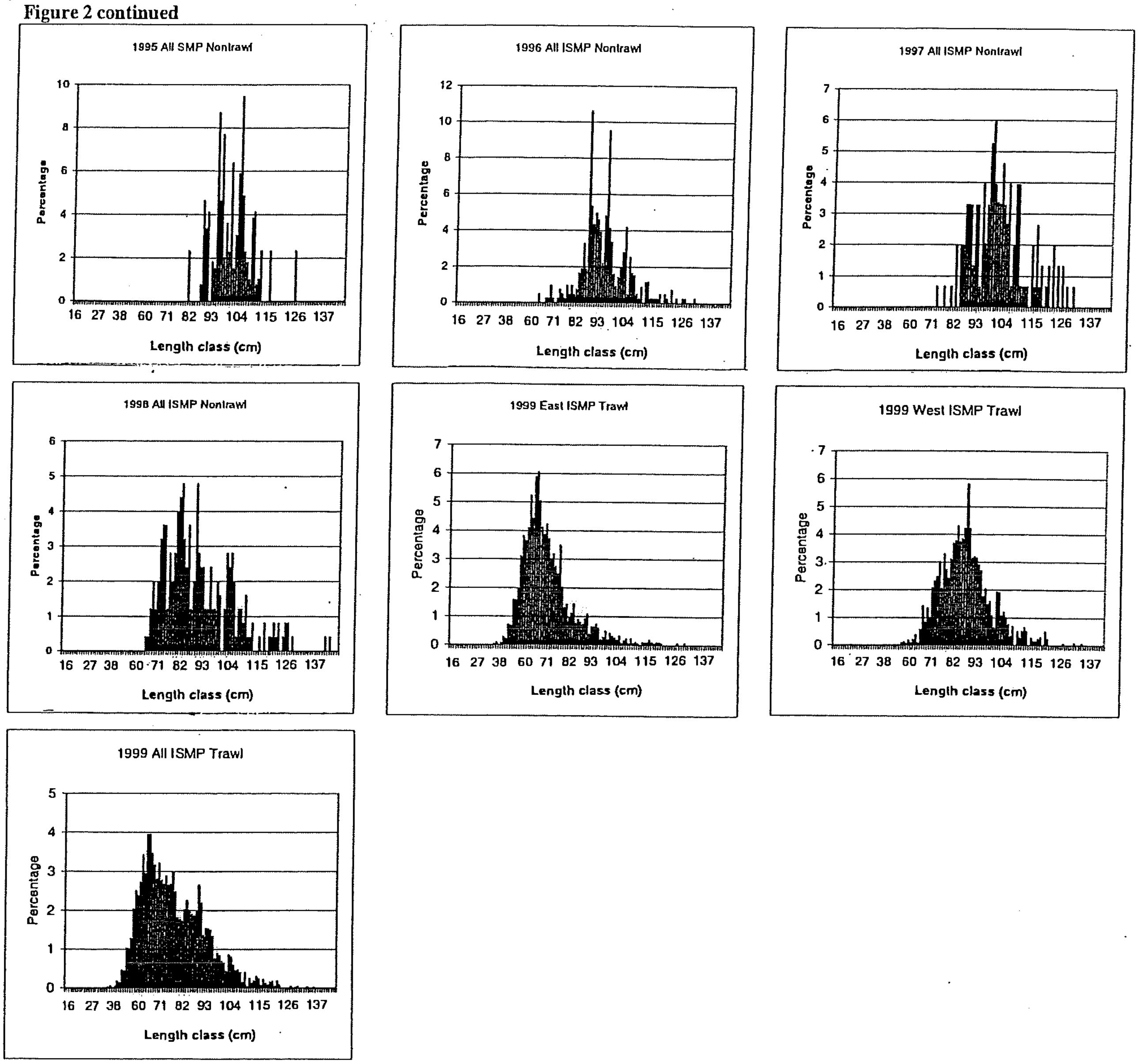


Figure 3. Percentage age composition data for pink ling in the South East Fishery. (Following Table 3.)

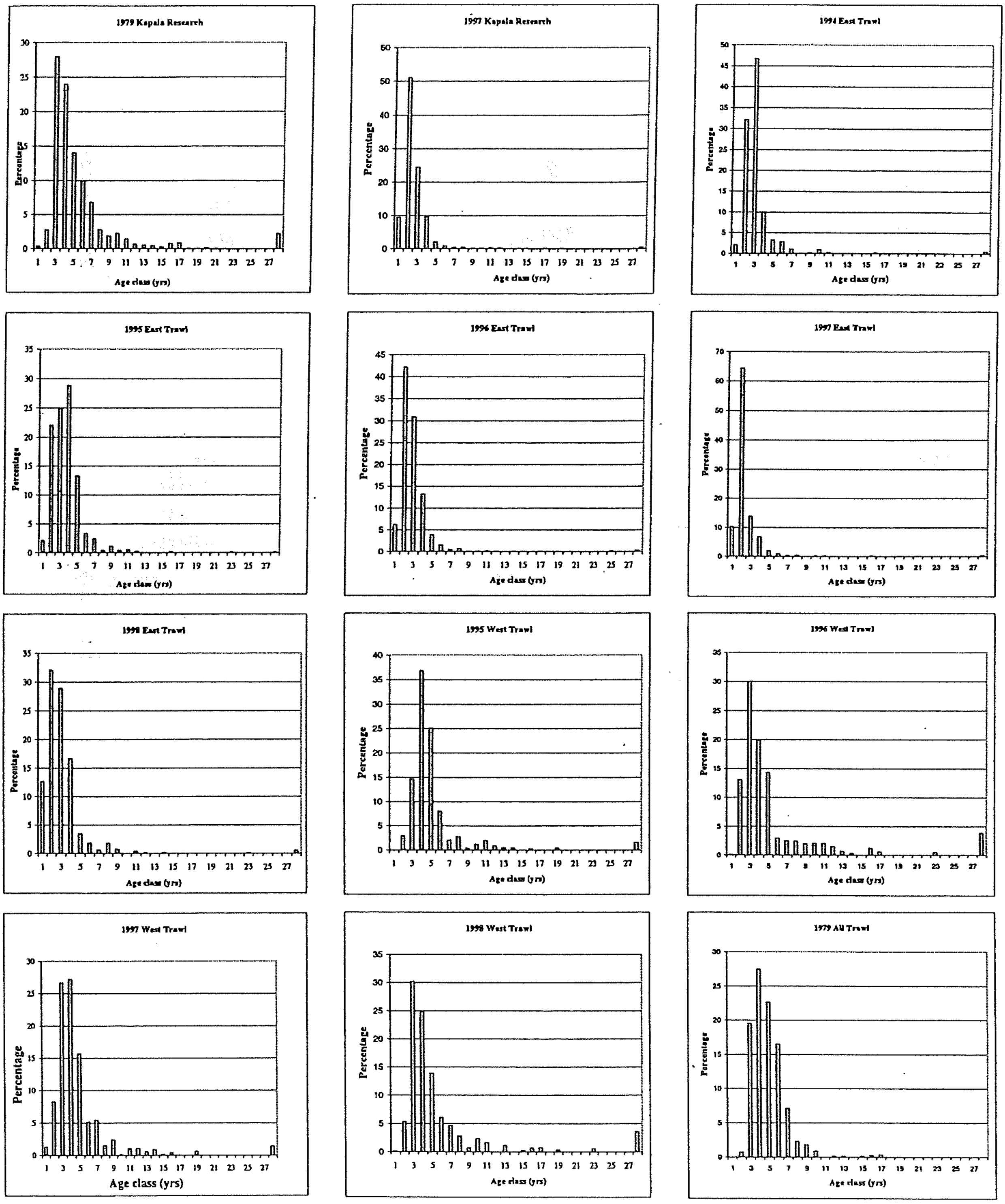


Figure 3 continued

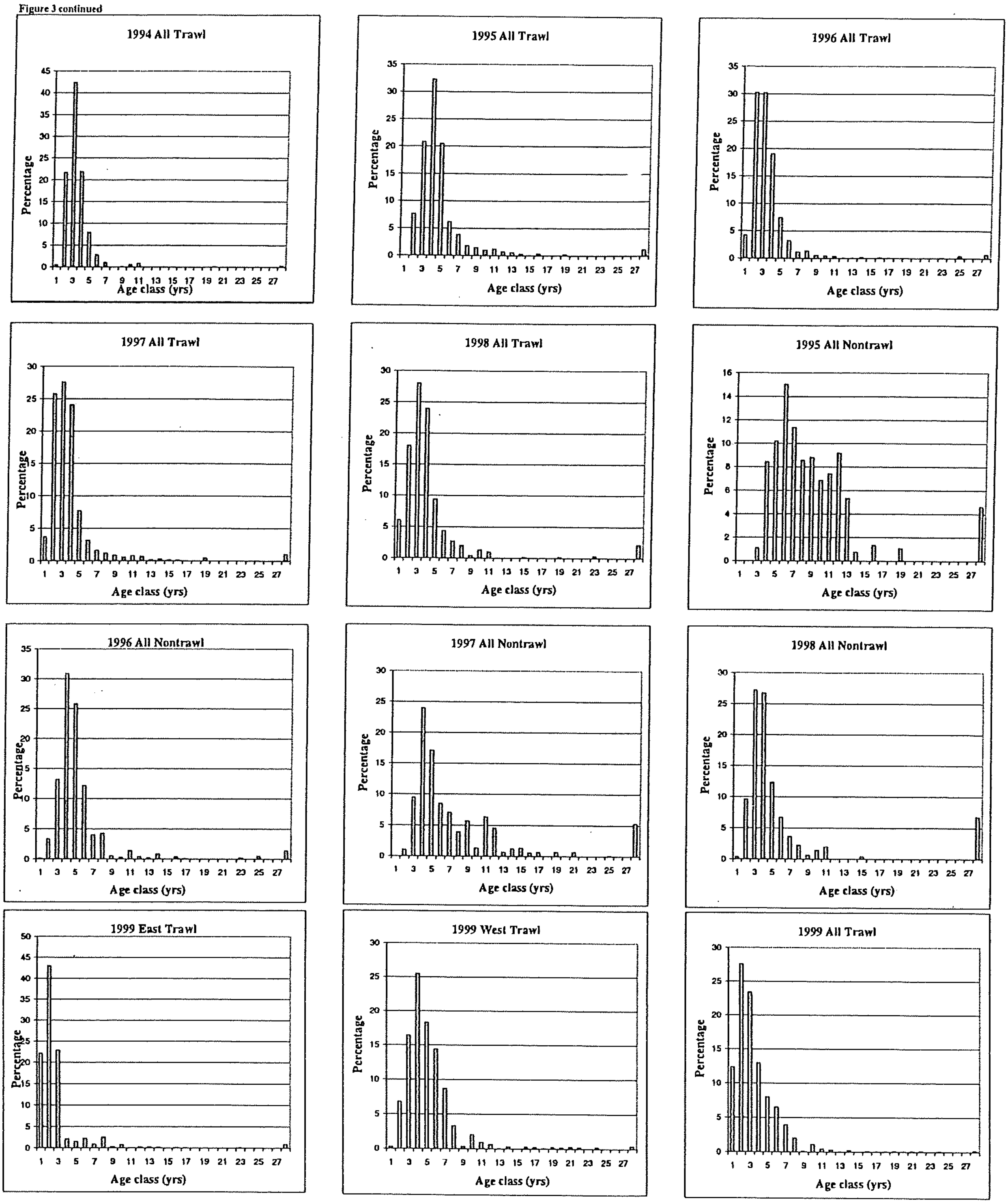


Figure 4a. Percentage length composition of discards from the South East Fishery pink ling catch, for all years, sectors and gear types where data are available. (From Table 4a.)

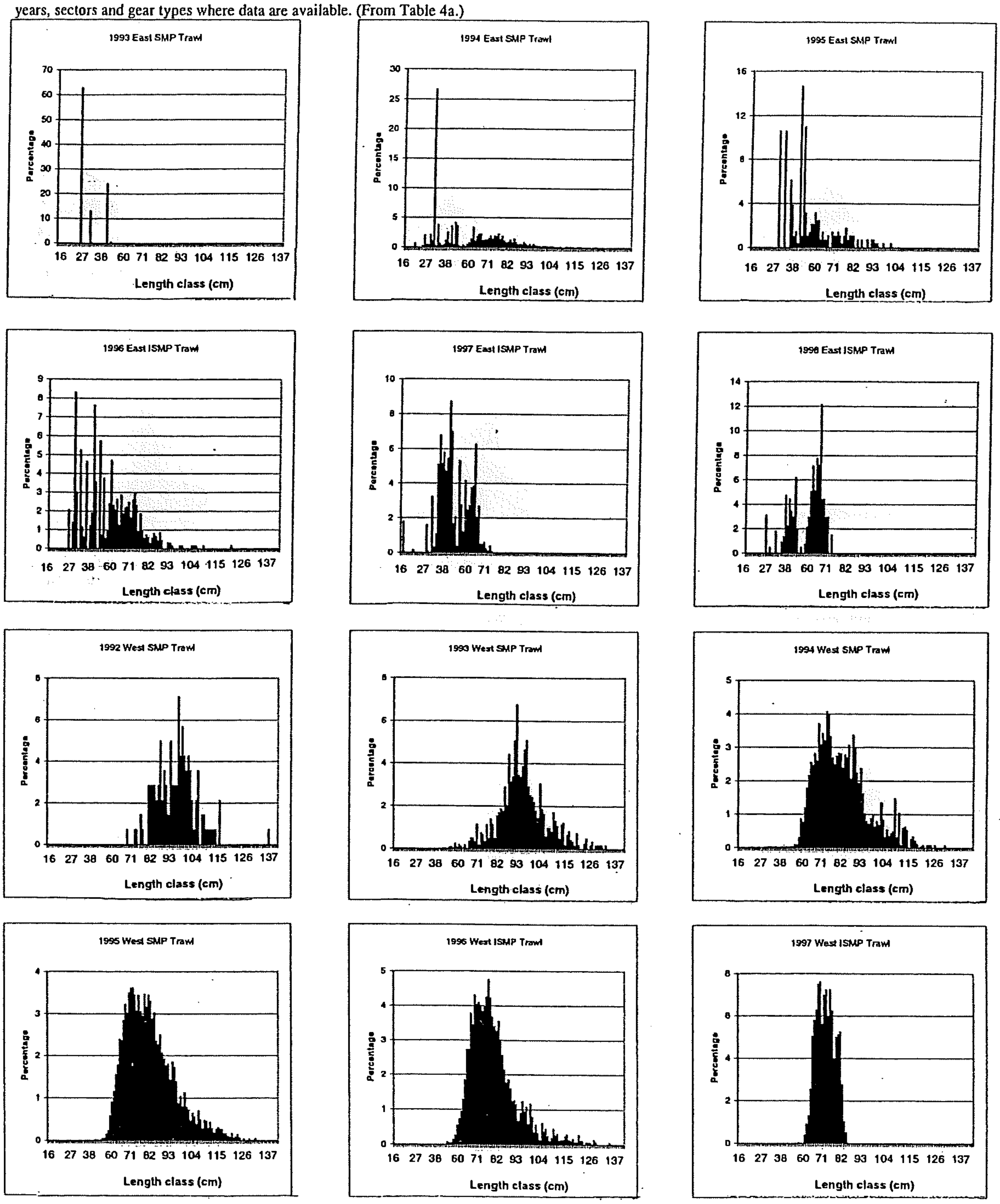


Figure 4a continued

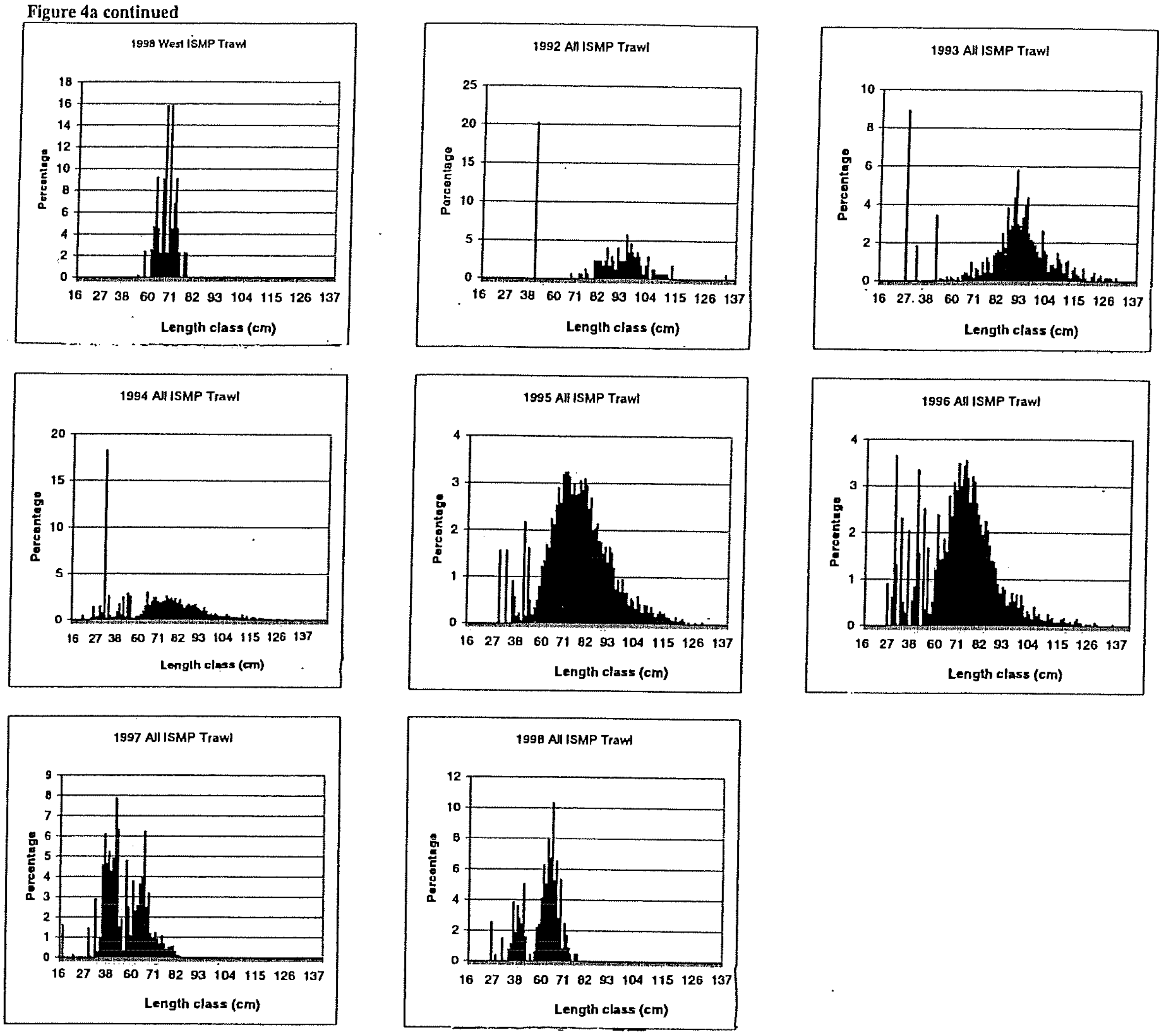
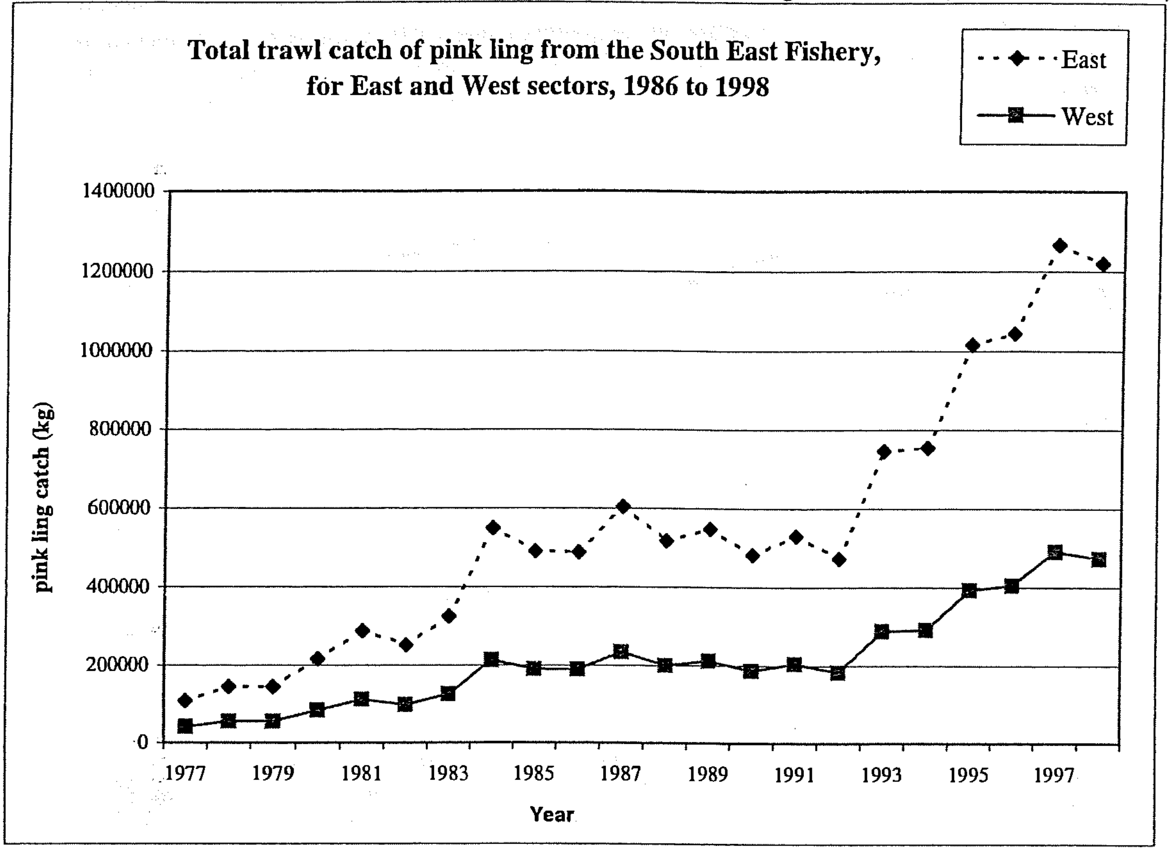


Figure 5. Total catch of pink ling from the South East Fishery by trawl gear (East and West sectors), and nontrawl (sectors combined), 1986 to 1998.Trawl catches from the SEF logbook records. (Presented in Table 5.)



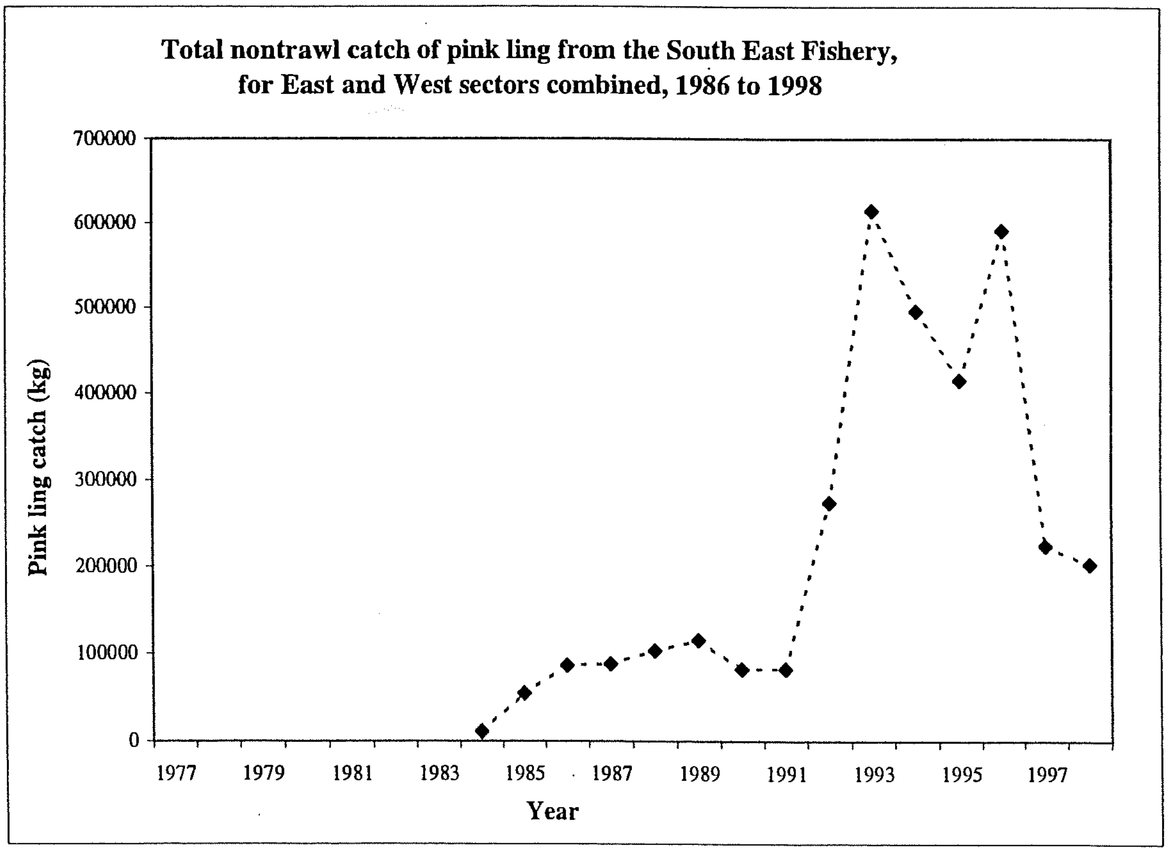


Figure 6a. Standardised CPUE for the eastern fishery (zones 10, 20, and 30) for all records with reported catches greater than 30 kg and for vessels which have been in the fishery for more than two years. "Geo. Mean" is simply the analysis of the geometric mean CPUE for each year. "Standardised" CPUE was : Ln(Catch-Effort) = Constant + Year + Month + Depth + Vessel + Depth x Month. The final term is an interaction term suggesting that the depth distribution of the fishery varies with season (Haddon 1999).

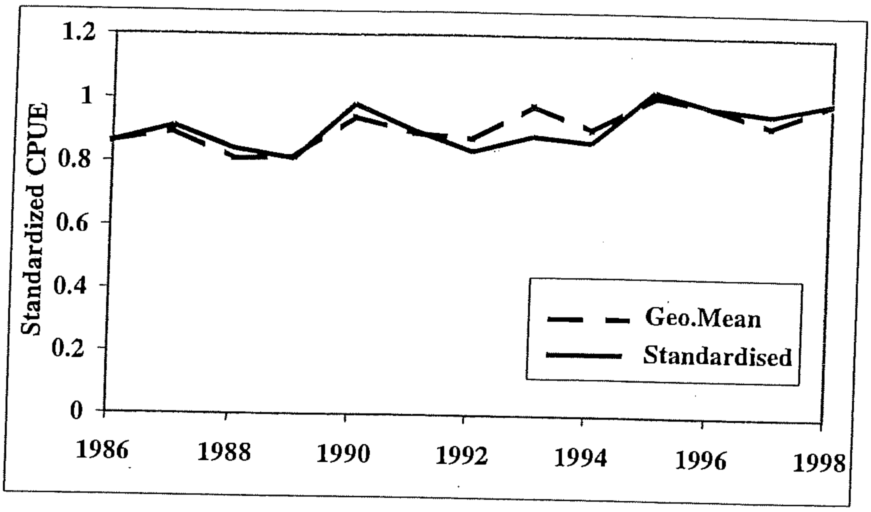
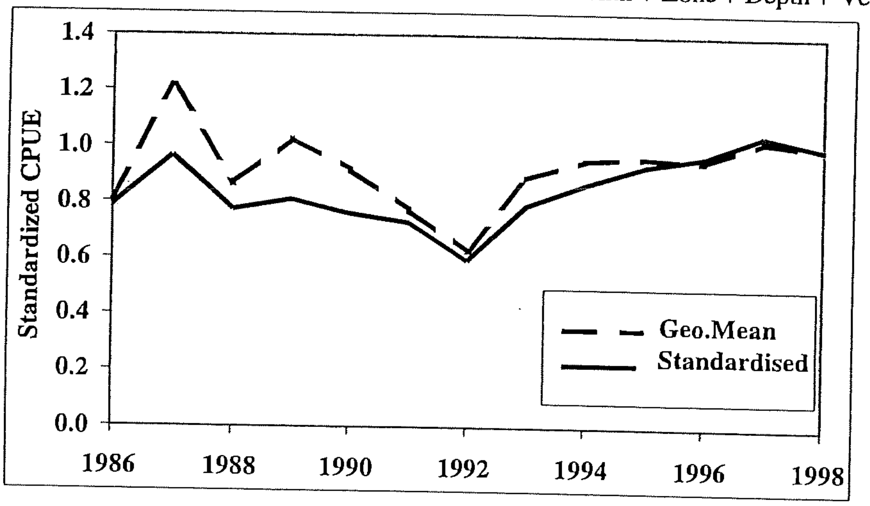


Figure 6b. Standardised CPUE for the western fishery (zones 40, 50, and 60) for all records with reported catches greater than 30 kg and for vessels which have been in the fishery for more than two years. "Geo. Mean" is simply the analysis of the geometric mean CPUE for each year. "Standardised" CPUE was : Ln(Catch-Effort) = Constant + Year + Month + Zone + Depth + Vessel (Haddon 1999).



Appendix 6

Additional CPUE standardization analyses for the South-East pink ling (*Genypterus blacodes*) fishery

K. Hodgson and M. Haddon

Additional CPUE Standardization Analyses for the South-East Pink Ling (*Genypterus blacodes*) Fishery.

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Summary

Previous examination of the Pink Ling fishery and the derivation of standardized indices of relative abundance as reported in Haddon (1999) provided impetus for further investigation. Two fisheries were recognized, a western fishery made up of the catches from zones 40, 50 and 60, plus an eastern fishery made up of the catches from zones 10, 20, and 30. Catch-effort data was initially standardised for these two fisheries by Haddon (1999) with data restrictions; only vessels with more than two years of data and records with reported catches of greater than 30 kg were included in the analyses.

For this report, all catch records were analysed, including small catches, and the results compared to the analyses using records of large catches (>30 kg) only. This was done firstly for all trawl vessels in the fishery and then for a sub-set of vessels; those deemed to be major or dominant players in the fishery. More complex models including interaction terms such as Zone*Depth were investigated in these analyses.

When all records were analysed, the statistically optimal model used for the eastern fishery was: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone x Vessel, describing 43 % of the catch-effort variation. The inclusion of the interaction term significantly changed the standardized catch rates between 1986 and 1992. This suggests a re-organisation of vessels among zones at this point, most likely a result of the introduction of ITQ's in 1992.

In the western fishery the best fitting model was: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Month x Depth, which successfully described 32 % of the catch-effort variation.

The main effect of the standardizations were to reduce the severity of the apparent fluctuations in real catch-rates through time. In the Western fishery there appears to have been a steady increase in catch rates since 1992. In the eastern fishery there appears to have been a slow and steady increase in catch rates since the fishery started

recording data, with two significant highs in 1990 and 1995. Whether this slight rise is enough to be biologically significant is debatable. For both fisheries the analysis of CPUE provides no negative impressions concerning the status of the fishery.

The standardised catch rate profiles for the western fishery using all records showed very little difference to that with data restrictions (>30 kg catches). In the eastern fishery the differences were more marked with catch rates considerably and consistently lower where all records were analysed; this is not surprising as only smaller catches were added to the analyses. The two eastern fishery analyses showed similar patterns overall, except between 1996 and 1998 where the two profiles estimated opposing directions of change. This may be related to a significant peak in the number of records reported with catches greater than 30 kg in 1997.

Excluding more minor boats in the fishery had the effect of removing statistically random noise from the data. As expected this had a negligible effect on the standardization of catch rates in both the eastern and western fisheries.

Examination of the distribution of Ling catches (Haddon 1999) suggested that in the eastern fishery there is a relatively shallow water fishery plus a more typical deeper water fishery. These two sub-fisheries, delineated at 200 m depth of catch, were analysed separately and standardised catch rates derived.

In the shallow fishery the best fitting model was: Ln(CE) = Constant + Year + Month + Vessel + Zone x Vessel, which described 25 % of the catch-effort variation when all records were used. There appears to be an overall steady decline in shallow water Ling biomass over time, except for a peak in the period between 1992 and 1995 which had relatively high standardized catch rates. The majority of shallow catches are small (<30 kg) and so when the data is restricted, N becomes very small (5,714 records) and the profile changes markedly. The peak between 1992 and 1995 is still outstanding for large catches only, but in contrast to that with all records, the overall the profile suggests a slight increase in catch rates over time.

The optimal statistical model for the standardisation of the deep fishery is: Ln(CE) = Constant + Year + Month + Zone + Vessel + Zone x Vessel, describing 23 % of the catch-effort variation when all records were used. The restriction of records to large catches made very little difference to the catch-effort profile, both displaying a slight increase over time.

The validity of these standardizations are questionable as the two depth zones may not reflect any real natural sub-division of the fish stock.

Introduction

Further analyses of the pink ling (*Genypterus blacodes*) commercial catch effort data were required to complement the new stock assessment analyses being carried out by CSIRO researchers. The objectives of this document are to provide catch-effort standardizations for pre-defined sub-sets of the data as required by particular questions being asked during the modelling process.

The particular analyses conducted were:

1. Repeat the standardization of catch rates for the eastern and western fisheries but including records where catches were less than 30kg.

2. Repeat standardization of catch rates as in 1. but only for those vessels which contributed appreciably to the fishery. Vessels were excluded from the analysis if they had been in the fishery (*i.e.* reporting Ling catch) for less than three years, caught an average of less than one tonne a year, had a median annual catch of less than 500 kg, or showed an obvious and radical change in fishing behaviour through time.

3. Conduct a standardization of catch rates for the eastern fishery separately for two depth ranges: less than 200m and greater than 200m. Catch rates less than 30 kg were included.

General Methods

The eastern fishery was defined as being zones 10, 20, and 30, while the western fishery was defined as being zones 40 and 50 (see Fig. 1, from Haddon, 1999). Zone 60 was excluded as less than 0.6% of the fishery catch comes from this region (Haddon 1999).

Analyses were conducted using records in the AFMA database which recorded pink ling catch. Only records from method 27 (single trawl) were used, and only where both catch and effort data were present. In previous analyses (Haddon 1999) observations were not restricted to single trawl, but were restricted to boats which had been in the fishery for more than 2 years and to catches greater than 30 kg (Haddon 1999).The absolute number of observations in these earlier analyses thus vary from those given here.

Ling Catch Effort Standardization.

Various statistical models were fitted to the available data with various combinations of factors. Because catch-effort data is typically considered to be at least log-normally distributed a General Linear Model was fitted to the natural logarithm of the catch-effort for each record (see Fig. 12 in Haddon, 1999). The models were built in a number of steps so as to monitor the increase in the amount of the variation in the catch-effort data described. The general log-linear model used was:

$$Ln(CE) = Const + a.Year + b.Month + c.Zone + d.DepthCat + e.VesselNo$$

or

$$\frac{C}{E} = e^{Const} e^{aYear} e^{bMonth} e^{cZone} e^{dDepthCat} e^{eVesselNo}$$

or subsets of this, or with the addition of interaction terms between depth and month, zone and month, or zone and vessel. The variables Year, Month, Zone, Vessel Number, and Capture Depth were all put into the analysis as dummy variables. The average depth of capture was restructured as a set of capture depth categories in the MS-Access database (Cat_Dep = Int(([Avg_Dep]/50)*50+25)). This was to avoid having to include some non-linear equation into the model when trying to account for the modal form of catch rates with depth (*cf.* Fig. 11, Haddon, 1999).

In all cases examined, Model 1 was limited to the factor Year (*Ln(CE) = Const + Year*). This is equivalent to and produces the same result as the analysis of geometric means.

All analyses were run using the GLM package inside Systat version 8, and this requires post-hoc hypothesis testing which was completed after the initial analysis to determine whether each term plays a significant part in determining the observed variation in catch-effort. By including Year as a dummy variable into the statistical model the parameter estimates for Year constitute the indices of relative abundance which are used in subsequent stock assessment modelling.

It should be noted that the output from a GLM does not guarantee that a relation exists between stock size and standardized catch per unit effort. It is possible that factors not included in the GLM model (through no information being available) may be obscuring any effects of changes in stock biomass. In this case, however, there are no other data available to be included in the statistical models so this analysis constitutes the most that can be done at present.

The Statistical Models

It is possible to define the so-called 'full model' for the set of factors being considered. This would include all of the factors and the entire set of interaction terms possible between them. Some of the interaction terms possible would be difficult to give a real interpretation and their value in describing the data is marginal. However, there is no doubt that the more parameters used in a statistical model the more likely we are to describe a larger proportion of the variation in the available data. But just adding more and more parameters to a model is not necessarily an improvement when there can be such things as parameter correlation. What is required is a compromise between the variability of the data described by the statistical model and its complexity.

One way of selecting such a compromise, which is becoming more and more accepted as such a criterion, is the use of the Akaike's Information Criterion (AIC). This is usually based around a maximum likelihood framework but, in the special case of a least squares estimation with normally distributed additive errors the AIC can be expressed as:

$$AIC\mathbf{1} = nLn\left(\hat{\sigma}^2\right) + 2K$$

$$\text{where} \qquad \hat{\sigma}^2 = \frac{\sum \varepsilon^2}{n}$$

(Burnham & Anderson, 1998)

Or analogously as,

$$AIC2 = Ln\left(\sum \varepsilon^2\right) + 2\left(\frac{K}{n}\right)$$

(Hilborn & Mangel, 1997)

where $\hat{\sigma}^2$ is the maximum likelihood estimator of σ^2, ε^2 is the estimated residual for the candidate model, K is the total number of estimated parameters, including the intercept and σ^2, and n is the total number of observations. The criterion is selected which gives rise to the smallest AIC (this includes negative numbers, thus -23001 is smaller than -23000).

Results:

1. Analysis of Eastern and Western single trawl fisheries, including all vessels and catches less than 30 kg.

Previously, catches of less than 30kg were excluded from the analyses in an attempt to focus on targeted fishing and major fishers, and away from small incidental catches or by-catch (Haddon 1999).

Inspection of the data revealed a significant number of small catch records in both the Eastern and Western fisheries (Table 1). Analyses were compared with and without the 30kg limit to investigate the importance of these small catches to the standardisation of catch rates.

In the eastern fishery Model 7 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel) described the greatest proportion of variability in the data- 43.6% (Table 2). It had the lowest AIC value of all models tested and thus accounted for the most variability in the data without becoming overly complex.

The standardized catch effort data (Model 7) and the simple geometric means (Model 1) showed different patterns of change through time (Figure 1). While the geometric means are variable, they suggest an overall decline in catch rate through time, and by inference a decline in stock biomass. Model 7 suggests a variable but slight overall increase in the relative catch rate (approx. 10%) over the 12 years of data, with two significant peaks around 1990 and 1995.

Model 5 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone) is Model 7 without the interaction term Zone*Vessel (Table 2). The two models show similar standardised catch rates except for the period 1986- 1991 (Figure 1). This period is prior to the quota system (introduced in 1992) and the proportion of vessels returning information is reported to be lower (Tilzey 1994). The difference in standardised catch rates may have been brought about by a re-distribution of vessels around the zones on the introduction of quotas.

In the western fishery the statistically optimal model was Model 8 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Month*Depth) (Table 3), accounting for the 31.7% of the variability in the data (Table 3). The main effect of the standardization was to reduce the severity of the change in catch rate that appeared to have occurred through time (compare Model 1, Figure 2). Model 5, which does not include the interaction term Month*Depth, had very similar standardized catch rates to Model 8.

The inclusion of the interaction term explained a further 3% only of the data variability, above the 28.7% explained by Model 5.

Western fishery annual standardized catch rates declined from 1986 reaching an overall low in 1992. After 1992 catch rates improved steadily to a maximum in 1997, almost double that of 1992 and 15% greater than that in 1986. In both fisheries, eastern & western, the standardized catch rates have declined slightly between 1997 and 1998 (Figures 1 & 2).

<u>Comparison with analyses using records of Pink Ling catches greater than 30 kg only.</u>

In the eastern fishery catch rate profiles for analyses conducted on all records ('All') and on records of catches greater than 30 kg only ('>30 kg') displayed similar patterns through time (Table 4, Figure 3). However, standardized catch rates for '>30 kg' were consistently lower than those for 'All' and were rather less severe in the apparent changes in CPUE (Figure 3). While the 'All' profile shows standardized CPUE above that of 1998 for almost 60% of the years analyzed, the '>30 kg' standardized CPUE are greater than 1998 in one instance only, 1995 (Figure 3). The two profiles change in different directions between 1996 and 1998; 'All' shows an increase between 1996 and 1997 when '>30 kg' shows a decrease, and vice versa between 1997 and 1998 (Figure 3).

In the western fishery the two profiles displayed a similar and consistent pattern (Table 4, Figure 4). The most obvious difference being the apparent 'smoothing' of the profile where catches less than or equal to 30 kg were excluded (Figure 4).

2. Analysis of Eastern and Western single trawl fisheries for major vessels.

The analyses in 1. were repeated using a sub-set of the data: records of catches by the major vessels contributing to the fishery only. Vessels were excluded from the analyses if they had been in the fishery (*i.e.* reporting Ling catch) for less than three years, caught an average of less than one tonne a year, had a median annual catch of less than 500 kg, or showed an obvious and radical change in fishing behaviour through time. This reduced the number of boats in the Eastern fishery analyses from 188 to 102, and from 82 to 47 in the Western fishery. The number of records in the analyses were reduced by approx. 7% in both the Eastern and Western fisheries (Table 5).

In the eastern region, Model 7 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel) described the greatest proportion of the available variability in the data- 41.7% (Table 6, Figure 5). Model 7 was also the optimal statistical model (Var% of 43.6), when records for all vessels were included (Table 2).

In the western area 30.8% of the catch-effort data was explained by Model 8 (Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Month*Depth) (Table 7). This model had the lowest AIC and described the greatest proportion of variability in the data when fitted to the full data-set (Table 3), as well as to the reduced data-set for dominant vessels only (Table 7).

The overall patterns of catch-effort for the eastern and western fisheries when dominant vessels only were included are the same as those where records for all vessels were included (Figure 7). Exclusion of the more minor vessel catch records from the data-set does not seem to have altered the fit of the models.

2. Analysis of Eastern Fishery in Two Depth Zones.

Inspection of the spatial distribution of Ling catches suggest two distinct fisheries in the eastern region, an inshore shallow fishery and an offshore fishery (Haddon 1999). Catches in the eastern region were therefore divided into shallow (occurring in less than 200 m depth) and deep (greater than or equal to 200 m depth) sub-fisheries and catch rates standardised separately.

In the Eastern fishery 21,996 of the 76,459 records (29%) were catches taken in shallow water. 74% of shallow catches were less than 30 kg, compared to only 28% in the deep water sub-fishery (Table 8).

In both depth categories Model 6 (Ln(CE) = Constant + Year + Month + Vessel + Zone + Zone*Vessel) provided the statistical best fit to the data, explaining 25.4% of the variability in the shallow fishery and 23.2% in the deep fishery (Table 9 & 10).

Catch rates in the shallow area were highly variable, increasing from 1991 to 1995 but then dropping rapidly between 1995 and 1996 to an overall low in 1998 (Figure 8). The standardised annual catch rate in 1998 was only 67% of that in 1985 and 54% of that in 1994 (Table 9, Figure 8).

In the deeper water catch rates were less variable (Figure 9).Generally, standardised catch rates have increased over the time period by about 20% since 1986 (Figure 9).

Comparison with analyses using records of Pink Ling catches greater than 30 kg only.

In the eastern shallow fishery catch rate profiles for analyses conducted on all records ('All') and on records of catches greater than 30 kg only ('>30 kg') showed a similar pattern, but large differences in the standardized catch rate values (Figure 10). The standardized catch rates for '>30 kg' were consistently and significantly lower than those for 'All'. Both analyses showed a significant jump in catch rates after 1992, decreasing again after 1995 (Figure 10). When the period between 1992-96 is ignored, the analysis of all records shows a decline in catch rates over time, while the analysis of large catches only suggests an increase in catch rates (Figure 10).

The large differences between the two analyses for the eastern shallow fishery are expected when such a large number (74% of the total, Table 8) are lost with the exclusion of catches less than 30 kg; only 5,714 records are left for analysis. In the deep fishery the exclusion of small catches had less of an impact on N, 38,978 records were still available for analysis, 72% of the total (Table 8). The two deep fishery the profiles were very similar and displayed a consistent pattern through time (Figure 11).

It is possible that the standardization of the data from the two depth zones does not reflect a natural sub-division of the fishery/fish stock. If this is the case the validity of the standardization is questionable.

References

Burnham, K.P. & D.R. Anderson (1998) *Model Selection and Inference. A practical Information-Theoretic approach.* Springer-Verlag, New York Ltd. 353p.

Haddon, M. (1999) *Standardisation of Catch/Effort data from the South-East Pink Ling fishery.* SEFAG Working Group Paper: May 1999. 16 p.

Hilborn, R. & M. Mangel (1997) *The Ecological Detective: Confronting Models with Data.* Princeton University Press, Princeton, New Jersey. 315 p.

Table 1. Number of records (N) for the Eastern and Western fisheries where Pink Ling catch is less than or equal to 30 kg and where catch is greater than 30 kg. %T is the percentage of the total no. of records in each of these categories.						
	Eastern fishery		**Western fishery**		**Both**	
Catch	**N**	**%T**	**N**	**%T**	**N**	**%T**
≤30 KG	31,914	41.6	8,558	28.9	40,472	38.1
>30 KG	44,841	58.4	21,059	71.1	65,900	61.9
TOTAL	76,755	100.0	29,617	100.0	106,372	100.0

Table 2. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for all records. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 7.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel**
Model 8	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	47.50	89.29	670.78	233.50	232.70	217.22	**166.77**	133.92
Resid SS	147589.9	144810.3	105520.5	86436.0	86246.5	85495.9	**83523.8**	84457.4
df Params	12	23	46	233	235	257	**353**	428
DF Resids	76742	76731	76412	76225	76223	76201	**76105**	76030
N	76755	76755	76459	76459	76459	76459	**76459**	76549
Var%	0.7	2.6	28.8	41.6	41.8	42.3	**43.6**	43.0
# Param	14	25	48	235	237	259	**355**	430
AIC	50211.874	48774.541	24727.313	9847.666	9683.856	9059.523	**7467.215**	8386.007
AIC2	11.903	11.884	11.568	11.373	11.371	11.363	**11.342**	11.355
DVAR%	0.0	1.9	26.2	12.8	0.2	0.5	**1.8**	1.2
YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	1.1936	1.1549	0.9493	0.9268	0.9296	0.9361	**0.8976**	0.9503
1987	1.2411	1.1960	0.9666	1.0161	1.0192	1.0408	**0.9734**	1.0534
1988	1.2486	1.1747	0.9900	1.0171	1.0131	1.0243	**0.9589**	1.0460
1989	1.2399	1.1889	0.9637	0.9352	0.9296	0.9361	**0.8590**	0.9493
1990	1.5023	1.4888	1.3034	1.2995	1.2892	1.3008	**1.1770**	1.3100
1991	1.3979	1.3593	1.1841	1.2105	1.2044	1.2349	**1.0887**	1.2238
1992	1.2662	1.2337	1.1549	1.0151	1.0171	1.0253	**1.0010**	1.0151
1993	1.3840	1.3512	1.2436	1.0274	1.0305	1.0336	**1.0141**	1.0367
1994	1.2789	1.2548	1.2032	1.0182	1.0274	1.0284	**1.0294**	1.0192
1995	1.2776	1.2624	1.3205	1.1653	1.1735	1.1818	**1.1924**	1.1759
1996	1.0523	1.0693	1.0909	0.9950	0.9970	1.0020	**0.9940**	1.0171
1997	1.0243	1.0222	1.0876	1.0450	1.0481	1.0492	**1.0263**	1.0629
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**	1.0000

Table 3. GLM results for the Western Pink Ling fishery (Zones 40 and 50) for all records. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 8.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel
Model 8	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth**

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	47.99	81.48	184.44	92.78	92.99	93.17	68.42	**42.23**
Resid SS	31731.6	30422.4	25053.9	22970.0	22902.7	22331.6	22650.7	**21924.3**
df Params	12	23	45	126	127	138	179	**321**
DF Resids	29604	29593	29423	29342	29341	29330	29289	**29147**
N	29617	29617	29469	29469	29469	29469	29469	**29469**
Var%	1.9	6.0	22.0	28.5	28.7	30.5	29.5	**31.7**
# Param	14	25	47	128	129	140	181	**323**
AIC	2070.52	844.64	-4689.09	-7086.19	-7170.66	-7892.81	-7392.71	**-8069.26**
AIC2	10.366	10.325	10.132	10.051	10.048	10.023	10.040	**10.017**
DVAR%	0.0	4.1	16.0	6.5	0.2	1.8	0.8	**3.0**

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	0.8187	0.8746	0.8049	0.8547	0.8624	0.8212	0.8573	**0.8462**
1987	1.2190	1.1877	1.0202	0.9773	0.9831	0.9231	0.9646	**0.9704**
1988	0.8878	0.9389	0.7906	0.7550	0.7596	0.7327	0.7535	**0.7423**
1989	1.1152	1.1377	0.8994	0.7866	0.7835	0.7423	0.7641	**0.7780**
1990	0.8344	0.8179	0.6551	0.7005	0.6942	0.6610	0.6771	**0.6880**
1991	0.8278	0.8538	0.7453	0.7364	0.7416	0.7161	0.7276	**0.7423**
1992	0.6096	0.6213	0.5051	0.5455	0.5406	0.5247	0.5423	**0.5406**
1993	0.8711	0.8878	0.6977	0.7305	0.7189	0.7096	0.7225	**0.7261**
1994	1.0419	1.0243	0.8420	0.8737	0.8702	0.8504	0.8720	**0.8694**
1995	0.9646	0.9666	0.8914	0.9185	0.9158	0.9213	0.9194	**0.9389**
1996	0.9940	1.0080	0.9522	0.9570	0.9695	0.9512	0.9753	**0.9550**
1997	1.0294	1.0377	1.0182	1.0325	1.0450	1.0419	1.0408	**1.0597**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

Table 4. GLM results for the Pink Ling fishery (Eastern & Western) for records where catch is greater than 30 kg. Results of the analyses are shown only for those models which were deemed statistically optimal in analyses presented in Tables 2 & 3.		
	Eastern Fishery	**Western Fishery**
	Model 7	**Model 8**
F	40.82	25.62
Resid SS	22696.1	9650.8
df Params	307	281
DF Resids	44384	20656
N	44692	20938
Var%	22.0	25.8
# Param	309	283
YEAR		
1986	0.8538	0.7945
1987	0.8834	0.9222
1988	0.8179	0.7498
1989	0.7804	0.7914
1990	0.9512	0.7453
1991	0.8923	0.7019
1992	0.8386	0.5758
1993	0.8958	0.7953
1994	0.8843	0.8772
1995	1.0481	0.9531
1996	0.9841	0.9685
1997	0.9465	1.0502
1998	1.0000	1.0000

Table 5. The number of records (N) for major vessels and for all vessels of the Eastern and Western Pink Ling fisheries. % All refers to the percentage of the fishery vessels which are deemed major vessels.			
Catch Records	**Eastern fishery**	**Western fishery**	**Both fisheries**
	N	**N**	**N**
Major Vessels	71,645	27,656	99,031
All Vessels	76,755	29,617	106,372
%All	93.3	93.4	93.1

Table 6. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for records of catches by dominant boats in the fishery. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 7.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel**
Model 8	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	34.11	79.24	600.58	317.22	314.76	280.75	**206.43**	144.32
Resid SS	134593.2	132003.1	97251.1	81538.4	81352.2	80585.1	**78719.0**	79605.5
df Params	12	23	46	147	149	171	**246**	342
DF Resids	71632	71621	71335	71234	71232	71210	**71135**	71039
N	71645	71645	71382	71382	71382	71382	**71382**	71382
Var%	0.6	2.5	27.9	39.6	39.7	40.3	**41.7**	41.0
# Param	14	25	48	149	151	173	**248**	344
AIC	45202.556	43832.399	22170.936	9793.816	9634.658	9002.341	**7479.946**	8471.267
AIC2	11.810	11.791	11.486	11.313	11.311	11.302	**11.281**	11.294
DVAR%	0.0	1.9	25.4	11.7	0.1	0.6	**2.0**	1.3

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	1.1320	1.0964	0.9076	0.9213	0.9240	0.9333	**0.8905**	0.9455
1987	1.1877	1.1445	0.9484	1.0192	1.0222	1.0450	**0.9734**	1.0576
1988	1.1723	1.1052	0.9570	1.0131	1.0090	1.0202	**0.9512**	1.0450
1989	1.1491	1.1019	0.9231	0.9259	0.9194	0.9250	**0.8470**	0.9399
1990	1.4106	1.4007	1.2763	1.3192	1.3073	1.3192	**1.1901**	1.3298
1991	1.3192	1.2815	1.1503	1.2226	1.2177	1.2548	**1.1041**	1.2374
1992	1.1889	1.1618	1.1152	1.0161	1.0192	1.0284	**1.0020**	1.0182
1993	1.3087	1.2763	1.2008	1.0263	1.0294	1.0336	**1.0121**	1.0346
1994	1.1865	1.1642	1.1468	1.0171	1.0263	1.0274	**1.0274**	1.0182
1995	1.1782	1.1665	1.2649	1.1700	1.1770	1.1865	**1.1960**	1.1818
1996	0.9920	1.0111	1.0704	1.0030	1.0060	1.0101	**1.0010**	1.0274
1997	1.0020	1.0000	1.0757	1.0523	1.0544	1.0555	**1.0305**	1.0714
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**	1.0000

Table 7. GLM results for the Western Pink Ling fishery (Zones 40 and 50) for records of catches by the dominant boats in the fishery. Depth is a set of 50m depth categories, Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 8.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Depth
Model 4	Ln(CE) = Const + Year + Month + Depth + Vessel
Model 5	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone
Model 6	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Month
Model 7	Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Zone*Vessel
Model 8	**Ln(CE) = Const + Year + Month + Depth + Vessel + Zone + Month*Depth**

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
F	52.13	78.99	168.90	113.19	113.17	110.49	84.43	**43.69**
Resid SS	29021.8	27847.7	23069.1	21410.2	21346.9	20811.5	21118.7	**20391.7**
df Params	12	23	45	91	92	103	128	**277**
DF Resids	27643	27632	27465	27419	27418	27407	27382	**27233**
N	27656	27656	27511	27511	27511	27511	27511	**27511**
Var%	2.2	6.2	21.7	27.3	27.5	29.3	28.3	**30.8**
# Param	14	25	47	93	94	105	130	**279**
AIC	1361.135	241.015	-4750.424	-6711.568	-6790.992	-7467.819	-7014.706	**-7680.342**
AIC2	10.277	10.236	10.050	9.978	9.975	9.951	9.967	**9.943**
DVAR%	0.00	4.00	15.50	5.60	0.20	1.80	0.80	**3.30**
YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
1986	0.8914	0.9352	0.8598	0.8122	0.8228	0.7780	0.8155	**0.7985**
1987	1.4106	1.3553	1.1331	0.9891	0.9950	0.9389	0.9782	**0.9891**
1988	0.9085	0.9589	0.7985	0.7483	0.7535	0.7276	0.7535	**0.7393**
1989	1.1491	1.1607	0.9130	0.7874	0.7843	0.7438	0.7680	**0.7804**
1990	0.8616	0.8403	0.6690	0.6984	0.6921	0.6597	0.6777	**0.6866**
1991	0.8311	0.8538	0.7445	0.7276	0.7334	0.7103	0.7204	**0.7349**
1992	0.6188	0.6256	0.5066	0.5417	0.5369	0.5210	0.5396	**0.5369**
1993	0.8834	0.8940	0.7012	0.7247	0.7132	0.7047	0.7182	**0.7204**
1994	1.0523	1.0356	0.8487	0.8676	0.8642	0.8462	0.8685	**0.8624**
1995	0.9851	0.9822	0.8923	0.9085	0.9057	0.9112	0.9112	**0.9296**
1996	0.9589	0.9656	0.9103	0.9427	0.9560	0.9399	0.9627	**0.9408**
1997	1.0336	1.0387	1.0161	1.0367	1.0492	1.0429	1.0460	**1.0618**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

Table 8. No of records in the shallow and deep Eastern sub-fisheries where catches were greater than 30 kg (>30 kg) and for all records (All). Unknown refers to records where no depth of trawl has been recorded.

# Records	Shallow	Deep	Unknown	Total
>30 kg	5,714	38,978	149	44,841
All	21,996	54,463	296	76,755

Table 9. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for records where catch was taken in less than 200 m depth. Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 6.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Vessel
Model 4	Ln(CE) = Const + Year + Month + Vessel + Zone
Model 5	Ln(CE) = Const + Year + Month + Zone + Vessel + Zone*Month
Model 6	**Ln(CE) = Const + Year + Month + Zone + Vessel + Zone*Vessel**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
F	117.50	64.36	35.30	34.96	32.83	**27.16**
Resid SS	32989.1	32889.3	26913.6	26907.5	26605.0	**26172.5**
df Params	12	23	188	190	212	**273**
DF Resids	21983	21972	21807	21805	21783	**21722**
N	21996	21996	21996	21996	21996	**21996**
Var%	6.0	6.3	23.3	23.4	24.2	**25.4**
# Param	14	25	190	192	214	**275**
AIC	8943.344	8898.700	4818.157	4817.149	4612.471	**4373.932**
AIC2	10.405	10.403	10.218	10.218	10.208	**10.197**
DVAR%	0.0	0.3	17.0	0.1	0.8	**2.0**
YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
1986	1.6537	1.6636	1.4134	1.4162	1.4391	**1.5144**
1987	1.7023	1.7194	1.4681	1.4696	1.4993	**1.5342**
1988	2.0730	2.0689	1.6537	1.6570	1.6922	**1.6955**
1989	1.9387	1.9309	1.5936	1.5888	1.5936	**1.5574**
1990	1.9640	1.9877	1.6703	1.6603	1.6871	**1.6389**
1991	1.6339	1.6258	1.3840	1.3758	1.4176	**1.3744**
1992	1.7700	1.7736	1.4903	1.4948	1.5174	**1.4814**
1993	2.3893	2.3821	1.8776	1.8889	1.8965	**1.8571**
1994	2.5193	2.5143	1.8294	1.8441	1.8368	**1.8645**
1995	2.3233	2.3048	1.7612	1.7683	1.7437	**1.8076**
1996	1.2943	1.2982	1.1019	1.1041	1.1264	**1.1096**
1997	1.1984	1.2032	1.1434	1.1422	1.1491	**1.1400**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

Table 10. GLM results for the Eastern Pink Ling fishery (Zones 10, 20 and 30) for records where catch was taken in greater than or equal to 200 m depth. Vessel relates to the database vessel number, the other dummy variables have meaningful names. F is the F-statistic from the overall ANOVA, the Resid SS is the residual sum of squares, N is the total number of observations, and AIC1 and AIC2 are the two forms of the Akaike's Information Criterion. The lowermost columns of data are the relative abundance indices for the respective years for each model shown in bold type. The optimal model by AIC is Model 6.

Model 1	Ln(CE) = Const + Year
Model 2	Ln(CE) = Const + Year + Month
Model 3	Ln(CE) = Const + Year + Month + Vessel
Model 4	Ln(CE) = Const + Year + Month + Vessel + Zone
Model 5	Ln(CE) = Const + Year + Month + Vessel + Zone + Zone*Month
Model 6	**Ln(CE) = Const + Year + Month + Vessel + Zone + Zone*Vessel**

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
F	35.95	74.04	77.06	77.79	72.44	**56.38**
Resid SS	78386.8	76611.2	62786.0	62520.5	61964.6	**60640.5**
df Params	12	23	182	184	206	**291**
DF Resids	54450	54439	54280	54278	54256	**54171**
N	54463	54463	54463	54463	54463	**54463**
Var%	0.8	3.0	20.5	20.9	21.6	**23.2**
# Param	14	25	184	186	208	**293**
AIC	19859.856	18633.979	8113.204	7886.428	7444.032	**6437.618**
AIC2	11.270	11.247	11.054	11.050	11.042	**11.023**
DVAR%	0.00	2.20	17.50	0.40	0.70	**2.30**

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
1986	0.8378	0.8130	0.8369	0.8479	0.8547	**0.8122**
1987	0.8090	0.7858	0.8163	0.8261	0.8454	**0.7788**
1988	0.8237	0.7827	0.8270	0.8278	0.8328	**0.7765**
1989	0.8073	0.7827	0.7734	0.7695	0.7741	**0.7096**
1990	1.1208	1.1208	1.1298	1.1140	1.1309	**1.0212**
1991	1.0661	1.0325	1.0534	1.0408	1.0608	**0.9493**
1992	1.0111	1.0000	0.8633	0.8702	0.8772	**0.8547**
1993	1.0294	1.0060	0.8470	0.8513	0.8513	**0.8411**
1994	0.9194	0.9021	0.8017	0.8114	0.8098	**0.8114**
1995	1.0212	1.0202	0.9389	0.9455	0.9503	**0.9531**
1996	0.9891	1.0020	0.9484	0.9522	0.9503	**0.9531**
1997	1.0284	1.0284	0.9950	0.9980	1.0000	**0.9734**
1998	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

Table 11. GLM results for the Eastern Pink Ling sub-fisheries (Shallow & Deep) for records where catch is greater than 30 kg. Results of the analyses are shown only for those models which were deemed statistically optimal in analyses presented in Tables 9 & 10.

	Shallow fishery	**Deep fishery**
	Model 6	**Model 6**
F	14.73	22.47
Resid SS	2683.7	20185.6
df Params	199	278
DF Resids	5514	38699
N	5714	38978
Var%	34.7	13.9
# Param	201	280
YEAR		
1986	0.7865	0.8772
1987	0.8115	0.8668
1988	0.807	0.8187
1989	0.7707	0.7851
1990	0.8897	0.9773
1991	0.8564	0.8967
1992	0.9101	0.8564
1993	1.1173	0.924
1994	1.478	0.8479
1995	1.4836	0.9831
1996	0.9406	1.0253
1997	0.9297	0.9637
1998	1	1

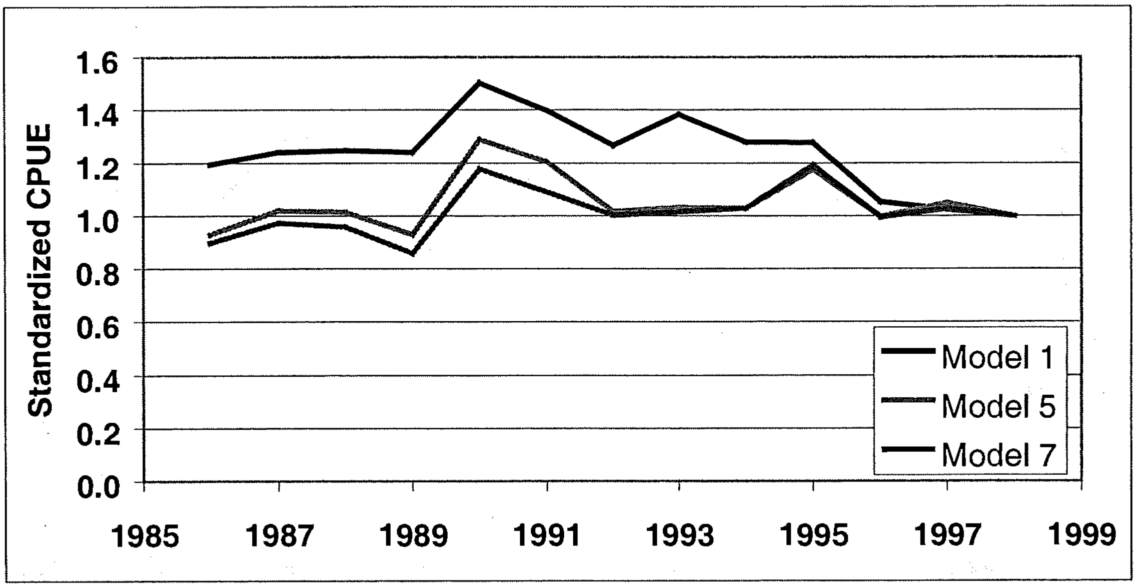

Figure 1. Standardized CPUE for the eastern fishery (zones 10, 20, and 30) for all records. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone. Model 7 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel (Table 1).

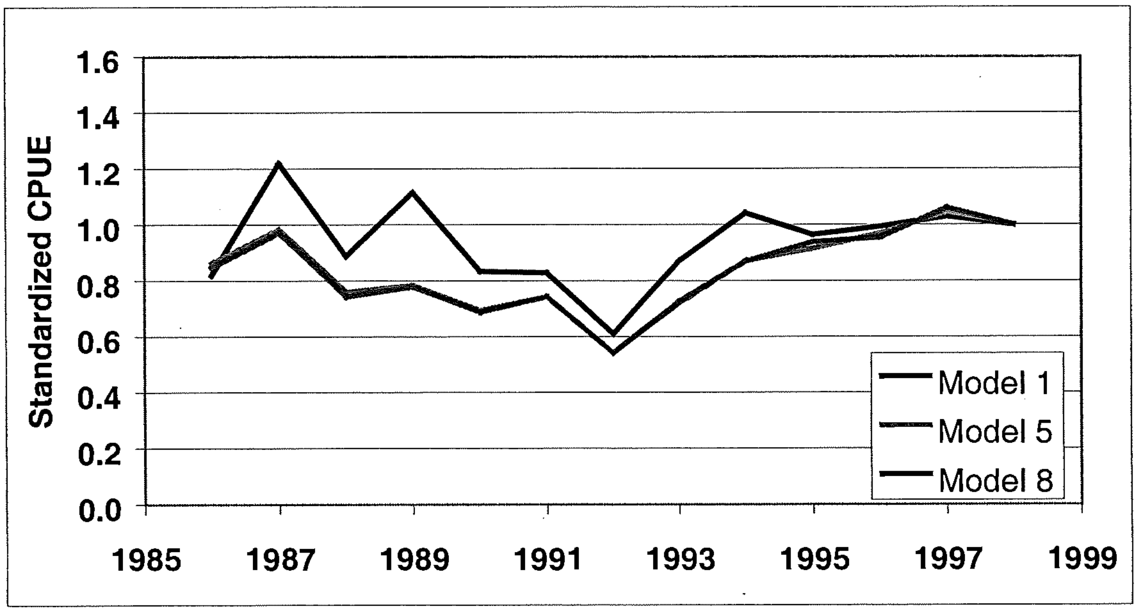

Figure 2. Standardized CPUE for the western fishery (zones 40 and 50) for all records. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone. Model 8 was the optimal statistical model : Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Month*Depth (Table 2).

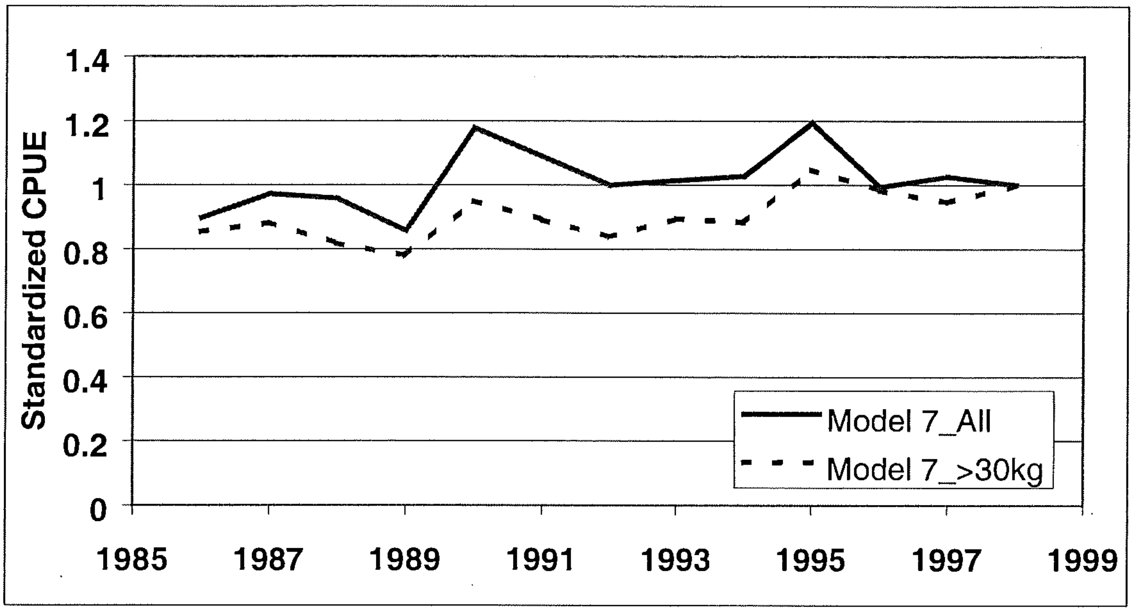

Figure 3. Standardized CPUE for the Eastern fishery (zones 10, 20 and 30) for all records (Model 7_All) and for records where catches were greater than 30 kg (Model 7_>30kg). Model 7 is the statistically optimal model: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone + Zone*Vessel (Tables 2 & 4).

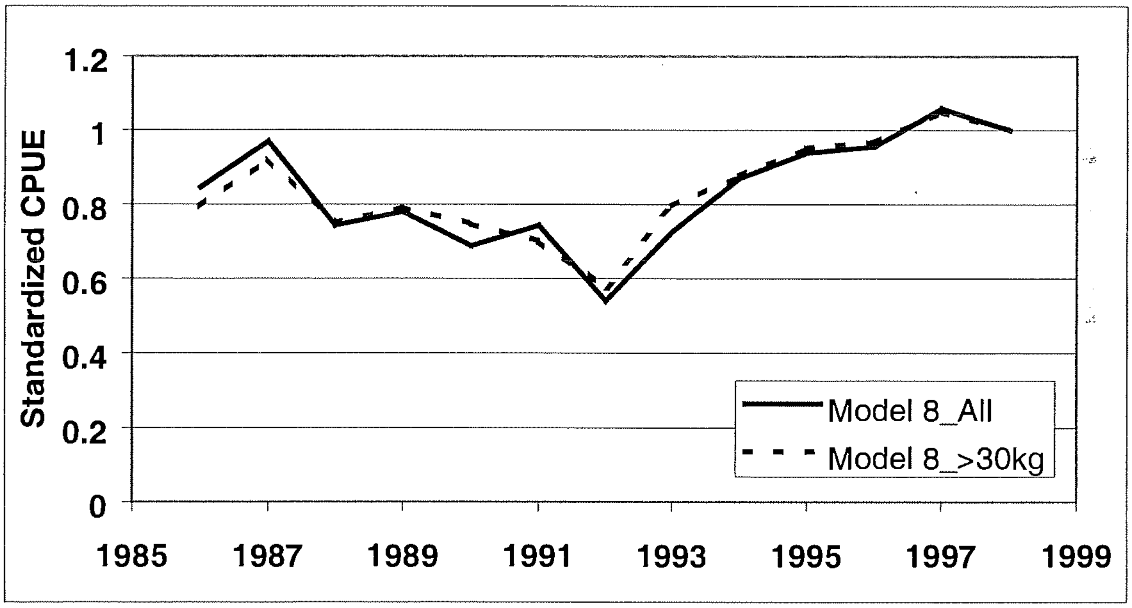

Figure 4. Standardized CPUE for the Western fishery (zones 40 and 50) for all records (Model 8_All) and for records where catches were greater than 30 kg (Model 8_>30kg). Model 8 is the statistically optimal model: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Month*Depth (Tables 3 & 4).

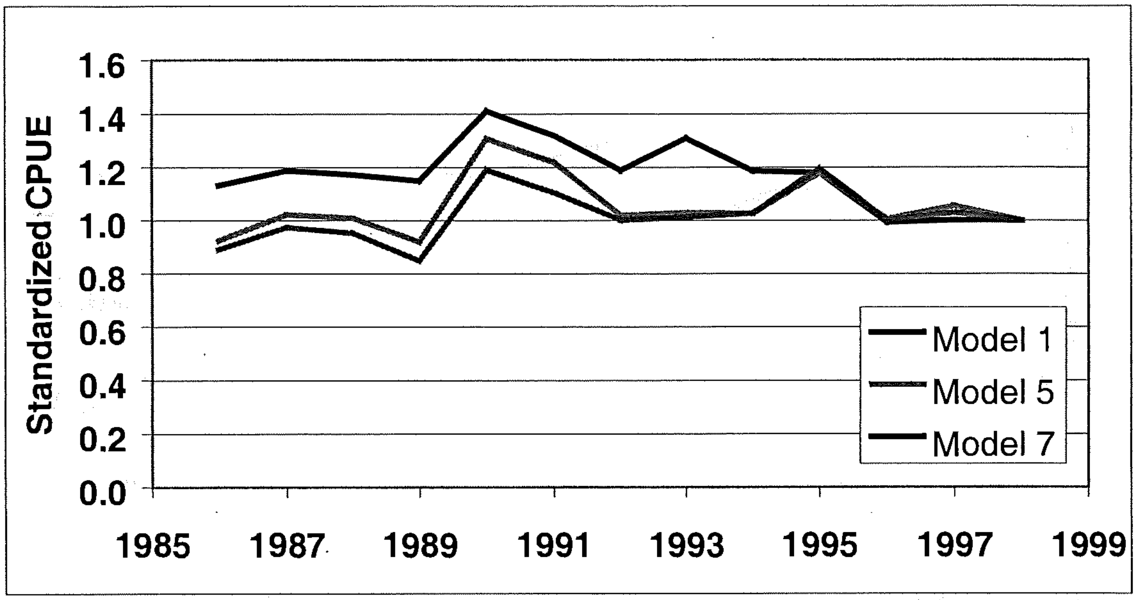

Figure 5. Standardized CPUE for the eastern fishery (zones 10, 20, and 30) for records of catches by the dominant boats in the fishery. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel. Model 7 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Zone*Vessel (Table 6).

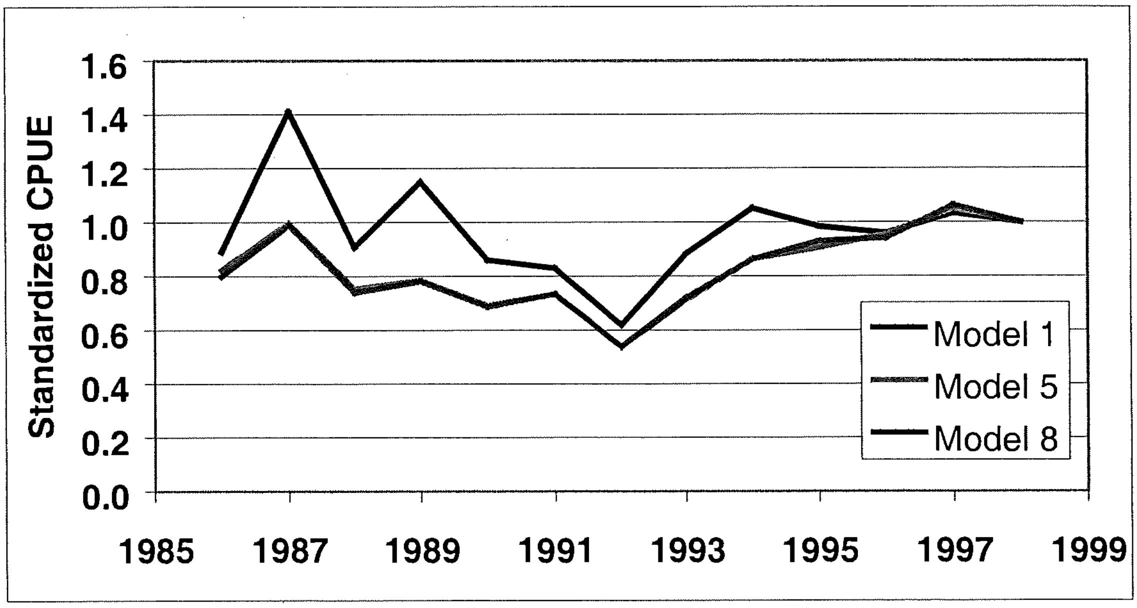

Figure 6. Standardized CPUE for the Western fishery (zones 40 and 50) for records of catches by the dominant boats in the fishery. Model 1 is simply the geometric mean CPUE for each year. Model 5 was: Ln(CE) = Constant + Year + Month + Depth + Vessel. Model 8 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Depth + Vessel + Month*Depth (Table 7).

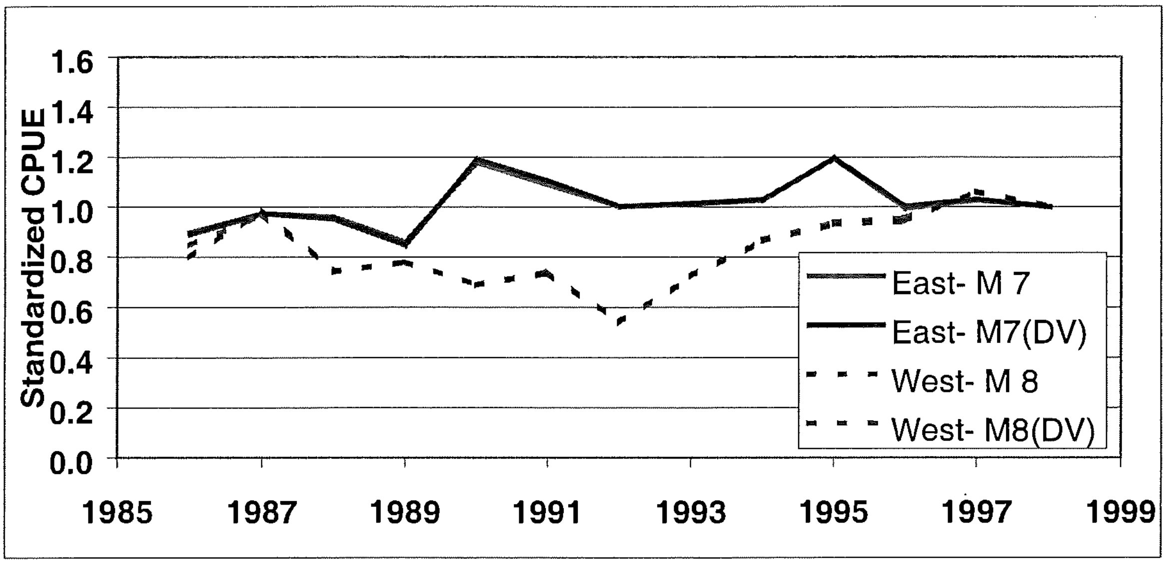

Figure 7. Standardized CPUE for the Eastern and Western fisheries for all records and for dominant vessel records only (DV). Model 7 was the optimal statistical model for the Eastern fishery: Ln(CE) = Constant + Year + Month + Depth + Vessel + Zone*Vessel (Tables 2 & 6). Model 8 was the optimal statistical model for the Western fishery: Ln(CE) = Constant + Year + Month + Zone + Depth + Vessel + Month*Depth (Tables 3 & 7).

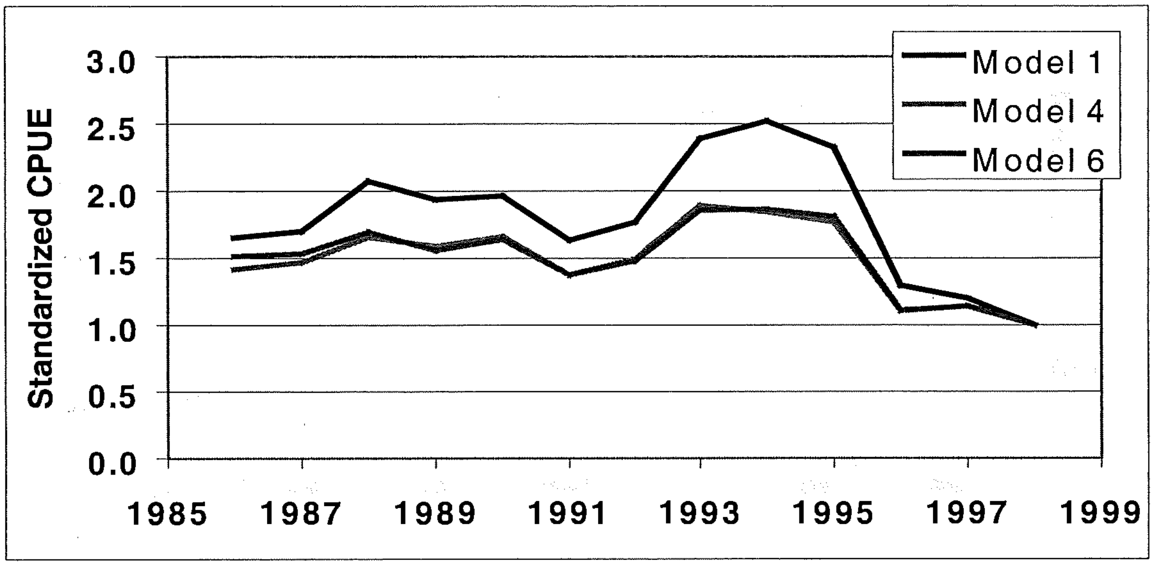

Figure 8. Standardized CPUE for the eastern fishery (zones 10, 20 and 30) for records where catch was taken in less than 200 m depth. Model 1 is simply the geometric mean CPUE for each year. Model 4 was: Ln(CE) = Constant + Year + Month + Vessel + Zone. Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Vessel + Zone + Zone*Vessel (Table 9).

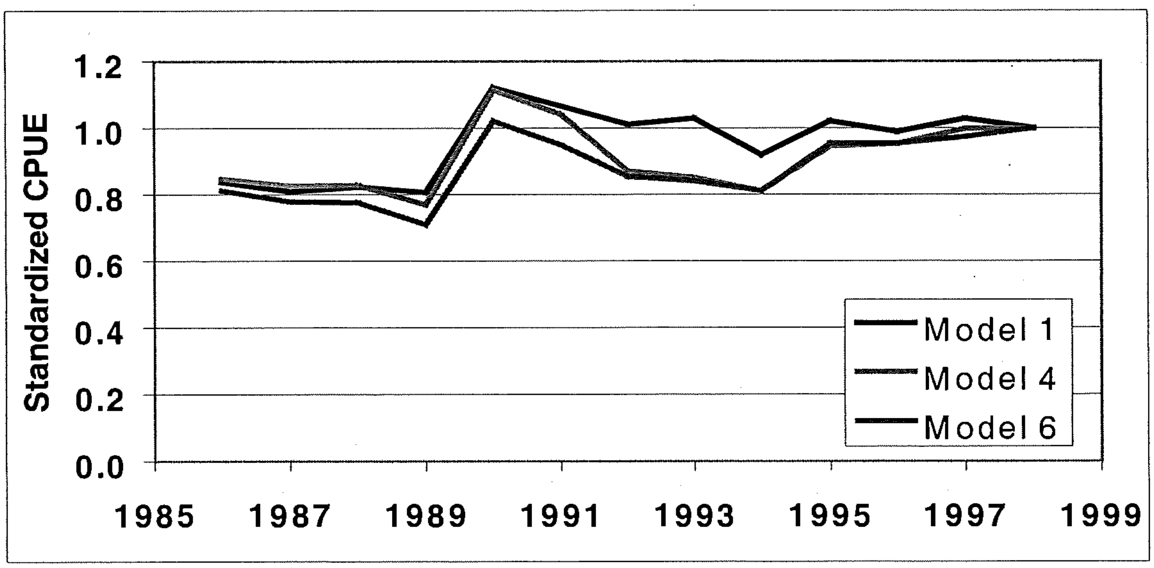

Figure 9. Standardized CPUE for the Eastern fishery (zones 10, 20 and 30) for records where catch was taken in greater than or equal to 200 m depth. Model 1 is simply the geometric average CPUE for each year. Model 4 was: Ln(CE) = Constant + Year + Month + Vessel + Zone. Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Vessel + Zone + Zone*Vessel (Table 10).

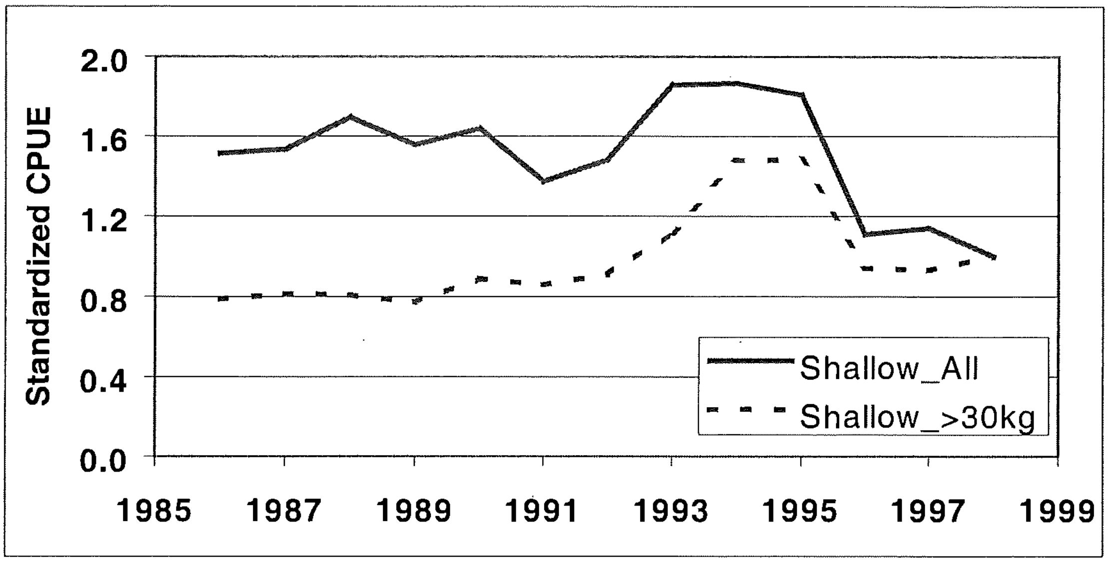

Figure 10. Standardized CPUE for the shallow eastern fishery (< 200 m depth) for all records (Shallow_All) and for records where Pink Ling catch was greater than 30 kg (Shallow_>30kg). Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Vessel + Zone*Vessel (Table 8).

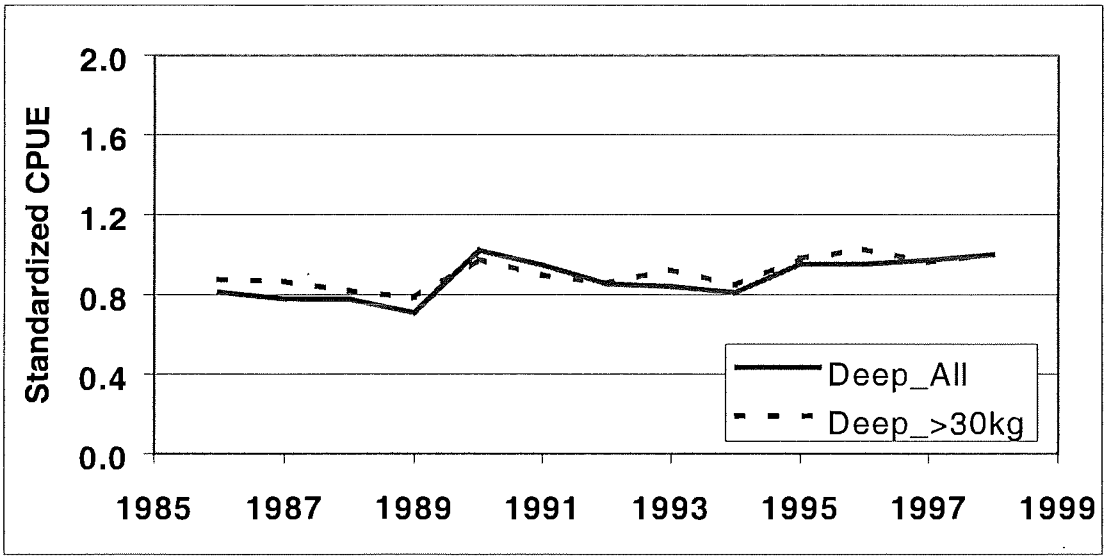

Figure 11. Standardized CPUE for the deep eastern fishery (≥ 200 m depth) for all records (Deep_All) and for records where Pink Ling catch was greater than 30 kg (Deep_>30kg). Model 6 was the optimal statistical model: Ln(CE) = Constant + Year + Month + Zone + Vessel + Zone*Vessel (Table 9).

Appendix 7

Initial stock assessment and forward projection of pink ling (*Genypterus blacodes*) in the South East Fishery

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INITIAL STOCK ASSESSMENT AND FORWARD PROJECTION OF PINK LING (*Genypterus blacodes*) IN THE SOUTH EAST FISHERY

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ABSTRACT

An initial stock assessment of pink ling (*Genypterus blacodes*), which uses the Integrated Analysis approach, is presented. The assessment uses annual catch-at-age, catch- and discard-at-length, catch-per-unit-effort (CPUE), landings and discard data for the years in which these are available. Pink ling are assumed to comprise a single stock, although a two stock hypothesis (east and west) is examined. There is a clear mis-match between the CPUE data (which indicate that pink ling biomass has been roughly stable since 1997) and the catch-at-age and -length data (which indicate a decline in the stock due to an increase in overall mortality without any compensating increase in recruitment). The estimated size of the pristine pink ling stock and its size in 1998 relative to pristine (current status) are both sensitive to the weight given to the CPUE data. Greater weights given to the CPUE data lead to greater estimates of the year-class strength of one-year olds in recent years and consequently to greater estimated CPUE and a better fit to the CPUE data at the expense of the fit to the catch-at-age and -length data. This results in a particularly poor fit to the earliest year classes. It might be argued that either of these data sources are not representative of the population due to changes in the behaviour of the fishery (e.g. after the introduction of ITQs in 1992). However, this conflicting signal between a steady CPUE and a declining mean catch-at-age and -at-length is also apparent in the Kapala research data - two research surveys conducted 20 years apart, in the same areas, which used the same survey design and fishing gear. The status of the stock is uncertain: 31% for the base case model but as low as 4% if the CPUE data are ignored. However, even given the base case model, forward projections indicate that an annual TAC of 2000 tons has a high probability (between 70 and 80%) of depleting the stock to below 20% of its pristine level after 20 years of fishing.

INTRODUCTION

Pink ling (*Genypterus blacodes*) are found mainly at 200-900m depth (Tilzey, 1994) off the east and south coasts of Australia (including Tasmania), and off New Zealand (Colman, 1995). A closely related species, rock ling (*Genypterus tigerinus*) occurs in the same areas but mainly at depths shallower than 60m (Last *et al*, 1983). Other related species occur off southern Africa (*Genypterus capensis*) and South America (*Genypterus chilensis*). Pink ling have been caught in reasonably large numbers by the South East Fishery (Fig 1) since the mid 1970's when the fishery moved into waters of 200m or deeper (Tilzey, 1994). They are primarily a by-catch of trawlers targeting blue grenadier and gemfish but have increasingly been targeted since the early 1980's as their market value has risen (Tilzey, 1994).

Pink ling are also caught by the South East Non-Trawl fishery as a by-catch of gillnetting in the southern shark fishery, and by traps, drop-lines and bottom-lines. Catches of pink ling by the non-trawl sector increased dramatically in 1992 and 1993 with the introduction of automatic longlining and because of increased targeting by gillnet fishers operating in the southern shark fishery (Smith and Tilzey, 1995). In 1992 a TAC for pink ling was introduced for the trawl component of the South East Fishery (then known as the SET). This was extended to include the non-trawl component in 1998. Quota is transferable between the trawl and non-trawl sectors.

Little is known about the productivity of pink ling and a formal stock assessment has not previously been conducted. A TAC was introduced for pink ling in 1992 and this has been increasing to allow expansion in the fishery (Fig 2). In 1997 the pink ling catch was the 5th greatest, by mass, of all quota species landed by the South East Fishery (Caton *et al*, 1998). The 1997 catch by all methods was worth roughly A$5.7 million (Caton *et al*, 1998).

This paper represents a first attempt to conduct a quantitative stock assessment of pink ling in SEF waters. An Integrated Analysis approach is used. This technique has been applied to a number of SEF species: eastern gemfish (Smith and Punt, 1998), blue grenadier (Punt *et al*, in press), blue warehou (Punt, 1999a), school whiting (Punt, 1999b).

BIOLOGICAL BACKGROUND

The stock structure of pink ling in SEF waters has been investigated by Daley *et al* (1999) using allozyme, genetic, morphometric and meristic techniques. Although certain of their tests may indicate significant differences between some regions these differences are not consistent and the majority of their investigations do not show significant differences between pink ling in different areas. The base case hypothesis used here therefore assumes a single pink ling stock. A possible east-west stock separation is considered by fitting the model separately to data from the east of Bass Strait only (zones 10-30), and from west of Bass Strait (zone 40-60) only.

Analyses of catch curve data have indicated that ling older than 10 years may have a lower natural mortality rate than those of 10 or younger (Smith *et al*, 1996, Morison *et al*, 1999).

The biological parameters used in this model are listed in Table 1. The parameters for the length-weight relationship were calculated using pooled length and weight data collected by CSIRO and TAFI as well as that used by Withel and Wankowski (1989). Those of the von Bertalanffy growth curve were calculated using data collected by the Central Ageing Facility (CAF), all available data held by the CAF were used. The values for the steepness of the Beverton-Holt stock-recruit relationship (h) and the proportion of mature fish that spawn each year (μ) were the same as those used by a New Zealand study (Horn & Cordue, 1996). However, they describe these choices as "precautionary" because the true parameter values are unknown.

DATA

The data used by the model include total annual landings, annual discard rates, catch rates, proportion caught-at-age, proportion caught-at-length, and proportion discarded-at-length. Age-length keys (ALKs) are used to calculate the variance in length for each age group.

The data used are described by Furlani *et al* (1999). Most data were collected from commercially caught fish but data collected during the Kapala research surveys off NSW in 1976/7, 1979/80 and 1996/7 are also used. Data on discarding were collected by the Integrated Scientific Monitoring Program (ISMP) and its predecessors (Garvey, 1996, Garvey 1998, Knuckey & Sporcic, 1999). Discard rates could not be estimated for the non-trawl component of the fishery, so those for the trawl component were assumed to apply to both. This assumption is unlikely to be valid because the trawl component takes smaller fish than does the non-trawl, however this may not be important because the discard rates are low.

CPUE

In the absence of fishery independent data, the assumption is often made that catch-per-unit effort (CPUE) for a particular species is proportional to the abundance of that species. It is possible to quantify the influence that some factors, other than abundance, have on CPUE and therefore to remove these influences i.e. to standardise the CPUE. This has been done, as far as possible, for pink ling through the application of General Linear Models (GLMs) (Haddon, 1999). Factors that may have influenced the CPUE trend but which could not be incorporated in this GLM include: increased targeting (compared to that on other species) in recent years; the effect of fluctuations in other species such as gemfish; changes in fishing pattern that may affect the vulnerability-at-length; environmental fluctuations that may have caused fish stocks to move.

The standardised CPUE for ling shows no clear overall trend over the time period considered (Fig 3) although there may be a slight increase. This implies that the abundance of ling in the length-classes that are available to the fishery has not undergone any major change during this period.

The standardised CPUE for the eastern area (zones 10-30) differs slightly from that for the western area (zones 40-60) (Fig 3). The east CPUE shows a steady but slow increase over the period considered whereas that of the west shows a slight decrease followed by a subsequent recovery. CPUE data are also available from two research surveys conducted by NSW Fisheries using the vessel Kapala (Andrew *et al*, 1997). A research survey that had been carried out in 1976/77 was repeated in 1996/7 in, as far as possible, the same areas and using the same survey design and fishing gear. These two data points are similar, indicating a flat CPUE series (Fig 3).

Catch-at-age and -length

The age distribution of the trawl catch has shown an overall shift towards younger animals since 1977 (Fig 4) although there is some sign of an increase in recent years particularly in the west. The non-trawl data show a decline in both length and age of the catch. The decline is most clear in the Kapala research data, both in the mean catch-at-length and catch-at-age data. Unlike the commercial data, the Kapala data are free of the complications of changes in fishing pattern and gear selectivity (Andrew *et al*, 1997). Note that the catch-at-length data for 1979-1982 were collected in the west, the only data available for the east prior to 1992 is that collected by the Kapala.

MODELLING METHODS

The model is described in detail in the appendix but is outlined briefly here. An integrated analysis approach is used (Methot, 1989). This approach is suitable for SEF species because it is able to make use of the wide variety of data sources that exist for these species and, unlike VPA methods, does not require an unbroken series of annual catch-at-age data.

An age-structured model (similar to that used for blue warehou; Punt, 1999a), is used and the length-structure of the population is also estimated. Vulnerability to fishing and the probability of a fish being discarded are modelled as functions of length. Fish greater than or equal to a specified length class are regarded as mature (i.e. part of the spawning stock); those below this length class are immature.

The model considers a period of 22 years (1977 to 1998) and assumes that the stock was close to pristine at the beginning of 1977. This is likely to be a reasonable assumption since ling were not targeted in the 1970's and catches of blue grenadier and gemfish were relatively small until the late 1970's (Tilzey, 1994).

The AD Model Builder package ver. 3.11 (Otter Research Ltd, 1999) was used to find the estimates of the model parameters that minimised the negative log-likelihood. The model has 72 parameters: fishing mortality values for each sub-fishery in each year in which it operated (22 for trawl and 15 for non-trawl); recruitment residuals for each year (22); parameters for the selectivity functions for the two sub-fisheries as well as for the Kapala research survey (6); parameters for the discard function (2); 2 parameters that relate the catch-rate data for the trawl and research catches to the modelled biomass; the size of the pristine stock (1); and natural mortality for ling aged 10 or younger and older than 10 (2).

The base case model considers pink ling to be a single stock. Two sub-fisheries are considered - the trawl and the non-trawl sub-fisheries. The Kapala research surveys represent a third sub-fishery but one which does not contribute to the annual landings. The Tasmanian trawl fishery appears to be distinctly different from that in other areas in that it operates in deeper water and consequently takes larger ling. Although Tasmanian catches are included in the data, a separate Tasmanian sub-fishery is not considered because the total annual landings by this sub-fishery form a small part of the total catch (Lyle *pers comm*).

The possibility of separate east and west stocks is considered by applying the model to data from only the east (SEF zones 10-30, see Fig 1) and from only the west (zones 40-60). The breakdown of non-trawl catches between the east and west is not known and the assumption was made that non-trawl catches are made in the west zone only. This is certainly not true for earlier years however the non-trawl landings are relatively small prior to 1992 (Fig 5a).

The sensitivity of the model to various assumptions is considered.

Projections

The stock was projected 20 years into the future under a range of possible future TACs. The TAC was assumed to be the same each year and was split between the trawl and non-trawl sub-fisheries according to a pre-specified ratio. In 1998 the non-trawl fleet took 10% of the pink ling catch, however in 1993 before the TAC became 'global', this sub-fishery took 40% of the year's pink ling catch. Therefore non-trawl:trawl catch ratio's of 10:90 and 40:60 were considered.

For each combination of future TAC and non-trawl:trawl catch ratio, 2000 projections of 20 years each were performed. Each projection used a different set of parameter values drawn from the posterior distributions of these parameters. Recruitment was assumed to deviate randomly from its expected value and this was simulated by drawing an annual recruitment residual (see equation A.3 in the appendix) from a log-normal distribution which had mean zero and c.v. 0.6.

AD Model Builder (Otter Research, 1999) was also used to estimate and make draws from the posterior distributions for the parameters of the model. This was done using the Markov Chain Monte Carlo (MCMC) algorithm (Gelman *et al.*, 1995; Punt and Hilborn, 1997). The recruitment residuals are assumed to have a truncated, log-normal prior. All other parameters are assumed to have priors that are uniform or uniform on a log-scale (Table 2).

RESULTS

Base case model

The estimated natural mortality for fish aged 10 or younger (0.29 y^{-1}) is greater than for those older than 10 (0.14 y^{-1}). The c.v. for the calculated recruitment residuals is 0.67.

The model is able to fit the landed catch (in mass) well, however there is a poor fit to the discard mass (Fig 5). The model indicates a lower rate of discarding at age than was observed by the ISMP. The fit to the CPUE data is poor (Fig 6)

The estimated vulnerability patterns are similar to what would be expected. The Kapala research surveys selected a wider size range of fish than the commercial fishery (Fig 7a); this is reasonable because the surveys were designed to cover a wide range of areas and depths (Andrew *et al*, 1997). The non-trawl sub-fishery takes a large size-range of fish, as would be expected. The selectivity pattern estimated for the trawl fleet when using data from only the east is wider than that estimated when using data from the only the west. The estimated discard selectivity indicates that fish larger than 60cm are unlikely to be discarded however even fish smaller than 60cm have a reasonably low probability of being discarded (Fig 7b).

The model estimated discard-at-length patterns do not fit the data well (Fig 8). The model fit is a compromise between years when juveniles dominate the discards and years when larger fish dominate. Unfortunately sample sizes are small for most years. The discard data do not contribute much information to the model.

CPUE and catch-at-age and -length data

The model is unable to reconcile the flat CPUE data with the declines in mean age and length in the catch. The estimated CPUE for the base case model shows a steady decline in the CPUE until 1995 after which there is an increase due to the estimated increase in the sizes of the first year classes.

The fits to the commercial catch-at-length data are reasonably good (Fig 9) although the model overestimates the number of small fish caught in some years.

Fits to the catch-at-age data are reasonably good, except that the number of 1-year old fish is overestimated in all years (Fig 10). This is due to the large recruitment residuals estimated for recent years (Fig 11). These keep the estimated CPUE high, thus improving the model fit to the CPUE data. If the CPUE data are not included in the model then the increase in the recruitment residuals in recent years is not as steep (Fig 11a).

These recruitments have a strong influence on the estimate of current stock status (i.e. spawning biomass relative to pristine B^{sp}_{98}/B_0); Fig 12a shows the trajectory of spawning biomass for the base case and for the 'No CPUE' sensitivity test. The base case model estimates a greater pristine biomass, as well as a greater stock size in 1998 relative to pristine (Table 3 and Fig 12a). The biomass available to each of the fleets (for the base case model) is shown (Fig 12c) along with the estimated spawning biomass for the east and west areas estimated separately.

The effect of the weight chosen for the CPUE data is illustrated in Figure 13. Greater values for $\left(2\sigma_q^2\right)^{-1}$ correspond to greater weight given to the CPUE data (i.e. see equation A.30). The pristine spawning biomass (B_0) and the spawning biomass in the current year relative to pristine (B_y^{sp}/B_0) increase with greater weight given to the CPUE data. The slope of the increase in the recruitment residuals during 1992-1997 period also increases. Low weights given to the CPUE data result in (unrealistically) high values of estimated fishing mortality (Fig 13d).

Other sensitivity tests

Sensitivity tests in which the value assumed for the steepness parameter (h) and the weight given to the catch-at-length and discard-at-length information are altered give similar results to the base case (Table 3). Not surprisingly, altering the proportion of mature animals that are assumed to spawn each year raises or lowers the absolute size of the estimated biomass of the stock but does not alter other results.

Changing the length-at-maturity alters the estimated biomass of the stock and has a strong influence on the estimate of stock status in 1998 (i.e. B_{98}^{sp}/B_0). This is because the recruitment anomalies (ε_y) for the two are the same but the fish take longer to reach maturity and therefore to contribute to the spawning biomass when the length-at-maturity is greater.

As discussed previously, leaving the CPUE data out of the model fit leads to much less optimistic estimates of stock status. This also occurs if recruitment is assumed to follow a Beverton-Holt stock-recruit curve exactly (i.e. $\varepsilon_y = 0$). The assumption that CPUE is related to the square root of biomass also leads to a lower estimate of stock status in 1998 (Table 3).

Leaving catch-at-length data out of the model fit leads to a small reduction in the estimate of stock status in 1998 but a small increase in B_0. Leaving the age data out, on the other hand, leads to a very large increase in both estimated stock status and B_0. This implies that the mis-match in the data is primarily between the catch-at-age data and the CPUE data with the length data contributing little information. When discards are not modelled (i.e. it is assumed that discarding does not take place) the results obtained are similar to the base case indicating that the discard data are not very influential (Table 3).

East and west only

The results for the east and west runs indicate lower stock status for 1998 (Table 3) than when all data are used together. Both show the recent increase in recruitment residuals seen in the base case results (Fig 11). Estimates of spawning biomass are shown in Figure 12.

Projections

Fig 14a shows the estimated spawning biomass and 90%-ile for the base case, projected 20 years into the future assuming a TAC of 2000t 10% of which is taken by the non-trawl sub-fishery. The predicted spawning biomass increases slightly after 1998 due to the recruitment of the recent large year-classes to the fishery. Thereafter the biomass declines steadily indicating that 2000t is not a sustainable TAC for this stock.

The probability of depleting the stock below 20% of its pristine level over a 20 year projection period for a range of TACs (with a 10:90 split of the TAC) is shown in Figure 14b. The effect of a 40:60 split is shown for the 2000t TAC. This increases the risk of depleting the stock below 20% of B_0 but this increase is relatively slight.

The probability that the spawning biomass will be less than 20% of B_0 after 20 years of fishing a constant TAC is shown in Figure 15, as a function of TAC. If the CPUE data are not included in the fit then the probability of depleting the stock below this level is very high, even for relatively low TACs. Even for the base case fit this probability exceeds 10% (a commonly accepted reference point) for TACs greater than approximately 1230t (if a 10:90 ratio is assumed) or 1160 (if a 40:60 ratio is assumed).

DISCUSSION

Hypotheses that could explain the existing data
This assessment has revealed two, apparently irreconcilable signals in the data. Firstly the CPUE data indicate a steady biomass of pink ling over the time period considered. Secondly, the catch-at-age and -length data indicate an increase in total mortality rate over this period with no indication of a compensating increase in year-class strength of one-year olds (i.e. recruitment), and consequently a decline in the stock size. CPUE and age and length data collected during Kapala research surveys off NSW in 1976/77 and 1996.97 show the same trends despite effectively identical survey design and gear in both years of the survey. This implies that these trends are not the result of changes in the behaviour of the fishery.

CPUE may not be a good indicator of abundance for this species because of changes in fishing practices and the behaviour of this species. Ling have increased in value since the early 1980s (Tilzey, 1994) and this has lead to increased targeting of this species. This might, at least in part, mask a simultaneous reduction in stock biomass. Fishing practices are also thought to have changed following the introduction of ITQs in 1992 with fishers targeting a wider variety of species (Prince, Baelde and Wright, 1997). However, as already stated, the Kapala research data are not subject to these changes and yet these also showed no change in CPUE and a decline in overall catch-at-length.

It has been observed that ling catches on particular grounds increase after these grounds have been trawled. This has been attributed to ling moving onto those grounds to feed on discarded waste from the fishing vessels (Smith and Tilzey, 1995). A tendency for ling to move onto trawl grounds would keep the CPUE for this species high, even if the stock size were reduced. The Kapala data is also likely to be affected by this behaviour, if it does take place.

Another possible hypothesis is that overall abundance of ling has not decreased, even though fishing pressure has increased the overall mortality rate of this species. It is also possible that ling have benefited from the reduction, due to fishing pressure, in other demersal stock biomassess, such as gemfish and deep-sea sharks. This would lead to increased survival and possibly increased recruitment, (although this was not evident in the data).

It is hoped that discussions conducted during the pink ling workshop will lead to the generation of alternative hypotheses to explain these data. Those hypotheses discussed above are:

1) The CPUE data give a good indication of abundance and the biomass of pink ling in 1998 is similar to that in 1997. A fishery has been operating over this time period therefore indications of an increase in total mortality (in the catch-at-age and -length data) are likely to be correct. Therefore the total number of fish must have increased but these fish are on average smaller and younger in 1998 than they were in 1977. Recruitment (and consequently the year-class strength of one-year olds) must have increased in recent years. These young fish are not seen in the catch data. Has the fishery been moving into deeper waters, avoiding them? Have they been discarded? The ISMP data does not show any increase in the proportion of younger fish discarded. Why do the

Kapala data show a clear decline in mean catch-at-age and -length even though the survey design was not changes between years?

2) The catch-at-age and -length data are correct but the CPUE does not give a good indication of the abundance of pink ling. This could be because ling are attracted to heavily trawled grounds because of the presence of discarded fish and offal. Thus CPUE is kept high as the overall ling biomass declines. Fishing mortality rates in ling are extremely high (possibly greater than 2.0 - Fig 6) and the biomass is extremely depleted (possibly as low as 4% - Table 3).

3) There are several ling stocks, some of which may be confined to very small areas and the fishery does not fish consistently on these stocks (i.e. individual stocks are fished heavily in some years but not at all in others). The various changes in biomass and mean age and length of these individual stocks cause confusion when the data are considered to come from a single stock.

Sustainable levels of catch
The size of the stock is not at all certain and neither, therefore, is its current size in relation to pristine. The sustainability of future catches is therefore not easily assessed. However, the current TAC of 2400t per annum is unlikely to be sustainable.

If a greater proportion of the TAC is caught by the non-trawl fleet this results in a greater depletion of the stock for the same level of TAC, however this effect is small. This result is dependant on the selectivity curve estimated for the trawl and non-trawl fisheries and these can change sufficiently with the addition of a single year's data to reverse this result (not shown).

CONCLUSION

The purpose of this document is to present the results of an initial attempt at assessing the pink ling stock. It is hoped that this will provoke discussion that will lead to refinement of the approach adopted here. It is clear that the pink link stock and its interaction with the South East Fishery is not yet properly understood.

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TABLES

Table 1. Values for biological parameters, used in the model.

Description	Value
Length-weight relationship:	
a	2.93e-3 $g.cm^{-1}$
b	3.139
von Bertalanffy growth curve:	
L_∞	101.335 cm
K	0.179 y^{-1}
$t0$	-2.045 y
Other:	
length-at-maturity	67[1] cm
steepness (h)	0.75
μ	0.90

[1] This is roughly the average of two lengths-at-50%-maturity that have been reported in the literature: 60 cm (Smith and Tilzey, 1995) and 72 cm (Lyle and Ford, 1993). It corresponds to an age of roughly 4 years.

Table 2. Prior distributions chosen for the model parameters, and weights for the components of the log-likelihood

Model Parameter	Upper and lower bounds of prior distribution	Form of prior distribution
m_1, m_2	exp(0.05), exp(0.5)	uniform on log-scale
ε_y	exp(-15), exp(15)	log-normal
$F_{f,y}$	exp(-20), exp(1)	uniform on log-scale
l_f^{50}, l_f^{95}	1, l_∞	uniform
d_f^{50}, d_f^{95}	1, l_∞	uniform
q_f	exp(-20), exp(12)	uniform on log-scale
R_0	exp(-5), exp(20)	uniform on log-scale
Weighting parameter	**Value (for base case)**	
N for catch-at-age (N_{ca})	50	
N for catch-at-age (N_{da})	25	
N for catch-at-length (N_{cl})	50	
N for discard-at-length (N_{dl})	25	
σ_c	0.05	
σ_d	0.3	
σ_q	0.3	
σ_R	1.0	

Table 3. Estimated values of quantities of interest for the base case model and several sensitivity tests. Values in italics are standard deviations ("*Std dev*"). B_0 is the pristine spawning biomass, B_y is spawning biomass in year y, F_y^f is fishing mortality for fleet f in year y, c.v. R is the c.v. of the estimated recruitment residuals and -lnL is the negative log-likelihood for this fit.

Model specification	B_0	B_{77}^{sp}	B_{98}^{sp}	B_{77}^{sp}/B_0	B_{98}^{sp}/B_0	F_{98}^1	F_{98}^2	c.v R	-ln L
Base-case	10921	10864	3415	99%	31%	0.314	0.082	0.50	662.9
Std dev	*1084*	*1083*	*1162*	*0.1%*	*8.8%*	*0.101*	*0.030*	*0.08*	
$h = 0.65$	11166	11110	3494	99%	31%	0.308	0.080	0.52	663.3
$h = 0.85$	10737	10680	3359	99%	31%	0.319	0.083	0.49	662.7
$\mu = 1.0$	12134	12072	3795	99%	31%	0.314	0.082	0.50	662.9
$\mu = 0.7$	8494	8450	2656	99%	31%	0.314	0.082	0.50	662.9
l_m = 60 cm	12181	12119	4973	99%	41%	0.315	0.082	0.50	662.8
l_m = 72 cm	9817	9766	2466	99%	25%	0.313	0.081	0.51	663.0
CPUE not used	8632	8574	326	99%	4%	2.319	0.728	0.46	641.8
$\varepsilon_y = 0$ *	9477	9419	1214	99%	13%	0.851	0.211	0.00	698.4
CPUE $\propto \sqrt{B}$	9335	9278	1443	99%	15%	0.694	0.195	0.44	657.3
No length data	11583	11522	2832	99%	24%	0.456	0.067	0.62	232.6
No age data	20393	20347	19820	100%	97%	0.079	0.021	0.84	480.5
Discards not used	9559	9504	2801	99%	29%	0.433	0.100	0.43	343.0
East only	5236	5196	729	99%	14%	0.770	0.000	0.69	403.8
West only	5337	5318	263	100%	5%	1.056	0.884	0.44	801.5

* no recruitment residuals

FIGURE CAPTIONS

Figure 1. Map showing the South East Fishery (SEF) management zones.

Figure 2. Agreed Total Allowable Catches (TACs) set for pink ling and actual landed catches since the inception of TACs for this fishery in 1992.

Figure 3. Standardised catch-per-unit-effort (CPUE) for the SEF trawl fishery for all areas "All areas (trawl)", and for zones 10 - 30 only "East (trawl)", and zones 40 - 60 only "West (trawl)" and unstandardised CPUE for the two Kapala surveys "Kapala research".

Figure 4. Mean and 90%-iles for observed catch-at-age and catch-at-length for the years in which data are available for (a) trawl, non-trawl and Kapala in all SEF areas combined, (b) trawl in the east (zones 10-30) and (c) the west (zones 40-60).

Figure 5. Observed (symbols) and model estimated (lines) (a) annual landings for the trawl (T) and non-trawl (NT) sub-fisheries, and (b) annual discards by the commercial fishery.

Figure 6. Observed and model estimated CPUE for (a) the trawl fishery and (b) the Kapala surveys (CPUE data were not available for the non-trawl sub-fishery).

Figure 7. Model estimated (a) vulnerability to being caught by the trawl, non-trawl or Kapala research surveys as a function of length; (b) vulnerability to being caught by the trawl sub-fishery in the east and in the west; and (c) probability of being discarded after being caught for the base case (all areas).

Figure 8. Observed and model estimated discard-at-length frequencies for the years for which data were available.

Figure 9. Observed and model estimated catch-at-length frequencies for the years for which length data were available for (a) the trawl sub-fishery, (b) the non-trawl sub-fishery, and (c) the Kapala surveys.

Figure 10. Observed and model estimated catch-at-age frequencies for the years for which age data were available for (a) the trawl sub-fishery; (b) the non-trawl sub-fishery and (c) the Kapala survey.

Figure 11. Estimated recruitment residuals ($\exp(\varepsilon_y)$ see equation A.3) for (a) the base case model (BC) and the sensitivity test in which the CPUE data are ignored (No CPUE); and (b) the base case model applied to data from the east only (East) and to data from the west only (West). Note that a value of 1 indicates no deviation from the stock-recruit relationship; a value of 2 indicates that recruitment is double that predicted by the stock-recruit relationship. The horisontal line indicates no deviation from the stock-recruit relationship.

Figure 12. The model estimated spawning biomass of pink ling from the base case model (Base case) and the sensitivity in which the CPUE data is ignored (No CPUE); (b) base case model estimates of the spawning biomass and the biomass available to the trawl and non-trawl sub-fisheries and to the Kapala research surveys; and (c) the estimated spawning biomass for the base case applied to the east only and to the west only.

Figure 13. The effect of changing the weight given to the CPUE data ($1/2\sigma_q$ see equation A.30) on the estimated values of (a) stock status in 1998 (B_{98}^{sp}/B_0) (b) pristine spawning biomass (B_0); (c) the slope of the recruitment residuals between 1990 and 1995; and (d) the estimated fishing mortality rates in 1998 for the trawl and non-trawl sub-fisheries.

Figure 14. (a) Median and 90%-ile for the spawning biomass of pink ling, values after 1998 are calculated by projecting the population forward under the assumption of an annual TAC of 2000t of which 10% is caught by the non-trawl sub-fishery. (b) The probability that the spawning biomass will fall below 20% of its pristine level (B_0) given a range of levels of catch and two different non-trawl:trawl ratios for splitting the TAC.

Figure 15. The probability that the spawning biomass will fall below 20% of its pristine level following 20 years of fishing at a constant TAC. Results are shown for the base case model for two non-trawl:trawl ratios for splitting the TAC and for the sensitivity in which the CPUE data are ignored (assuming a 10:90 split of the TAC). The horisontal dotted line indicates the 10% level, often adopted as a reference point.

Appendix: The population dynamics model and likelihood function

Numbers at age

The number of animals at the start of year y that are of age a ($N_{y,a}$) is given by:

$$N_{y,a} = \begin{cases} N_{y,1} & \text{if} \quad a=1 \\ N_{y-1,a-1}\, e^{-Z_{y-1,a-1}} & \text{if} \quad 1<a<x \\ N_{y-1,x-1}\, e^{-Z_{y-1,x-1}} + N_{y-1,x}\, e^{-Z_{y-1,x}} & \text{if} \quad a=x \end{cases} \qquad \text{(A.1)}$$

where $N_{y,1}$ is the number of 1-year old animals at the start of year y (see A.3),

$Z_{y,a}$ is the instantaneous total mortality rate on fish of age a during year y (see A.6),

x is the age at which a plus group is formed.

At the beginning of 1977 the stock is assumed to have been pristine and at deterministic equilibrium:

$$N_{1977,a} = \begin{cases} N_{1977,1} & \text{if} \quad a=1 \\ N_{1977,a-1}\, e^{-M_{a-1}} & \text{if} \quad 1<a<x \\ N_{1977,x-1}\, e^{-M_{x-1}} \big/ \left(1-e^{-M_x}\right) & \text{if} \quad a=x \end{cases} \qquad \text{(A.2)}$$

where M_a is the instantaneous natural mortality rate for fish of age a.

Recruitment

The number of 1-year old fish at the start of year y is given by:

$$N_{y,1} = B^{sp}_{y-1} \big/ \left(\alpha + \beta B^{sp}_{y-1}\right)\, e^{\varepsilon_y} \qquad \text{(A.3)}$$

where: B^{sp}_{y-1} is the spawning biomass during year y-1 (see A.9),

ε_y is the recruitment residual for year y, and

α and β are parameters of the stock recruit relationship and are defined in terms of h, a parameter which specifies the steepness of the curve (Francis, 1992):

$$\alpha = A_0\,(1-h)/(4hR_0) \qquad \text{(A.4)}$$

$$\beta = (5h-1)/(4hR_0) \qquad \text{(A.5)}$$

where R_0 is a parameter whose value is estimated during the model fitting procedure, and

A_0, the deterministic, unexploited spawning biomass, is given by:

$$A_0 = \alpha R_0 / (\beta R_0 - 1).$$

The recruitment at the start of the first year of fishing ($N_{1977,1}$) is given by:

$$N_{1977,1} = A_0 / (\alpha + \beta A_0)\ e^{\varepsilon_1}$$

Total mortality rate

The instantaneous total mortality rate on fish of age a during year y is given by:

$$Z_{y,a} = M_a + \sum_f \sum_l \left(S_{f,l}\ F_{f,y}\ P_{l,a}\right) \qquad \text{(A.6)}$$

where: M_a is the instantaneous natural mortality rate for fish of age a:

$$M_a = \begin{cases} m_1 & \text{for} \quad a \leq 10 \\ m_2 & \text{for} \quad a > 10 \end{cases} \qquad \text{(A.7)}$$

$S_{f,l}$ is the vulnerability of fish in length-class l to being caught by sub-fishery f ($f = 1$ for the trawl sub-fishery, $f = 2$ for the non-trawl sub-fishery, and $f = 3$ for the Kapala research surveys),

$F_{f,y}$ is the fully-selected instantaneous fishing mortality rate for sub-fishery f during year y, and

$P_{l,a}$ is the proportion of fish of age a that are in length-class l, given by:

$$P_{l,a} = \int_{l-0.5}^{l+0.5} \ln \mathrm{N}\left(\tilde{l}, \sigma_a^2\right)\ d\tilde{l} \qquad \text{(A.8)}$$

where: $\ln \mathrm{N}\left(\tilde{l}, \sigma_a^2\right)$ is a log-normal distribution with median $\tilde{l}$ and age-dependant variance σ_a^2.

Spawning biomass

The spawning biomass during year y (B_y^{sp}) is defined as the biomass at the middle of the year:

$$B_y^{sp} = \mu \sum_a \left(N_{y,a} \, e^{-Z_{y,a}/2} \, w_a^m \right) \tag{A.9}$$

where μ is the proportion of mature fish that breed each year,

w_a^m is the average mass of mature fish of age a:

$$w_a^m = \sum_{l=l_m}^{l_{max}} P_{l,a} \, w_l \tag{A.10}$$

l_m is the (knife-edged) length-at-maturity, and

w_l is the mass of a fish in length-class l ($w_l = al^b$).

Vulnerability

The vulnerability of a fish in length-class l to being caught by sub-fishery f ($S_{f,l}$) is given by:

$$S_{f,l} = \begin{cases} e^{-\ell n 20 (l^{mid} - l)^2 / (l^{mid} - l_f^{95})^2} & \text{for } f = 1 \text{ or } 3 \\ (1 + e^{-\ell n 19 (l - l_f^{50})/(l_f^{95} - l_f^{50})})^{-1} & \text{for } f = 2 \end{cases} \tag{A.11}$$

where l_f^{mid} is the length-class at which a fish is most vulnerable to being caught by sub-fishery f,

l_f^{50} is the length-at-50% vulnerability for sub-fishery f,

l_f^{95} is the length-at-95% vulnerability for sub-fishery f.

These equations force the vulnerability curves for the trawl sub-fishery and for the Kapala research surveys to be dome-shaped, and that for the non-trawl sub-fishery to be logistic (S-shaped).

Discard probability

The probability that a fish in length-class l that has been caught will be discarded (d_l) is given by:

$$d_l = \begin{cases} (1+e^{-\ell n 19(l-d_f^{50})/(d_f^{50}-d_f^{5})})^{-1} & \text{for } f = 1 \text{ or } 3 \\ e^{-\ell n 20(l-d_f^{\max})/(d_f^{\max}-d_f^{95})} & \text{for } f = 2 \end{cases} \tag{A.12}$$

where d_f^p is the length-class at which there is a p% chance that a fish caught by sub-fishery *f* will be discarded, and

$d_f^{\max}$ is the length-class at with the chance that a fish caught by sub-fishery *f* will be discarded, is at its maximum.

Available biomass

The biomass of fish that are available to be caught and landed by sub-fishery *f* during year *y* ($B_{f,y}^{av}$) is defined as:

$$B_y^{av} = \sum_a \left(N_{y,a}\; e^{-Z_{y,a}/2}\; w_{f,a}^{av}\right) \tag{A.13}$$

where $w_{f,a}^{av}$ is the average mass of fish of age *a* that are available to sub-fishery *f*:

$$w_{f,a}^{av} = \sum_l (1-d_l)\, S_{f,l}\; P_{l,a}\; w_l \tag{A.14}$$

CPUE

The expected catch-per-unit effort for sub-fishery *f* ($CP\hat{U}E_{f,y}$) is assumed to be proportional to the biomass that is available to that sub-fishery:

$$CP\hat{U}E_{f,y} = q_f\; B_y^{av} \tag{A.15}$$

where: q_f is a constant of proportionality for sub-fishery *f*.

Landings and discards

The model estimated number of fish of age *a* that are caught during year *y* by sub-fishery *f* ($\hat{C}_{f,y,a}$) is given by:

$$\hat{C}_{f,y,a} = \frac{F_{f,y}}{Z_{y,a}} N_{y,a} (1 - e^{-Z_{y,a}}) \sum_l \left[S_{f,l} \, (1 - d_l) \, P_{l,a} \right] \tag{A.16}$$

Similarly, the model estimated number of fish of age *a* that are caught in year *y* by sub-fishery *f* but are subsequently discarded ($\hat{D}_{f,y,a}$) is given by:

$$\hat{D}_{f,y,a} = \frac{F_{f,y}}{Z_{y,a}} N_{y,a} (1 - e^{-Z_{y,a}}) \sum_l \left[S_{f,l} \, d_l \, P_{l,a} \right] \tag{A.17}$$

The model estimated number of fish in length-class *l* that are caught during year *y* by sub-fishery *f* ($\hat{C}_{f,y,l}$) is given by:

$$\hat{C}_{f,y,l} = F_{f,y} \, S_l \, (1 - d_l) \sum_a \left\lfloor N_{y,a} (1 - e^{-Z_{y,a}}) \, P_{l,a} / Z_{y,a} \right\rfloor \tag{A.18}$$

Similarly, the model estimated number of fish in length-class *l* that are caught during year *y* by sub-fishery *f* but are subsequently discarded ($\hat{D}_{f,y,l}$) is given by:

$$\hat{D}_{f,y,l} = F_{f,y} \, S_l \, d_l \sum_a \left\lfloor N_{y,a} (1 - e^{-Z_{y,a}}) \, P_{l,a} / Z_{y,a} \right\rfloor \tag{A.19}$$

The total mass of fish landed by sub-fishery *f* during year *y* ($\hat{C}_{f,y}$) is given by:

$$\hat{C}_{f,y} = \sum_l \hat{C}_{f,y,l} \, w_l \tag{A.20}$$

Similarly, the total mass of fish discarded by sub-fishery *f* during year *y* ($\hat{D}_{f,y}$) is given by:

$$\hat{D}_{f,y} = \sum_l \hat{D}_{f,y,l} \, w_l \tag{A.21}$$

The likelihood function

The negative of the logarithm of the likelihood (-ln L) is given by:

$$-\ln L = \sum_i L_i \tag{A.22}$$

where the L_i are described below. In all cases, summations over years include only those years for which data are available.

Recruitment residuals

The annual recruitment residuals (ε_y) are assumed to be log-normally distributed with mean zero and cv σ_r^2. They are assumed to be independent of one another (no serial correlation):

$$L_1 = \left(2\sigma_r^2\right)^{-1} \sum_y \varepsilon_y^2 \tag{A.23}$$

Landings

The errors in the observed mass of annual landings are assumed to follow a log-normal distribution with mean $\hat{C}_{f,y}$ and a c.v. of σ_c^2

$$L_2 = \left(2\sigma_c^2\right)^{-1} \sum_f \sum_y (\ln C_{f,y}^{\text{obs}} - \ln \hat{C}_{f,y})^2 \tag{A.24}$$

where $C_{f,y}^{\text{obs}}$ is the observed mass of the catch landed by sub-fishery f during year y.

Discards

Similarly, the contribution to the negative log-likelihood by the mass of the discarded catch is given by:

$$L_3 = \left(2\sigma_c^2\right)^{-1} \sum_f \sum_y (\ln D_{f,y}^{\text{obs}} - \ln \hat{D}_{f,y})^2 \tag{A.25}$$

where $D^{obs}_{f,y}$ is the observed mass discarded by sub-fishery f during year y.

Catch-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood is weighted by assuming that a sample of N_{age} fish was sampled each year. The errors in the proportion caught-at-age for the landed catch are assumed to be normally distributed.

$$L_4 = -N_{age}\sum_f \sum_y \sum_{a=1}^{20+} \rho^{obs}_{f,y,a}\, \ell n(\hat{\rho}_{f,y,a}) \qquad \text{(A.26)}$$

where: $\rho^{obs}_{f,y,a}$ is the observed proportion that fish of age a made up of the catch by sub-fishery f during year y, and

$\hat{\rho}_{f,y,a}$ is the model estimated proportion that fish of age a made up of the catch by sub-fishery f during year y for:

$$\hat{\rho}_{f,y,a} = \hat{C}_{f,y,a} / \sum_{a'} \hat{C}_{f,y,a'} \qquad \text{(A.27)}$$

Fish aged 20 or older are grouped into a single plus class (20+). This is done because the observed data for older fish is more likely to be in error because of the smaller sample sizes for these ages and because older fish are more difficult to age.

Catch-at-length

The contribution of the catch-at-length information to the negative log-likelihood is calculated in the same way as that of the catch-at-age, assuming a sample of N_{len} fish:

$$L_5 = -N_{len}\sum_f \sum_y \sum_l \rho^{obs}_{f,y,l}\, \ell n(\hat{\rho}_{f,y,l}) \qquad \text{(A.28)}$$

where: $\rho^{obs}_{f,y,l}$ is the observed proportion that fish in length-class l made up of the catch in year y for sub-fishery f, and

$\hat{\rho}_{f,y,a}$ is the model estimated proportion that fish from length-class l made up of the catch in year y for sub-fishery f:

$$\hat{\rho}_{f,y,l} = \hat{C}_{f,y,l} / \sum_{l'} \hat{C}_{f,y,l'} \qquad \text{(A.29)}$$

Discard-at-length

Similarly, the contribution to the negative log-likelihood of the proportion discarded at length (L_6) is based on a sample of N_{dlen} animals and equation A.28 is used with "proportion caught-at-length" substituted by "proportion discarded-at-length".

CPUE

Errors in the *CPUE* information are assumed to be log-normally distributed with mean generated by the model and c.v. σ_q.

$$L_7 = \left(2\sigma_q^2\right)^{-1}\sum_f \sum_y \left(\ln CPUE_{f,y} - \ln C\hat{PUE}_{f,y} \right)^2 \tag{A.30}$$

where $CPUE_{f,y}$ is the observed catch-per-unit-effort for sub-fishery *f* during year *y*.

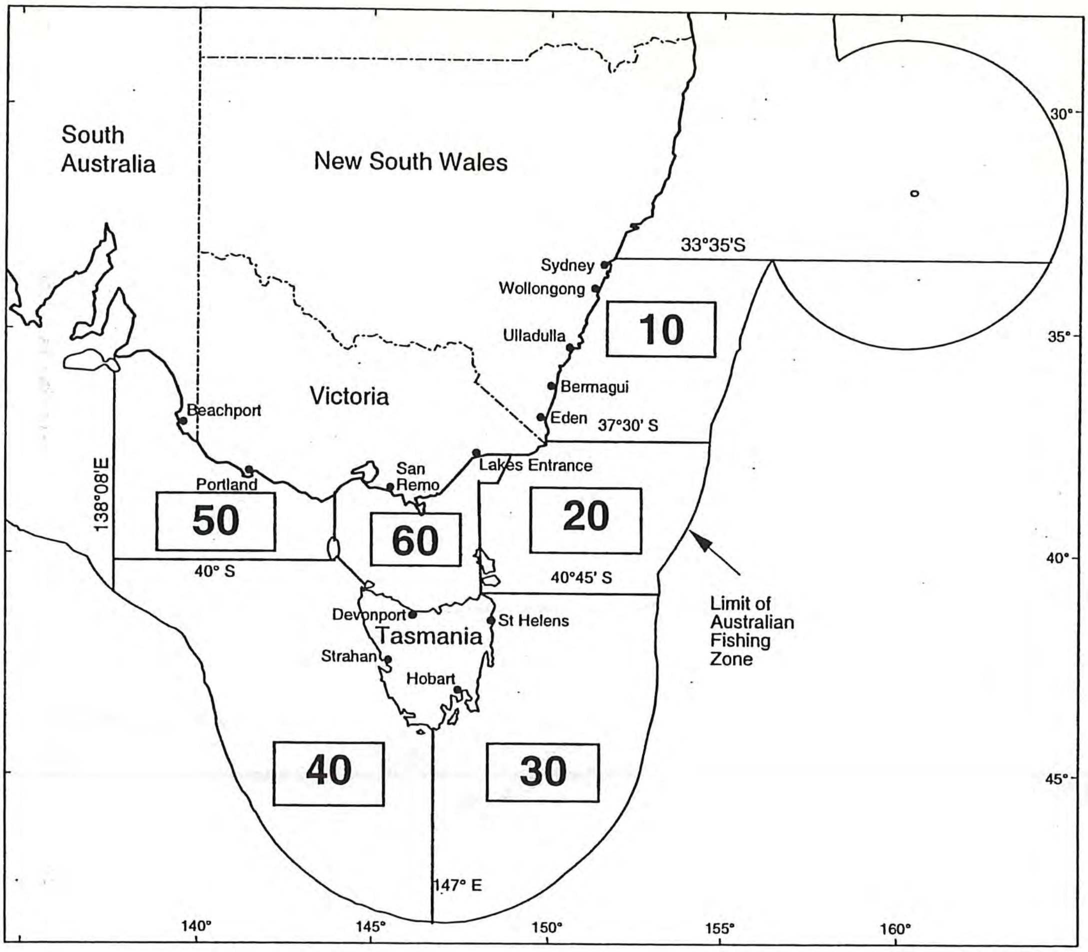


Figure 1

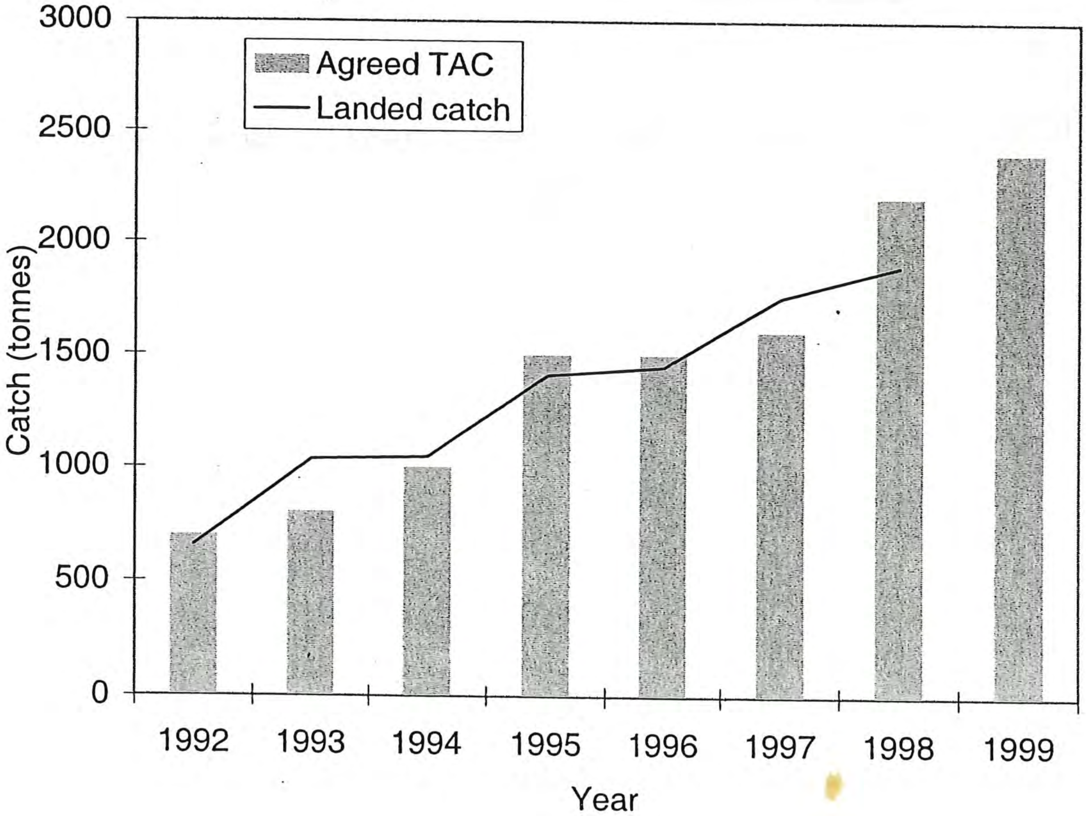


Figure 2

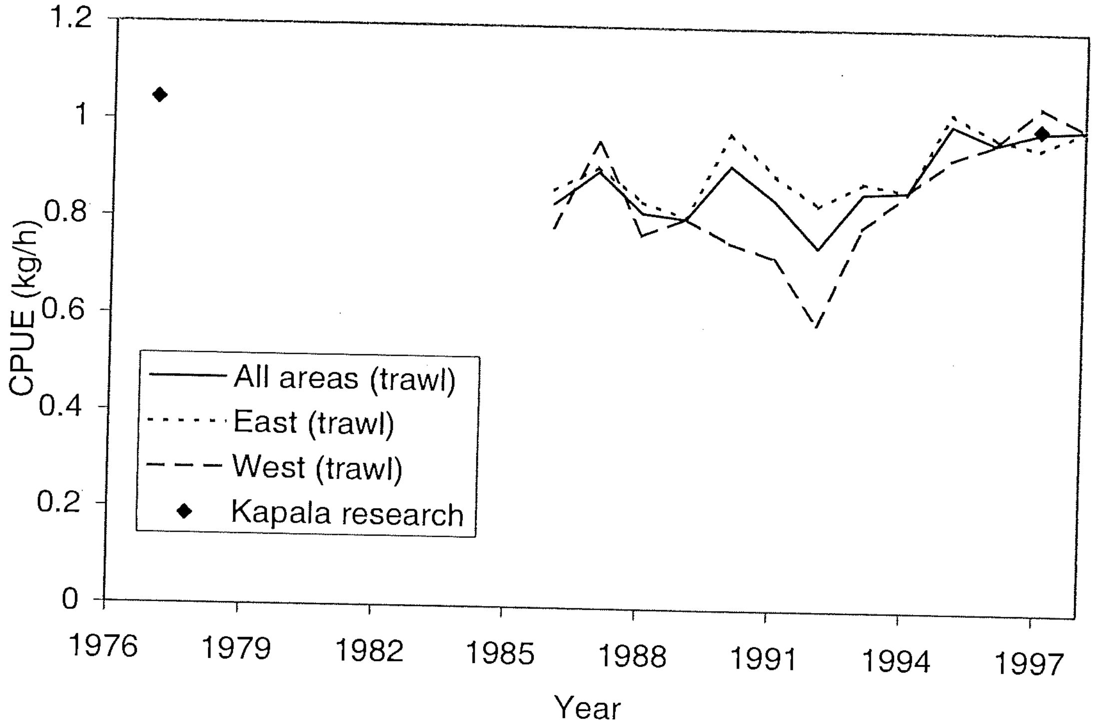

1.2
1
0.8
0.6
0.4
0.2
0
CPUE (kg/h)
All areas (trawl)
East (trawl)
West (trawl)
Kapala research
1976
1979
1982
1985
1988
1991
1994
1997
Year

Figure 3

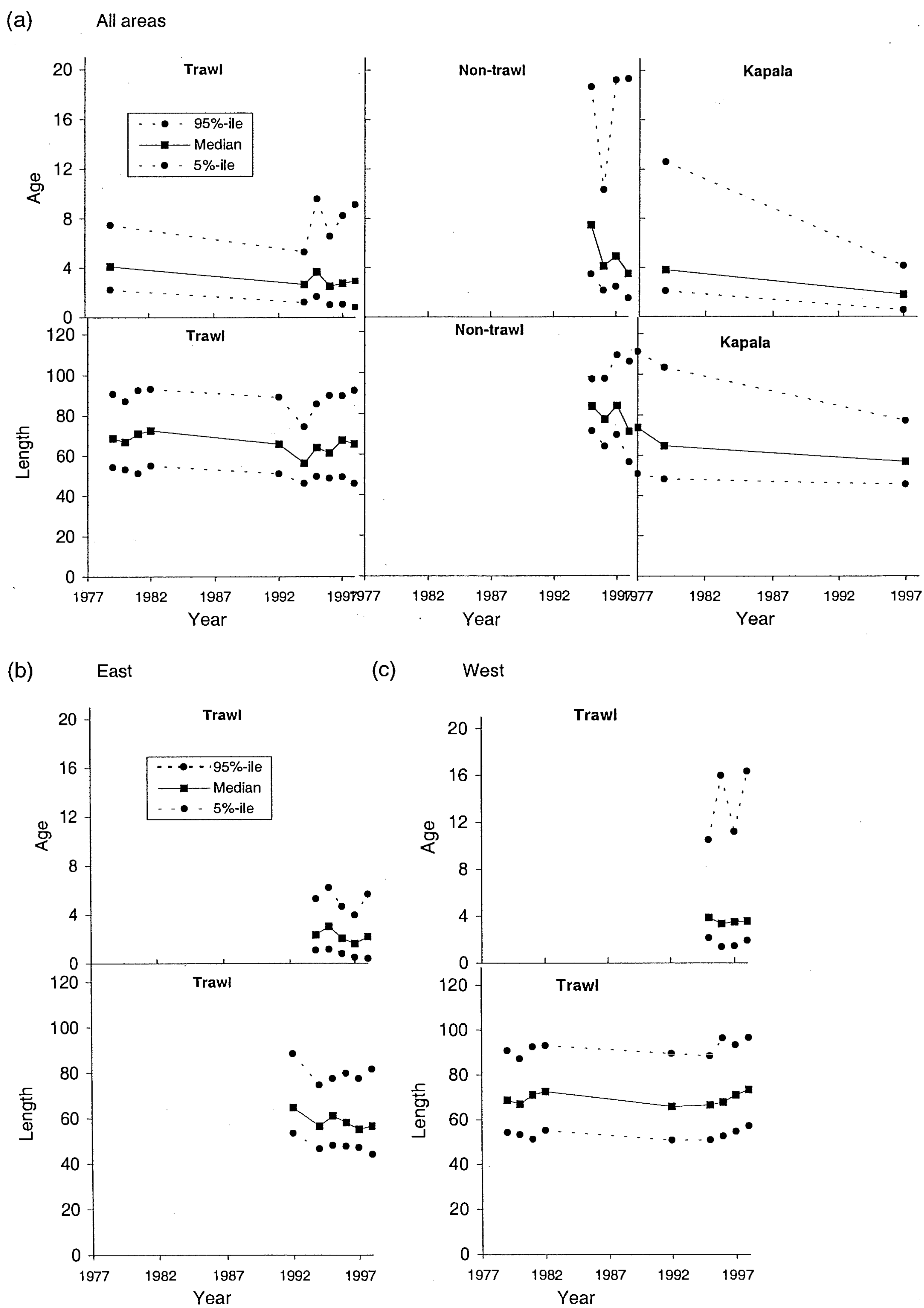
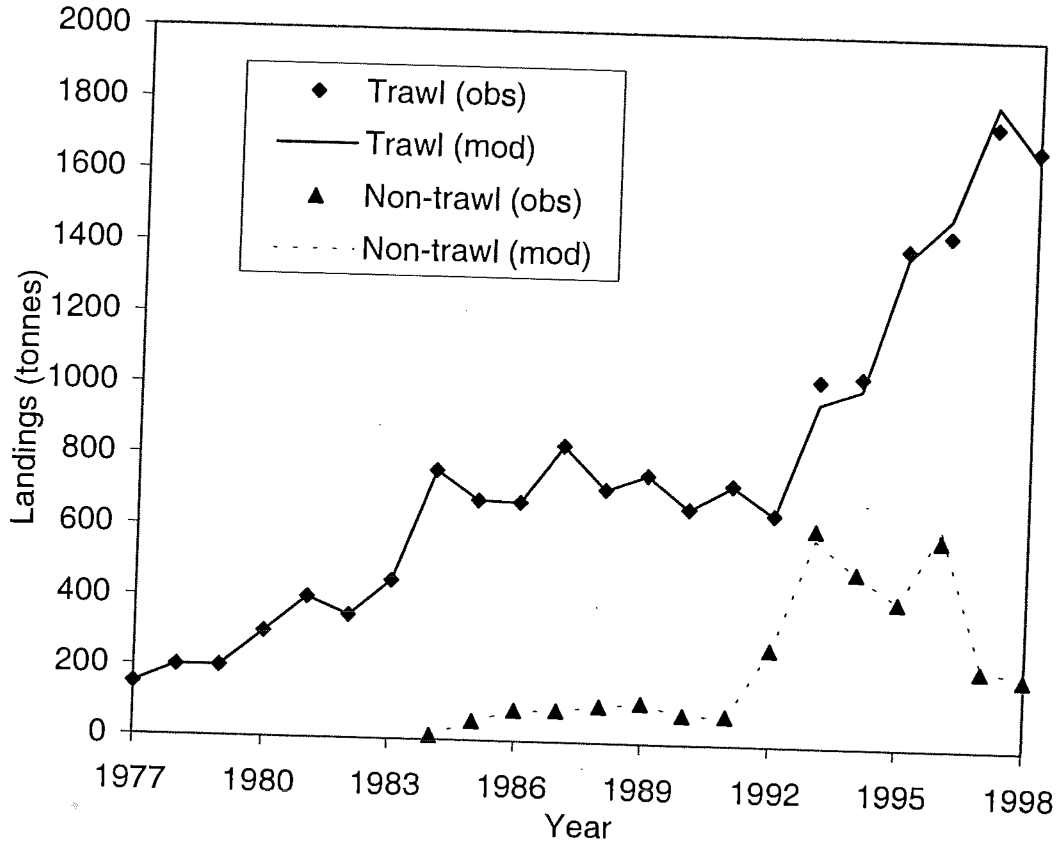

(a) All areas
Trawl
Non-trawl
Kapala
95%-ile
Median
5%-ile
Age
Length
Year
(b) East
(c) West
Trawl
Age
Length
Year

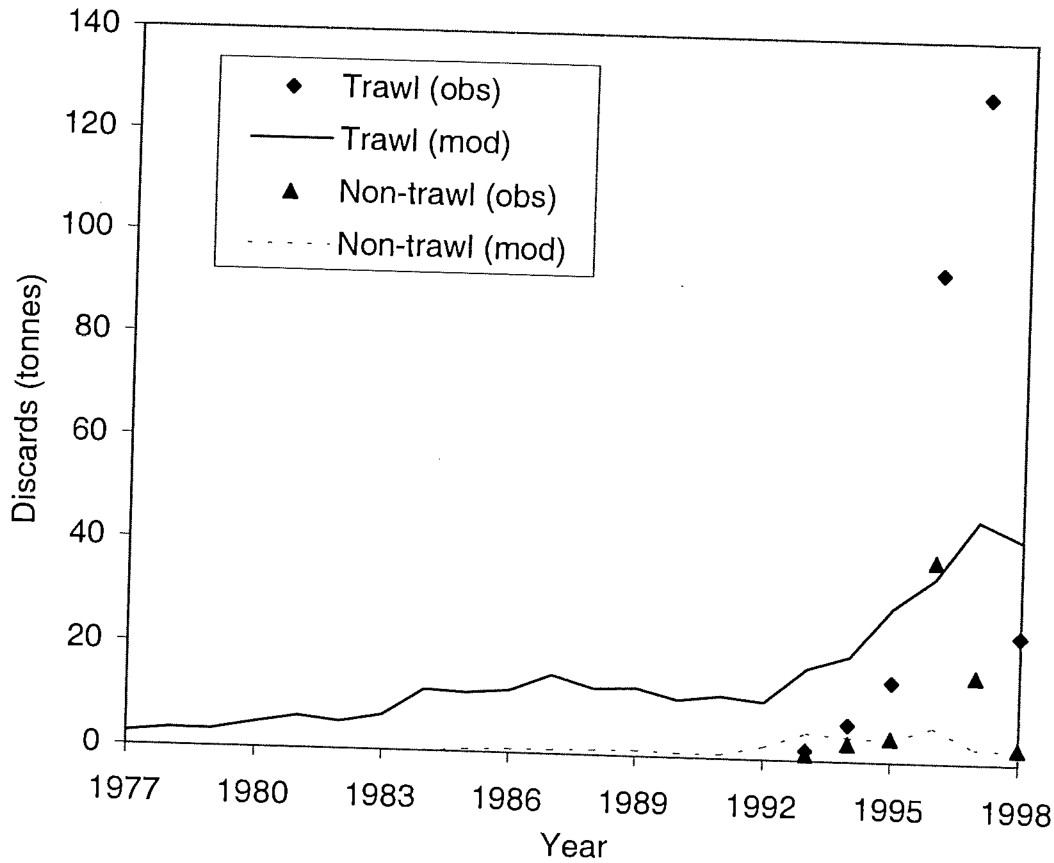
Figure 4

(a)



2000
1800
1600
1400
1200
1000
800
600
400
200
0
Landings (tonnes)
Trawl (obs)
Trawl (mod)
Non-trawl (obs)
Non-trawl (mod)
1977
1980
1983
1986
1989
1992
1995
1998
Year

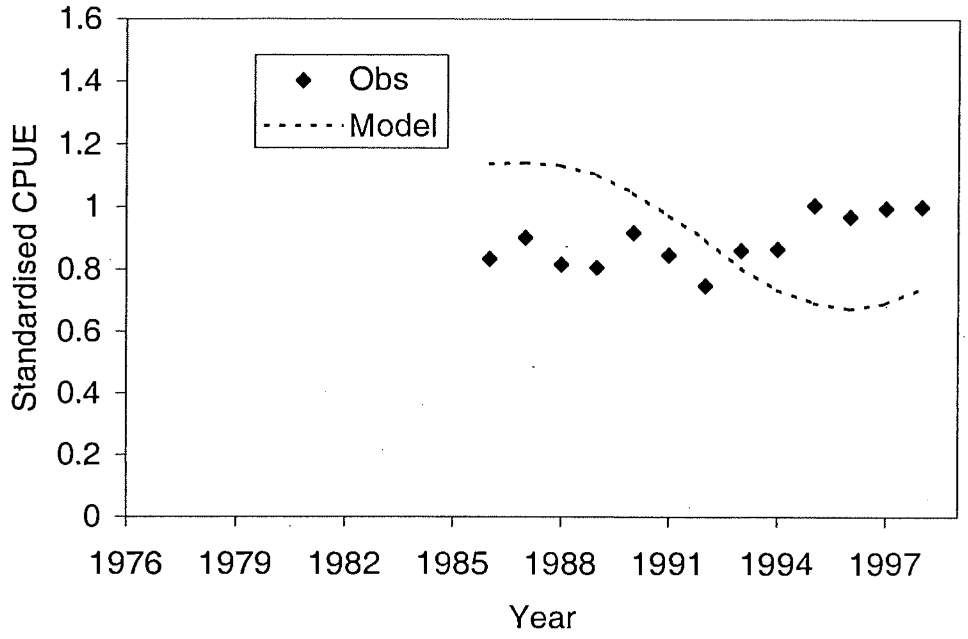
(b)



140
120
100
80
60
40
20
0
Discards (tonnes)
Trawl (obs)
Trawl (mod)
Non-trawl (obs)
Non-trawl (mod)
1977
1980
1983
1986
1989
1992
1995
1998
Year

Figure 5

(a)


Obs
Model
Standardised CPUE
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1976
1979
1982
1985
1988
1991
1994
1997
Year

(b)

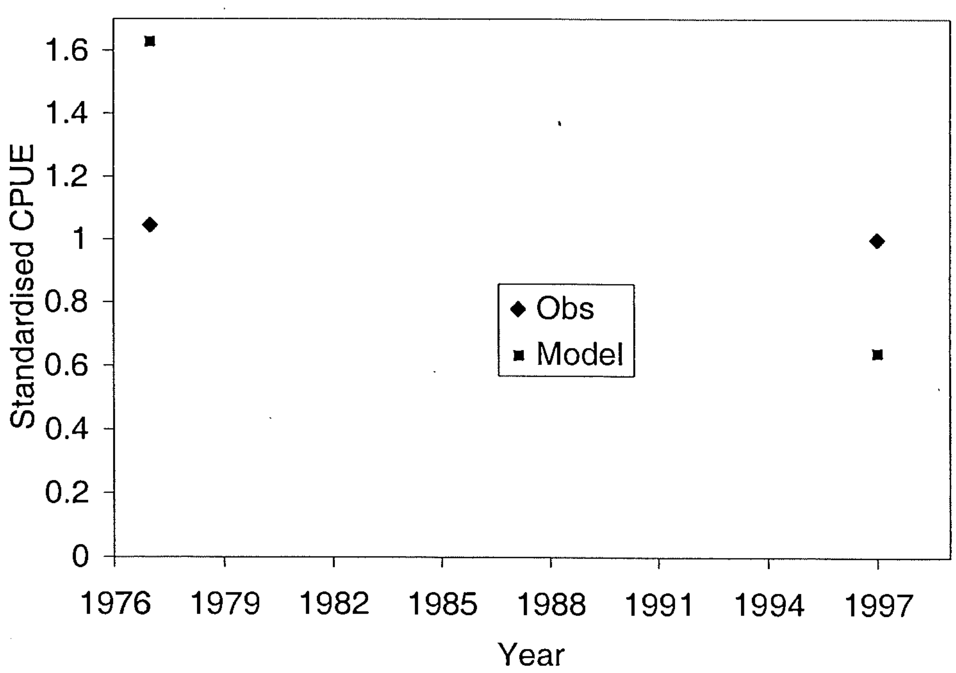
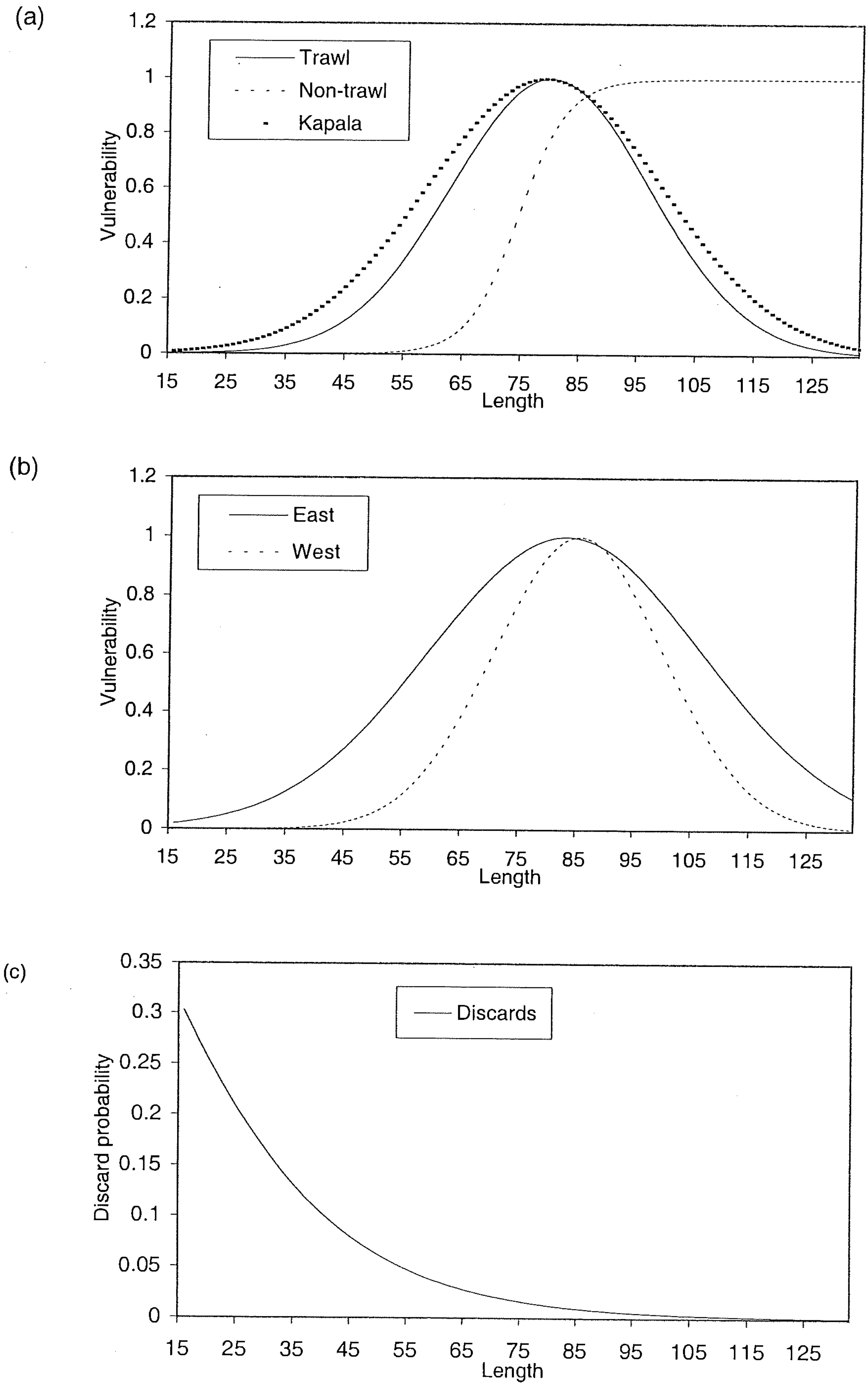

Obs
Model
Standardised CPUE
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1976
1979
1982
1985
1988
1991
1994
1997
Year

Figure 6



(a)
1.2
1
0.8
0.6
0.4
0.2
0
Vulnerability
Trawl
Non-trawl
Kapala
15
25
35
45
55
65
75
85
95
105
115
125
Length
(b)
1.2
1
0.8
0.6
0.4
0.2
0
Vulnerability
East
West
15
25
35
45
55
65
75
85
95
105
115
125
Length
(c)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Discard probability
Discards
15
25
35
45
55
65
75
85
95
105
115
125
Length

Figure 7

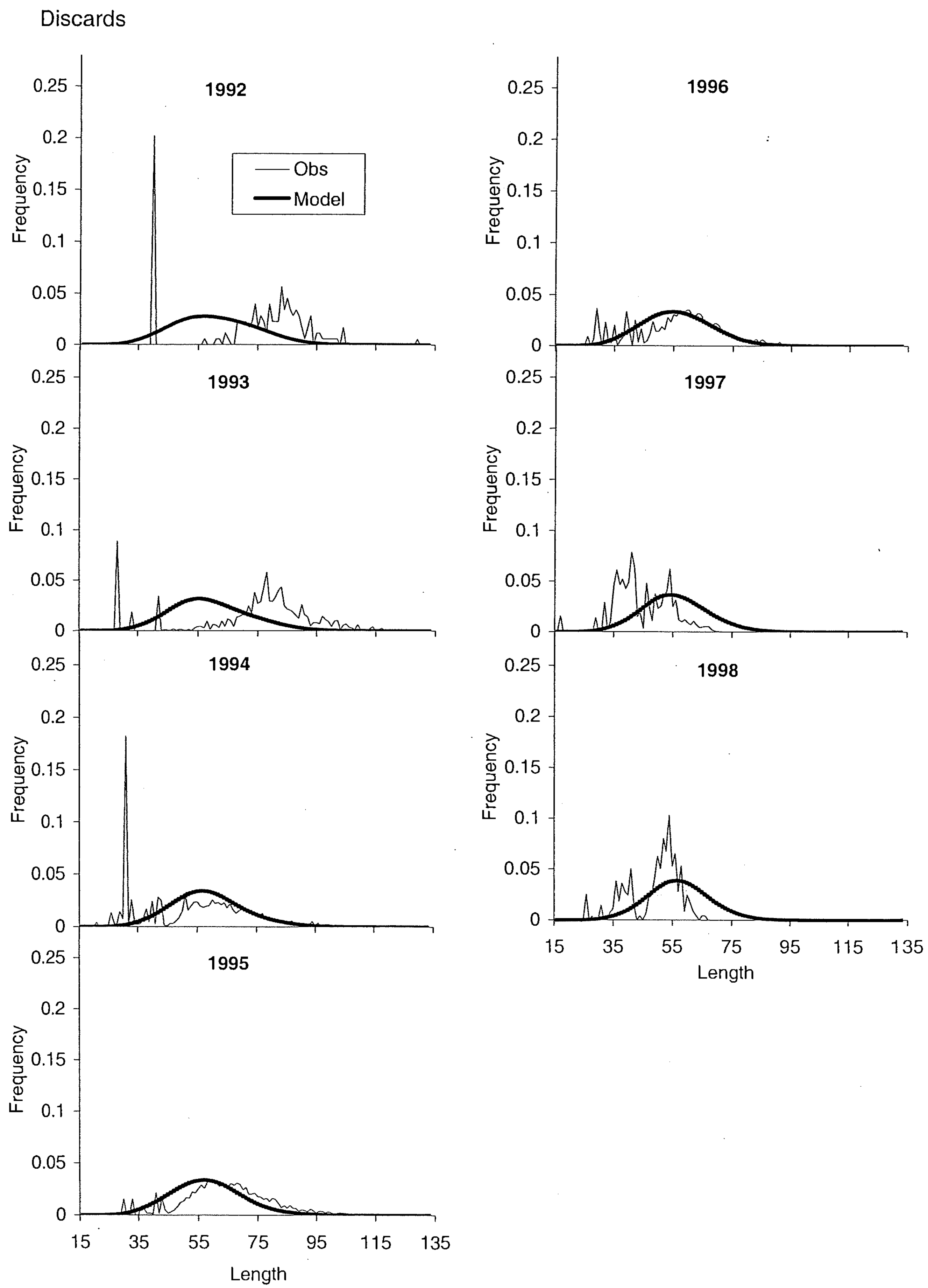
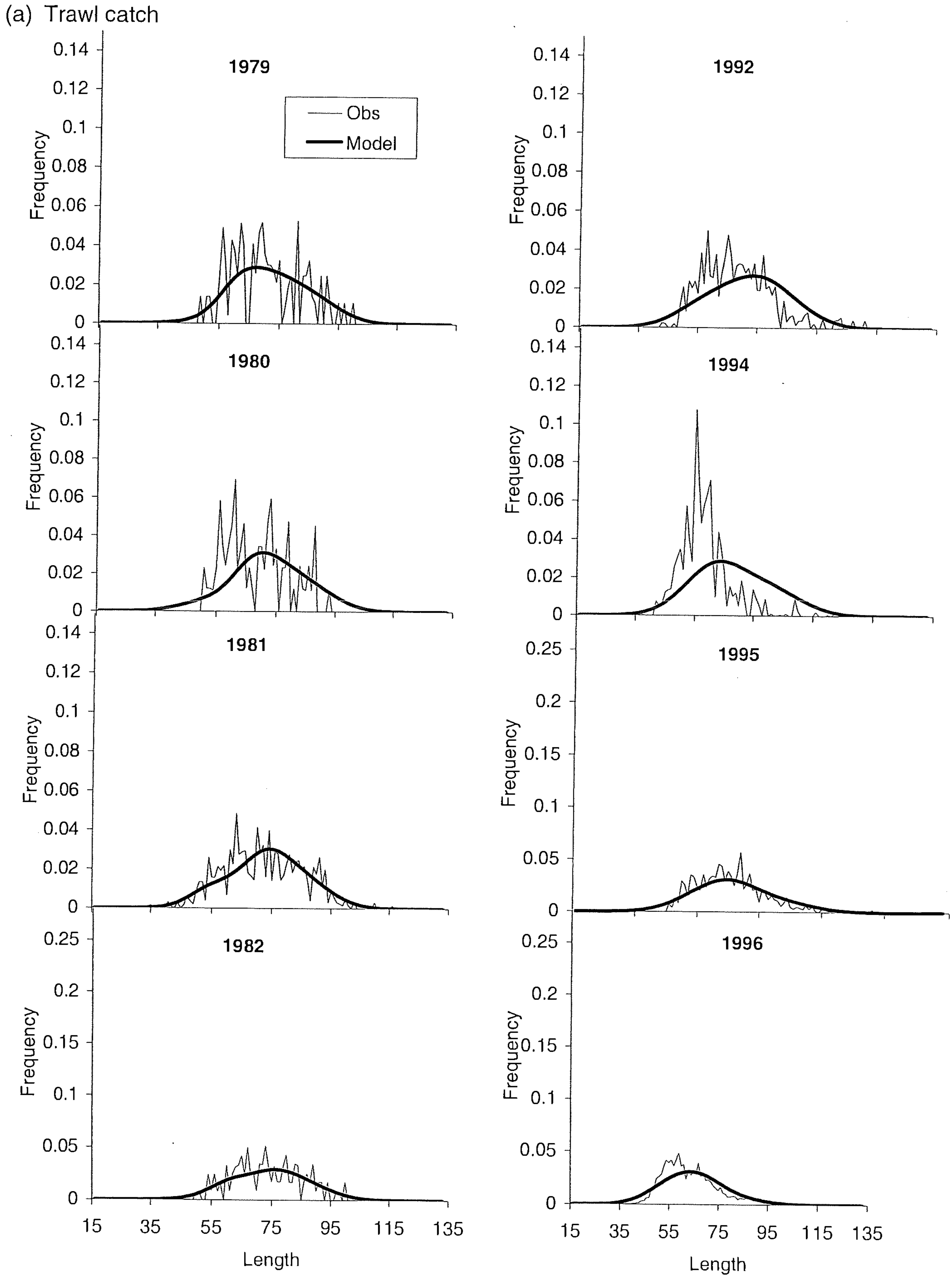

Discards
1992
1993
1994
1995
1996
1997
1998
Obs
Model
Frequency
Length
0.25
0.2
0.15
0.1
0.05
0
15
35
55
75
95
115
135

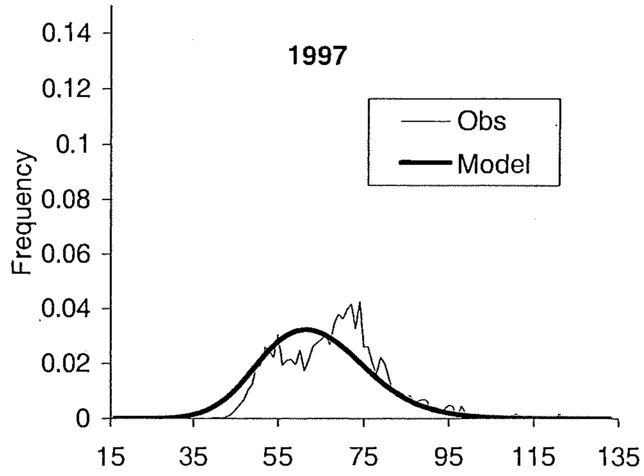
Figure 8



(a) Trawl catch
1979
1980
1981
1982
1992
1994
1995
1996
Obs
Model
Frequency
Length
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.25
0.2
0.15
0.05
15
35
55
75
95
115
135

Figure 9

(a cont.) Trawl catch-at-length



(b) Non-trawl catch-at-length

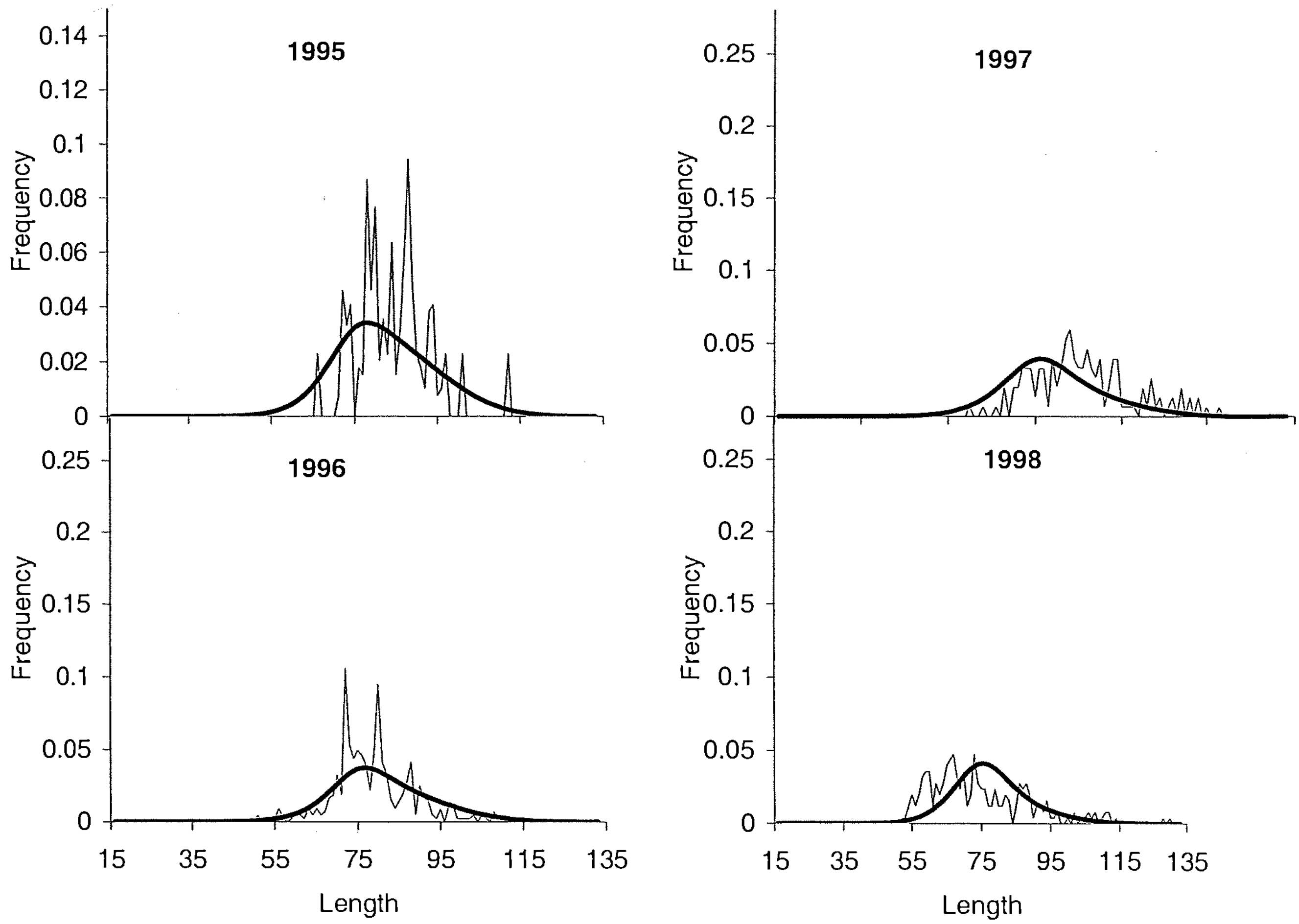


Figure 9

(a) Trawl catch-at-length

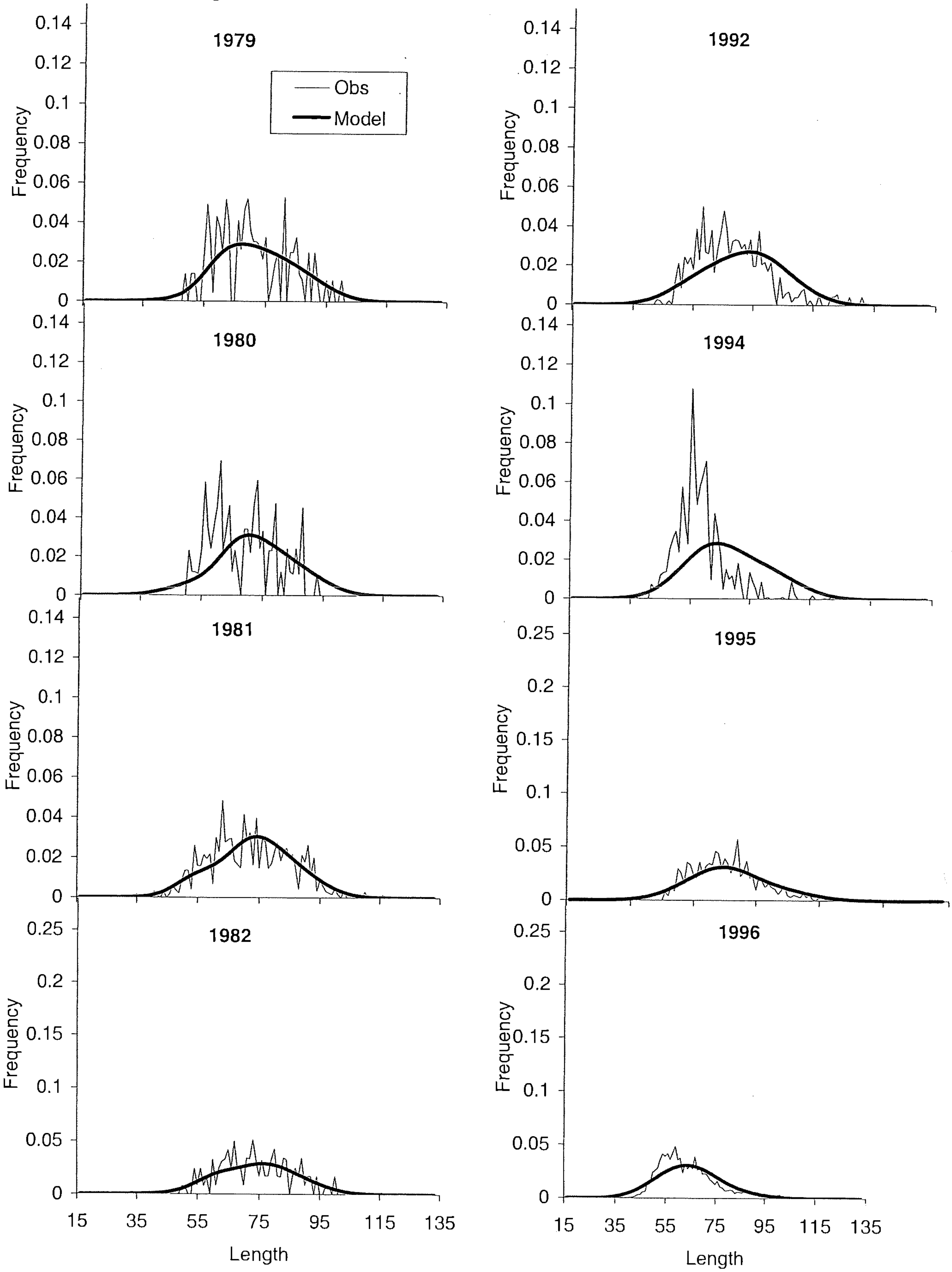


Figure 9

(c) Kapala catch-at-length

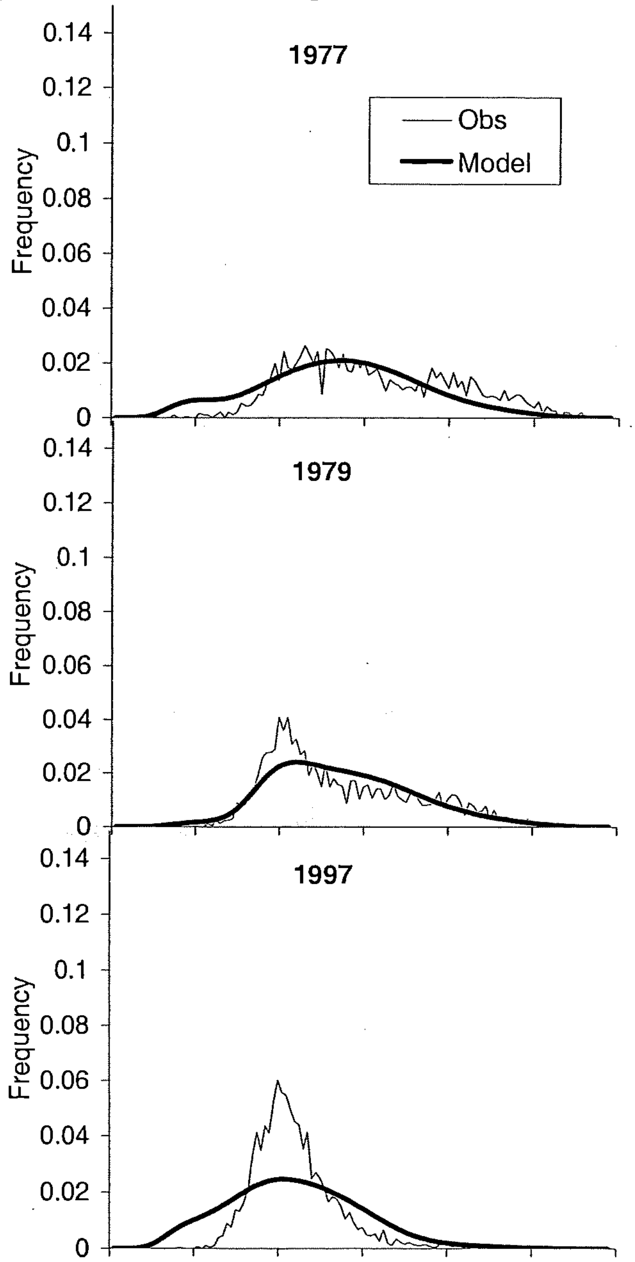


Figure 9

(a) Trawl catch-at-age

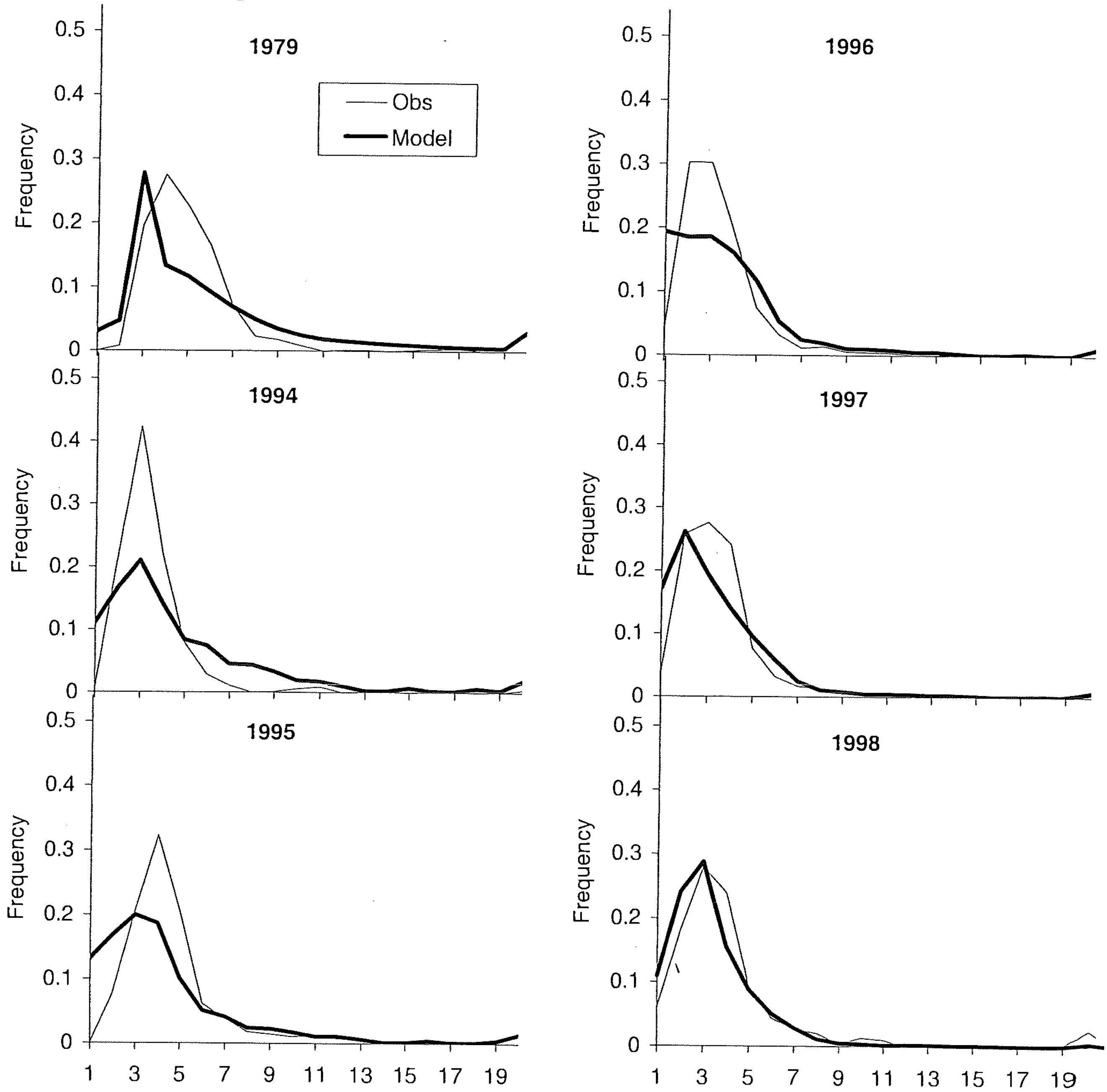
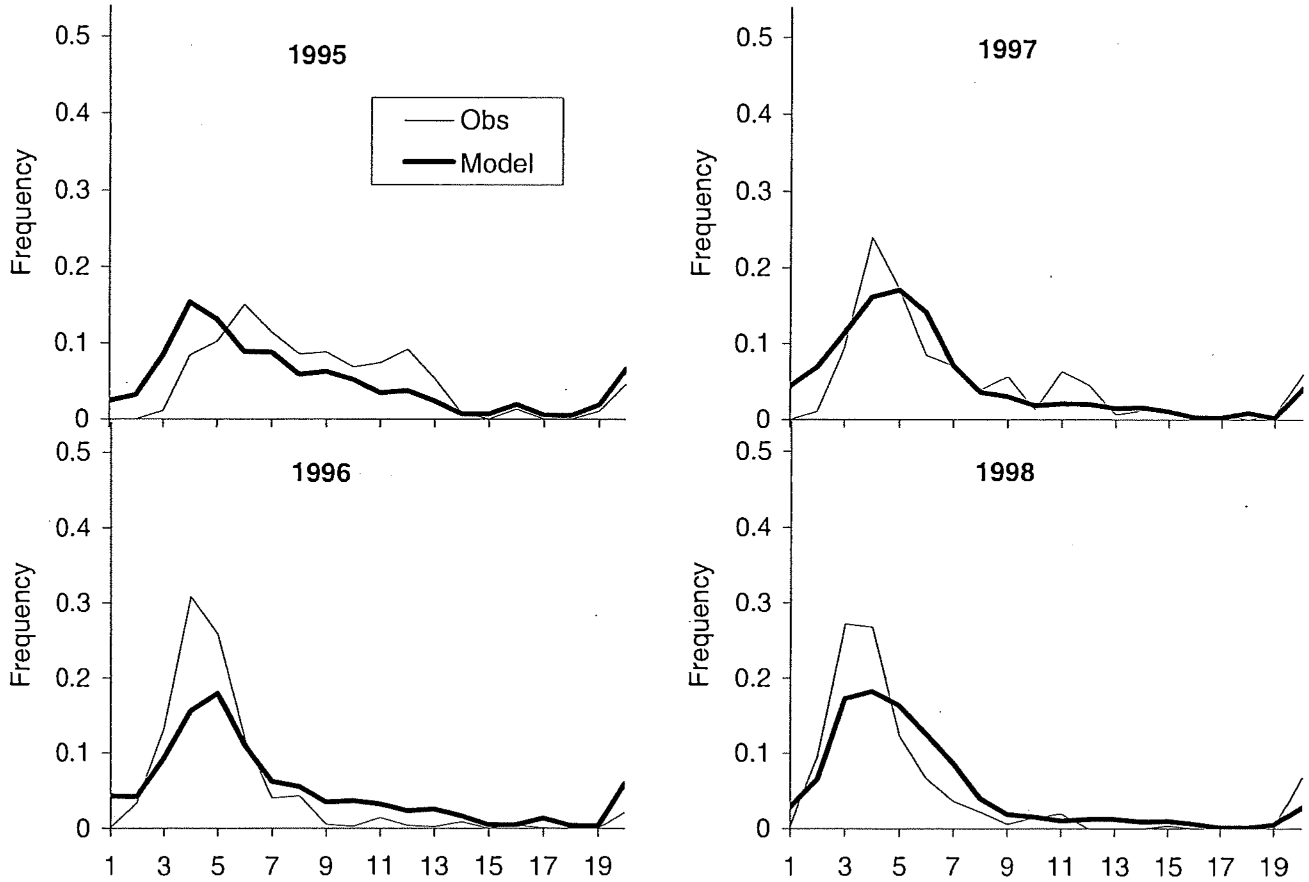


Figure 10

(b) Non-trawl catch-at-age



(c) Kapala catch-at-age

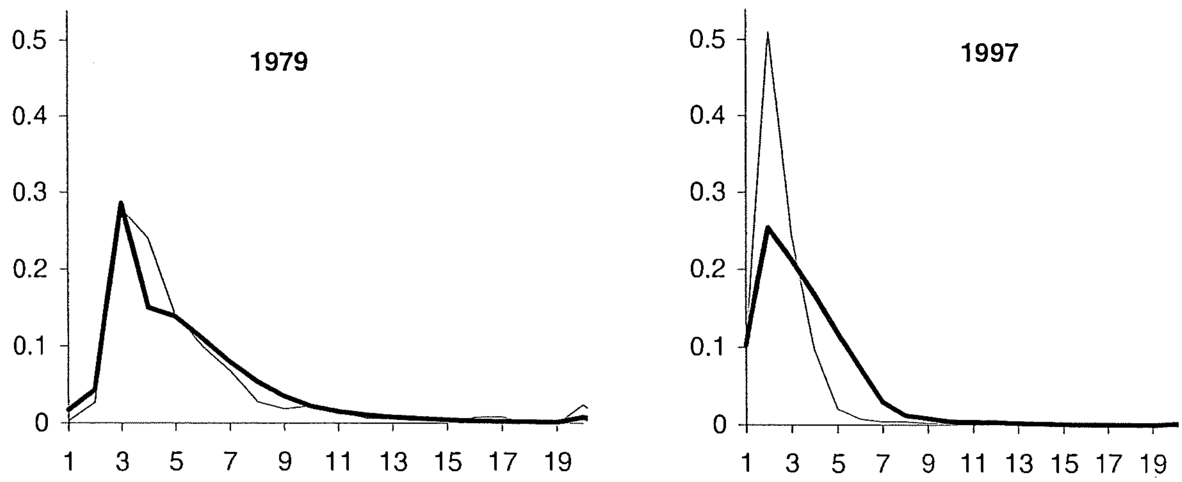


Figure 10

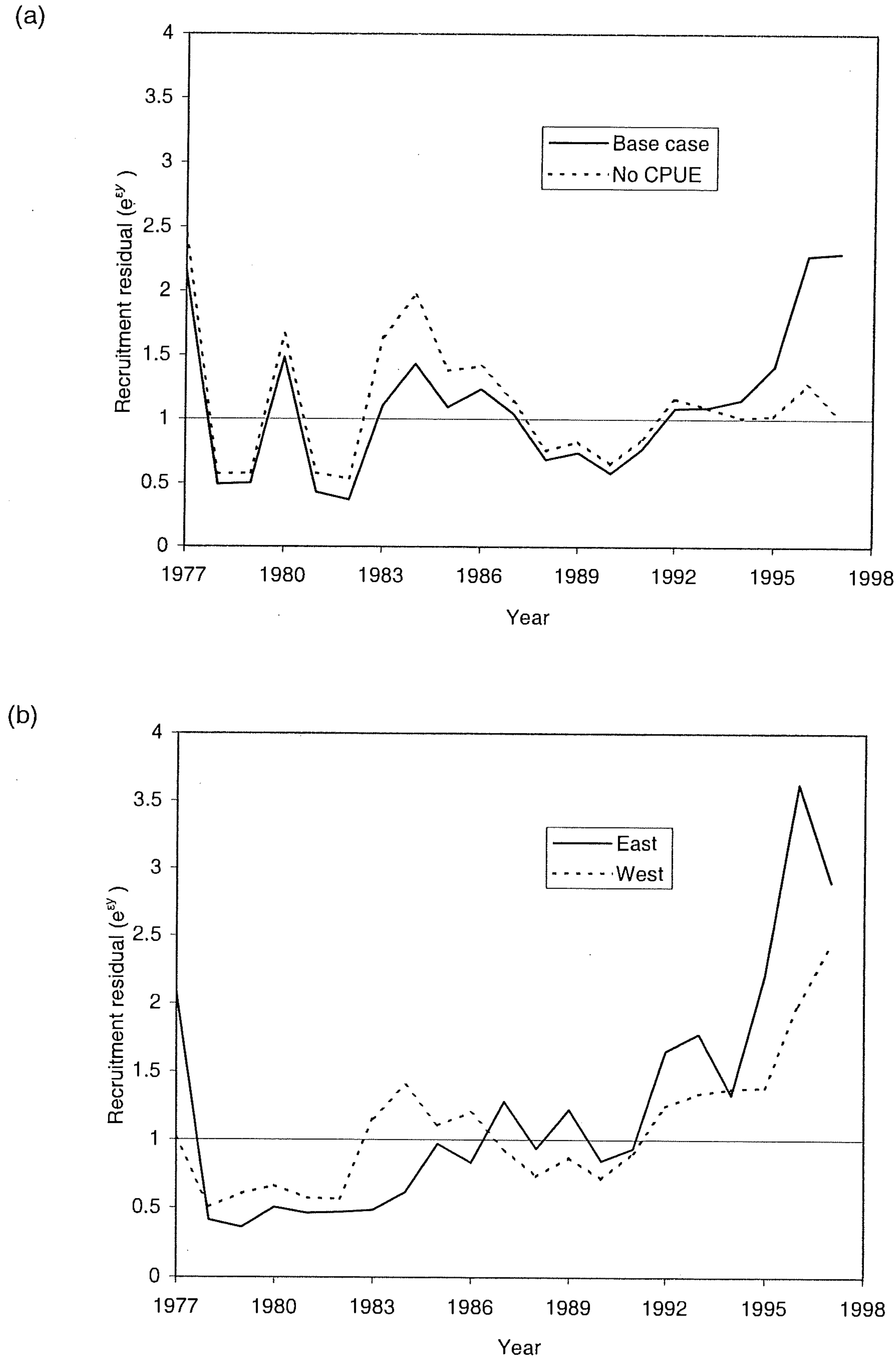

(a)
Base case
No CPUE
Recruitment residual (e^{ε_y})
4
3.5
3
2.5
2
1.5
1
0.5
0
1977
1980
1983
1986
1989
1992
1995
1998
Year
(b)
East
West
Recruitment residual (e^{ε_y})
4
3.5
3
2.5
2
1.5
1
0.5
0
1977
1980
1983
1986
1989
1992
1995
1998
Year

Figure 11

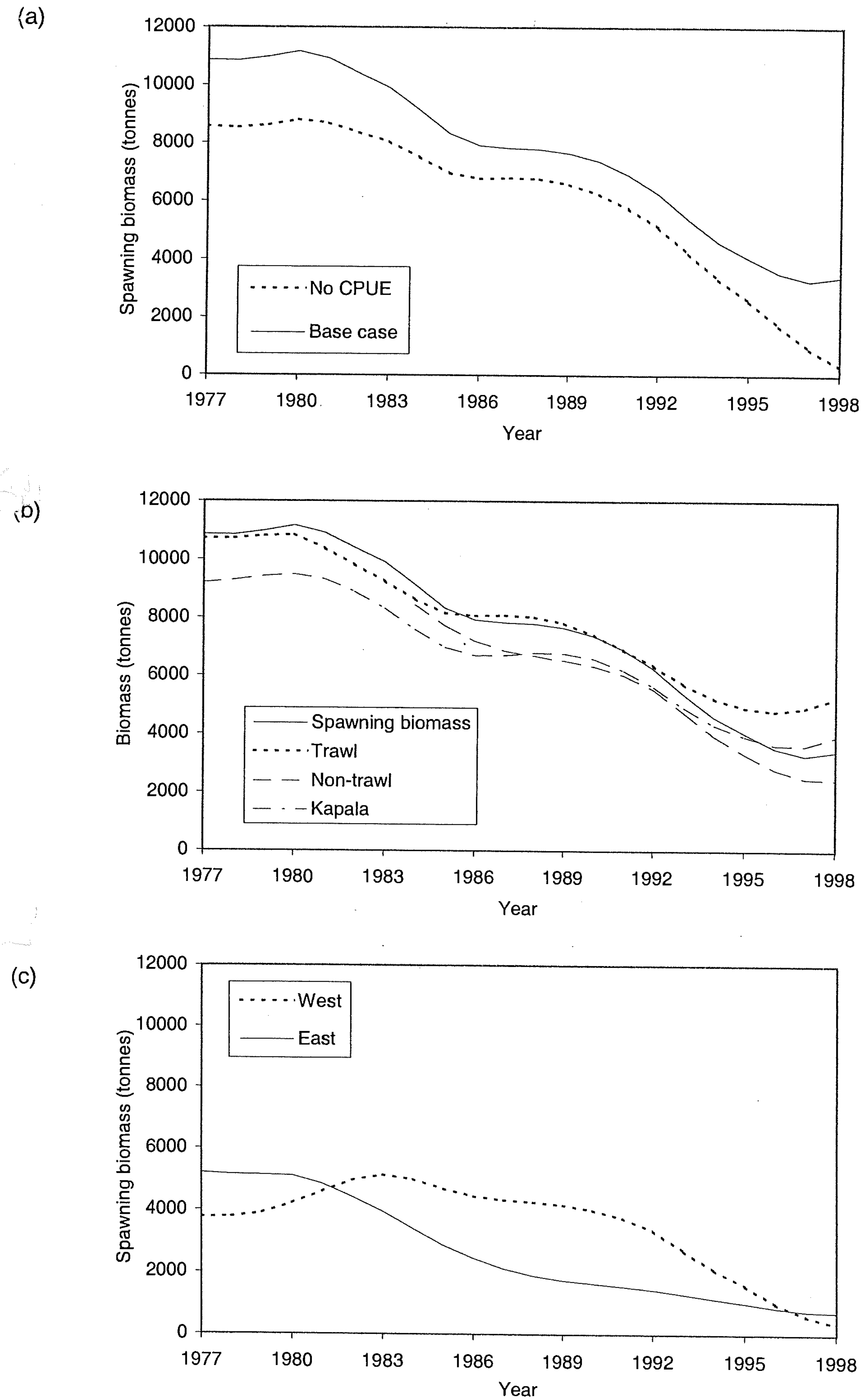

(a)
12000
10000
8000
6000
4000
2000
0
Spawning biomass (tonnes)
No CPUE
Base case
1977
1980
1983
1986
1989
1992
1995
1998
Year
(b)
12000
10000
8000
6000
4000
2000
0
Biomass (tonnes)
Spawning biomass
Trawl
Non-trawl
Kapala
1977
1980
1983
1986
1989
1992
1995
1998
Year
(c)
12000
10000
8000
6000
4000
2000
0
Spawning biomass (tonnes)
West
East
1977
1980
1983
1986
1989
1992
1995
1998
Year

Figure 12

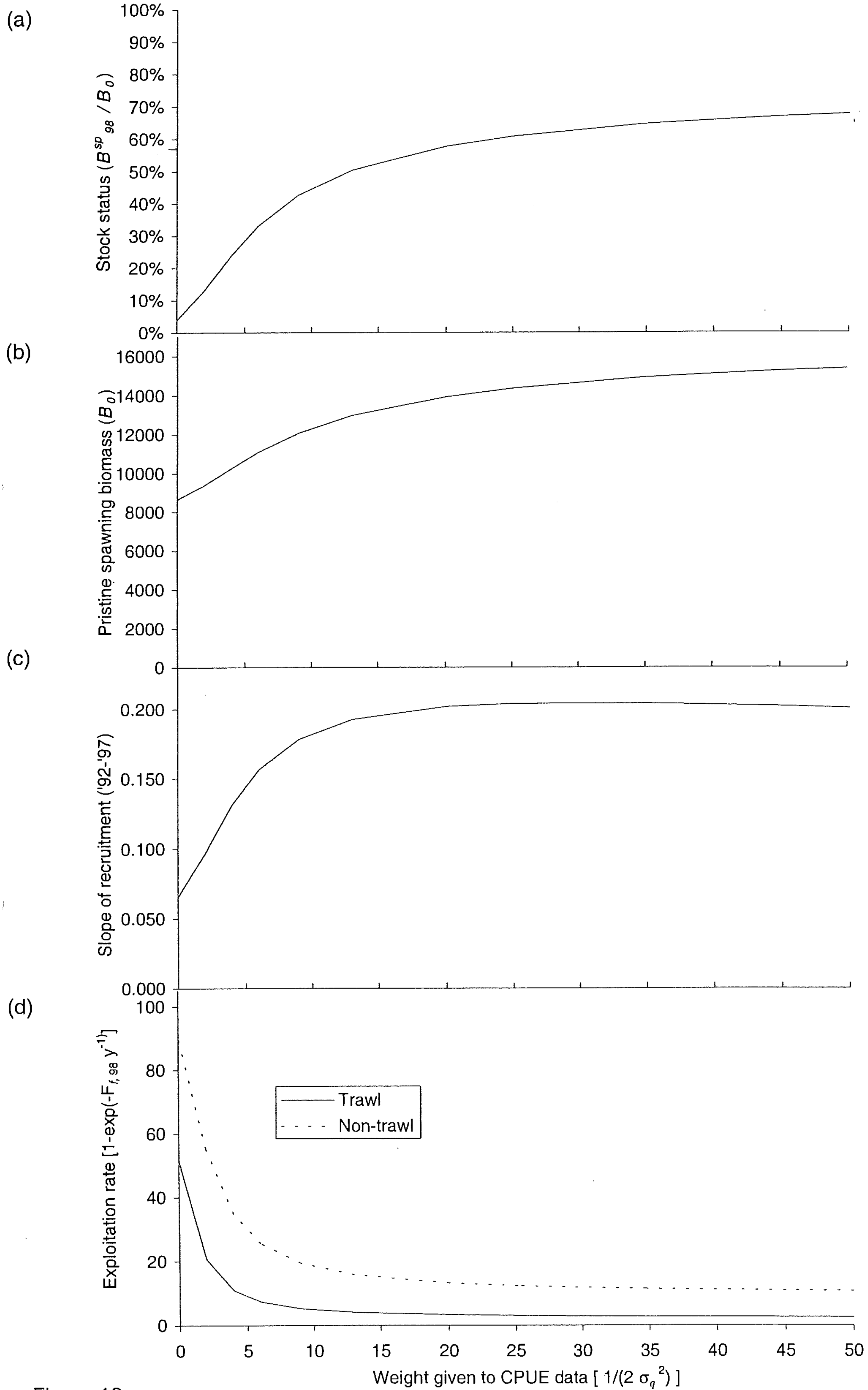
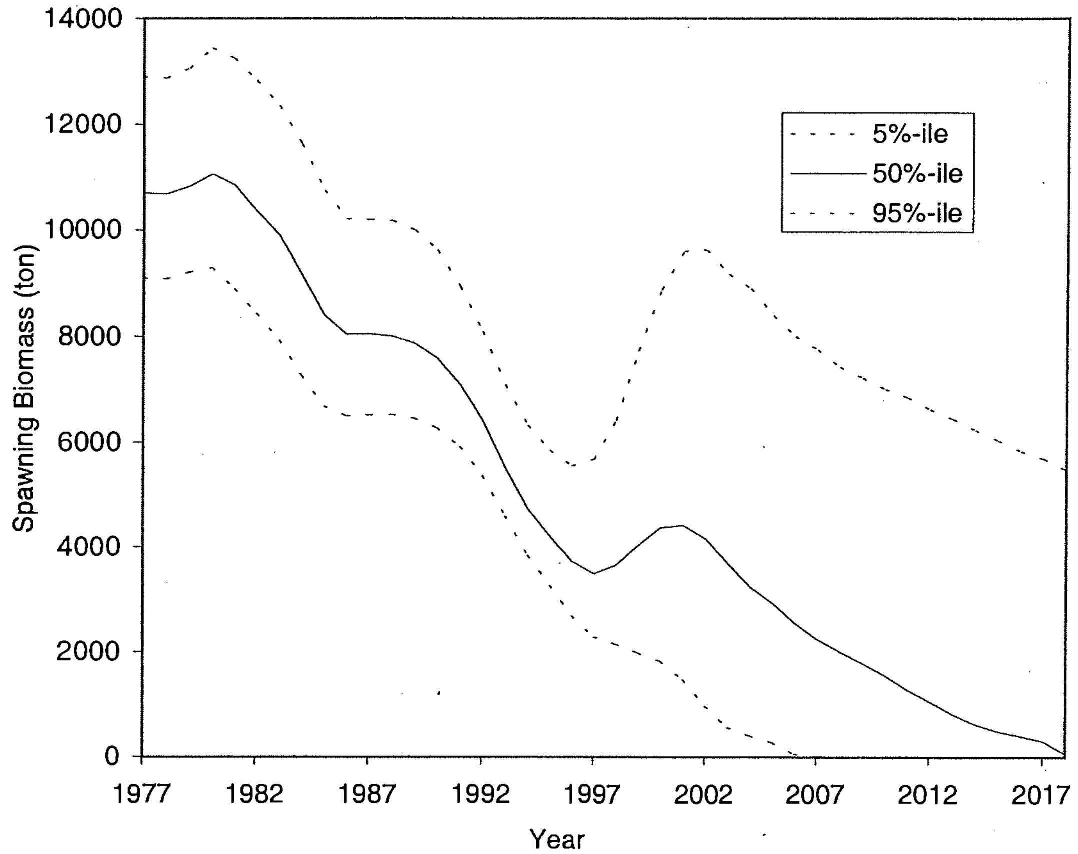

(a)
Stock status (B^{sp}_{98} / B_0)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
(b)
Pristine spawning biomass (B_0)
16000
14000
12000
10000
8000
6000
4000
2000
0
(c)
Slope of recruitment ('92-'97)
0.200
0.150
0.100
0.050
0.000
(d)
Exploitation rate [1-exp(-$F_{f,98}$ y^{-1})]
100
80
60
40
20
0
Trawl
Non-trawl
0
5
10
15
20
25
30
35
40
45
50
Weight given to CPUE data [1/(2 σ_q^2)]

Figure 13

(a)


14000
12000
10000
8000
6000
4000
2000
0
Spawning Biomass (ton)
1977
1982
1987
1992
1997
2002
2007
2012
2017
Year
5%-ile
50%-ile
95%-ile

(b)

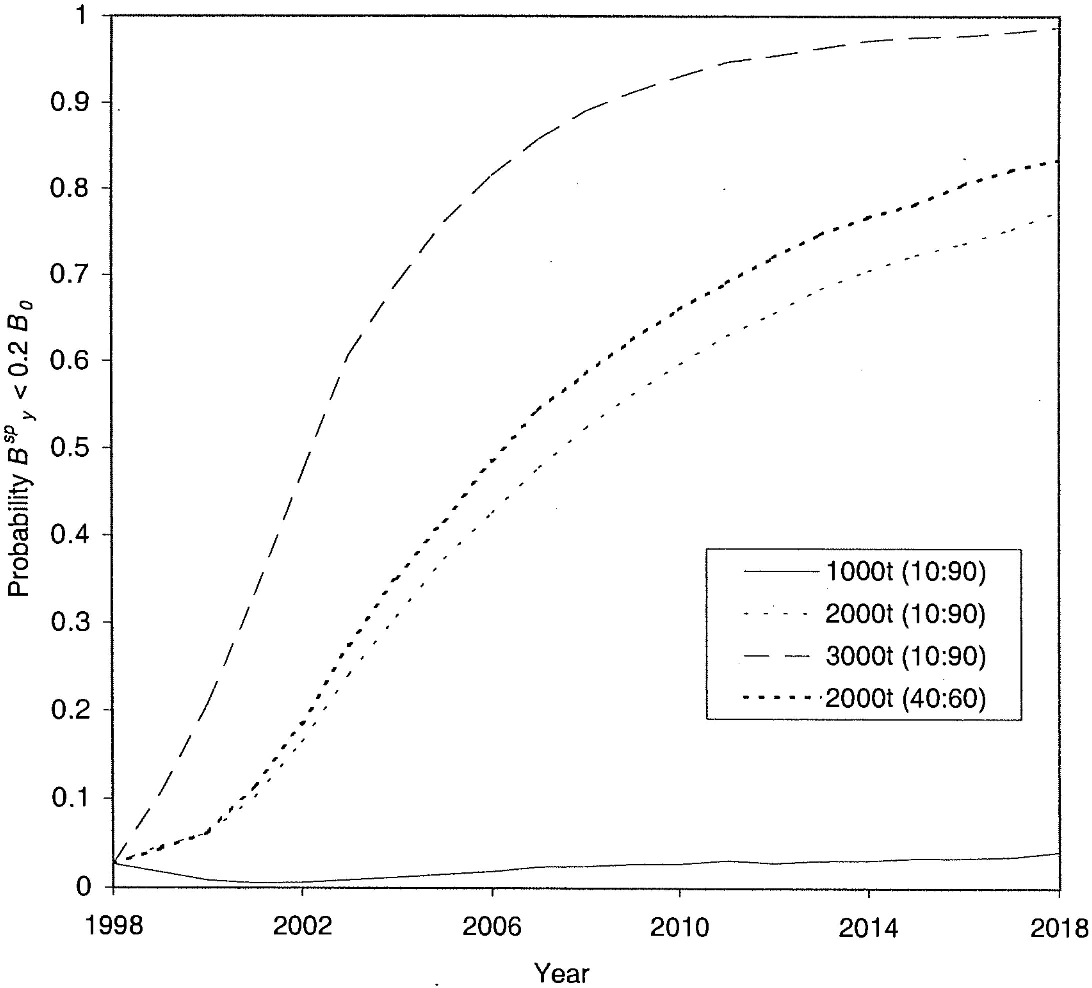
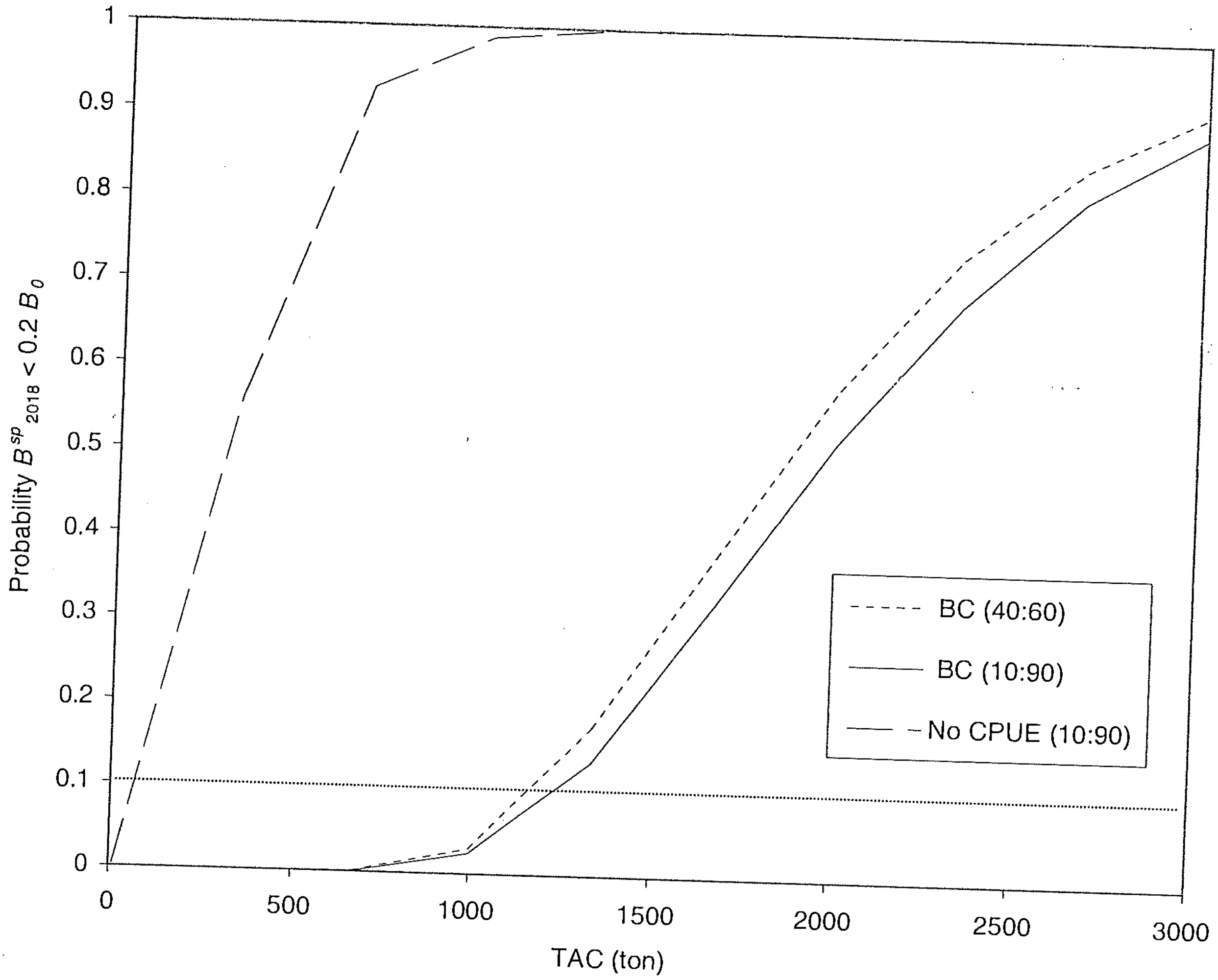

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Probability $B^{sp}_y < 0.2\ B_0$
1998
2002
2006
2010
2014
2018
Year
1000t (10:90)
2000t (10:90)
3000t (10:90)
2000t (40:60)

Figure 14



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Probability $B^{sp}_{2018} < 0.2\ B_0$
0
500
1000
1500
2000
2500
3000
TAC (ton)
BC (40:60)
BC (10:90)
No CPUE (10:90)

Figure 15