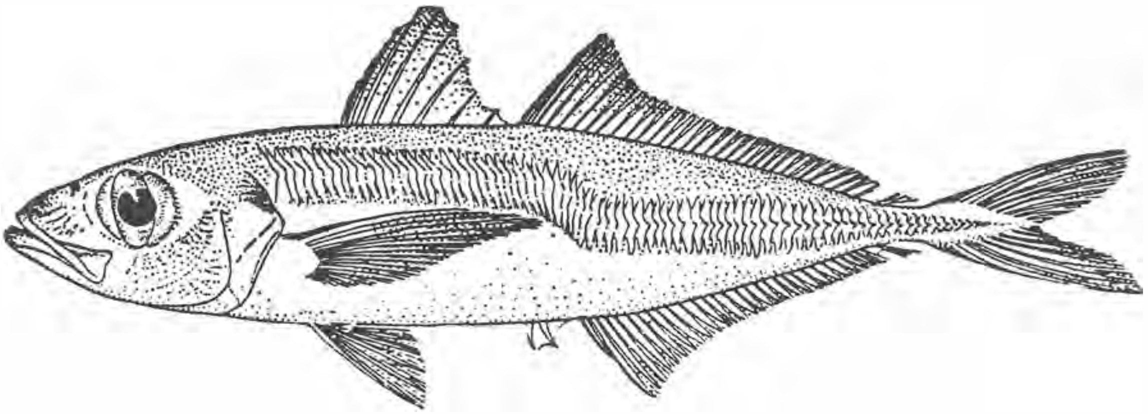
Jack Mackerel Resource Assessment In South Eastern Australian Waters

Alan Jordan, Grant Pullen and Howel Williams (Project Supervisor)

Final Report to the Fishing Industry Research and Development Council

Project DFT2Z



Tasmanian Department of Primary Industry, Fisheries and Energy
Sea Fisheries Research Laboratories - Crayfish Point
Taroona, Tasmania

May 1992

CONTENTS

1 INTRODUCTION

1.1 Background

The commercial fishery for jack mackerel in Tasmania dates back to the first year of white settlement. Since that time the fishery in southeastern Australia has typically been small and secondary in importance. It is only recently that the fishery has seen significant growth with the establishment in Tasmania of an industrial fishing enterprise in 1985. This venture used purse seine fishing vessels landing fish to a floating fish reduction plant based at Triabunna on Tasmania's east coast. The fishery targets dense surface and sub-surface schools which form during spring, summer and autumn in eastern Tasmanian waters. The nature of schooling and hence the vulnerability of jack mackerel to fishing varies seasonally.

The Division of Sea Fisheries (DSF) introduced a monitoring program for the fishery in 1985. This program, which is continuing, collects catch and effort data through a compulsory fishing logbook system, and basic biological data. The first three years of the monitoring program was jointly funded by the Fishing Industry Research Council.

The fishery developed rapidly from 1985, with landings of over 40,000 tonnes being made in the 1986/87 season, making the jack mackerel fishery the largest single species fishery by weight in Australia. At this time the Tasmanian Government was concerned that a continuation of the rapid development of the fishery would lead to hasty investment and further increases in catches that could prove to be unsustainable. DSF researchers were also concerned that whilst the fishery had demonstrated no obvious interannual variability in its short history, it was likely that variability would occur. The severity, frequency and causes of any variability would be an important factor in the productivity of the fishery and the stability of the fishing industry exploiting the resource.

In order to prevent overcapitalisation in the mackerel fishery, further access to the Tasmanian fishery was limited in May 1987 to allow development of a management plan. In August 1989 the interim management arrangements were replaced by the Tasmanian Jack Mackerel

Management Plan. Under this plan the fishery was managed by output controls in the form of a total allowable catch (TAC) allocated as quota. Assessments of resource size were not available and TACs were based on the previous highest catches of the fishery.

The two major management priorities for research presenting at this time were the need to:

- develop methods that could be used to assess the size of the fishery and thus enable TACs to be set on scientific criteria,
- assess the potential for interannual variability in jack mackerel stocks.

In 1987 a proposal for research into these matters was submitted to the Fishing Industry Research Council. The program was approved in 1988 and work commenced in December 1988. This commencement coincided with the occurrence of a severe decline in the commercial fishery caused by changes in oceanographic conditions. The severity of the effects on the commercial fishery are indicated by the total catch for the 1988/89 season which was the lowest on record at 8,865 tonnes. In subsequent years the fishery has recovered toward previous catch levels despite the severe financial impact of the poor 1988/89 season.

1.2 Background to the research

The major research priorities identified in the previous section were the need to develop assessment methods and to assess the potential for variability in the fishery.

Traditional fishery assessment models and assumptions do not usually fit schooling pelagic fish stocks well. This makes their assessment very difficult and uncertain. We are developing cohort analyses, in the form of virtual population analysis (VPA), of the population. This type of analysis is not appropriate for real-time monitoring but rather is useful for historical analysis and calibration of abundance indices.

We do not yet have an appropriate time series of date from the fishery on which to base a robust VPA. There are also a number of problems that need to be quantified before a VPA can be conducted on our data. For instance, we know that the catchability of different age classes varies during the fishing season and that this affects selectivity, vulnerability and our estimates of mortality. We are trying to resolve these problems, in the meantime we have been interested in developing techniques to directly monitor stock abundance.

Acoustic surveys and aerial surveys have proved to be useful for estimating stock abundance in many similar pelagic fisheries. We have been particularly interested in investigating the use of acoustics in deriving abundance indices for jack mackerel, and also determining whether the nature of spawning permitted acoustic estimates of spawner biomass. Aerial surveys also offer some scope for rapid assessments of biomass of surface schools.

The importance of interannual variability in the jack mackerel fishery was unknown prior to this research proposal in 1988. Many pelagic fisheries overseas have shown strong signs of variability, and it was considered likely the jack mackerel fishery may also fluctuate. At this time we were interested in detecting any evidence of fluctuation and if so the causes and the effects on the fishery and the fish stocks.

These considerations led to the development of the research proposal submitted to the Fishing Industry Research Council (Section 6).

2 OBJECTIVES

The objectives of the study were:

- to develop methods for estimating the abundance of jack mackerel to enable appropriate TACs to be set.
- to describe and assess what factors cause interannual variability in availability of jack mackerel to the fishery.
- to collect data on the reproductive biology and early life history of jack mackerel.

3 SUMMARY

3.1 Development of methods to estimate abundance

3.1.1 Hydroacoustic assessment of schooling fish

Sonar mapping techniques were trialed to assess their applicability to the assessment of the Tasmanian jack mackerel resource (Document 1). This technique used the abundance of schools of fish as a relative index of the abundance of a resource. Significant problems were encountered adapting this method for the jack mackerel fishery, the shortcomings identified suggesting this method has little application for this species.

Two major factors contributed to the failure of this method. The first was the low abundance of jack mackerel schools. Few targets were encountered even under good schooling conditions. The researchers who developed this method suggested that patchy distribution and unfavourable schooling conditions drastically reduced the effectiveness of sonar mapping. The low number of targets counted renders the calculation of an index meaningless. The second factor was that the abundance of schools identified by sonar mapping appeared to be a poor index of abundance. The index derived from the density of fish schools determined by sonar mapping did not vary in proportion to the apparent abundance of fish. The method appeared to be more sensitive to changes in the distribution and behaviour of schools than their abundance.

3.1.2 Hydroacoustic assessment of spawning fish

Our results suggest that the spawning behaviour of jack mackerel makes hydroacoustic survey techniques unsuitable for estimating spawner biomass. We found that jack mackerel spawned over an extensive area of the shelf break rather than in discrete areas (Document 3). Spawning extended beyond the borders of our sampling area off Tasmania's east - an acoustic survey of an area of this size would be logistically demanding. In addition we have found that jack mackerel are serial spawners. An estimate of spawner abundance from one survey would therefore only represent an estimate for an unknown proportion of the population spawning at that time.

Finally the positive identification of spawning schools by hydroacoustics has not yet been achieved. Research trawling targeted at echo sounder marks on the shelf break at the peak of the spawning period in 1990 and 1991, did not yield fish in spawning condition. However, as with other serial spawners there may be diel periodicity in spawning and spawning schools may form during periods that were not sampled in this study.

3.1.3 Rapid assessment technique

The rapid assessment technique was developed to measure the biomass of large areas of schooling fish observed near the end of some fishing seasons. The method uses aerial photography and echo sounders to estimate the volume of these schools, and underwater photography to estimate their packing density (Document 2).

Intensive monitoring of schooling conditions to determine when the assessment should be conducted was undertaken during the program. Personnel on board commercial and research vessels observed schooling conditions while in the field. Close contact was maintained with fishers and the aerial spotter to obtain feedback on schooling activity. Numerous flights with the spotter during the later months of fishing seasons were also undertaken. A stereographic method to measure the area of surface schools was developed in association with the Hydro Electric Corporation. Several underwater photographic techniques to determine school packing rates were investigated. The most promising of the these methods involves using stereo pairs from which measurements may be taken. These measurements are calibrated by photo pairs of a reference frame of which the precise geometry is known.

Conditions necessary to undertake the method have not occurred during the period of the study making a proper assessment of the method difficult. Further field trials of the underwater photographic method are also required to determine if the photographic technique is suitable, or to further develop this technique.

As was the case with the sonar mapping trials, the development of this method was hampered by variable and 'abnormal' schooling conditions. Variability in schooling is a characteristic of the fishery and so assessment techniques must accommodate this.

3.1.4 Egg production method

Egg production methods have been used to estimate the spawning biomass of a number of species overseas and has recently been applied to orange roughy off the east coast of Tasmania. However there a number of specific criteria that need to be met before this technique can be applied. With regard to jack mackerel most of the problems in meeting these criteria are related to the difficulty in obtaining a representative sample of the spawning population.

The availability of mature fish to the commercial fishery declines during the spawning season. This is associated with the movement of mature fish out to the shelf break from the fishing grounds further inshore. The spatial separation of spawning and non-spawning fish makes estimates of the spawning fraction of the population difficult as they are not equally vulnerable to the sampling gear.

Estimates of both spawning frequency and batch fecundity are also essential to the egg production method. Difficulties in sampling hydrated females and females with postovulatory follicles from either the commercial fleet or research trawling meant that spawning frequency could not be estimated (Document 7). Estimates of batch fecundity could not be made given the lack of females at an advanced stage of gonad. We have however, characterised the structure of atretic (reabsorbed) follicles by histology and estimated the occurrence of such follicles in various gonad stages (Document 7). This procedure is vital when adjusting batch fecundity estimates due to atretic loss.

Another requirement for the egg production method is that the overall distribution of spawning is known and that sampling is representative and inclusive of the entire spawning area. During each year of sampling we found that spawning occurred throughout the area of our sampling, and as the range of the adults is much greater, it is likely that an unknown portion of the population spawned outside the sampling area.

There would also be a need to estimate spawning frequency and batch fecundity on an annual basis as it has been shown that there may be considerable interannual variability in these parameters. Interannual variability in the productivity of the waters off the east coast of

Tasmania will probably have an impact on the amount of energy available to jack mackerel for reproduction in the following spawning season. It is therefore likely that jack mackerel will show variability in the frequency and size of spawning. The decrease in jack mackerel egg production seen during the 1990 season supports this view.

3.2 Assessment of interannual variability

The shelf waters of the east coast of Tasmania have experienced a considerable amount of interannual variability in oceanography and productivity in the three years of this study (1988-1991). This has provided a valuable opportunity to document the changes in both oceanography and productivity and assess the impact of variability on the jack mackerel population.

The three years of ichthyoplankton sampling have provided an understanding of the effects of interannual variability on spawning areas and times (Document 3), and its influence on the vulnerability of jack mackerel to the commercial fishery. The distribution of jack mackerel eggs over the three years supports the contention that spawning is concentrated on the shelf break. The presence of eggs and larvae along the entire east coast from December to March 1988/89 confirms that jack mackerel were spawning in the area at this time. As spawning also occurred along the entire east coast in both 1989/90 and 1990/91, it appears that spawning distribution was unaffected by the warmer water temperatures associated with the La Niña event.

Sea surface temperatures only differed by up to 1.5°C during the peak of the spawning period between years, most warming occurring in late summer and autumn, after most spawning had finished. Despite the interannual differences in surface temperatures the strong thermal stratification in 1989 led to bottom water temperatures on the shelf break varying little between years and actually being coolest in the La Niña year of 1988/89.

This suggests that jack mackerel spawn on, or near the bottom on the shelf break and spawning was unaffected by warming in the surface waters. This is further supported by the fact that spawning time and duration did not differ between the three years, with spawning restricted to the summer period of mid December to late February. Hence, the lack of fish during the spawning season in 1989 appears to be unrelated to any variability in spawning behaviour. However, the spawning period is associated with a period of low availability of mature fish to the fishery, the majority of the catch consisting of immature fish. So while mature fish were present on the shelf break during the spawning season, the distribution of the immature fish during this period is still unknown. The movement of mature fish back into east coast shelf waters after spawning also did not occur in this season, their distribution at this time is also unknown.

The interannual variability in productivity in east coast waters was examined by detailing the changes in the abundance and biomass of krill (*Nyctiphanes australis*) and its relationship with the changes in regional oceanography (Document 5). *Nyctiphanes australis* is the principle food source for jack mackerel during the summer and autumn period. As the commercial purse seine fishery is dependant on surface feeding schools, any change in the availability of krill will directly affect the availability of fish to the fishery. Krill were virtually absent from shelf waters during the summer of 1988/89 and resulted in the absence of surface schools and hence fish available to the fishery. Krill biomass was much higher in the 1989/90 and 1990/91 seasons resulting in the return of surface feeding schools and reasonable summer catches.

Part of our work has also been involved in assessing the effects of interannual variability on spawning success and larval survival which could be expressed in the fishery as variable recruitment. While egg densities varied considerably over the three years it is not clear whether such differences resulted from differences in egg mortality or differences in the level of egg production. However, it is clear that interannual variability in larval densities did not result from differences in larval mortality. The range of possible causes for differences in egg and larval densities are detailed in Document 4.

Variability in larval survival was examined in 1989 and 1990 by comparison of larval growth rates determined from an examination of otolith microstructure (Document 6). Despite low zooplankton productivity in the La Niña year of 1989, larvae showed rapid growth. It appears that the low productivity is coincident with a shift in the zooplankton community to one dominated by small copepods, resulting in larvae having no impact on prey densities, and no significant decrease in growth rates leading to a greater cumulative mortality.

3.3 Reproductive and early life history

Larval sampling carried out over the past three years has greatly increased our knowledge on the spawning behaviour and early life history of jack mackerel (Document 3). The distribution of spawning is large, with spawning occurring along the entire east coast in all three years of this study. As the distribution of adult fish extends well beyond the east coast it is likely that our sampling is only covering an unquantified portion of the overall spawning distribution. Spawning is concentrated on the shelf break, with the high densities of eggs at inshore stations in the 1989 season appearing to result from the rapid advection of eggs inshore. Despite this inshore advection there doesn't appear to be a consistent pattern of recruitment to inshore nursery areas, at least during the larval phase.

Spawning time was consistent in all three years, starting in late December and ending in late February. However, the bulk of the spawning always occurred in the first few weeks of the season with egg and larval densities dropping off rapidly in February. The periodicity in spawning activity appears to be closely linked to the lunar cycle, with peaks in spawning associated with full and new moons. The selective advantage of this relationship is unknown.

The reproductive biology of jack mackerel was determined through histological and microscopic examination of gonad samples collected from both the commercial fleet and research trawling (Document 7). Length at maturity analyses found that 50% of the female fish were sexually mature at 31.5 cm FL, all fish being mature by 37.0 cm FL. This is larger than previous estimates for jack mackerel from Tasmanian waters resulting from the more accurate criteria of sexual maturity used in this study. An examination of oocyte frequency distributions has shown that jack mackerel are serial spawners, although it is not possible to predict the number of spawnings per year from the number of size frequency modes. The analysis also found a high incidence of atretic (reabsorbed) follicles indicating the importance of determining rates of atresia when estimating both batch and annual fecundity.

4 FUTURE RESEARCH

The results of the present study have major implications for future research on the Australian jack mackerel fishery. We now know that interannual variability occurs, and we have gained some knowledge of its immediate impact on the distribution of adults and larval abundances. The longer term effects of environmental variability on the stock, are however, an unknown.

Variability in spawning success and larval survival will influence future levels of recruitment to the fishery. Obvious changes in the year-class strength of recruits should result from any significant variability in the larval survival of that cohort. The monitoring program maintained by the DSF is capable of detecting relative changes in year-class abundance, and we are particularly interested in examining the relative abundances of year-classes recruiting to the fishery in 1992 onwards. These newly recruiting cohorts will originate from spawnings occurring from 1989. The magnitude of change in relative year-class strength will also provide information on the long-term effects of environmental variability on the yield of the stock and the sensitivity of recruitment to stock levels.

The indirect effects of environmental variability on adult stocks are more difficult to assess but may be important for a number of reasons. The availability of schooling adult fish on the fishing grounds appears to be closely related to the abundance of krill. In the absence of krill, 'normal' schooling behaviour breaks down and adults are displaced from the grounds as they search for alternative sources of feed. Switching to alternative food sources may carry penalties for jack mackerel such as reduced nutritional value, longer handling time, increased foraging time, exposure to other predators, etc. These factors may contribute to increases in natural mortality rates, decreases in growth rates and poorer condition factors. Lower condition factors may in turn reduce the survival of over-wintering fish and reduce the size and/or quality of the subsequent spawn.

It is difficult to identify whether natural mortality rates fluctuate in response to environmental variability. However, our monitoring program does provide information that can be used to examine cohort growth rates and thus provide insights into any changes that may occur in growth rates that have occurred since 1989. In addition we are re-examining our otolith collection for unusual banding patterns that may indicate stress. From these indicators we hope to be able to infer whether mortality rates are likely to have been effected by environmental variability. This will be of particular relevance to Virtual Population Analysis in this fishery as changes in natural mortality from year to year need to be accounted for.

The scope for further assessment research appears to be limited. Hydroacoustic assessments of either spawner biomass or school abundance are not suitable. The assessment of end-of-season school size has still to be tested and awaits the occurrence of appropriate schooling conditions. The application of an egg production model for assessment will require a great deal of further research to provide estimates of annual rates of spawning frequency and batch fecundity as well as estimates of egg abundance.

5. DETAILS OF THIS STUDY

Documents 1 to 9.

DOCUMENT 1

Assessment of sonar mapping techniques in the Tasmanian jack mackerel fishery

INTERNAL REPORT

Assessment of sonar mapping techniques in the Tasmanian jack mackerel fishery

Grant Pullen and Howel Williams

Internal Report

NOT FOR CITATION WITHOUT PERMISSION FROM THE AUTHOR

Sea Fisheries Research Laboratories - Crayfish Point
Division of Sea Fisheries
Tasmanian Department of Primary Industry, Fisheries and Energy

INTRODUCTION

The seasonal presence of large surface schools of jack mackerel (*Trachurus declivis*) in south-eastern Australian waters is well known (Hynd and Robins, 1967; Williams, 1981; Williams *et al.* 1987). Surface schools are readily visible to aerial survey (Williams, 1981). While aerial surveys have the advantage of being able to cover large areas they cannot, however, account for fish present in sub-surface schools. Logbook data from the Tasmanian jack mackerel fishery indicates that substantial proportions of schools may be sub-surface, this ratio changing during the fishing season (Williams and Pullen, in prep.).

Faced with the problem of assessing pelagic fish resources the Californian Department of Fish and Game has developed an assessment methodology to measure fish schools that is independent of their position in the water column (Smith, 1970; Smith, 1975; Mais, 1974). This technique, called sonar mapping, has been used to assess a number of pelagic fish species found along the west coast of America (Smith, 1975; Mais, 1974). The technique involves measuring fish schools using a fixed beam sonar along a series of transects. The main advantage of sonar mapping over hull mounted "downward" looking echo sounders is that sonar mapping encounters one to two orders of magnitude more fish school targets (Mais, 1974). By calculating the number of schools per area swept an index of abundance can be calculated, and used as an indicator of temporal changes in fish abundance. Further research has increased the sophistication of the method with the aim of measuring the biomass of school targets, thus producing an absolute measure of abundance (Mais, 1974; Hewitt *et al.* 1976).

The sonar mapping technique was seen as a method that may have utility for assessment of the Tasmanian jack mackerel resource. Since 1985 jack mackerel has formed the basis of a substantial purse seine fishery operating on the east coast of Tasmania. Little information, however, is available on the abundance of the species. Trials to develop the technique, and assess its applicability under Tasmanian conditions, were carried out by the DSF as part of the jack mackerel assessment program.

METHODS

Sonar mapping trials were conducted between 1988 and 1991 on the DSF research vessel FRV *Challenger*. The sonar utilised was a Simrad SQ 270 (transmits and receives at 27 kHz, output power 4 mW).

Routine transects were conducted off the east coast of Tasmania between St. Helens and Eaglehawk Neck, with transects running from inshore to the shelf break. Two transect designs were used during the study (design 1 and design 2), the original design being altered at the end of 1988 to facilitate larval sampling carried out in conjunction with the sonar mapping trials. Design 1 comprised a series of 6 continuous zigzags along the coast totalling 122 nautical miles. Design 2 comprised of 7 transects (plus one supplementary transect) running east to west totalling 100 nautical miles (or 122 nautical miles including the supplementary transect). Figure 1 shows both transect designs used during the study.

The vessel conducted transects at approximately eight knots, the sonar operating in a fixed position at 90° to the boats heading. The angle of tilt was generally kept at 3°. The sonar range used was from 250m to 1250m. The range chosen was the maximum one yielding a good signal without excessive noise from bottom echoes.

When a school was detected the boats position and distance from the school was recorded. The water depth was also noted. If possible an estimate of the school size was made, schools being designated small, medium or large. It was expected that experience of the range of target sizes encountered would be quickly gained, allowing consistent classification of target size. In January 1990 a colour printer was interfaced to the sonar to produce a hard copy of the soundings on each transect.

Further ad hoc sounding was carried out during the study to familiarise the operator with the equipment and procedure.

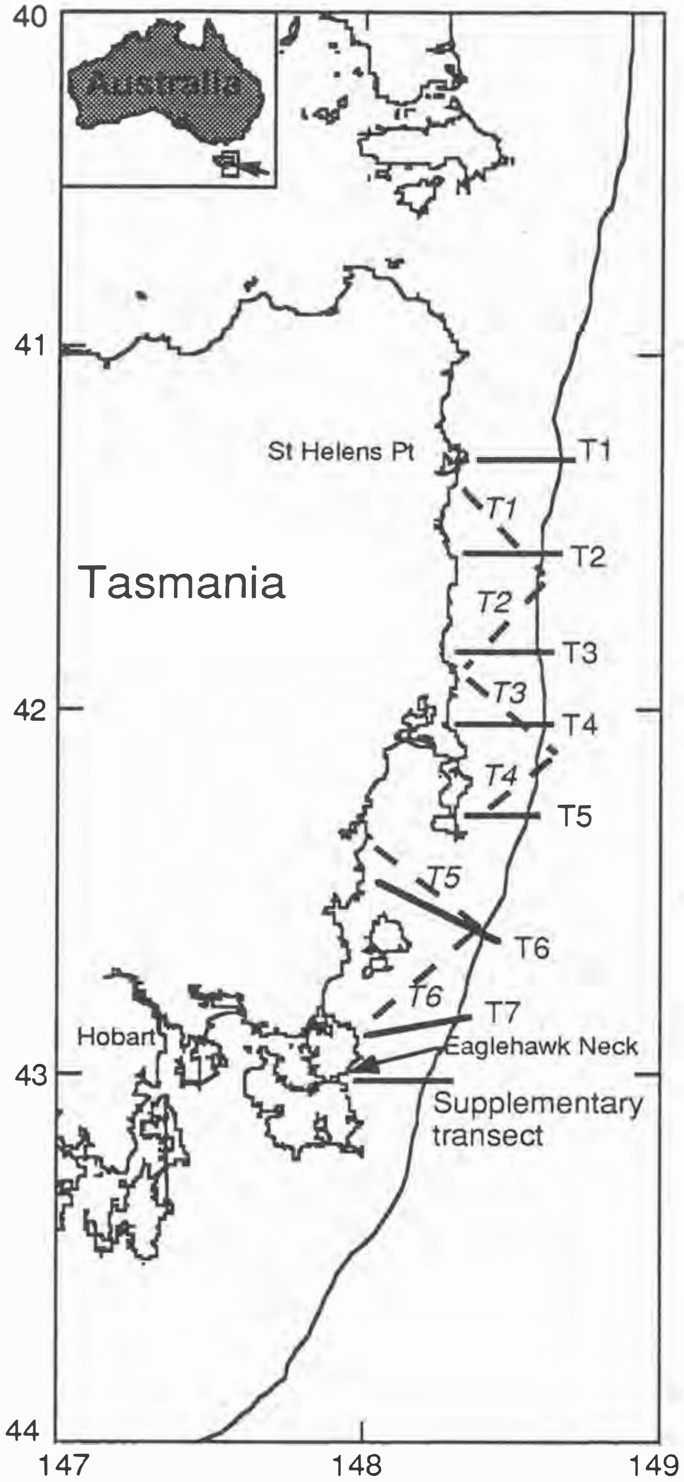


Figure 1. Position and numbering of sonar mapping transects. Broken lines and italics indicate Design 1. Unbroken lines and plain text indicate Design 2. (*Indicative positions only*)

RESULTS

During the study 49 transects were completed totalling 799.5 nautical miles. The total number of targets identified was 150, equating to a contact rate of 0.188 targets/nautical mile sounded. The number of schools counted per transect ranged from 0 to 18, the mean being 3.06 targets. Table 1 presents details of transects undertaken. The date of completion, transect design, number of targets identified each transect and the number of targets/nautical mile each cruise is given.

The contact rate achieved during the study was very low, significantly hampering development of the methodology and the adaptation of operating procedures for local conditions. Due to these difficulties the method cannot be considered developed to an operational level.

As contact rate has been so low abundance indices including the area swept (ie sonar contacts/nm^2), have not been calculated. It is possible that if large differences in contact rates between years had been observed abundance indices may have indicated broad changes in abundance. However, as the rates observed during this study were low, and differences negligible, no inferences regarding seasonal changes in abundance can be made.

DISCUSSION

During the study jack mackerel exhibited significant variation in schooling behaviour associated with changes in oceanographic conditions, and the El Niño/Southern Oscillation (Williams and Pullen, in prep.; Jordan *et. al.*; Harris *et. al.*). The distribution, size and availability of schools varied considerably over this period (Williams and Pullen, in prep; personal obs.). This variation is reflected in commercial landings, 37,915, 8,865, 12,688 and 21,286 tonnes being landed during the 1987/88 1988/89, 1989/90 and 1990/91 seasons respectively (although other factors may also have had some affect on landings during this period). The 1988/89 season is the most severely affected season to date, schools being virtually absent from traditional fishing areas for five months of the 'normal' season (Williams and Pullen, in prep.).

Table 1. Details of transects completed.

Cruise/ transect no.	Date	Transect design no.	Targets identified (number)	Number of Targets/nm.
CR155/6	5/1/88	1	3	
CR155/5	5/1/88	1	4	
CR155/4	16/1/88	1	4	
CR155/3	6/1/8	1	5	0.190
CR159/6	23/2/88	1	4	
CR159/5	23/2/88	1	1	
CR159/4	24 & 25/2/88	1	6	
CR159/3	25/2/88	1	1	
CR159/2	1/3/88	1	4	
CR159/1	1/3/88	1	0	0.131
CR179/6	5 & 6/12/88	1	3	
CR179/5	6/12/88	Aborted 1	1	
CR179/4	6 & 7/12/88	1	13	
CR179/3	7/12/88	1	18	
CR179/2	7/12/88	1	5	
CR179/1	7/12/88	1	2	0.344
CR193/7	28/2/89	2	3	
CR193/6	28/2/89	2	4	
CR193/5	28/2/89	2	0	
CR193/4	1/3/89	2	5	
CR193/3	1/3/89	2	0	
CR193/1	2/3/89	2	2	0.159
CR217/6	14/12/89	2	2	
CR217/5	13/12/89	2	9	
CR217/4	13/12/89	2	14	
CR217/3	12/12/89	2	4	
CR217/2	12/12/89	2	1	
CR217/1	12/12/89	2	2	0.390
CR218/7	6/1/90	2	6	
CR218/6	6/1/90	2	2	
CR218/5	7/1/90	2	3	
CR218/4	7/1/90	2	3	
CR218/3	7/1/90	2	0	
CR218/2	8/1/90	2	0	
CR218/1	8/1/90	2	2	0.16
CR219/7	23/1/90	2	2	
CR219/6	23/1/90	2	4	0.16
CR224/7	15/3/90	2	0	
CR224/6	15/3/90	2	1	
CR224/4	14/3/90	2	0	
CR224/3	13/3/90	2	1	
CR224/2	13/3/90	2	0	
CR224/1	13/3/90	2	0	
Supplementary transect	16/3/90	2	0	0.197
CR249/5	22/1/91	2	0	
CR249/4	22/1/91	2	1	
CR249/3	22/1/91	2	3	
CR249/2	23/1/91	2	1	
CR249/1	23/1/91	2	1	0.096

This historical variation in schooling behaviour suggests that sonar mapping techniques are not applicable to jack mackerel as recent literature suggests that the number of schools present in Tasmanian shelf waters is a poor index of mackerel abundance. The substantial variations experienced appear to have been a function of the distribution and behaviour of schools responding to changes in oceanographic conditions, rather than dramatic changes in mackerel abundance (Williams and Pullen, in prep.; Jordan *et. al.* in prep.; Harris *et. al.* 1991). Given that variability in the oceanography, and subsequently schooling behaviour, is likely to continue, an index based on the availability of schooling fish may be more sensitive to changes in schooling conditions than temporal changes in abundance.

The contact rate experienced during the study was too small to facilitate development of the method, or allow meaningful analysis of results. Smith (1975) detected 1,729 targets (*Engraulis mordax* and *Trachurus symmetricus*) along a 63 nautical mile transect producing a contact rate of 27.444 schools/nautical mile. In the present study the contact rate seen was only 0.188 schools/nautical mile.

The low contact rate appears to have been due to the extreme patchiness of mackerel distribution, and the speed and distances which mackerel travel. Mackerel schools often appear in large numbers in a relatively small area, while being absent from adjacent waters. Schools are also highly mobile. Patchy distribution, and unfavourable schooling behaviour, of the target species were identified by Mais (1974) as the main reasons why the method may not be successful.

Mais (1974) reports similar difficulties adapting the technique for assessment of mackerel species in California. He found that acoustic surveys proved ineffective for any realistic assessment of *Trachurus symmetricus*, due to difficulties locating and identifying schools in the open sea, and their extremely patchy distribution. While the abundance of *Scomber japonicus* was too low to allow proper assessment Mais (1974) concluded that it was doubtful that the method could be applied to this species, also due to its patchy distribution.

In conclusion it would appear that several factors may invalidate the technique. Firstly it appears that mackerel abundance is not directly proportional to school contact abundance, due to the dynamic nature of schooling behaviour. Secondly, other studies have found the method to have little use in cases where the distribution of schools is very patchy and where the contact rate is low.

ACKNOWLEDGMENTS

The authors are grateful to the skipper (Geof Darcey) and crew (Mathew Francis and George Marris) of FRV *Challenger* for their assistance during the course of the study. Thanks to Alan Jordan, Judy Marshall and Greg Jenkins for assistance in the field. This study was jointly funded by the State and the Fishing Industry Research and Development Trust Account (DFT2Z).

REFERENCES

Harris, G. P., Griffiths, F. B., Clementson, L. A., Lyne, V., and Van der Doe, H. (1991). Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. Journal of Plankton Research. Vol 13. Supplement, pp. 109-31.

Hewitt, R.P, Smith P.E. and Brown, J. C. (1976). Development and use of sonar mapping for pelagic stock assessment in the Californian Current Area Fishery Bulletin; vol.74, No.2.

Hynd, J. S. and Robins, J. P. (1967). Tasmanian tuna survey. Report of first operational period. Tech. Pap. Div. Fish. Oceanogr. CSIRO 22.

Jordan, A., Pullen, G., Marshall, J. and Williams, H. (in prep). The temporal and spatial spawning patterns of jack mackerel, *Trachurus declivis* (Pisces: Carangidaae), over the three years 1988-91 in eastern Tasmanian waters.

Mais, K. (1974). Pelagic fish surveys in the Californian Current. Bull Dep. Fish Game St. Calif., 162:1-79

Smith, P. E. (1970). The horizontal dimensions and abundance of fish schools in the upper mixed layer as measured by sonar. Proceedings of an International Symposium on Biological Sound Scattering in the Ocean, pp. 563-600. Ed. by G. B. Farquhar. Maury Centre for Ocean Science, 629 pp.

Smith, P. E. (1975). Precision of sonar mapping for pelagic fish assessment in the Californian Current area. J. Cons. int. Explor. Mer, 38(1): 33-40.

Williams, H. and Pullen, G. (in prep). Schooling behaviour of jack mackerel *Trachurus declivis* (Jenyns), as observed in the Tasmanian purse seine fishery.

Williams, H., Pullen, G., Kucerans, G. and Waterworth, C. (1987). The jack mackerel purse seine fishery in Tasmania, 1986-87. Tech. Rep. Mar. Lab. Dep. Sea Fish. (Tasm.). 19

Williams, K. (1981) Aerial survey of pelagic fish resources off south east Australia 1973 - 1977. CSIRO Marine Labs. Rep. 130.

Young, J. W., Jordan, A., Bobbi, C., Johannes, R E., Haskard, K. and Pullen G. (in prep) Seasonal and interannual variability in krill (*Nyctiphanes australis*) stocks and their relationship to the jack mackerel (*Trachurus declivis*) fishery off eastern Tasmania, Australia.

DOCUMENT 2

Development and application of methods for measuring the biomass of schooling jack mackerel; the rapid assessment technique

INTERNAL REPORT

Development and application of methods for measuring the biomass of schooling jack mackerel - the Rapid Assessment Technique (RAT)

Grant Pullen and Howel Williams

Internal Report

NOT FOR CITATION WITHOUT PERMISSION FROM THE AUTHOR

Sea Fisheries Research Laboratories - Crayfish Point
Division of Sea Fisheries
Tasmanian Department of Primary Industry, Fisheries and Energy

INTRODUCTION

Under the Tasmanian Jack Mackerel Management plan the mackerel fishery is managed by output controls in the form of a Total Allowable Catch (TAC). Given that no stock assessment of the jack mackerel resource is available the TAC is not based on objective criteria. In the short term the TAC has been set at previous catch levels. Monitoring is conducted to detect any sign that fishing pressure is too high. Until an assessment can be made, no increase in the TAC can be considered.

In 1988 a joint DSF/FIRDTA research project was initiated, one of the objectives of this program was to develop and assess methods for determining the abundance of jack mackerel, and the appropriate TAC each year. One method examined as part of these objectives was the rapid assessment technique (RAT). The RAT is an amalgam of techniques developed to assess the biomass of surface schooling jack mackerel. Rather than providing an estimate of population biomass, this would represent an estimate of minimum biomass.

The seasonal schooling behaviour of jack mackerel around Tasmania is well documented, schools typically forming on the east coast of Tasmania between October/November and May/June (Hynd and Robins, 1967; Williams, 1981; Williams *et al.* 1987; Williams and Pullen, in prep).The Tasmanian jack mackerel fishery is based on the seasonal availability of these schools which are vulnerable to purse seine fishing. Schools are small at the beginning of a season, sub-surface schools being more prevalent than surface schools. As the season progresses school size increases, and surface schools become common. At the end of some seasons very large surface schools covering a significant area have been observed (Figure 1) (Williams and Pullen, in prep). It is at this time that the largest proportion of the mackerel population is visible in surface schools. The RAT was developed to measure the biomass of these large bodies of fish.

The RAT attempted to estimate school biomass by estimating the volume of the school and the density of fish within it. Estimates of volume can be derived from aerial photography and ship born echo sounder giving measures of the surface area and depth of schools, underwater photography can determine the packing rate, and the length/weight of fish can be estimated from the underwater photographs, or from catch sampling.

Figure 1. Large surface schools of jack mackerel near Maria Island.

METHODS

Development, and assessment of the potential, of the RAT was undertaken between 1988 and 1991. During this period the schooling behaviour of mackerel on the east coast of Tasmania was monitored to determine when schooling conditions were suitable for assessment. Monitoring was most intensive during the later months of the season (April-June) when schooling conditions are most likely to be appropriate. Personnel onboard commercial and research vessels observed schooling behaviour while in the field. Close liaison with fishers and the aerial spotter was maintained to obtain feedback on schooling conditions. Numerous flights with the spotter were also made during the later months of the season.

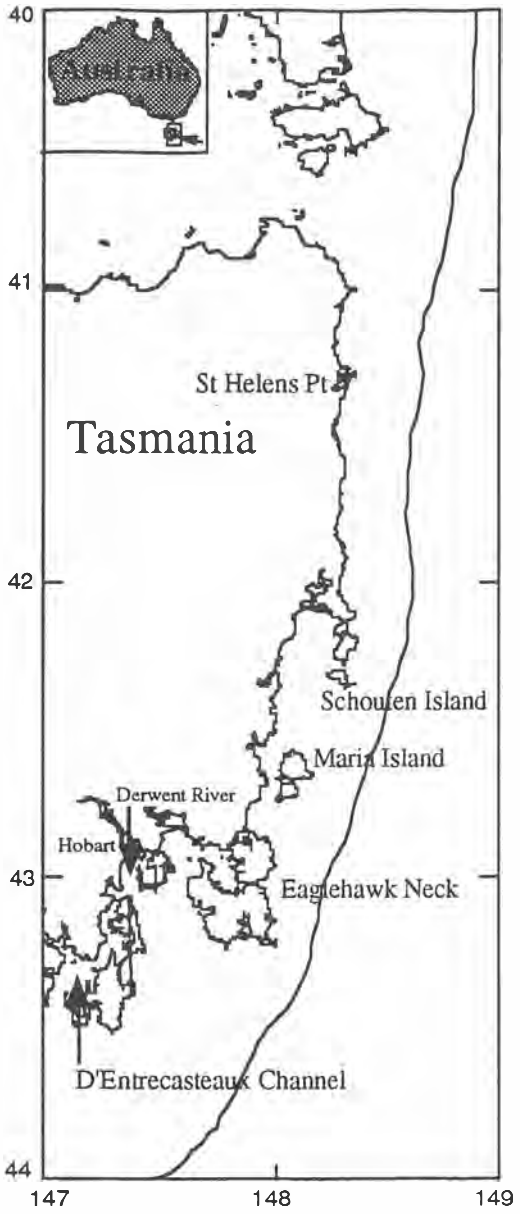


Figure 2. The east coast of Tasmania, and study area.

Aerial photography - Surface area of schools

A method to measure the surface area of fish was developed in association with the Hydro Electric Corporation (HEC). The method was based on standard techniques used in surveying and engineering, in which the HEC has considerable experience. This technique uses two metric cameras mounted in an aeroplane to obtain photo pairs of a target. Computerised analysis of these photo pairs can give estimates of distance. The HEC was contracted to undertake this portion of the work, providing aeroplane time (including camera operator and navigator) film, processing and enlargements and calculations of the surface area of schools. The aeroplane charter time was the most expensive part of this operation, subsequent calculations of area being a quick and routine process.

Liaison with the HEC was maintained to inform them of schooling conditions. If conditions were appropriate the procedure could be undertaken at relatively short notice. The work plan for an assessment was to fly from Hobart up the south and east coast (Figure 2). A DSF officer was to accompany flights identifying schools, and advising which targets should be photographed. The budget allowed several flights to be carried out, depending on their duration, if conditions were not ideal.

Underwater photography - School packing rates/fish density

Three methods for estimating the packing rate of schools were investigated. Two methods were based on single camera techniques, while the third used a stereo camera configuration. Nickonus V cameras were used for all three trials.

Graves method

This method assumes that all fish in a school are the same (known) size. By photographing a reference object at a range of distances a "photo to actual" calibration factor can be determined. As the size of fish is known measurements of fish on a photo, together with the calibration factor, allows the distance of fish from the camera to be calculated. The density of fish can be estimated from the number of fish in a defined area (Graves, 1976). Preliminary development of this method was undertaken during 1988. A reference ruler with half metre alternate black and white strips was constructed. Trial photographs were taken in the Derwent River and the D'Entrecasteaux Channel (Figure 2). Photographs were taken in approximately 10 metres of water to take advantage of natural light. Ektachrome 400 ASA film was used. Photographs were taken at half metres intervals up to 10 metres from the ruler, depending on visibility. Several pictures were taken at each distance, with and without a flash.

ii) Vertical stick method

This method was developed from 1988 to 1990 in association with the Surveying Department of the University of Tasmania. The "vertical stick" method involved taking a photo up through a school of fish. The camera is deployed on the end of a rod of known length, the rod is lowered into a school and the camera triggered. As the depth of the camera is known the volume of water photographed can be calculated, the fish in that volume counted, and a packing rate estimated.

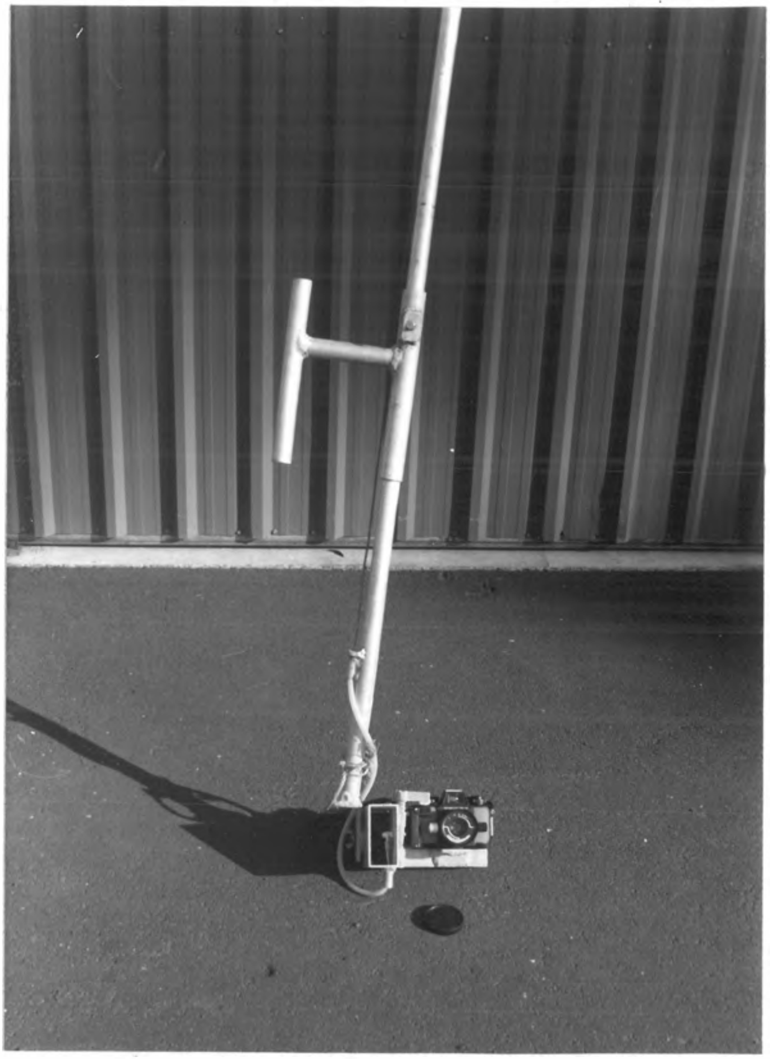


Figure 3. The "vertical stick" camera system.

A photograph and diagram of the "stick" developed are shown in Figures 3 and 4 respectively. The apparatus was constructed from aluminium. The main shaft was 4 metres long (graduated in metre lengths) with a sliding anchor bracket to be slotted over the gunwales of a dinghy, a screw nut was used to fasten the slider in the desired position. The camera was attached to the mounting plate by screw into the camera tripod socket, which could be swivelled to the desired angle. The camera was fired by remote trigger attached to the trigger wire running up the main shaft. To trigger the wire was pulled away from the pole, effectively shortening the wire and pulling the trigger down onto the camera shutter. A spring on the trigger pulled it back to the "ready" position after firing.

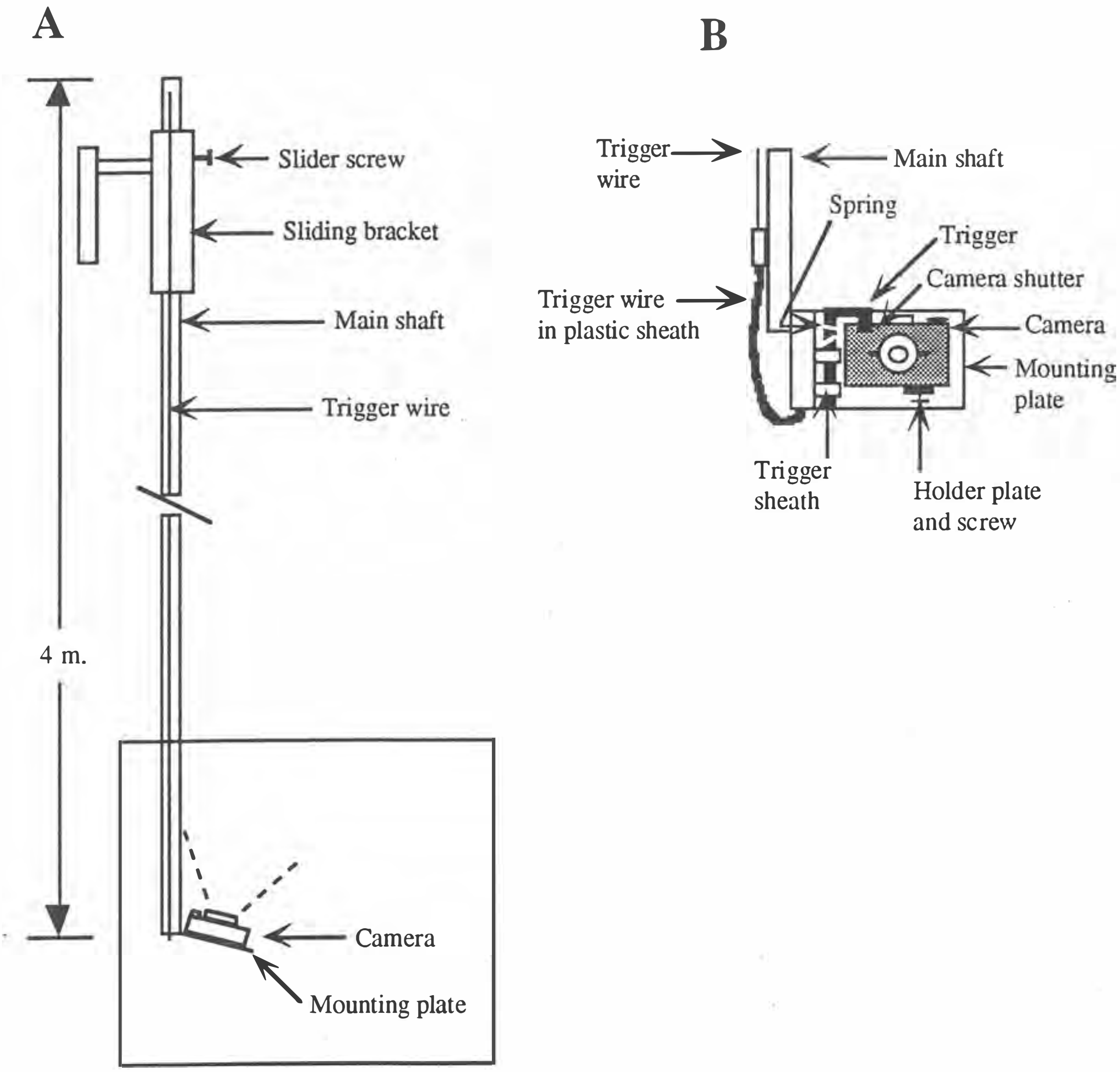


Figure 4. Diagram of the "vertical stick" camera system. A: Side view of whole unit. B: Camera mounting. (*not to scale*)

Field trials of the "stick" were conducted in April 1990 using an aluminium dinghy launched from FRV *Challenger*. Trials were undertaken in traditional fishing areas between Schouten Island and Eaglehawk Neck (Figure 2).When a good target was located the dinghy was launched and positioned in front of the school. The motor was then killed, and the camera lowered. If the school was stable enough it would surround the dinghy, and the camera was triggered. The best targets were the largest most vigorous schools , those creating "white" water being most stable. Kodak 400 ASA Tmax black and white professional film was used.

iii) Stereo camera method

This method was also developed in association with the University of Tasmania. Two cameras mounted in parallel on a rigid frame, gave stereo pairs from which distance, and hence packing rates could be estimated.

The aluminium apparatus was 70 cm wide and 97 cm high, and could be deployed by diver, or from the surface. The main handle and trigger were detached if used underwater, and the underwater handles and trigger utilised. When deployed from the surface the bottom half of the apparatus (with cameras) were held below the surface, and the above-water trigger used. The cameras were fastened to the mounting plate by screw into the tripod socket. The camera shutters were fired by depressor levers attached to the rocker arm, as the trigger was tightened the rocker arm rotated pushing the depressors onto the camera shutters. One depressor was a screw that could be adjusted to ensure both levers touch the shutters at the same time, producing simultaneous photographs. The trigger tension O ring provided resistance to hold the trigger in the "ready" position. A photograph and diagram of the stereo frame are shown in Figures 5 and 6 respectively.

In order to calculate distances from the photo pairs calibration of the apparatus must first be undertaken from photographs of a reference frame. Reference points on the reference frame were accurately measured to determine their x,y and z relationships. These measurements provided a spatial correlation to correct and calibrate all the factors which determine the size and position of images on the film. The University of Tasmania has developed software that calculates a calibration from the digitised positions of the reference points on both stereo pairs. The position of the cameras may vary slightly each time that the apparatus is used. To allow recalibration for each session several photographs of the frame were taken on the first exposures of each film used. The size of fish, nearest neighbour distances, vertical alignment and packing rates can be calculated by the software package from digitised positions of snouts and tails on each pair of exposures.

Figure 5. The stereo camera mounting frame.

Trial photos of the frame were taken from a range of distances to determine the optimum distance from which routine calibration photos should be taken. Photographs were taken by diver with the frame suspended just off the sea bottom. The optimal distance was defined as the closest distance at which the whole frame could be seen in both photo pairs.

Field trials of the stereo method were undertaken during April and May 1991. Trials were conducted as described for the "vertical stick" method. Ektachrome 400 ASA slide film was used. While it was originally planned that the reference frame would be photographed in the horizontal plane it proved easier on *Challenger* to photograph in the vertical plane. The frame was lowered over the side and photos taken with the cameras looking straight down.

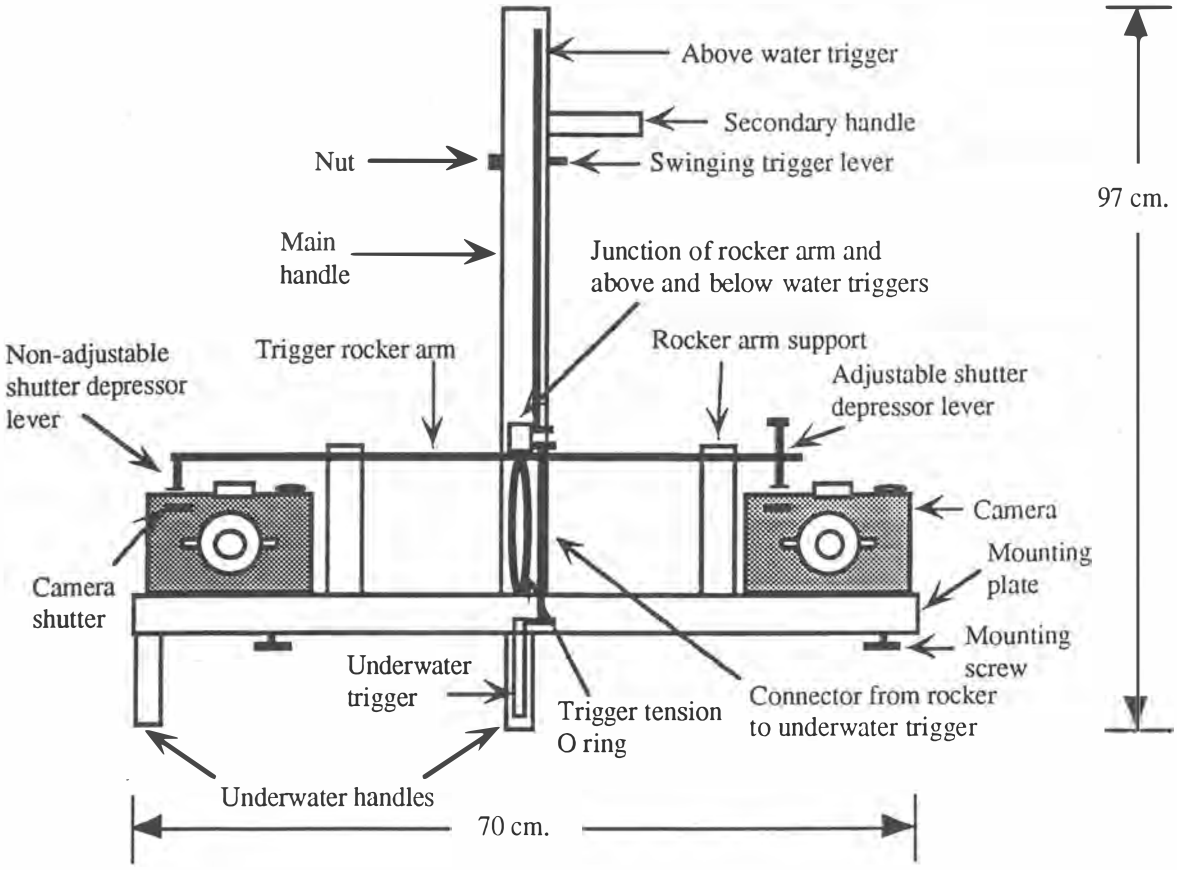


Figure 6. Diagram of the stereo camera mounting frame. (*not to scale*)

Echo sounding - School depth

The average depth of surface schools was to be determined by sounding over target schools with FRV *Challenger*. While the vessel may be expected to affect schooling behaviour to some degree commercial vessels routinely sound over schools to determine their size, suggesting this is a valid method of measuring school height. Trials soundings were undertaken in April 1990 and April and May 1991, targets being those located for the camera trials

RESULTS

Schooling conditions suitable for undertaking a RAT assessment did not occur during the study. No assessment was attempted during the 1988/89 season as the method was in the early stages of development, schooling conditions during this period were also very marginal. Schooling conditions during the 1989/90 and 1990/91 seasons also proved unsuitable, the large surface schools required not forming during those years. During the last month of the 1990/91 season the spotter reported some large schools, however, these were deep schools with little surface area.

The lack of "good" schooling conditions also hampered development of the different techniques which make up the method. As the conditions under which the technique was to be conducted did not occur, proper field testing and development was difficult.

Aerial photography

Because an assessment was not executed no aerial photography was undertaken. Although the theory behind the method is sound, field tests under operational conditions are required to properly assess the methods practicality.

Underwater photography.

Development of the Graves method did not continue past preliminary stages as other methods appeared more promising. The initial photographs of the reference stick produced good results suggesting development of a calibration factor could be made.

Field trials of the "vertical stick" technique demonstrated practical problems with this method. Even when a stable school was encountered, and the school surrounded the dinghy, fish did not school within a ring of approximately a metre from the dinghy. This experience suggested that a method to look into the school was required. The camera apparatus operated as planned, however, minor problems were experienced with the trigger mechanism.

The stereo camera equipment proved easy to operate both underwater and from the surface. Trials indicated that the optimal distance for photographing the reference frame was 2.5m to 3m. Despite spending many hours searching, field trials of the apparatus were hampered by difficulties locating good targets. As a result no useable pictures of schooling fish have yet been produced. Proper assessment of the potential of the unit from this trial is difficult.

Echo sounding

As no assessment has been undertaken this operation has not been applied. Trials indicate that soundings of stable schools can effectively be undertaken by *Challenger*. Field testing under operational conditions are required to verify this.

DISCUSSION

Testing and development of the RAT methodology has been hampered by variable schooling conditions experienced during the study. This variation appears to be due to changes in local oceanographic conditions associated with fluctuations in the El Niño/Southern Oscillation index (Williams and Pullen, in prep.; Jordan, *et al.* in prep.; Harris, *et al.* 1991; Young, *et al.* in prep.) The 1988/89 fishing season was most severely affected by this phenomenon, this period being defined as a La Niña event. The degree to which schooling was influenced during the two subsequent seasons (1989/90 and 1990/91) is hard to estimate, however, it seems that the influence of the La Niña progressively lessened over this period (Jordan, *et al.* in prep.; Young, *et al.* in prep.).

While no assessment, or testing under "real" conditions, was undertaken significant development of the different methodologies was achieved. Experience of the practical problems associated with the technique was also gained. This experience suggests that the importance of monitoring schooling should not be overlooked. An understanding and real time monitoring of schooling behaviour is critical to the success of the technique. This procedure also requires the dedication of significant resources.

Whilst the aerial survey methods for measuring surface school area have not been tested, the significant experience of the HEC proved highly applicable in their development. The expertise, and specialised analytical equipment available provided a ready and reliable method for this study.

Development of a practical method for estimating school packing rates was more difficult. The literature describes a number of methods developed to estimate fish packing rates, some of which utilise stereo-photo pairs and some single photos (Graves, 1976; Aoki, *et al.* 1986; Long, *et al.* 1985; Long and Aoyama, 1985; Klimley and Brown, 1983). Difficulties in obtaining good photographs, from which reliable quantitative measurements can be made are a feature of the limited literature on this topic. One of the basic problems is deploying a camera near, or in, a school of fish. The speed and mobility of mackerel suggest that diver operated systems are not appropriate. In this project we have increased the mobility of the system by fastening the camera(s) to an apparatus which could be lowered near, or into, a school from a boat. Another alternative is a remote operated vehicle with cameras attached, the added cost of which would be considerable.

The stereo camera and reference frame technique appears to hold considerable potential, and may be more accurate than similar techniques described in the literature (Jon Osborn, pers. comm.). The technique has been developed by the University of Tasmania primarily to measure the packing rates of orange roughy. Projects in both New Zealand and Australia utilise the expertise and equipment and have constructed sophisticated remote camera frames in order to obtain the necessary photo pairs. The application of the method for schooling mackerel, however, requires further development and field testing before it can be considered operational.

The logistics required on standby to undertake an assessment are considerable, with no guarantee that they will be utilised given the vagaries of schooling behaviour. Our present understanding of mackerel schooling behaviour does not allow us to predict the occurrence of suitable conditions and it will therefore be difficult to properly assess the usefulness of the technique in the future.

ACKNOWLEDGMENTS

The authors are grateful to Jon Osborn from the University of Tasmania for his considerable assistance with the underwater photographic techniques. We would also like to thank the staff of the HEC for their help in designing the aerial survey technique. The assistance of the skipper (Geoff Darcey) and crew (Mathew Francis and George Marris) of FRV *Challenger* is gratefully acknowledged. Thanks also to the commercial mackerel fishers, and the commercial spotter who gave personnel many interesting flights. Sea Fisheries personnel Carl Waterworth, Gwiedo Kucerans, Alan Jordan, Judy Marshall, Will Zacharin and Robert Green also gave invaluable assistance in the field on commercial and research cruises, undertaking liaison duties and providing coxswain and diver support. The camera mounting frames were constructed by Bob Hodgson. This study was jointly funded by the State and the Fishing Industry Research Development Trust Account (DFT2Z).

REFERENCES

Aoki, I., Inagaki, K. and Long, L. V. (1986). A stereo photographic method for measuring the spatial position of fish. Bulletin of the Japanese society of Scientific Fisheries. 52(12), 2069-2077

Graves, J. (1976). Photographic method for measuring spacing and density within pelagic fish schools at sea. Fisheries Bulletin. 75, 230-234

Harris, G. P., Griffiths, F. B., Clementson, L. A., Lyne, V. and Van der Doe, H. (1991). Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. Journal of Plankton Research. Vol 13. Supplement, pp. 109-31.

Hynd, J. S. and Robins, J. P. (1967). Tasmanian tuna survey. Report of first operational period. Tech. Pap. Div. Fish. Oceanogr. CSIRO 22.

Jordan, A., Pullen, G., Marshall, J. and Williams, H. (in prep). The temporal and spatial spawning patterns of jack mackerel, *Trachurus declivis* (Pisces: Carangidaae), over the three years 1988-91 in eastern Tasmanian waters.

Klimley, A. P. and Brown, S. T. (1983). Stereophotography for the field biologist: measurements of lengths and three-dimensional positions of free swimming sharks. Marine Biology. 74, 175-185

Long, L. V. and Aoyama, T. (1985). Photographic measurement for obtaining the length, aspect and bearing of free-swimming fish from their spatial position. Bulletin of the Japanese society of Scientific Fisheries. 51(2), 191-195

Long, L. V., Aoyama, T and Inagaki, K. (1985) A stereo photographic method for measuring the spatial position of fish. Bulletin of the Japanese society of Scientific Fisheries. 51(2), 183-190

Williams, H. and Pullen, G. (in prep). Schooling behaviour of jack mackerel *Trachurus declivis* (Jenyns), as observed in the Tasmanian purse seine fishery.

Williams, H., Pullen, G., Kucerans, G. and Waterworth, C. (1987). The jack mackerel purse seine fishery in Tasmania, 1986-87. Tech. Rep. Mar. Lab. Dep. Sea Fish. (Tasm.). 19

Williams, K. (1981) Aerial survey of pelagic fish resources off south east Australia 1973 - 1977. CSIRO Marine Labs. Rep. 130.

Young, J. W., Jordan, A., Bobbi, C., Johannes, R. E., Haskard, K. and Pullen G. (in prep) Seasonal and interannual variability in krill (*Nyctiphanes australis*) stocks and their

relationship to the jack mackerel (*Trachurus declivis*) fishery off eastern Tasmania, Australia.

DOCUMENT 3

The temporal and spatial patterns of spawning of jack mackerel, *Trachurus declivis*, over the three years 1988-91 in eastern Tasmanian waters

TO BE SUBMITTED TO FISHERIES BULLETIN U.S.

The temporal and spatial patterns of spawning of jack mackerel, *Trachurus declivis* (Pisces: Carangidae), over the three years 1988-91 in eastern Tasmanian waters.

A. Jordan, G. Pullen, J. Marshall , and H. Williams.

Sea Fisheries Research Laboratories, Department of Primary Industry, Fisheries and Energy, Crayfish Point, Taroona, Tasmania 7053, Australia.

bstract

hthyoplankton surveys conducted during the summer and autumn of 1988/89, 1989/90 and 90/91 along the east coast of Tasmania determined the spatial and temporal patterns of eggs and rvae of jack mackerel, Trachurus declivis and indicates that the species spawns along the entire st coast during summer. Jack mackerel eggs were most abundant on shelfbreak stations dicating spawning is concentrated in this region, although rapid onshore transport in 1988/89 sulted in high concentrations on the shelf. Larvae were evenly dispersed over the shelf with the stribution of larval ages showing no indication of inshore recruitment. Back calculation of awning dates suggests that T. declivis shows a semi-lunar spawning rhythm. Large interannual fferences in sea surface temperatures and vertical thermal structure were apparent, with the armer waters and strong thermal stratification in summer of 1988/89 resulting from the minance of subtropical East Australian Current (EAC) water on the shelf. The fact that the stribution and timing of spawning appears to be unaffected by the interannual differences in eanography suggests that the mature population spawns in deeper water that is unaffected by the arming in the surface waters.

Introduction

Jack mackerel, Trachurus declivis is a temperate carangid distributed around southern Australia and New Zealand. In Australia the species is found from Shark Bay in Western Australia to mid-New South Wales and around Tasmania (Lindholm and Maxwell 1988). Very little is known about the reproductive biology and early life history of the species. The seasonal pattern of gonad development in south east Australian waters indicates a late spring to midsummer spawning season (Webb 1976). Williams et al (1987) suggests that during the summer mature fish leave the inshore fishing grounds moving out into deeper water to spawn (probably at the shelf break) returning when they are in spent condition.

In 1985 a purse seine fishery began operating on the east coast of Tasmania targeting surface and sub-surface schools that appear seasonally in that region, usually from October to June (Williams and Pullen in press). The majority of fishing activity occurs close to shore (within three nautical miles), typically in less than 50 metres of water (Williams et al 1987). Catches increased rapidly with landings of 39,749 tonnes in the 1986/87 season making it the largest single species fishery by weight in Australia (Williams and Pullen in press). However, both catches and the duration of the season have been considerably reduced in subsequent seasons. This was most apparent in the 1989/89 season with the disappearance of Trachurus declivis from surface waters resulting in landings of only 8,150 tonnes. The decreases in catches have been linked to the absence of the krill, Nyctiphanes australis, the principal prey species of T. declivis in shelf waters, resulting in the absence of schools available to the fishery (Young et al. in prep). The interannual variability in krill production in these waters results from the changing influence of nutrient poor subtropical and nutrient rich subantarctic water masses on the region Harris et al (1991). In years when subtropical waters dominate the east coast, such as during the summer of 1988/89, water temperatures are high and productivity is low, and large zooplankters, principally N. australis are largely absent (Harris et al. 1991). This event appears to be associated with a major El Niño/Southern Oscillation (ENSO) event in the southern hemisphere, known as a La Niña event in these waters (Harris et al. 1991).

Niño events are known to effect the spatial and temporal spawning patterns of pelagic pulations (Hammann 1991, Le Clus 1990, MacCall 1979, Muck et al 1987). There is also idence that larval survival and subsequent recruitment strength is influenced by El Niño events incident with warming, altered food production and changes in transport regimes (see review in iley and Incze 1985).

this study we use results from three years of ichthyoplankton surveys to determine the location, ning and duration of spawning of Trachurus declivis on the east coast of Tasmania. The fluence of the variability in oceanography and productivity associated with the 1988/89 La Niña ent on the spawning distribution of T. declivis is also discussed.

aterials and Methods

rvey Design and Methods

hthyoplankton were sampled from the east coast of Tasmania at approximately fortnightly ervals between December and April 1988 to 1991 (Table 1). Samples were collected at fixed tions on 8 transects along the east coast of Tasmania from St Helens Point (Transect 1) in the rth to Eaglehawk Neck (Transect 8) in the south (Figure 1). Transects consisted of 3 stations signated as inshore (at a depth of 30-50 m), midshelf (70-100 m), and shelfbreak (0.5 Nm shore of the shelfbreak at an average bottom depth of 150 m). Additional offshore stations were mpled in 1988/89 during cruises 89-2 (transects 1,4,5,6,7,8) and 89-3 (transects 1,3,5,7) (Fig.

mples were collected with a 45 cm diameter bongo net with 500 μm mesh. Each station nsisted of an oblique tow to a maximum depth of 100 m, bottom depth permitting, at a tow eed of approximately 2 knots. At each station the net was sent to the required depth quickly, ld there for 1-2 minutes and then retrieved on an oblique path. Filtered volume was estimated ing calibrated flowmeters. Sampling was restricted to the hours of 0600 to 2000 hrs. A nperature/depth probe and 20 kg depressor was attached to the net during each tow. The depth stribution of larvae was assessed during cruise 89-2 at the midshelf station of transect 7, with a bottom depth of 90-95 m. At this station a series of six oblique tows were made in the order of progressively shallower depths between 78 m and the surface. Samples from one net were fixed in 95% ethanol, and the other in 10% seawater formalin buffered with sodium ß glycerophosphate.

During cruises 91-1 and 91-2 microzooplankton was sampled at each station with a vertical free fall plankton net (Heron 1982) with a 70 cm ring and 150 µm mesh. With the vessel stationary the net was dropped at 1 m.sec^{-1} for 40 sec sampling 15.4 m^{-3} from the surface to 40 m. The sample was immediately preserved in 10% seawater formalin buffered with sodium ß glycerophosphate.

Laboratory methods

Trachurus declivis eggs and larvae were sorted from plankton samples in a rotatable sorting ring under a dissecting microscope. Eggs were identified using characters defined for *T. declivis* by Crossland (1981) from artificially fertilized eggs which had a mean diameter of 0.998 mm and mean oil globule diameter of 0.266 mm. Further characters were based on the description of *Trachurus symmetricus* eggs by Ahlstrom and Ball (1954), including dorsal body and oil globule pigmentation and the anterior position of the oil globule in late stage eggs. On this basis of these specific characters we classified eggs as *T. declivis*. However, due to the difficulty in accurate identification of early stage eggs, only late stage eggs (ie. those with the first sign of the characteristic dorsal and oil globule pigmentation and anterior position of the oil globule, equivalent to egg stages d-f in Ahlstrom and Ball (1954) were used in estimates of egg abundance and distribution. Several other carangid species are known to occur in the study area but only two species, the trevally *Psuedocaranx dentex* and pilotfish *Naucrates ductor*, are known from more than just a few specimens (May and Maxwell 1986). The eggs and larvae have been described for both *P. dentex* (James 1976, as *Caranx georgianus*) and *N. ductor* (Sanzo 1931), the eggs being easily separated from those of *T. declivis* on the basis of egg diameter and pigmentation. Details of arval identification are given in Jordan (in prep).

Larvae were separated into three developmental stages- preflexion, flexion, and postflexion. Specimens for otolith analysis were randomly selected from each sample up to a maximum of 20 arvae. For stations with more than 20 larvae subsamples were taken proportional to the number of dividuals in each developmental stage to ensure an unbiased estimate of the age distribution of rvae. Standard length (SL;tip of snout to hypural crease or tip of notochord in preflexion larvae) as measured under a dissecting microscope with a ocular micrometer. Validation and counting ocedures used in this study are detailed in Jordan (in prep) and follow procedures outlined in ampana and Nielson (1985).

ıe spawning dates of Trachurus declivis from the east coast of Tasmania were determined by ;eing a subsample of larvae from all three years. However, dates were determined for larvae ught in February and March 1990 by substituting larval lengths into the growth trajectory timated for larvae from this year (Jordan in prep). Based on the development rate of T. mmetricus eggs and larvae at temperatures similar to those in this study, 2-3 days till hatching 'arris 1961) and 5-6 days between hatching and first feeding (Theilacker 1978), the time interval :tween spawning and the formation of the first daily growth increment in T. declivis was timated to be 8 days.

the laboratory the zooplankton samples from the drop net were fractionated into two size tegories (150-500 µm and >500 µm) to provide a quantitative measure of the size range of ıoplankton suitable for Trachurus declivis larvae, as determined by Young and Davis (1992). ımples were washed with a steady stream of tap water through firstly a 500 µm, then a 150 µm reen. The 150-500 µm fraction was then resuspended and filtered by aspiration through a eweighed glass microfiber filter. The filters were then oven dried at 70 C for 36 hours and eighed to an accuracy of 0.1 µg. The dry weight biomass were then expressed as milligrams per)0 cubic metre.

atistical Analysis

order to assess the differences in age composition of Trachurus declivis, larvae collected from e three designated sampling areas (1- inshore, 2- midshelf, 3- shelfbreak), ages were pooled by :ar for each area. Kolmogorov-Smirnov (KS) tests were used to make multiple comparisons of declivis age frequency distributions between areas (1-2, 2-3, 3-1). Significance levels for this st were adjusted to comply for multiple comparisons (Steele and Torrie 1980). Comparisons of microzooplankton densities for cruises 91-2 and 91-3 were made between areas using the Kruskal-Wallis test, corrected for ties. The Tukey-type test (Zar 1984, p.199) was used to make multiple comparisons of areas.

Results

Egg distributions

1989

The distribution of *Trachurus declivis* eggs in early January 1989 was quite even along the entire east coast, suggesting that spawning was occurring throughout the study area.(Fig. 2A). However, the higher densities on transects 3 and 4 indicates more spawning in this central region. No obvious trend in cross shelf distribution was apparent apart from the rapid decrease in egg densities at offshore stations. By late January eggs were absent from transect 1 in the north but consistent on all other transects sampled with a trend towards increasing abundances across the shelf in the south. Eggs were caught in temperatures between 15.3^{o} C and 18.4^{o} C. The mean egg density during the month was 21.71 100 m^{-3}.

1990

Trachurus declivis eggs were caught on all transects, except transect 4 and 8, during January ndicating spawning occurred throughout the study area (Fig. 2B). There is some indication owever that spawning shifted slightly south during the month. No eggs were caught at inshore tations with most eggs (86.7%) confined to stations on the shelfbreak. Water temperature ncreased by 1.7^{o} C during the month with eggs caught between 16.2^{o} C and 17.9^{o} C. Mean egg lensities for the month were 1.60 100m^{-3}.

991

he distribution of *Trachurus declivis* eggs in early January show evidence of spawning along the ntire coast south of transect 1, with shelfbreak stations on transects 3 and 6 showing highest bundances (Fig 2C). By late January eggs were present at only three stations indicating spawning

1 all but ceased along the coast apart from some in the area of Maria Island (transect 6). No eggs re caught at inshore stations with 94.8% of all eggs confined to shelfbreak stations. Sea surface nperatures varied little for the month with eggs caught between 15.5°C and 16.4°C. Mean egg ısities were 5.38 100 m^{-3} but with two stations recording densities greater than 70.0 100 m^{-3}.

rval Distributions

89

achurus declivis larvae were caught on all transects during 1989, although the densities were nsistently higher on the southern section of the coast (transects 4-8) during January (Fig.3A). nsities were also consistently higher at both inshore and midshelf stations in early January hough by late January there were high numbers of larvae on the shelfbreak on transects 7 and 8. larvae were caught at offshore stations apart from a small number on transect 8 in the south. e age frequency distribution of larvae from midshelf was significantly different from inshore tions, with a higher proportion of older larvae (>15 days) (Fig. 4A, Table 2). By late February nsities were uniform on all transects and showed no pattern across the shelf (Fig. 3A). Mean val densities ranged from 57.40 100 m^{-3} in cruise 89-2 to 3.60 100 m^{-3} in cruise 89-4.

90

rvae were confined to the most northern transects in early January 1990 with highest densities f St Helens Point (Fig. 3B). By late January larvae were uniformly distributed along the coast t absent from inshore stations north of transect 5. While the age range of larvae was similar ross the shelf, the distribution of ages were significantly different between inshore and elfbreak stations, which had a higher proportion of older larvae (>15 days) (Fig. 4B, Table 2). ımbers of larvae decreased significantly by mid February with larvae present at only three tions. Mean larval densities ranged from 6.58.100 m^{-3} in cruise 90-2 to 0.14.100 m^{-3} in cruise -4.

1991

Larvae were caught at all stations in early January with highest densities at transects 5 and 7, although there was no clear cross shelf pattern (Fig. 3C). Mean larval densities for this period was 0.30 100 m^{-3}. By late January however larval numbers had decreased significantly to a mean density of 0.01 100 m^{-3} and larvae were present at only 9 stations. Their distribution along the coast was still quite uniform. Both distributions and densities showed little change in late February although no larvae were present on shelf break.

The age distribution of larvae was not significantly different across the shelf with few larvae older than 15 days being caught in any area (Fig. 4B, Table 2).

Zooplankton distributions

Microzooplankton biomass was significantly higher at inshore and midshelf stations than those on the shelfbreak in both early and late January 1991(Table 3). Spatial distribution of samples also indicates that biomass was consistently higher in areas north of transect 5 during the month (Fig 5). Biomass also increased during January in all regions from a mean biomass of 2.57 mg.100m^{-3} during cruise 91-2 to 7.02 mg.100m^{-3} during cruise 91-3.

Vertical distributions

Trachurus declivis larvae were taken from the surface to the maximum depth sampled (75 m), but the vast majority were found in the depth range of 20-40 m just above the thermocline (Fig 6). While this reflects distributions during a period of strong stratification the distribution is likely to be more evenly dispersed during periods when the water column was well mixed (eg. Feb 1991, Fig.9).

Spawning times

In all three years, spawning was restricted to the summer months of December, January and February (Fig. 7). The earliest estimated spawning date did not differ by more than 9 days etween the years with the earliest spawning occurring in the summer of 1990-91. The latest)awning was very similar in all years with only three larvae accounting for the slightly later)awning in February 1990 (Fig. 7B).

he distribution of spawning dates indicates that spawning is essentially continuous throughout ıe spawning season. The absence of a cohort spawned in late January 1989 is more likely to be ıe to the extended time between cruises, resulting in the reduced vulnerability of larvae to the ımpling gear, than a complete cessation of spawning during this period. This is confirmed by the :esence of *Trachurus declivis* eggs in samples taken at this time (cruise 89-3) (Fig. 2A).

/hile spawning was essentially continuous there is clear periodicity in the data with most peaks in)awning activity separated by approximately 14 days and apparently associated with both full and :w moons. This association appears to break down in the last peak in spawning in 1991 and the te January peak in 1990. However, the spawning dates for the late January cohort in 1990 may)t reflect the exact spawning cycle as the spawning dates of this cohort were obtained from age ;timates from the length at age data (Jordan in prep). The fact that this apparent periodicity was 'esent in all three years suggests that it reflects a consistent semi-lunar spawning rhythm in *rachurus declivis*.

ydrography

:a surface temperatures for the summers of 1988/89, 89/90 and 90/91 reflected the effect of asonal warming and the changing influence of warmer northerly and cooler southerly water on e east coast (Fig 8). Temperatures generally increased during the summer period reaching a peak te in February. Temperatures varied markedly between years, the summer of 1988/89 being the armest year of the three year study period, 1990/91 the coolest, and 1989/90 somewhat termediate. Temperatures in all years varied along the coast reflecting the influence of warmer ater from the north and cooler water from the south, and across the shelf, particularly in the ırth, reflecting the fact that warmer northerly waters originated offshore and at times moved onto e shelf.

In mid December 1988 temperatures were uniform along the coast except for a sharp temperature front in the north (Fig 8A). This warmer water had affected the entire outer shelf by mid January although waters were cooler inshore. Warming continued through January with warmest water on the outer shelf. By late February the warmer northerly water had flooded the entire shelf with water up to 20.6° C on the outer shelf in the north.

Temperatures in December 1989 were uniform in the south, while in the north warmer water was present on the outer shelf, with water up to 2.0° C cooler inshore (Fig. 8B). This warmer water dominated the entire shelf in January and February with evidence of continued warming during this period. Temperatures however were up to 2.0° C cooler than for the same period in 1989.

Temperatures were consistently cooler during the summer of 1990/91 reflecting the reduced influence of water from the north (Fig. 8C). Water was relatively uniform during December and early January, however by late January warmer water was present on the outer shelf in the north. This water had retreated by late February with the advance of cooler southerly waters with temperatures up to 3.0° C cooler than for the same period in 1989.

Summer vertical temperature structure from transects 3 and 7 (T3,7) in 1989, 1990 and 1991 reveals clear interannual differences in the amount of thermal stratification during summer (Fig. 9A-B). A strong thermocline is evident on both transects in January 1989 between warm water of northerly origin forming a shallow (30 m) mixed layer and cooler bottom water. By late February a strong temperature front was present on the outer shelf on T3 resulted in rapid warming of the water column. Temperatures remained cooler on T7 with the upper mixed layer remaining across the entire shelf. In mid December 1989 waters on T7 were only weakly stratified with cool surface waters across the shelf. By late January waters on both transects had warmed with a deepening of the thermocline in the south. The thermal structure on both transects remained the same during February. Waters were well mixed during the entire summer of 1991 with little sign of warming or stratification.

iscussion

ie distribution of Trachurus declivis eggs over the three years indicates that spawning occurs ong the entire east coast of Tasmania. There was no evidence of spawning activity being centred a particular section of the coast although at times certain stations recorded significantly higher nsities than those adjacent. Eggs in January were recorded in sea surface temperatures ranging om 15.3° C to 18.4° C, however these do not cover the beginning of the spawning period in all ree years as indicated by the backcalculated spawning dates (Fig. 7A-C). The minimum surface nperature eggs were caught in was 14.7° C recorded in mid December on transect 7 during iise 91-1. These temperatures are consistent with those recorded by Farris (1961) for Trachurus mmetricus off California who found more than 80% of eggs between 14.0° C and 18.5° C. He ncluded that temperature is important, but not the controlling factor in the spatial distribution of awning in T.symmetricus.

hile the overall distribution of Trachurus declivis in Australian waters extends well outside the idy area (NSW to Shark Bay WA), the relationship between spawning populations on the east ast of Tasmania and those outside the study area in unknown. Trachurus declivis are known to awn around the entire coast of Tasmania (Furlani pers comm), and in the Great Australian Bight tevens et al. 1984), where they form a distinct population from those in the south-east of istralia (Richardson 1982). Information on the relationship between fish from New South Wales d Tasmanian waters is sparse. Based on the appearance of surface schools, Maxwell (1979) ggested that with the approach of summer, fish from New South Wales move into Tasmanian iters following the 17° C isotherm as part of a southern seasonal migration. However, there is a ident demersal population in east coast Tasmanian waters during winter (May and Blaber 1989, ebb and Wolfe 1977), although some migration into east coast waters is likely during spring and nmer as the biomass of fish is highest in these waters at this time (Williams 1981). This is ther supported by Furlani (pers comm) who found the highest abundances of carangid larvae on nsects on the east coast of Tasmania, the majority of these larvae being those of T. declivis. rther information is needed on possible migration of T. declivis before conclusions can be drawn on the relationship between spawning and spatial and temporal distribution of the adult population.

The fact that *Trachurus declivis* eggs were consistently most abundant at stations situated on the shelf break in the summer of both 1990 and 1991 suggests that spawning is concentrated in this area. The distribution of eggs across the shelf was much more uniform in 1989 although still only 24% of eggs were caught inshore. The determination of specific spawning sites from patterns of egg distributions are influenced by the direction and rates of advection, and the ages of eggs when sampled. Farris (1961) estimated the development rate of *Trachurus symmetricus* eggs for three stages of development at a range of temperatures. When this model is applied to eggs of *T.declivis* it is estimated that at a mean temperature of 16.5° C the stages identified in this study would be between 32 and 62 hours old. Current meter records from the shelf break off Maria Island taken during the summer of 1983-4 indicates that alongshore currents speeds rarely exceeded 20 cm sec^{-1} and greatly exceeded onshore currents during summer (Huyer et al. 1988). This suggests that that transport of eggs from the spawning area may be slow. Alongshore currents were also strongly fluctuating with flow reversals associated with variations in the coastal winds (Huyer et al. 1988). These flow reversals may also reflect that fact that the central part of the sampling area lies at boundary between subantarctic and subtropical waters both of which in summer show periods of rapid advances and retreats (Harris et al. 1987). In years when subtropical water dominates the east coast and floods the shelf, as was the case during January 1989 (Fig ?), flow in the top 50-100 m is dominated by this current (Harris et al. 1987). Hence, patterns of generalised flow are difficult to estimate as the regional oceanography shows both short and long term variability. Flow patterns will also vary along the east coast due to the greater influence southerly flowing subtropical water in the north and the northerly flowing subantarctic water in the south. However, the dominance of alongshore transport suggests that spawning was centred along the shelf break in 1990 and 1991, although the situation is unclear regarding spawning distribution in 1989. Either spawning occurred across the entire shelf, or onshore movement of eggs was rapid in hat year. The absence of surface schools in inshore waters (Williams 1989), and the low bundance of fish on the shelf during the spawning period of 1989 (G. Pullen. pers obs.)

ggests that rapid advection of eggs inshore from the shelfbreak is the more likely cause for the served distribution. This is further supported by the fact that the bulk of the spawning in this ar occurred at a time when the entire east coast of Tasmania was dominated by subtropical water at flooded the shelf break resulting in a dominant southerly and onshore flow.

e inference that spawning is concentrated in the shelf break area is supported by data on the stribution of mature fish. Firstly there is a low availability of mature fish to the inshore mmercial fishery during the spawning season, which Williams et al (1987) suggests is possibly e to the movement of mature fish into deeper water to spawn. The absence of post-ovulatory licles in fish sampled from the fishery (Marshall et al in prep) also suggests that spawning fish spatially separated from the inshore population. May and Blaber (1989) also found that the mass of Trachurus declivis in the upper slope region of the Maria Island area peaked in bruary, indicating the movement of fish into the area. The availability of mature Trachurus churus in South Africa waters is low during the spawning period associated with the movement fish offshore to spawn (Crawford 1980). Spawning in T.trachurus is concentrated on the lfbreak in these waters, although some offshore spawning does occur (Shannon and Pillar 86). The rapid decrease in egg numbers at offshore stations suggests that spawning in T. livis is concentrated on the shelfbreak. This is in contrast to Trachurus symmetricus which are own to spawn up to 1000 miles offshore (Ahlstrom and Ball 1956) and Trachurus murphyi ich spawn across the entire zone of the subtropical convergence from the Chilean shelf to New aland (Evseenko 1987). The fact that T.declivis have never been recorded offshore, and form a tinct population from T.declivis in New Zealand waters (Richardson 1982) suggests that shore spawning is unlikely.

awning by Trachurus declivis on Tasmania's east coast occurred only during the summer nths of December to February in all three years. The timing of spawning by fish outside the dy area may differ as a shift in spawning time with latitude is known to occur in other species Trachurus (Ahlstrom 1969). Maxwell (1979) suggested that T. declivis in New South Wales ters spawn earlier (October to January) than those off Tasmania. However those in the Great stralian Bight spawn during summer with the bulk of spawning finished by March (Shuntov

1969). Three years of data indicates that the beginning of spawning and its duration varies little between years, starting in mid December and ending in late February. However as larval abundances in all three years peaked in early January, reflecting intense spawning in late December, and larval densities decreased rapidly by mid February, it appears that the bulk of the spawning activity takes place in the first few weeks of the season.

The considerable interannual differences in sea surface temperature and thermal stratification during the three years of the study can be explained by the varying influence of subtropical and subantarctic waters on the east coast. The regional oceanography of eastern Tasmanian waters is determined by a combination of the local westerly wind stress and large scale oceanographic circulation dominated by the warm, stratified, nutrient poor East Australian Current (EAC) water, and cool, well mixed nutrient rich water of subantarctic origin (Harris et al. 1987). The boundary that separates these two water masses is defined as the subtropical convergence (STC) , the northern edge of which in summer lays at times to the north of Maria Island and sometimes to the south (Harris et al. 1987). The position of the STC shows considerable interannual variability and has been coupled with interannual variations in westerly winds (Harris et al. 1988). The warmer sea surface temperatures and increase in thermal stratification seen during the summer of 1988/89 resulted from a reduction in the westerly wind stress and increased influence of EAC water from the north, this event being linked to a major El Niño/ Southern Oscillation (ENSO), or La Niña event in the southern hemisphere (Harris et al. 1991). While warmer water temperatures were experienced again during the summer of 1989/90 they were mainly restricted to the outer shelf with cooler waters dominating inshore. The decrease in subtropical influence during the summer of 1990/91 resulted in cooler water temperatures over the shelf during the entire spawning season.

Despite the increased subtropical influence in the summer of 1988/89, surface temperatures during the early part of the spawning period (mid Dec to mid Jan) in the three years only differed by a maximum of 1.5° C. However, during the spawning period of 1988/89 the subtropical EAC water only dominated the upper 50 m, strong stratification resulting in bottom water in early January in this year actually being cooler (12.7° C to 13.8° C) than for the same period in 1990 (13.7° C to 15.5° C) and the mid December period in 1991 (Fig. 9C). As a result of these factors, the warm ater event of 1988/89 appears to have had little effect on the spawning population of Trachurus clivis. As spawning appears to be concentrated in deeper water in the region of the shelf break, awning fish in 1988/89 apparently moved from inshore waters into deeper water as normal and awning was unaffected. However, despite the low availability of mature fish to the inshore hery during the spawning period (Williams et al. 1987) there appears to be some movement of h between the shelf break and inshore waters as some mature fish are still caught at this time larshall et al. in prep). While the fishery is primarily based on immature fish during the awning period it is not known whether these fish migrated south into cooler water or also oved into deeper water. The disappearance of both mature and immature T. declivis from inshore aters on the east coast during the 1988/89 season appears to be driven by the disappearance of its incipal prey species, Nyctiphanes australis, from these waters (Young et al. in prep). Trachurus clivis on the upper continental slope feed almost exclusively on the lanterfish, Lampanyctodes ctoris (Blaber and Bulman 1987), which occurs in large concentrations close to the shelf break d upper continental slope in east coast Tasmanian waters (May and Blaber 1989). The biomass L. hectoris in the Maria Island area is highest in summer, corresponding to the spawning period T. declivis (May and Blaber 1989). It is possible that mature T. declivis concentrate in the shelf eak/upper slope region at this time in response to the increase in L. hectoris biomass and not rely as a result of a spawning migration. The change in mean length of fish caught in the hery, which shows a marked increase during April and May (Williams et al. 1987), suggests at mature fish do not move back into inshore waters immediately after spawning but continue to ed on the upper slope for some time. The movement of mature fish back into inshore areas ring autumn, resulting in the increase in mean school size and subsequent autumn peak in ndings in the fishery (Williams and Pullen in press), is most likely in response to the increase in australis biomass at this time (Young et al. in prep).

e effect of the 1988/89 warm water event on the overall spawning distribution of Trachurus clivis is difficult to assess as it is likely that only an unquantified portion of the spawning pulation was sampled, so shifts in the bounds of the spawning area may not have been served. The effects of El Niño events on the spatial distribution of spawning is well documented for a number of pelagic species (Arntz 1986, Le Clus 1990, Mc Call 1979, Walsh et al. 1980). Spawning distributions of several species shifted polewards during such years, including anchovy in the Benguela current region (Le Clus 1990) and anchovetta (Walsh et al. 1980) and sardines (McCall 1979) off South America. However, Muck et al (1987) found that Trachurus murphyi, who normally have an offshore spawning distribution, respond to warm conditions by restricting spawning to coastal waters. A similar increase in inshore spawning activity was noted during an El Niño year for the northern anchovy (Brodeur et al. 1985). There is also some evidence that some south American clupeiod populations migrate into deeper water during strong El Niño events (Arntz 1986). While spawning changes have often been directly related to variability in water temperature it is also possible that changes in spawning location is an adaptive response to spawn in an area which makes best use of the spatial patterns of ocean stability to provide suitable feeding conditions and favourable transport (Lasker 1981, Shelton and Hutchings 1989). The fact that T. declivis spawned as normal along the east coast during the warm water event of 1988/89 appears to result from the fact that spawning occurs in deeper waters in the region of the shelf break away from the subtropical waters that dominated the surface layers.

The timing and duration of spawning during El Niño years is known to vary for a number of pelagic species, including anchovy and pilchards in South African waters (Le Clus 1990) and anchovy and sardines the Californian current (Ahlstrom 1967), although there is no clear trend for early or late spawning. However, the importance of temperature in determining spawning time in such species is unclear, as timing may be determined by temporal patterns of ocean stability and favourable transport, as suggested for anchovy (Shelton and Hutchings 1990). Both the timing and duration of the spawning season for Trachurus declivis appears to be unaffected by the variability in water temperatures and thermal stability in east coast waters. More work is needed before the factors determining the temporal patterns of spawning in this species will be understood.

The semi-lunar periodicity in spawning activity in Trachurus declivis indicates that peaks in spawning are closely associated with full and new moons. Although lunar reproductive cycles are well documented for tropical species (Johannes 1978, Milton and Blaber 1991, Davis and West in

:ss), such cycles appear to be rare in fish from temperate waters. Whether the development of :h cycles in T.declivis is related to purely an environmental cue or possible increases in nsport of eggs due to increased tidal transport is unknown.

spite the fact that cross shelf currents on the east coast of Tasmania appear to be relatively weak ring summer (Huyer et al. 1988) the presence of early stage larvae at inshore stations in all three ars indicates that cross shelf transport is occurring. The shelf on the east coast, particularly in : north, is relatively narrow being only 20 km wide in places. Therefore a 5 day old larvae uld only have to travel on average 2 cm sec^{-1} to cover the distance between the shelf break and hore waters. When the southward flowing EAC water moves in over the shelf, as happened ring the summer of 1988/89 onshore transport appears to be particularly strong. However it is t clear that such onshore transport is related to the recruitment of larvae into inshore nursery bitats. Firstly, there was no clear pattern in larval densities across the shelf apart from the higher hore densities found during early January 1989. Secondly, there was no apparent increase in val ages from offshore to inshore stations in any year which would result if there was nificant cross shelf transport associated with inshore recruitment from a shelfbreak spawning a. While the age range of larvae was similar between areas in all three years, at times the age tribution differed. This was particularly significant in 1990 when there was a large proportion older larvae still present on the shelfbreak. If the trend in microzooplankton densities, which s significantly lower on the shelfbreak during the main spawning period in 1991, is a standard ture then there appears to be an advantage in rapid inshore recruitment. Hence, variability in shore transport may be a significant source of mortality by maintaining larvae in poor feeding as or even loss of larvae to offshore waters.

iley and Incze (1985) identifies the most important influences of El Niño events on early life tory stages are altered food production, warming, and changes in transport regimes. All of se factors are known to have shown considerable variability during the three year study period h anomolous onshore transport during 1988/89 already identified as a source of variability in tribution. In relation to altered food production, Harris et al (1991) detailed a general decline in rient condition in south east Tasmanian shelf waters during the La Niña summer of 1988/89 with a shift in the structure of the zooplankton community, with the elimination of large zooplankters and the domination of populations of small copepods. This differential response to oligotrophic conditions by different members of the pelagic food web is similar to that experienced in the Californian current region during an El Niño event (Smith 1985). Young and Davis (1992) studied the diet of Trachurus declivis larvae during the summers of 1988/89 and 1989/90 and found that despite the shift in prey taxa between years, with the exclusion of calyptopid stage Nyctiphanes australis and dominance of small copepods in the guts in 1988/89 mirroring their abundance in the plankton, there was no evidence of food limitation during this year. This may be related to the strong vertical stability experienced during the entire spawning period creating suitable prey concentrations in the upper mixed layer, corresponding to the vertical distribution of arval T. declivis (Fig 6). The conditions for suitable feeding conditions is supported by Jordan (in prep) who found T. declivis larvae showed rapid growth in these years which he suggested may e attributable to the warmer water temperatures associated with the La Niña event. Although the tability of the upper mixed layer and its influence on food aggregations has been identified as nportant factor controlling larval survival (Lasker 1981, Peterman and Bradford 1987), the lack f data on the vertical distribution of microzooplankton in these years precludes any assessment of s importance in interannual differences in survival of T. declivis larvae.

is clear from the data that egg densities varied considerably between the three years of the study. owever, the differences in the timing of cruises in relation to the spawning cycle and the fact that timates were made from different cohorts means that a direct comparison of egg densities tween years is not possible. However the magnitude of the decrease in egg abundances between 88/89 and 1989/90 suggests that there may have been a severe decline in reproductive output in 89/90. A decline in egg production as a result of El Niño events had been documented for veral species (De Martini 1991, Hay and Brett 1988, Lenarz and Echeverria 1986). Several idies have have demonstrated that naturally occurring food limitations may result in fluctuations fecundity (Hay and Brett 1988, Hunter and Leong 1981), decreases in egg production resulting m a decrease in batch fecundity (De Martini 1991), or shortening of the spawning season unter et al. 1985). During autumn in a normal year Trachurus declivis utilize the large biomass yctiphanes australis, its main prey source in shelf waters, resulting in fat reserves of up to (Miezitis and Wright 1979). The disappearance of N. australis from east coast shelf waters ng 1988/89 season (Young et al in prep) led to a subsequent decrease in fat reserves during year (G. Pullen personal observation). As spawning occurs prior to the peak in prey ability in the following season it is likely that most of the energy available for reproduction is rolled by the amount of fat stored in the previous summer, as suggested for Engraulis mordax Iunter and Leong (1981). Hence the decrease in the amount of energy available for oduction may have resulted in the the observed decrease in egg production in the summer of /90. However it is possible that some of the decrease in egg abundances resulted from a shift e spawning distribution.

owledgments

hank the captain and crew of the F. R. V. Challenger for their assistance during the course of study. Thanks to G. Jenkins and C. Waterworth for assistance in the field and P. Bonham for l sorting of samples. This work was supported by a grant from the Australian Fishing Industry arch and Development Trust Account (DFT2Z).

Citations

Ahlstrom, E.H. (1967) Co-occurrence of sardine and anchovy larvae in the California current region and Baja California. CalCOFI Rep. 11:117-135.

Ahlstrom, E.H. (1969) Distributional atlas of fish larvae in the Californian current region: jack mackerel, Trachurus symmetricus, and Pacific hake, Merluccius productus, 1951 through 1966. Calif. Coop. Oceanic Fish. Invest. Atlas. 11:1-92.

Ahlstrom, E.H., and O.P. Ball (1954) Description of eggs and larvae of jack mackerel (Trachurus symmetricus) and distribution and abundance of larvae in 1950 and 1951. U.S. Fish Wildl. Ser.Fish. Bull No. 97, 56:209-245

Arntz, W.E. (1986) The two faces of El Niño 1982-83. Meeresforschung. 31(1), 1-46.

Bailey, K.M., and L. S.Incze (1985) El Niño and the early life history and recruitment of fishes in temperate marine waters.In, Wooster, W.S., and D.S. Flurharty (eds.), El Niño north: Niño effects in the eastern subarctic Pacific Ocean, p. 143-165. Wash Sea Grant Prog., Univ. Wash., Seattle.

Blaber, S.J.M., and C.M. Bulman (1987) Diets of fishes of the upper continental slope of eastern Tasmania: content, calorific values, dietary overlap and trophic relationships. Mar. Biol. 95:345-356.

Brodeur, R.D., D.M. Gadomski, W.G. Pearcy, H.P. Batchelder, and C.B. Miller (1985) Abundance and distribution of ichthyoplankton in the upwelling zone off Oregon during anomalous El Niño conditions. Est. Coast. Shelf. Sci. 21:365-378.

Campana, S.E., and J.D. Nielson (1985) Microstructure of fish otoliths. Can. J. Fish. Aquat. Sci. 42:1014-1032.

Crawford, R.J.M. (1980) Seasonal patterns in South Africa's Western Cape purse-seine fishery. J. Fish Biol. 16:649-664.

ossland, J. (1981) Fish eggs and larvae of the Hauraki Gulf, New Zealand. N.Z. Min. Agr. & Fish. Fish. Res. Bull. 24:61pp.

vis, T.L.O., and G.J. West (in press) Maturation, reproductive seasonality and spawning frequency in one-band sea-perch, Lutjanus vittus (Quoy and Gaimard), from the North West Shelf of Australia. Fish. Bull. U.S.

Martini, E.E. (1991) Annual variations in fecundity, egg size, and the gonadal and somatic conditions of the Queenfish Seriphus politus (Sciaenidae). Fish. Bull. U.S. 89:9-18.

seenko, S.A. (1987) Reproduction of Peruvian jack mackerel, Trachurus symmetricus murphyi, in the southern Pacific. J. Ichth. 27(3):151-160.

rris, D. (1961) Abundance and distribution of eggs and larvae and survival of larvae of jack mackerel (Trachurus symmetricus). U. S. Fish. Wildl. Serv., Fish. Bull. 61:247-279.

mmann, G.M. (1991) Spawning habitat and egg and larval transport, and their importance to recruitment of pacific sardine, Sardinops sagax caeruleus, in the gulf of California. In, Kawasaki, T., S. Tanaka, Y. Toba, and A. Taniguchi (eds), Long term variability of pelagic fish populations and their environment, p. 271-292. Pergamon Press, Oxford.

rris, G.P., C. Nilsson., L.A. Clementson and D. Thomas. (1987) The water masses of the east coast of Tasmania: seasonal and interannual variability and the influence on phytoplankton biomass and productivity. Aust. J. Mar. Freshwater. Res. 38:569-90.

rris, G.P., P, Davies., M, Nunez, and G. Meyers (1988) Interannual variability in climate in Tasmania and its effect on freshwater and marine fisheries. Nature. 333:754-757.

rris, G.P., F.B. Griffiths., L.A. Clementson., V. Lyne and H. Van der Doe (1991) Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. J. Plankton. Res. 13:109-131.

y, D.E., and J.R. Brett (1988) Maturation and fecundity of Pacific herring (Clupea harengus pallasii): An experimental study with comparisons to natural populations. Can. J. Fish. Aquat. Sci. 45:399-406.

Heron, A.C. (1982) A free fall plankton net with no mouth obstructions. Limn. Ocean. 27:380-383.

Hunter, J.R., and R. Leong. (1981) The spawning energetics of female northern anchovy, Engraulis mordax. Fish. Bull. U.S. 79:215-230.

Hunter, J.R., N.C.H. Lo., and R.J.H. Leong (1985) Batch fecundity in multiple spawning fishes. In, Lasker, R. (ed.), An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy, Engraulis mordax. NOAA Tech Rep. NMFS 36:67-77.

Huyer, A., R.L. Smith, P.J. Stabeno, J.A. Church, and N.J. White (1988) Currents off south-eastern Australia: results from the Australian coastal experiment. Aust. J. Mar. Freshwater Res. 39:245-288.

James, G.D. (1976) Eggs and larvae of the trevally Caranx georgianus (Teleostei: Carangidae). N. Z. J. Mar. Freshwater Res. 10(2):301-310.

Johannes, R.E. (1978) Reproductive strategies of coastal marine fishes in the tropics. Environ. Biol. Fish. 3:65-84.

Jordan, A.R. (in prep) Age and growth of larval jack mackerel, Trachurus declivis, (Pisces: Carangidae), from eastern Tasmanian coastal waters. Aust. J. Mar. Freshwater Res.

Lasker, R. (1981) The role of a stable ocean in larval fish survival and subsequent recruitment. In, Lasker, R. (ed.), Marine fish larvae, p. 80-87. Wash. Sea Grant Prog., Univ. Wash., Seattle.

Le Clus, F. (1990) Impact and implications of large-scale environmental anomalies on the spatial distribution of spawning of the Namibian pilchard and anchovy populations. S. Afr. J. Mar.

Sci. 9:141-159.

narz, W.H., and T.W. Echeverria. (1986) Comparison of visceral fat and gonad fat volumes of yellowtail rockfish, Sebastes flavidus, during a normal year and a year of El Niño conditions. Fish. Bull. U.S. 84:743-745.

ıdholm, R. and J.G.H. Maxwell (1988) Stock separation of jack mackerel Trachurus declivis (Jenyns, 1841) and yellowtail T. novaezelandiae (Richardson 1843) in southern Australian waters, using principal component analysis. CSIRO Marine Labs. Rep. 189

:Call, A.D. (1979) Population estimates for the waning years of the Pacific sardine fishery. CalCOFI Reps. 20:72-82.

ıcCall, A.D. (1983) Variability of pelagic fish stocks off California. In Proceedings of the expert consultation to examine changes in abundance and species composition of neritic fish resources. FAO Fisheries Report No. 291(2):17-36

ırshall, J. M., G. Pullen, and A.R. Jordan (in prep) Reproductive biology and sexual maturity of jack mackerel, Trachurus declivis (Jenyns), in eastern Tasmanian waters.

ıxwell, J.G.H. (1979) Jack mackerel. CSIRO Div. Fish. Oceanogr. Fishery Situation Report 2, 18p.

ıy, J.L., and S.J.M. Blaber (1989) Benthic and pelagic fish biomass of the upper continental slope off eastern Tasmania. Mar. Biol. 101:11-25.

ıy, J.L., and J.G.H. Maxwell (1986) Field guide to trawl fish from temperate waters of Australia. CSIRO, Hobart. pp 216-222.

lezitis, O., and A.D.Wright (1979) Variations in the chemical composition of jack mackerel Trachurus declivis (Jenyns) from commercial fishing for FPC production 1973-1974. Tasm. Fish. Res. 22:30-39.

ilton, D.A., and S.J.M Blaber (1991) Maturation, spawning seasonality, and proximate spawning stimuli of six species of tuna baitfish in the Solomon Islands. Fish. Bull. U.S. 89:221-237.

Muck, P., O, Sandoval de Castillo, and S. Carrasco (1987) Abundance of sardine, mackerel and horse mackerel eggs and larvae and their relationship to temperature, turbulence and anchovetta biomass off Peru. ICLARM Studies and Reviews No. 15:268-275.

Peterman, R.M. and M.J. Bradford (1987) Wind speed and mortality rate of a marine fish, the northern anchovy, (Engraulis mordax). Science (Wash., DC) 235:354-356.

Richardson, B.J. (1982) Geographical distribution of electrophoretically detected protein variation in Australian commercial fishes. I. Jack mackerel, Trachurus declivis Jenyns. Aust. J. Mar.Freshw. Res. 33:917-26.

Sanzo, L. (1931) Uova stadi embrionali e post-embrionali di Naucrates ductor. L. Mem. R. Com. Talassogr. Ital. 185.

Shannon, L.V., and S.C. Pillar (1986) The Benguela ecosystem:Part III. Plankton. Oceanogr. Mar. Biol. Ann. Rev. 24:65-170.

Shelton, P.A., and L. Hutchings (1989) Ocean stability and anchovy spawning in the southern Benguela Current region. Fish. Bull. U.S. 88:323-338.

Shuntov, V.P. (1969) Some features of the ecology of pelagic fishes in the Great Australian Bight. Probl. Ichthyol. 9:801-9

Smith, P.E. (1985) A case history of an anti-El Niño to El Niño transition on plankton and nekton distribution and abundances. In, Wooster, W.S., and D.S. Flurharty (eds.), El Niño north: Niño effects in the eastern subarctic Pacific Ocean, p. 166-187. Wash Sea Grant Prog., Univ. Wash., Seattle.

tevens, J.D., H.F. Hausfeld., and S.R.Davenport (1984) Observations on the biology, distribution and abundance of Trachurus declivis, Sardinops neopilchardus and Scomber australasicus in the Great Australian Bight. CSIRO Marine Labs. Rep. 164.

ıeilacker, G.H. (1978) Effect of starvation on the histological and morphological characteristics of jack mackerel, Trachurus symmetricus, larvae. Fish. Bull. U.S. 76:403-414

alsh, J.J., T.E. Whitledge, W.E. Esaias, R.L. Smith, S.A. Huntsman, H. Santander, and B.R. de Mendiola. (1980) The spawning habitat of the Peruvian anchovy, Engraulis ringens. Deep-Sea Res. 27A:1-27.

ebb, B.F. (1976) Aspects of the biology of the jack mackerel Trachurus declivis (Jenyns) from southeast Australian waters. Tasmanian Fish.Res. 10:1-14.

ebb, B.F., and D.C. Wolfe (1977) Trawl data from a survey around Tasmania by the F.V. Zeehan, July 1975 to June 1976. Tas. Fish. Res. 21:15-23.

illiams, H. (1989) Jack mackerel go walkabout. Fishing Today 2(1):31-32.

illiams, H., G. Pullen., G. Kucerans, and C. Waterworth (1987) The jack mackerel purse seine fishery in Tasmania, 1986-1987. Tech. Rep. Mar. Lab. Dep. Sea Fish. (Tasm.). 19,p32.

illiams, H., and G. Pullen (in press) Schooling behaviour of jack mackerel, Trachurus declivis (Jenyns), observed in the Tasmanian purse seine fishery. Aust. J. Mar Freshw. Res.

illiams, K. (1981) Aerial survey of pelagic fish resources off south east Australia 1973 - 1977. CSIRO Marine Labs. Rep. 130.

ɔung, J.W., and T.L.O. Davis. (in press) Feeding ecology, and interannual variations in the diet of larval jack mackerel, Trachurus declivis (Pisces: Carangidae) from coastal waters of eastern Tasmania. Mar Biol.110.

ɔung, J.W., A.R. Jordan, C. Bobbi, R. Johannes, K. Haskard, and G. Pullen (in prep) Seasonal and interannual variability in krill (Nyctiphanes australis) stocks and their relationship to the jack mackerel (Trachurus declivis) fishery off eastern Tasmania.

Australia.

Zar , J. H. (1984) Biostatistical analysis (2nd Ed) Prentice -Hall, Inc., Englewood Cliffs, New Jersey. 718pp.

ble 1. Summary of sampling dates and transects sampled during three years of the study.

Cruise	Date	Transects Sampled
89-1	5-7 December 1988	T 2-7
89-2	11-14 January 1989	T 1-8
89-3	23-26 January 1989	T 1,3,5,7
89-4	27 February-2 March 1989	T 1-8
89-5	4-12 April 1989	T 1-8
90-1	12-14 December 1989	T 1-7
90-2	5-8 January 1990	T 1-8
90-3	22-25 January 1990	T 1-8
90-4	14-20 February 1990	T 2-8
90-5	13-16 March 1990	T 1-8
91-1	19-20 December 1990	T 7,8
91-2	2-7 January 1991	T 1-8
91-3	21-31 January 1991	T 1-8
91-4	18-28 February 1991	T 1-8
91-5	18-20 March 1991	T 6,7,8
91-6	8-9 April 1991	T 6,7,8

Table 2. Probability values from the Kolmogorov Smirnov comparisons of age frequency distributions between areas, (1- inshore, 2- midshelf, 3- shelfbreak) ** refers to statistically significant differences

Year	Area 1-2	Area 2-3	Area 3-1
1989	0.034**	0.706	0.092
1990	0.321	0.159	0.068**
1991	0.401	0.306	0.494

able 3. (A) Probability values from the Kruskal-Wallis comparison of microzooplankton nsities between areas. (B) Probability values from the Tukey-type test of multiple comparisons tween areas.

(A) Cruise	Areas
CR 91-2	0.014
CR 91-3	0.002

(B) Cruise	Area 1-2	Area 2-3	Area 3-1
CR 91-2	> 0.50	< 0.02	< 0.04
CR 91-3	> 0.50	< 0.02	< 0.01

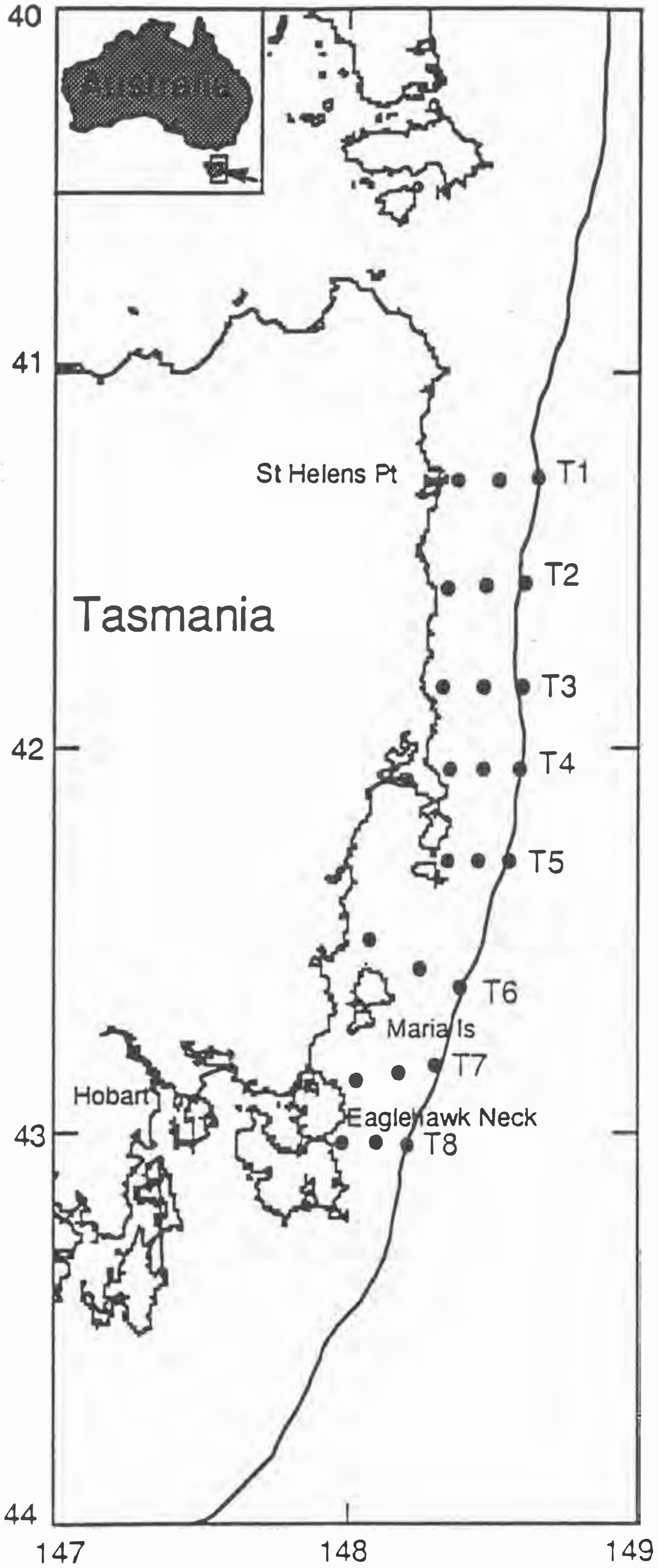
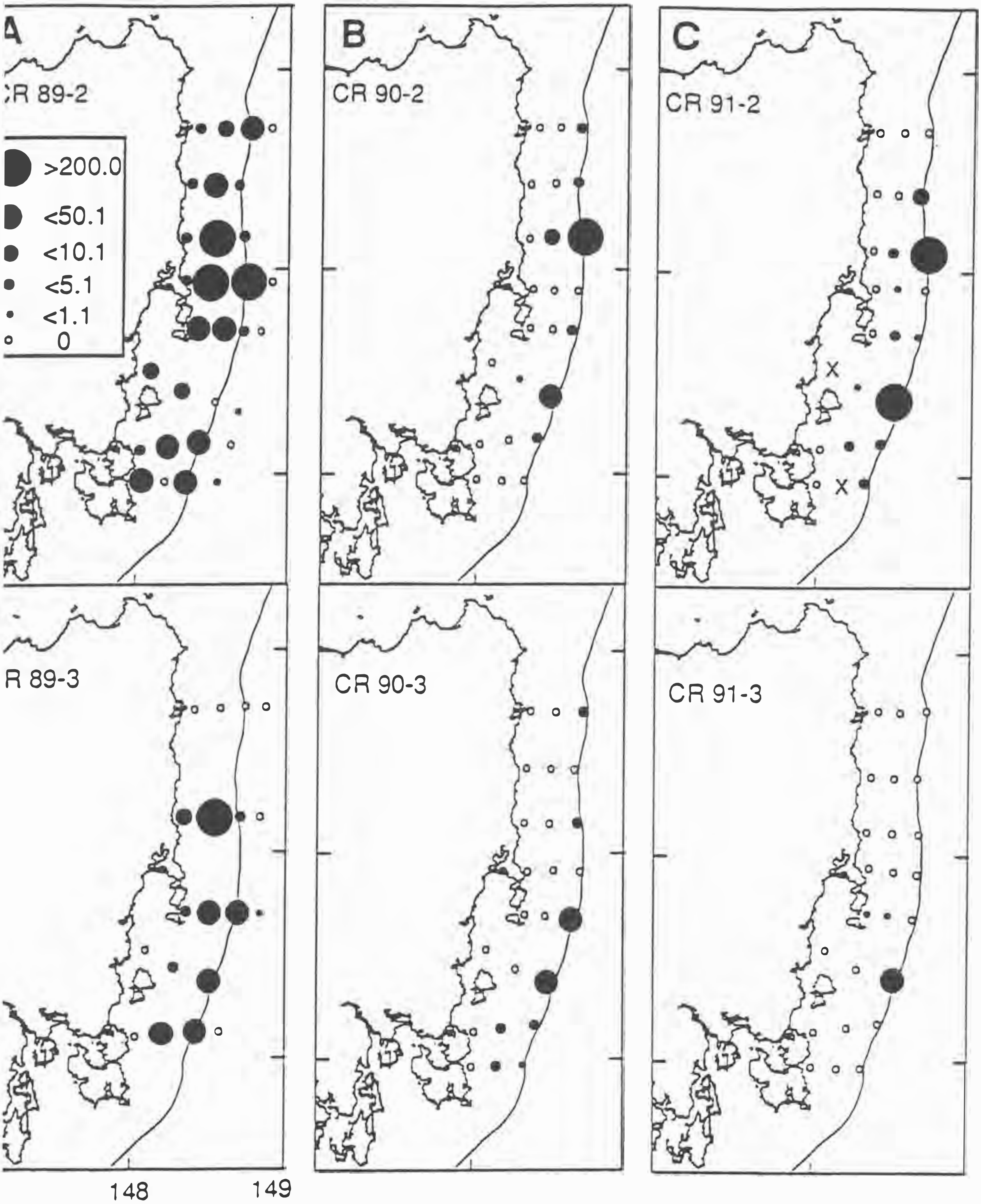


Figure 1. Position of ichthyoplankton sampling stations located on eight transects along the east coast of Tasmania, Australia.



igure 2. Expanding symbol plot of *Trachurus declivis* egg concentrations (no. 100 m^{-3}) during January (A) 1989, (B) 1990 and (C) 1991. Note additional offshore stations sampled during CR 89-2 and CR 89-3. X indicates no data.

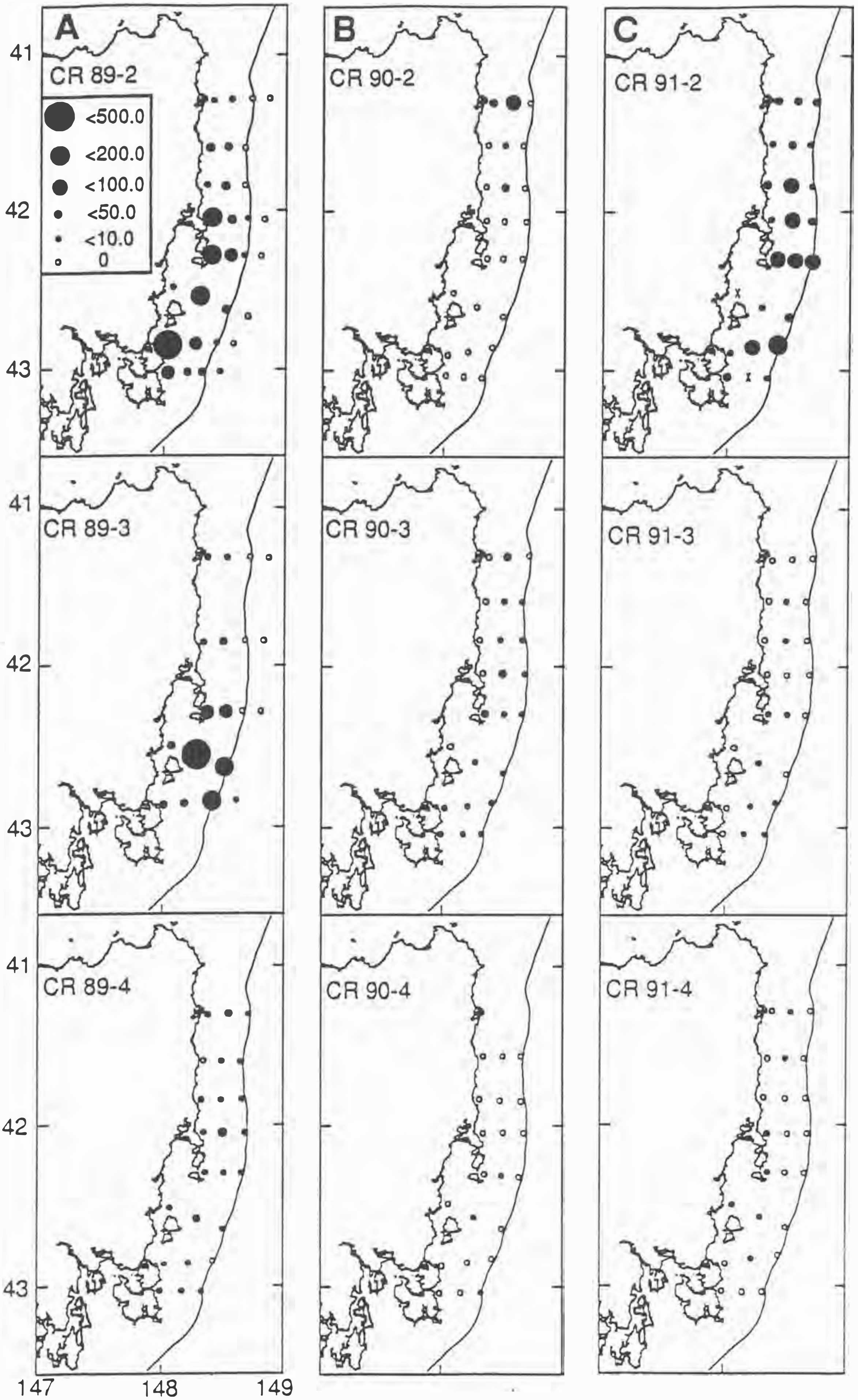


Figure 3. Expanding symbol plot of Trachurus declivis larval concentrations (no. 100 m^{-3}) during January (A) 1989, (B) 1990 and (C) 1991. Note additional offshore stations sampled during CR 89-2 and CR 89-3. X indicates no data.

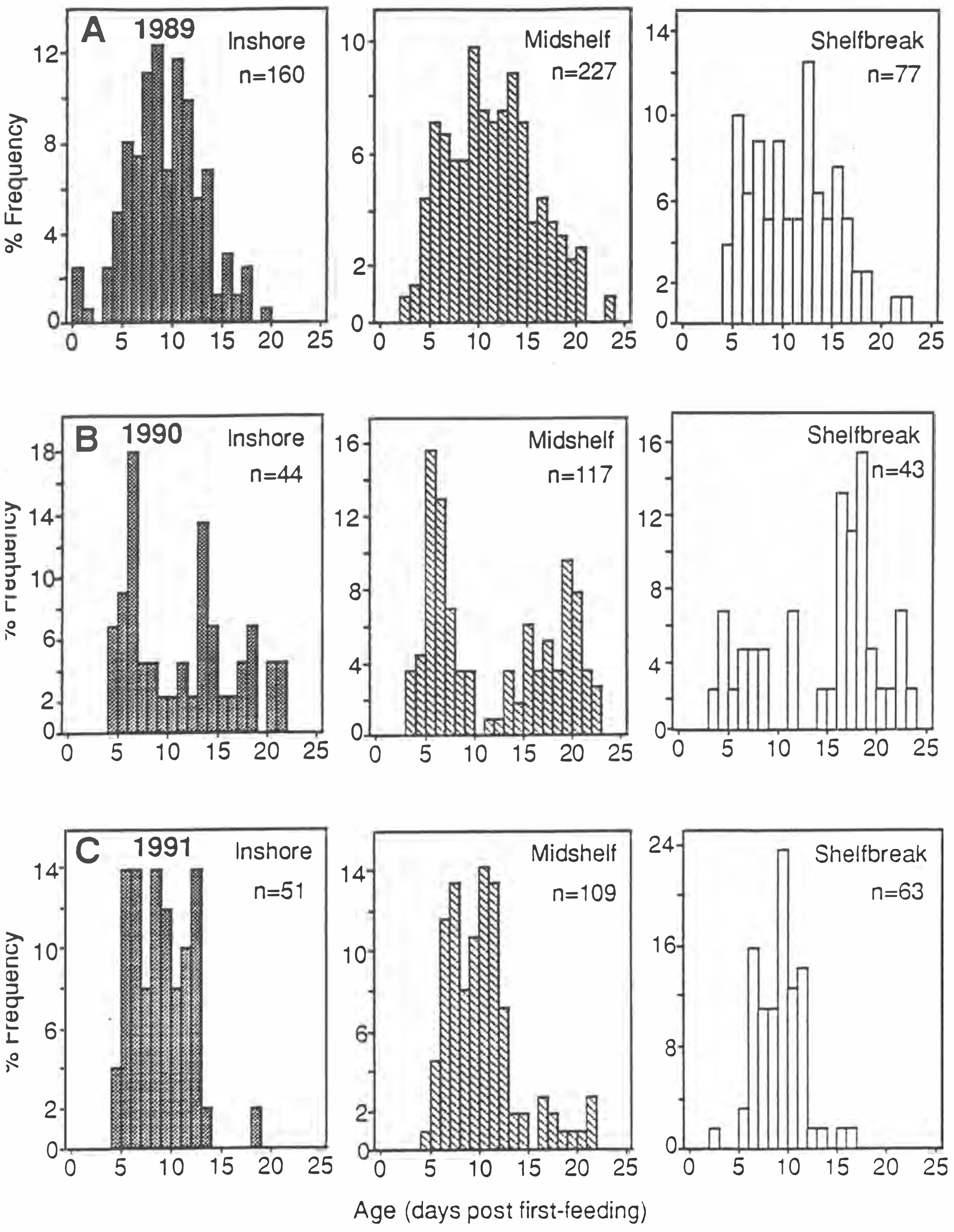


Figure 4. Age frequency distributions by area of larvae collected during (A) 1989, (B) 1990 and (C) 1991.

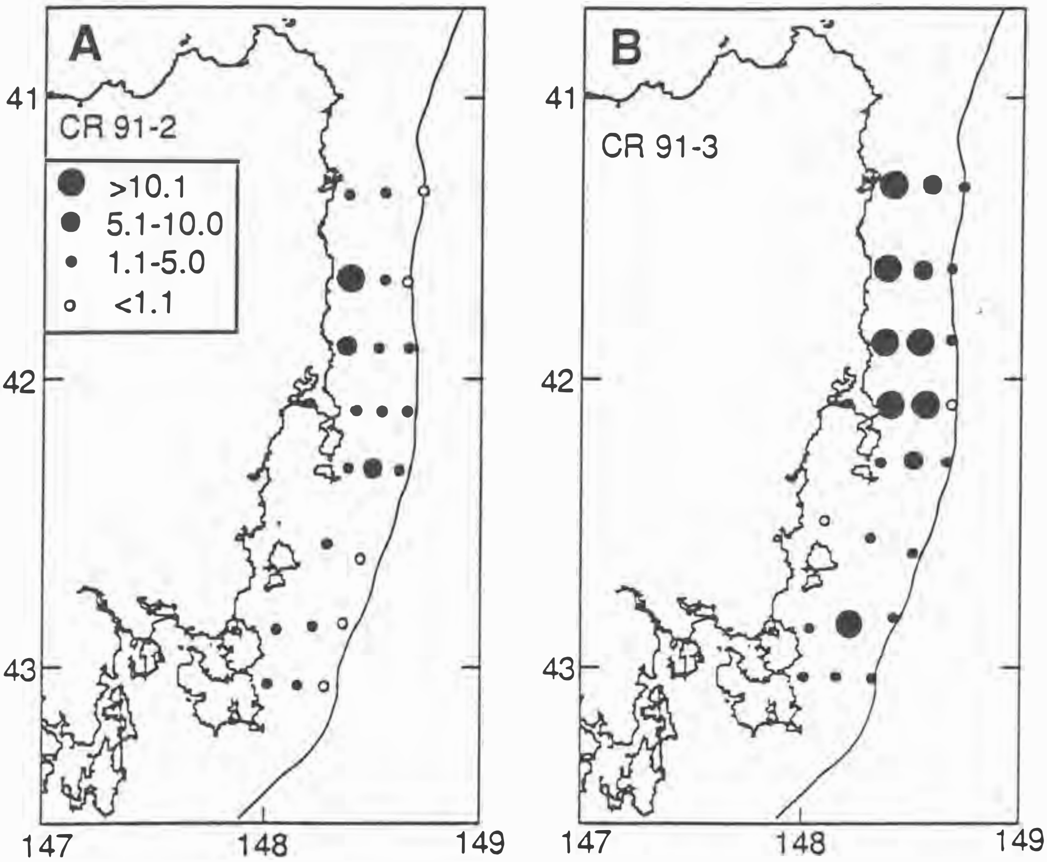


Figure 5. Expanding symbol plot of microzooplankton concentrations (mg. 100 m^{-3}) during (A) early January (CR 91-2) and (B) late January (CR 91-3) 1991. + represents no data.

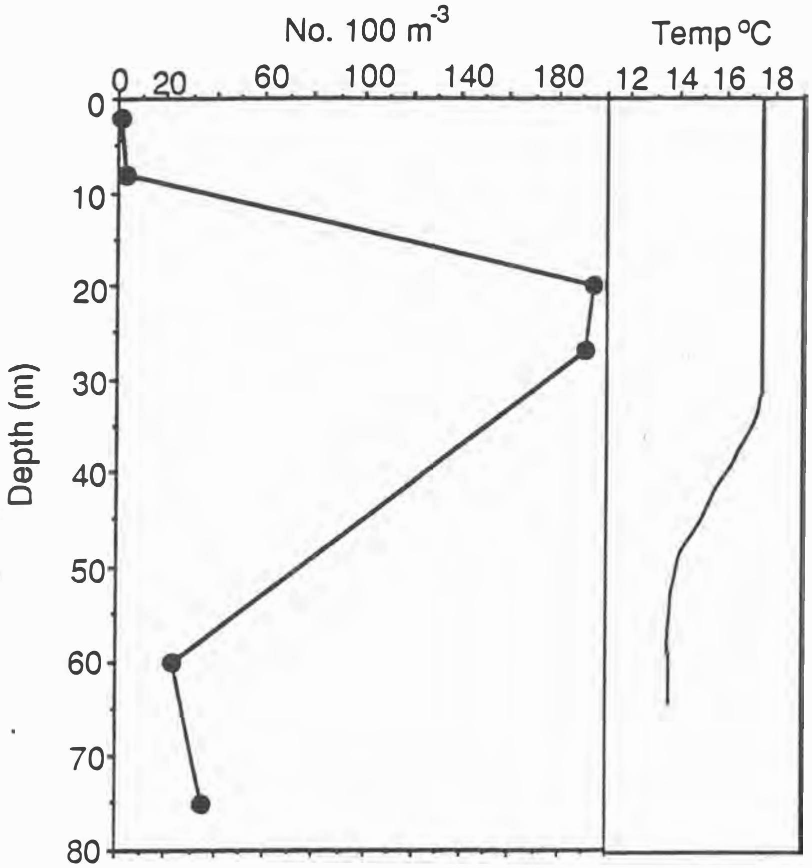


Figure 6. Vertical distribution of Trachurus declivis larvae and vertical temperature profile during late January 1989 (CR 89-3) at the midshelf station on transect 7

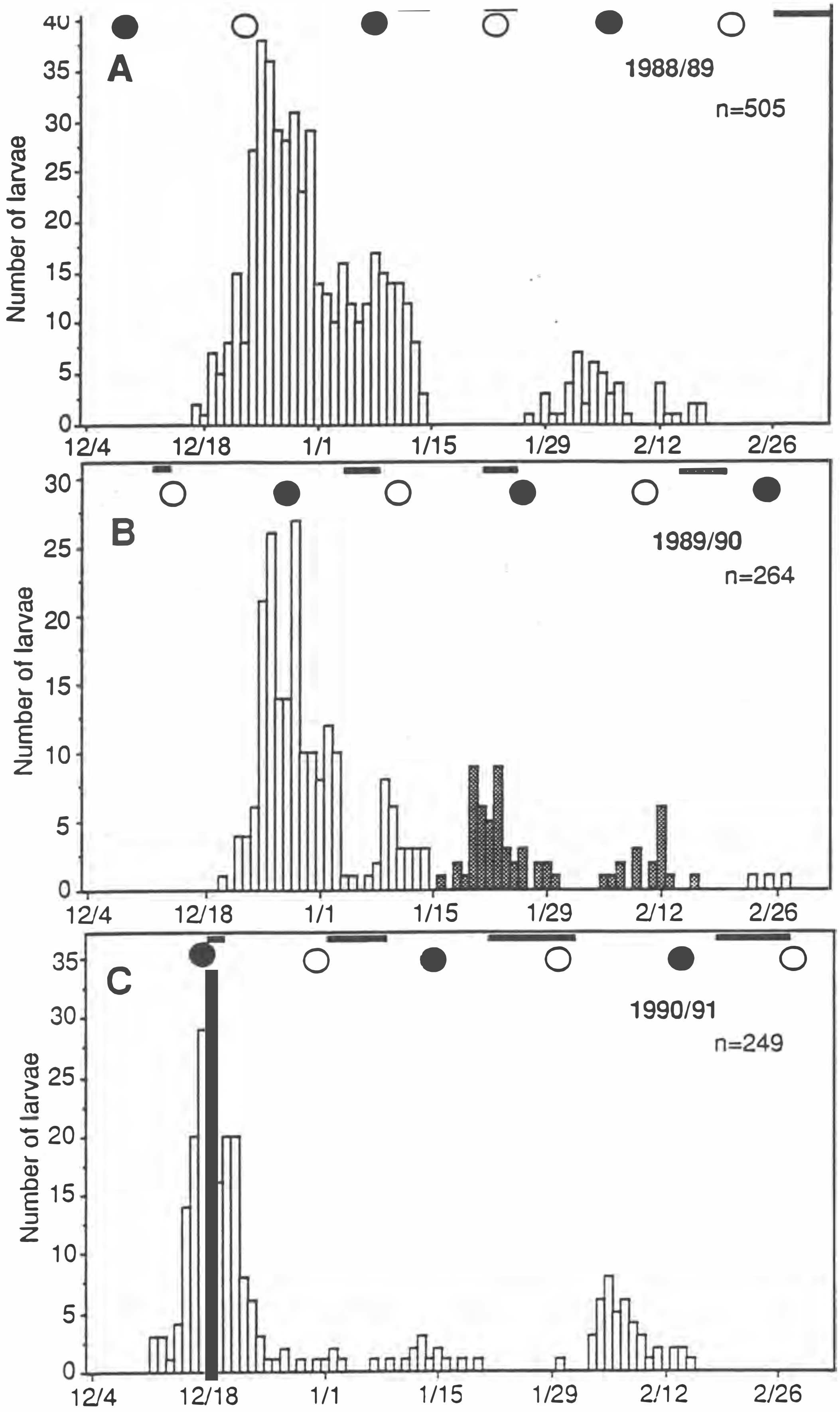


Figure 7. Spawning dates for Trachurus declivis larvae collected during (A) 1988/89, (B) 1989/90 and (C) 1990/91. Dates based on back-calculation from date of capture minus apparent age of larvae and a 8 day interval between spawning and the formation of the first daily growth increment. Open circles represent dates of full moon, closed circles that of new moons.

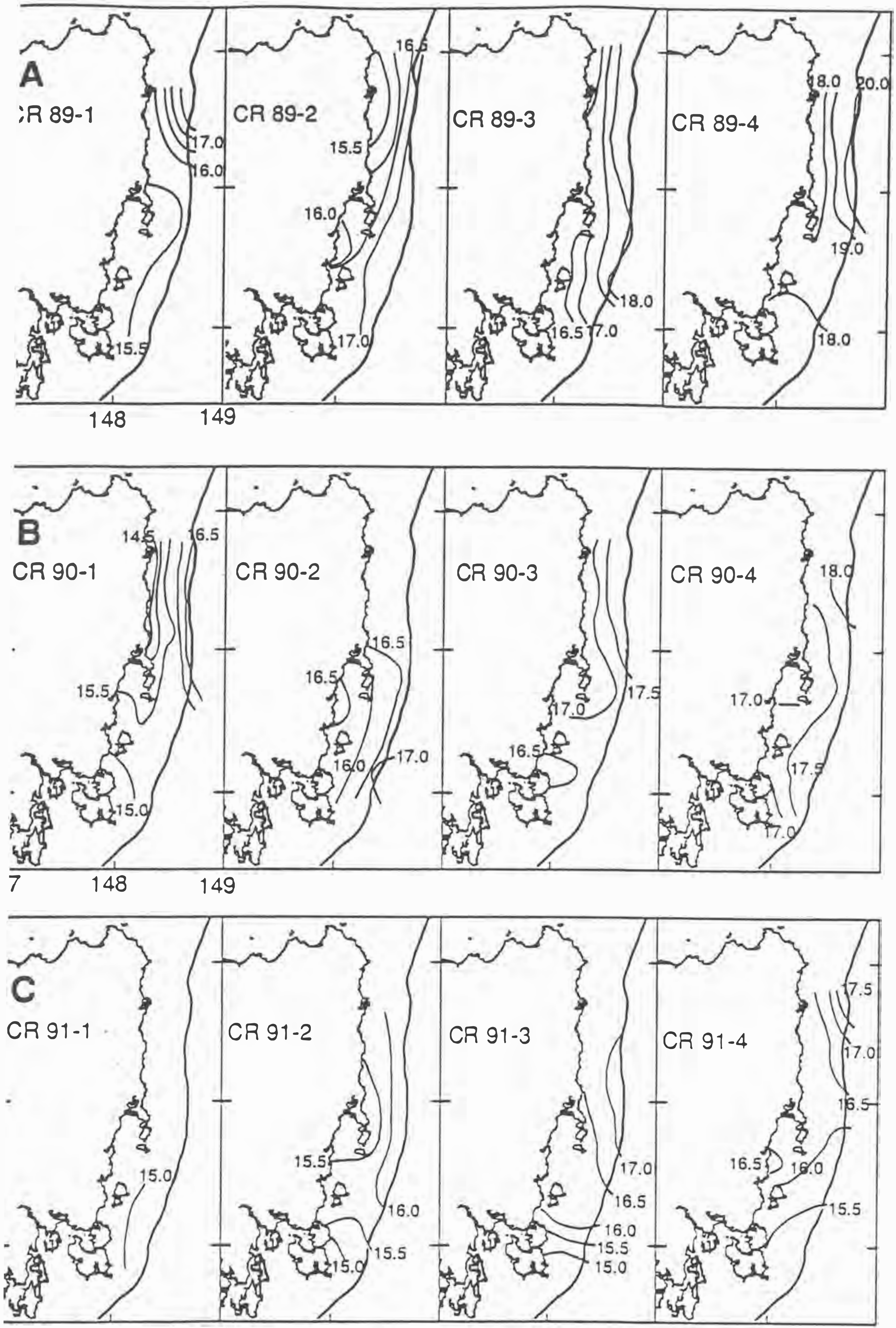


Figure 8. Distribution of sea surface temperature (^{o}C) along the east coast of Tasmania during (A) 1988/89, (B) 1989/90 and (C) 1990/91

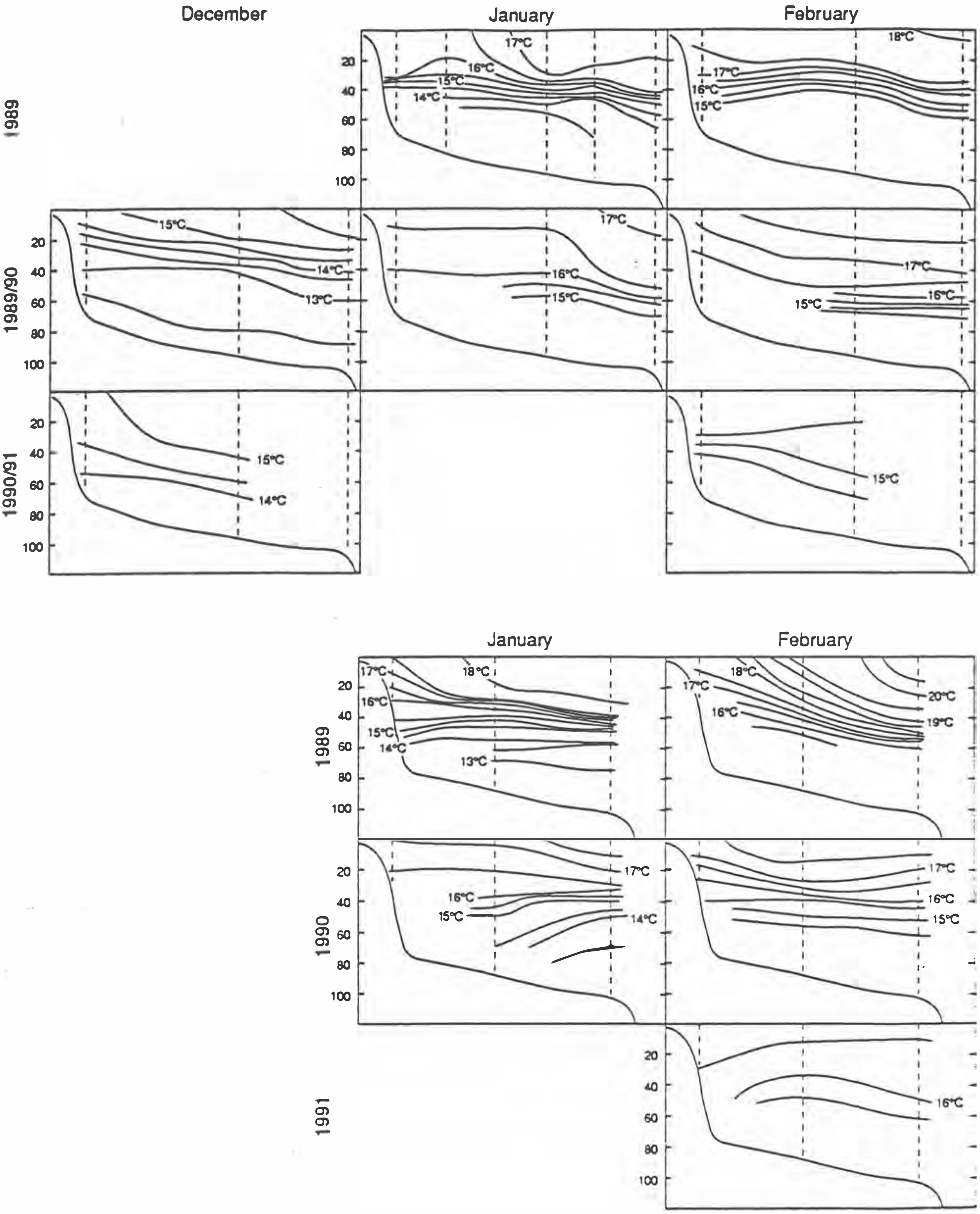


Figure 9. Vertical sections of temperature (°C) across (A) transect 3 and (B) transect 7 during the summers of 1988/89, 1989/90 and 1990/91

DOCUMENT 4

Interannual variability in the oceanography of the east coast of Tasmania and its effect on jack mackerel, *Trachurus declivis*, larvae

PROCEEDINGS OF THE AUSTRALIAN SOCIETY FOR FISH BIOLOGY, LARVAL BIOLOGY WORKSHOP

Interannual variability in the oceanography of the east coast of Tasmania and its effects on jack mackerel (*Trachurus declivis*) larvae.

A. Jordan

Sea Fisheries Research Laboratories, Department of Primary Industry, Fisheries and Energy,
Crayfish Point, Taroona, Tas, 7053.

troduction

hile the actual mechanisms responsible for El Niño events around the world are not completely derstood and may vary with latitude and between events, the oceanographic conditions that cur during such events are well documented. It is clear that El Niño events result in warm sea rface temperatures, deepening of the thermocline and changes in wind driven Ekman transport lucing coastal upwelling (Mysak 1986).

ıring the summer of 1988/89 the east coast of Tasmania experienced a period of ocean riability, known as a La Niña, that has been linked to the large scale ocean/atmosphere coupling the southern hemisphere associated with a El Niño/Southern Oscillation (ENSO) event (Harris *al.* 1991). The regional oceanography of this area is determined firstly by the local westerly nd stress and secondly by the large scale oceanographic circulation dominated by the warm, trient poor East Australian Current (EAC) and cool, nutrient rich water of subantarctic origin. ıring summer the shelf on the east coast is episodically flooded with EAC water, while westerly nds occasionally moves subantarctic water up onto the east coast (Harris *et al.* 1987). The undary that separates these two water masses is defined as the subtropical convergence, the sition of which shows significant interannual variability (Harris *et al.* 1987).

e summer of 1989 saw an increase in subtropical influence resulting from a reduction in the sterly wind stress and increasing influence of EAC water from the north. This situation led to a ıge of physical processes on the shelf break, such as warm sea surface temperatures (Figure 1a) d strong thermal stratification (Figure 2a). Whilst no data are available, it is likely that the luced westerly wind stress decreased Ekman transport, and increased influence of the EAC on shelf affected cross shelf mixing. The past two years have seen a much greater influence of oantarctic waters with resultant cooler sea surface temperatures (Figure 1b,c) and less atification (Figure 2b). However, given the dynamic nature of mesoscale eddies and fronts on east coast intrusions of warm EAC water have episodically occurred.

Harris *et al* (1991) provided a detailed analysis of the effects of the 1988/89 La Niña event on the water column stratification, nutrient cycling and production and structure of the food chain in south east Tasmanian waters. They detailed a general decline in nutrient conditions of the shelf waters up to the summer of 1988/89 with an associated shift in community structure. There was a reduction in algal biomass, and almost total elimination of large zooplankters (principally the euphausiid *Nyctiphanes australis* and salps *Thalia democratica* and *Salpa maxima*) from shelf waters. These conditions led to populations of small copepods dominating, which are less affected by levels of production as they can switch from herbivory to omnivory (Cushing 1989). This appreciable compositional change in the zooplankton community in oligotrophic conditions is similar to that found in the California current region (Smith 1985) and indicates a differential response to ENSO events by different members of the pelagic food web.

The variability in both physical and biological processes experienced in these waters during the La Niña year of 1988/89 and subsequent 'normal' years are likely to impact on the spawning behaviour and survival of eggs and larvae in these waters. Physical processes likely to have an impact including changes in temperature, horizontal advection, vertical stability and turbulence. While data on physical processes are sparse for the shelf region of the east coast, the presence in summer of EAC eddies, shelf fronts and wind driven transport and turbulence makes this area highly variable. Biotic factors which are important include changes in the abundance and distribution of predator and prey communities, and the amount of food available for energy storage and mobilization for reproduction.

The larval sampling program conducted on the east coast of Tasmania between January and April 1989-91 has provided an opportunity to assess the impact of the oceanographic variability on the spawning and early life history stages of jack mackerel (*Trachurus declivis*). The purpose of this paper is to discuss the potential impact of this variability on both spawning adults, eggs and larvae, and what factors may have influenced interannual variability in egg and larval abundances. The range of possible effects on jack mackerel spawning, and eggs and larvae resulting from such variability is summarised in Table 1.

fects on Spawning Population

awning time and distribution

alysis of three years of jack mackerel egg and larval distributions, and backcalculated spawning tes from otolith ageing suggests that neither the spawning area, time or duration for jack ckerel on the east coast of Tasmania were affected by the La Niña event on 1989. Spawning in three years began in late December and continued till late February with the bulk of spawning curring in January in all years. Spawning was continuous throughout the sampling area with ghest egg densities at shelfbreak stations, and no evidence of a major concentration and shift in awning area. The data suggests that the response of adult jack mackerel to the La Niña event s to move from the shelf waters onto the shelfbreak/slope area, their normal site of spawning.

veral workers have identified a shift in spawning time in response to interannual differences in ter temperature. Gunn *et al* (1989) estimated that spawning of blue grenadier on the west coast Tasmania differed between years by a month and suggested that such changes resulted from erannual differences in water temperature. Spawning distribution however was unaffected. are and Lambert (1985) also related timing of peak spawning of Atlantic mackerel to changes in ter temperature which they concluded is a regulator of spawning activity and oogenesis.

her species may respond to warm water conditions by changing their spawning distribution. ch changes during El Niño years are well documented for a number of pelagic species. awning distributions of several species shifted polewards during such years , including chovy in the Bengeula current region (Le Clus 1990), and anchovetta (Walsh *et al.* 1980) and rdines (Mc Call 1979) off South America. There is also some evidence that some South nerican clupeiod populations migrate into deeper water during strong El Niño events (Arntz 86). It is also possible that changes in spawning time and location is an adaptive response to awn in an area and time which makes best use of the seasonal and spatial patterns of ocean bility to provide suitable feeding conditions and favourable transport (Lasker 1981, Shelton and tchings 1989). The fact that jack mackerel spawning time, area and duration was consistent in all three years suggests that this may be an adaptive response to spawning in an area with high physical and biological variability.

Energy available for reproduction

The influence of an El Niño event on gonad condition and egg production has been documented for several species with the most immediate effect being a decline in reproductive output (De Martini 1991, Hay and Brett 1988, Lenarz and Echeverria 1986). Experimental and observational studies have demonstrated that naturally occurring food limitations may result in fluctuations in fecundity (Hay and Brett 1988, Hunter and Leong 1981). Variability in egg production may result from decreased batch fecundity in serial spawners (De Martini 1991), changes in mean egg weight (Tanasichuk and Ware 1987), or changes in the duration of the spawning season (Hunter *et al.* 1985). The link between food abundance and reproduction however depends on the dynamics of the prey communities and the spatial and temporal pattern of fat storage and mobilization for spawning.

As previously mentioned, El Niño events almost always result in decline in zooplankton production (Mc Gowan 1985). The situation is no different on the east coast of Tasmania, with the largest decrease occurring in the larger sections of the plankton (Harris *et al.* 1991). The principal food source of jack mackerel late in summer and autumn in the krill species *Nyctiphanes australis* (Webb 1976) resulting in fat reserves up to 12% by April. In the summer of 1989 *N. australis* disappeared from south east Tasmanian waters (Harris *et al.* 1991) and a subsequent decrease in fat reserves was evident during this year. The bulk of spawning the following year is known to occur before the peak in feeding so it is likely that the most of the energy available for reproduction is controlled by the amount of fat stored in the previous summer, as suggested by Hunter and Leong (1981) for *Engraulis mordax*. This may have a direct impact on batch fecundities through a process of folicular atresia (Hay and Brett 1988), and could result in a decrease in egg production in the summer of 1990.

'fects on Eggs and Larvae

ɔundance and distribution of prey

ıe change in the structure of the zooplankton community in the summer of 1989 identified by ırris *et al.* (1991) in southeast Tasmanian waters clearly affected the abundance of prey available jack mackerel larvae. Distribution of prey may also have been affected due to the strong ·atification throughout the spawning season. Young and Davis (in press) analysed the diet of :k mackerel larvae from this year and identified that although there was a shift in prey taxa tween years, with the exclusion of calyptopid stage *N. australis* in the guts in 1989 mirroring ɜir absence in the plankton, there was no evidence of food limitation during this year.

ɔundance and distribution of predators

edation on fish eggs and larvae appears to be a major source of mortality (Hunter 1981), hough its dominance appears to change through different early life history stages (Hewitt *et al.* 85). Hunter (1981) lists crustaceans, chaetognaths, medusea, ctenophores and planktivorous h as known predators of fish eggs and larvae. Whilst we have no data on the likely predators or ɜdation rates of jack mackerel eggs and larvae, the large compositional change in the plankton ring the La Niña year of 1989 suggests that the level of predation may have been significantly duced.

ɔrizontal advection

veral studies have suggested that interannual differences in advection of eggs and larvae can sult in significant mortalities and subsequent recruitment variability (Bailey 1981, Nelson *et al.* 77). In several species this advection is responsible for cross shelf transport of eggs and larvae inshore nursery areas (Cowan and Shaw 1988, Parish *et al.* 1981) with offshore advective sses controlled by the local hydrographic conditions. The shelf waters of the east coast of smania show significant interannual variability in local hydrography dominated in summer and tumn by the interaction of EAC eddies, shelf fronts and subantarctic water masses (Harris *et al.*

1987). The Maria Island area, the area of highest egg and larval densities in 1989, was defined by Harris *et al.* (1987) as a region of large scale advective processes with episodic effects of mesoscale physical processes superimposed.

Obviously trying to interpret patterns of advection of eggs and larvae in such a dynamic area is a difficult task, with current reversals possible on the shelf over a few days (Pearce 1981). With the reduction in the wind stress and increased influence of EAC water in the La Niña year of 1989 patterns of shelf advection would have been affected. There is clearly some mechanism of onshore advection of eggs and larvae from spawning sites on the shelf break/slope region to inshore waters. It is also clear that such interannual variability in shelf transport may be an important source of mortality for jack mackerel eggs and larvae. While we are presently analysing the age distribution of larvae sampled on cross shelf transects to investigate possible patterns of larval advection, assessing possible offshore advective losses is impossible due to the lack of offshore stations and suitable physical data.

Vertical stability

The hypothesis that ocean stability influences food aggregations for larvae and hence larval survival (Lasker 1981) has been supported by a number of workers (Peterman and Bradford 1987, Walsh et al 1980). The reduction in the westerly wind stress during the summer of 1989 resulted in greater vertical stability during the spawning period (Figure 2a), compared to 1990 (Figure 2b). It is possible that the stability experienced in 1989 resulted in lower larval mortality rates than during the windier and less stable summer of 1990. The lack of data on the vertical distribution of microzooplankton in these years precludes any assessment of its importance in interannual differences in larval survival.

Interannual differences in egg and larval densities

While it is difficult to assess the impact of interannual variability in the range of physical and biological processes outlined on spawning and egg and larval survival, it is clear from the data that there were large interannual differences in egg and larval densities. Jack mackerel pre-flexion nsities were down from 53.8/100m-3 in 1989 to 2.8/100m-3 in 1990 (Table 2a). This relates to pre-flexion larval density in 1990 only 5.2 % of that in 1989. Jack mackerel egg densities owed a similar decrease between years, with densities in 1990 only 8.6% of that in 1989 (Table). While the egg and larval densities are not directly comparable due to estimates of each stage sulting from different cohorts, the magnitude of the decrease in densities is similar for both ges. This suggests that the interannual variability in larval densities did not result from fferences in larval mortality but resulted from either differences in egg mortality (due to edation, anomolous transport, or both) or differences in the level of egg production. Given the crease in densities seen in all larval taxons between years (Table 2b), the processes driving erannual variability in larval production must of affected a wide range of spawning taxons.

hile it is possible that the variability in jack mackerel egg and larval abundances may result in riable year class strength, understanding what processes are driving this variability will viously involve a greater understanding of the physical oceanography of the area as well as ncurrently measuring survivorship and recruitment, together with population fecundity and ndition.

References

Arntz, W.E. (1986). The two faces of El Niño 1982-83. *Meeresforschung*. **31**(1), 1-46.

Bailey, K.M. (1981). Larval transport and recruitment of Pacific hake, *Merluccius productus*. *Mar. Ecol. Prog. Ser.* **6**, 1-9.

Cowan, J.H., and R.F.Shaw. (1988). The distribution, abundance, and transport of larval sciaenids collected during the winter and early spring from the continental shelf waters off West Louisiana. *Fish Bull. U.S.* **86**, 129-141.

Cushing, D.H. (1989). A difference in structure between ecosystems in strongly stratified waters and those that are only weakly stratified. *J. Plankton Res.* **11**, 1-13.

DeMartini, E.E. (1991). Annual variations in fecundity, egg size, and the gonadal and somatic conditions of the Queenfish *Seriphus politus* (Sciaenidae). *Fish. Bull. U.S.* **89**, 9-18.

Gunn, J.S., B.D, Bruce. D.M. Furlani., R.E. Thresher and S.J.M. Blaber. (1989). Timing and location of spawning of Blue Grenadier, *Macruronus novaezelandiae* (Teleostei : Merlucciidae), in Australian coastal waters. *Aust. J. Mar. Freshwater Res.*, **40**, 97-112.

Harris, G.P., C. Nilsson., L.A. Clementson and D. Thomas. (1987). The water masses of the east coast of Tasmania: seasonal and interannual variability and the influence on phytoplankton biomass and productivity. *Aust. J. Mar. Freshwater. Res.* **38**, 569-90.

Harris, G.P., F.B. Griffiths., L.A. Clementson., V. Lyne and H. Van der Doe. (1991). Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters*J. Plankton. Res.* **13**,109-131

Hay, D.E., and J.R. Brett. (1988). Maturation and fecundity of Pacific herring (*Clupea harengus pallasii*): An experimental study with comparisons to natural populations. *Can. J. Fish. Aquat. Sci.* **45**, 399-406.

witt, R.P., G.H. Theilacker and N.C.H. Lo. (1985). Causes of mortality in young jack mackerel. *Mar. Ecol. Prog. Ser.* **26**, 1-10.

nter, J.R.(1981). Feeding ecology and predation of marine fish larvae. *In* Lasker, R. (ed.), Marine fish larvae, p. 33-79. Wash. Sea Grant Prog., Univ.Wash,Seattle.

nter, J.R., and R. Leong. (1981). The spawning energetics of female northernanchovy, *Engraulis mordax. Fish. Bull. U.S.* **79**, 215-230.

nter, J.R., N.C.H. Lo., and R.J.H. Leong. (1985). Batch fecundity in multiple spawning fishes. In Lasker, R. (ed.), An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy, *Engraulis mordax.* NOAA Tech Rep. NMFS 36, 67-77.

sker, R. (1981). The role of a stable ocean in larval fish survival and subsequent recruitment. *In* Lasker, R. (ed.), Marine fish larvae, p. 80-87. Wash. Sea Grant Prog., Univ. Wash., Seattle.

Clus, F. (1990). Impact and implications of large-scale environmental anomalies on the spatial distribution of spawning of the Namibian pichard and anchovy populations. *S. Afr. J. Mar. Sci.* **9**, 141-159.

narz, W.H., and T.W. Echeverria. (1986). Comparison of visceral fat and gonad fat volumes of yellowtail rockfish, Sebastes flavidus, during a normal year and a year of El Niño conditions *Fish. Bull. U.S.* **84**, 743-745.

cCall, A.D. (1979). Population estimates for the waning years of the Pacific sardine fishery. *CalCOFI Reps.* **20**, 72-82.

cGowan, J.A. (1985). El Niño 1983 in the Southern Californian Bight. *In* Wooster, W.S., and D.S. Flurharty (eds.), El Niño north: Niño effects in the eastern subarctic Pacific Ocean, p. 166-187. Wash Sea Grant Prog., Univ. Wash., Seattle.

Mysak, L.A. (1986). El Niño, interannual variability and fisheries in the north east Pacific Ocean. *Can. J. Fish. Aquat. Sci.* **43**, 464-497.

Nelson, W.R., M.C. Ingham and W.E. Schaaf. (1977). Larval transport and year-class strength of Atlantic menhaden, *Brevoortia tyrannus*. *Fish Bull.U.S.* **75**, 23-41.

Parrish, R.H., C.S. Nelson, and A. Bakun. (1981). Transport mechanisms and reproductive success of fishes in the California Current. *Biol Oceanogr.* **1**(2), 175-203

Pearce, A. (1981). A brief introduction to descriptive physical oceanography. CSIRO Div. Fish. Oceanogr. Rep 132. 51pp.

Peterman, R.M. and M.J. Bradford. (1987). Wind speed and mortality rate of a marine fish, the northern anchovy (*Engraulis mordax*). *Science* (Wash., DC) **235**,354-356.

Shelton, P.A., and L. Hutchings. (1989). Ocean stability and anchovy spawning in the southern Benguela Current region. *Fish. Bull. U.S.* **88**, 323-338.

Smith, P.E. (1985). A case history of an anti-El Niño to El Niño transition on plankton and nekton distribution and abundances. *In* Wooster, W.S., and D.S. Flurharty (eds.), El Niño north: Niño effects in the eastern subarctic Pacific Ocean, p. 166-187. Wash Sea Grant Prog., Univ. Wash., Seattle.

Tanasichuk, R.W., and D.M. Ware. (1987). Influence of interannual variations in winter sea temperature on fecundity and egg size in Pacific herring (*Clupea harengus pallasi*). *Can. J. Fish. Aquat. Sci.* **44**, 1485-1495.

Ware, D.M., and T.C. Lambert. (1985). Early life history of Atlantic mackerel (*Scomber scombrus*) in the Southern Gulf of St. Lawrence. *Can. J. Fish. Aquat. Sci* **42**, 577-590.

Webb, B.F. (1976). Aspects of the biology of the jack mackerel *Trachurus declivis* (Jenyns) from southeast Australian waters. *Tasmanian Fish.Res.* **10**, 1-14.

alsh, J.J., T.E. Whitledge, W.E. Esaias, R.L. Smith, S.A. Huntsman, H. Santander, and B.R. de Mendiola. (1980). The spawning habitat of the Peruvian anchovy, *Engraulis ringens*. *Deep-Sea Res.* **27**A, 1-27.

oung, J.W., and T.L.O. Davis. (In press) Feeding ecology, and interannual variations in diet of larval jack mackerel, *Trachurus declivis* (Pisces: Carangidae) from coastal waters of eastern Tasmania. *Mar Biol.*.

Table 1.Summary of effects on jack mackerel spawning, and eggs and larvae resulting from physical and biological variability experienced during the La Niña conditions of 1989.

Variable	**Effect**
Effects on adults	
Spawning time/duration	xx
Spawning area	xx
Condition factor/fat	+
Fecundity	?
Effects on eggs/larvae	
Prey abundance/distribution	xx
Predator abundance/distribution	?
Horizontal advection	?
Vertical stability	?

xx - no effect
+ - effect
? - unknown

ble 2. Comparison of 1989 and 1990 mean densities (no.100m-3). (a) Jack mackerel egg and
val stages. (b) All other larval taxons.

	Years	
	1989	1990
. Jack mackerel		
eggs	18.6	1.6
pre - flexion	53.8	2.8
flexion	2.7	0.5
post-flexion	0.5	0.3
. Larval Taxons		
orpaeniformes	5.6	0.5
euronectiformes	1.4	0.1
diformes	0.3	0.0
traodontiformes	1.5	0.3
rciformes	1.1	0.1
upeiformes	0.2	0.1
identified	1.1	1.7

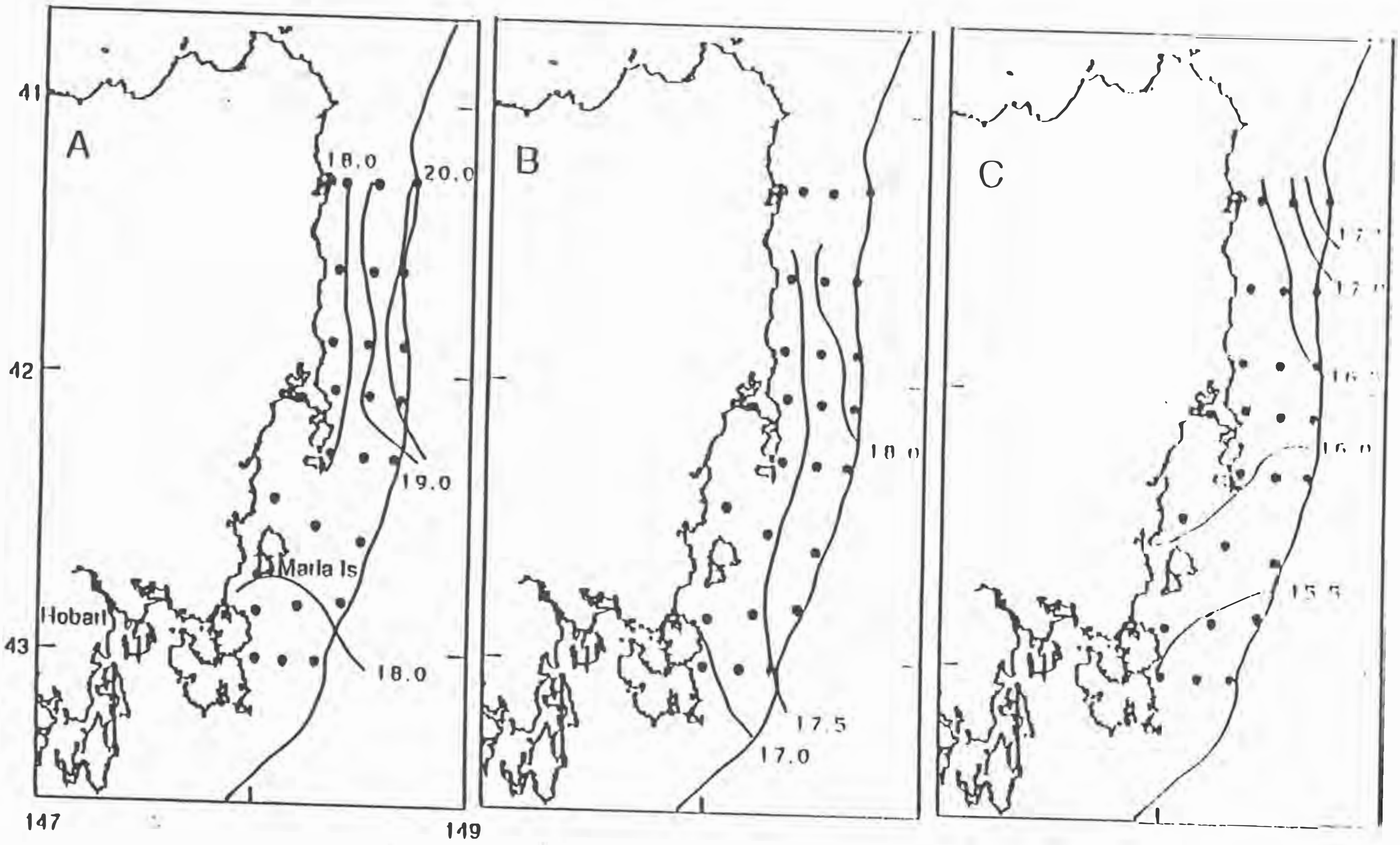


Figure 1. Plots of sea surface temperature for the east coast of Tasmania during February 1989-91 based on data taken during research cruises. • indicates sampling stations. A. February 26-28th, 1989. B. February 18-20th 1990

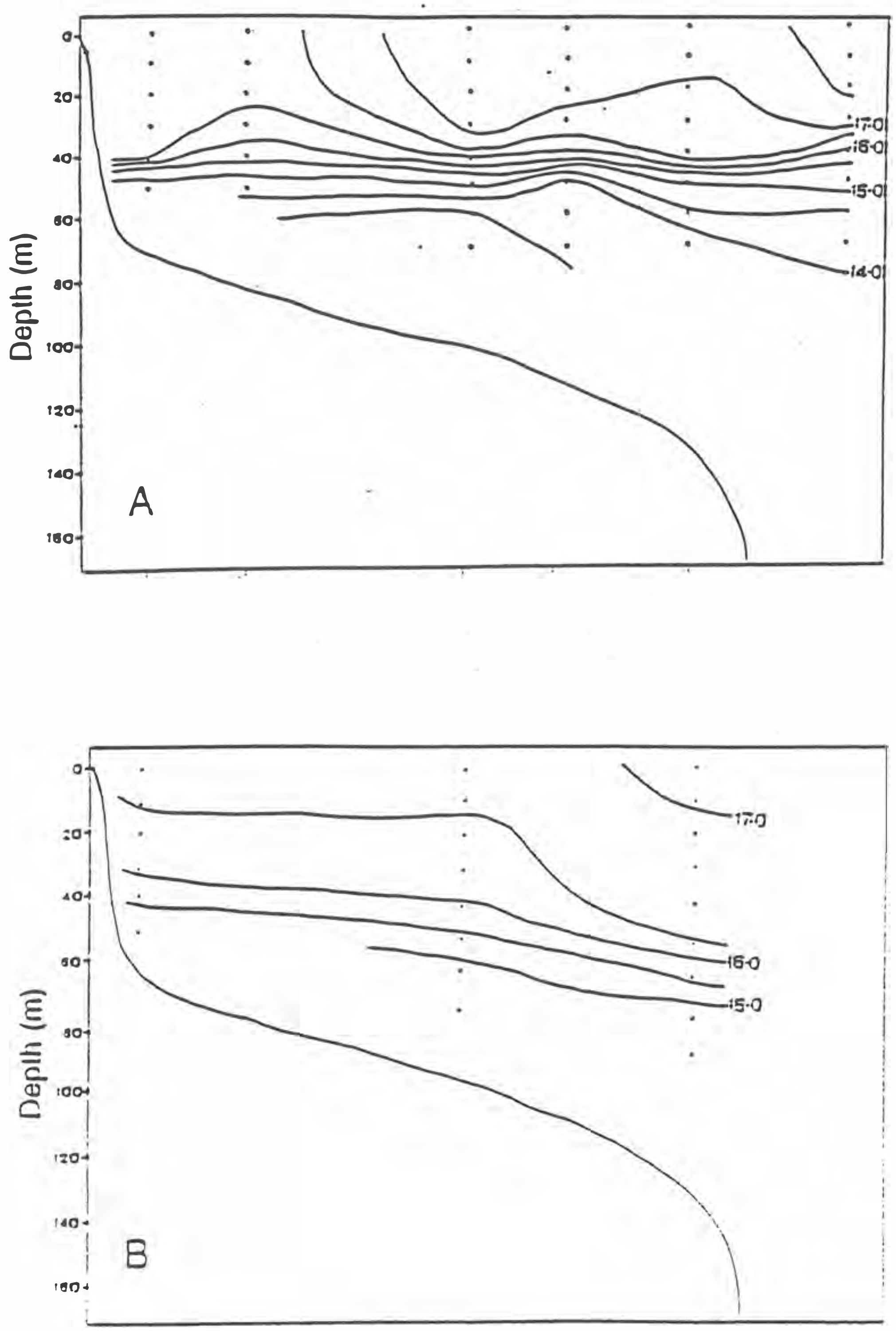


Figure 2. Profiles of water temperature across the shelf break on transect due south of Maria Island (see Fig. 1). A. Profile taken 24th Jan 1989. B. Profile taken 23rd Jan 1990.

DOCUMENT 5

Seasonal and interannual variability in krill (*Nyctiphanes australis*) stocks and their relationship to the jack mackerel (*Trachurus declivis*) fishery off eastern Tasmania

SUBMITTED TO MARINE BIOLOGY

Seasonal and interannual variability in krill (Nyctiphanes australis) stocks and their relationship to the jack mackerel (Trachurus declivis) fishery off eastern Tasmania, Australia.

J. W. Young[1], A. R. Jordan [2], C. Bobbi [1,3], R. E. Johannes[1], K. Haskard[1] and G. Pullen[2]

1. CSIRO Marine Laboratories GPO Box 1538, Hobart, Tasmania, 7001, Australia.

2. Sea Fisheries Research Laboratories, Department of Primary Industry, Fisheries and Energy, Crayfish Point, Taroona, Tasmania, 7053, Australia.

3. present address: Inland Fisheries Commision 127 Davey St. Hobart, Tasmania, 7001, Australia

Abstract

Krill (*Nyctiphanes australis*) were collected from the east coast of Tasmania between October 1989 nd April 1991. Krill biomass was significantly higher in autumn than at other times. The size tructure of the population was dominated by juveniles except in autumn and spring 1990 when here was a significant increase in the proportion of adult size classes. Our data on vertical distribution were inconclusive, but indicated that this species does not migrate vertically on a egular basis. Instead it appears to form aggregations of particular size classes which vary both emporally and spatially. Gut fullness of jack mackerel (*Trachurus declivis*), a major predator of *N. australis*, increased to a maximum in autumn when *N. australis* stocks were at their highest, and corresponded with the highest monthly catches by the fishery. Their stomachs were also dominated by adult size classes during this period. The virtual absence of *N. australis* in 1989 and the ubsequent failure of the jack mackerel fishery in that year underline the intimate relationship between these two species. We suggest that the absence of *N. australis* resulted from an influx of ubtropical northern waters low in nutrients, corresponding with a major La Niña event at that ime.

Introduction

Seasonal and interannual variations in the movements of water masses can have profound effects on the structure of marine communities (Cushing 1982). Decreased productivity and subsequent changes in the structure of the zooplankton community appears to be a common response to the intrusion of warm water into cooler regions and decrease in wind mixing, particularly during El Niño years (McGowan 1985, Fulton and LeBrasseur 1985, Sambrotto 1985, Smith 1985).

Off eastern Tasmania seasonal and interannual levels of productivity are determined by the interaction of warm, nutrient poor East Australian Current (EAC) water and cool nutrient rich subantarctic water (Harris et al. 1987, 1991). During the summer of 1988/89 the shelf waters of south east Tasmania experienced an increased influence of subtropical waters and an associated decrease in production, apparently associated with the large El Niño / Southern Oscillation (ENSO), or La Niña event of 1988 (Harris et al. 1991). Harris et al (1991) found that this event led to the loss of large zooplankters, particularly the euphausiid *Nyctiphanes australis*, from the system.

Nyctiphanes australis (krill) is a major component of the zooplankton community in coastal waters of south-eastern Tasmania (Blackburn 1980, Nyan Taw and Ritz 1979, Ritz and Hosie 1982). Ritz and Hosie (1982) found this species in high densities throughout the year in Storm Bay, although easonal differences were apparent. *Nyctiphanes australis* is the main prey of many coastal bird nd fish species in Tasmanian waters (O'Brien 1988), including the carangid *Trachurus declivis*, which feeds almost exclusively on *N. australis* in surface waters during summer and autumn Webb 1976). A rapidly developing purse seine fishery for *Trachurus declivis* has operated near Maria Island on the east coast of Tasmanian since 1985, with annual landings growing to 39,750 onnes by 1987 (Williams et al. 1987). The Tasmanian fishery is dependant upon surface schools f jack mackerel that are feeding on *N. australis* swarms. As a consequence, it is likely that hanges in N. australis abundance may have a direct effect on jack mackerel schooling behaviour nd the amount of fish available to the commercial fleet (Williams and Pullen in press).

his paper is the result of a collaborative study between CSIRO and the Tasmanian Department of ea Fisheries (DSF) and aims to (1) describe aspects of the biology of Nyctiphanes australis ollected from a site off Maria Island and (2) examine variability in the abundance and biomass of I. australis in relation to seasonal and interannual variations in the physical oceanography of astern Tasmania and the local jack mackerel (Trachurus declivis) fishery.

Iaterials and methods

Iyctiphanes australis was sampled on both fine (< km) and coarse scales (1 - 10 kms) in the icinity of Maria Island, eastern Tasmania between January 1989 and April 1991 (Fig. 1). Samples ere collected from a site off Reidle Bay, Maria Island at approximately monthly intervals from ctober 1989 to January 1991 to examine variations in the density and population structure of N. ustralis. To examine variability in N. australis abundance and biomass between years, sampling as also done at a coarse scale from a grid of stations inshore and on the continental shelf in the icinity of Maria Island at fortnightly to monthly intervals during the fishing season from January April in 1989, 1990 and 1991 (Fig. 1, Table 1, see also Young and Davis in press).

t Reidle Bay plankton was collected from replicate tows day and night along the 80 m depth ontour. Surface tows and oblique tows to ~40 m were made either simultaneous or onseculatively. Ring nets equivelant to one side of an Ocean Instruments 70 cm bongo net were sed. Nets were cylindrical-conical with a mesh apeture of 500 µm and an open area ratio of 5:1. A eneral Oceanics mechanical flowmeter, hung inside each net, was used to record the volume of ater sampled. All tows were made at ~3 knots from the CSIRO inshore research vessel R. V. cottsman and lasted ~10-20 mins. Maximum depth was measured using a divers depth gauge ith maximum depth indicator. For 11 tows where flowmeters were not used volume filtered was stimated from the regression of flowmeter count versus tow time (Flowcount = 3045 x towtime(mins) + 6477, $r^2 = 0.55$, n=123). Flowmeters were calibrated over a measured mile in the Derwent River. All nets were dyed blue to reduce net avoidance (Le Brasseur et al. 1967). Samples were preserved in buffered 5% seawater formalin. Temperature and salinity data from depths of 10 and 50 m were obtained from the monthly records of the CSIRO coastal monitoring station off Maria Island (42° 36'S, 148° 16'E) (Harris et al. 1987).

Coarse scale sampling consisted of single tows at each station from the DSF research vessel F. R. V. Challenger. All sampling was completed in daylight hours (06.00 to 20.00 h). Each sample consisted of an oblique tow to a maximum depth of 100 m, bottom depth permitting, at a tow speed of ~3 knots. At each station the net was sent to the required depth quickly, held there for 1-2 minutes and then retrieved on an oblique path. Bongo nets with mouth opening of 45 cm, 500 µm mesh netting and an open area ratio of 5:1 were used. Volume of water filtered was estimated as in the fine scale study. Temperature and depth were recorded with a temperature–depth probe attached below the net . Surface temperatures were recorded directly from the on board temperature recorder (± 0.01C°). Samples from one side of the bongo were fixed in 95% ethanol; the other in buffered 5% seawater formalin.

In the laboratory, samples of *Nyctiphanes australis* were split to a manageable size (mean 157 ± 19.7[95% CI] individuals per subsample) using a Folsom Splitter and the subsample counted. Each individual was measured from the tip of the rostrum to the end of the telson (Standard 1 of Mauchline 1980) and grouped into 4 size classes [≤ 5mm (I); 5.1 to 7.5 mm (II); 7.6 to 11mm (III); ≥11.1 mm (IV)]. These size classes corresponded approximately to calyptopis and furcilia stages (I), post-larvae (II), adolescents (III) and adults (IV) (Sheard 1953, Hosie 1982). Formalin–preserved specimens from each size class were measured, oven–dried at 60°C for ~4h and weighed (± 0.005 mg). There was no change in the relationship between length and weight of *N. australis* (ANCOVA, P >0.10).

Stomachs of jack mackerel (*Trachurus declivis*) were collected from January to June 1990 from the ommercial fishery which operates around Maria Island during this time (Williams and Pullen in ress). For each fish examined length to caudal fork (LCF, mm), wet weight and gut weight was ecorded. Gut contents were dominated by Nyctiphanes australis, although amphipods (Themisto uadichaudii), calanoids, crab zoea and fish larvae were also present, but as these taxa represented ess than 1% of the diet (C. Bobbi, unpubl. data) they were not considered further . Nyctiphanes ustralis from each stomach were suspended in water, split to a manageable size (see above) and ounted into their respective size groupings.

ata analysis

otal sample size was estimated using the formula: Count x 2^n, where n is the number of splits Omori and Ikeda 1984). Biomass (B) of N. australis in each sample was estimated from the quation:

$$B = \sum_{s=1}^{4} [P_s . N_t . W_s]$$

here Ps is the numerical proportion of a size class in the sample, N_t the total number in the ample, W_s is the mean dry weight of the size class (Table 2) and s is the number of size classes. he abundance of N. australis was calculated by dividing the estimated number caught by the olume of water filtered. Similarly, biomass was calculated by dividing total estimated biomass by he volume of water filtered.

omparisons of density (abundance and biomass) between seasons, depths (surface/oblique) and mes of day (day/night) were made on data from the fine scale study using multiway ANOVA. The istribution of density values of samples was skewed, therefore data were transformed to best pproximate the assumptions of normality and equal variance among the residuals (Zar, 1984). We xamined changes in the proportions of individual size classes between seasons using contingency bles with loglinear analysis (Dobson 1983), based on the assumption that the number of yctiphanes australis in each size class at a given station followed a multinomial distribution.

Stations were divided into season (spring 1989 to summer 1990/1991[n=6]), time of day (day or night), and depth (surface or oblique). Size classes III and IV were pooled to obtain sufficient numbers in this class. Initial analyses showed significantly greater variation than would be expected by random variability (e.g. for day oblique tows within a season, chisquare = 6894, df = 142, p < 0.0001). A close inspection of the data revealed that the extra variability was due to single samples (patches) being dominated by a particular size category. Therefore, the usual chisquare tests were replaced by F-tests, with the chisquare statistic allowing for the extra–multinomial variation in the denominator.

Interannual differences in *Nyctiphanes australis* biomass were compared using ANOVA on the coarse scale data. Selection for prey size was examined using Pearre's C index (Eqn. 3, p. 915 in Pearre 1982). Each size class of *N. australis* was treated as an individual taxon and its proportion in the environment was compared with that in the stomachs of individual predators.

Results

Physical oceanography

Fine scale. Surface temperatures increased from 12°C in winter to ~ 17°C in late summer and early autumn in 1990 (Fig. 2) due to seasonal warming and the intrusion of subtropical East Australia Current (EAC) water onto the shelf. Salinity increased over this period from 35.1 to 35.6 parts per thousand. The 17°C, 35.6 ppt signature is characteristic of EAC water (see Fig. 1 in Harris et al. 1987), which intruded onto the shelf in summer-autumn 1990 resulting in stratification at this time. The watercolumn was well mixed in late autumn to late spring 1990 and stratified in summer when a short pulse of high temperature, high salinity EAC water intruded onto the shelf (Fig. 2). The pulse however did not persist as it did in the summer of 1990.

Coarse scale. Sea surface temperatures for the summer and autumn of 1989, 1990 and 1991 reflected seasonal warming and the changing influence of warmer northerly and cooler southerly water on the region (Fig. 3). In general, 1989 may be characterised as the warmest year of the hree year study period, 1991 the coolest, and 1990 somewhat intermediate. It is worth noting, ıowever, that even during the 'coolest' year of 1991 temperatures > 17°C were recorded in parts of he study area.

n early January 1989 surface waters were between 16.0°C and 17.0°C. By late January warmer vater of northerly origin, previously identified as EAC water began to spill across the shelf lominating the area by late February. By April warm water still dominated the area although some :ooling was apparent. In early January 1990 most water in the study area was between 16.0°C and .6.5°C. By February warmer water from the north had moved into the area with temperatures ıround 17.5°C. The advance of cooler southerly waters in March resulted in the partial retreat of varm water.

[emperatures in summer of 1991 were consistently cooler than previous years reflecting the educed influence of warmer northerly water. By late February waters were as much as 3.2°C :ooler than for the same period in 1989. However March saw an advance of warmer water from he north, with temperatures varying by 1.8°C between the northerly and southerly transects. Rapid :ooling had taken place by April as cooler water pushed up from the south.

:onsiderable interannual variability in thermal stratification is apparent in the three years of the tudy (Fig. 4). The strong thermocline that existed in the summer (Jan-Feb) of 1989 weakened luring autumn, although a temperature gradient of ~ 3 °C was still present between surface and ıottom waters. In January 1990 the thermocline was both deep (~ 55m) and distinct. In the ollowing months the mixed layer had shallowed and the thermocline had become weaker. During ate summer and autumn in 1991 the water column was well mixed with no sign of thermal tratification . However, the March profile from the northern transect shows the presence of a trong thermocline resulting from the advance of a shallow layer of warm water from the north Fig. 4).

Seasonal changes in abundance and population structure

In the fine scale study a total of 159 tows were made, spread over six seasons between October 1989 and January 1991 (Table 1). Abundance in individual samples ranged from 0 to 358 individuals m^{-3} (Biomass 0 to 51 mg. m^{-3}). In general, *Nyctiphanes australis* abundance and biomass increased to a maximum in autumn 1990, declining through winter with a gradual increase in spring (Fig. 5). Abundance and biomass were compared between season, depth and time of day using multiway ANOVA. Empty cells in the first two seasons (sampling initially consisted of oblique tows during the day) meant that this analysis was eventually restricted to four seasons (autumn 1990 to summer 1991). Abundance values were transformed to Ln (abundance + 1) as this best stabilized the variance of the residuals. *Nyctiphanes australis* abundance differed significantly between seasons but not between time of day or depth. No significant interaction was found between season, depth and time of day (Table 3), indicating that seasonal effects were not significantly different at different depths or times of day. *Nyctiphanes australis* abundance was highest during autumn 1990. Biomass values were initially transformed to (Biomass + 1)$^{-1}$ as this gave the most even distribution of residuals versus fitted values. There was a significant difference in biomass between seasons but not with depth, time of day or their interactions (Table 4), which mirrored that found for the abundance data.

The size class structure of *Nyctiphanes australis* was dominated by stage I and II individuals throughout the study period indicating continuous reproduction (Fig. 6). However, pulses of stage II and IV *N. australis* were noted in late spring in 1989 and 1990 and also in autumn 1990 (Fig 5). Closer examination revealed that there was significant variation in the size distributions of *N. ustralis* between seasons (F = 5.85; df = 10, 300; p < 0.001), and between different depths and imes (F = 4.85; df = 6, 300; p < 0.001), but no interaction between season, depth or time of day F = 0.52; df = 24, 276; p > 0.05). Because of unequal replication and for ease of interpretation. ifferent depth and time combinations were analysed separately for season effects. For day oblique ows, size distributions varied significantly between seasons (F = 6.82; df = 10, 166; p< 0.001). pecifically, summer 1989-1990 and spring 1990 differed from the other four seasons (F = 15.24.

lf = 4, 172, $p < 0.001$). In summer 1989–1990 large–sized (size classes III and IV) N. australis vere almost absent from the population (size classes III and IV comprised only 2% of the total by iumbers), whereas in spring 1990 large-sized N. australis comprised nearly half the population 43% of total). The relative proportions of size classes in the remaining seasons were not ignificantly different from each other ($F = 1.16$; $df = 6, 166$; $p > 0.05$). Size distributions of N. ustralis from day surface tows were not significantly different between seasons ($F=1.92$, $df=8,$ 2, $p>0.05$).

t night there was no significant difference in size distributions between surface and oblique tows F=0.17, $df=6, 52$, $p>0.05$). We therefore combined data from both sets of tows and found that at ight there was a significant difference in size distributions between seasons ($F=3.30$; $df=10, 60$; p 0.01). Larger-sized N. australis dominated the night samples in spring 1990, reflecting the attern seen in the daytime samples. No night samples were taken in summer 1990.

ut contents of Trachurus declivis

tomachs from 115 Trachurus declivis were examined from fish sampled between January and une 1990. Fish ranged in size from 190 to 370 mm length to caudal fork (LCF) and were omprised of two modal classes: one at between 190 to 280 mm LCF and another at between 290 o 370 mm LCF. Their diet was dominated almost entirely by Nyctiphanes australis. However, ifferences were noted in the relative proportions of the different size classes at different times of he fishing season. The proportion of size classes I and II N. australis in the stomachs of rachurus declivis was significantly different between months, and was higher at the beginning of he fishing season than at the end (ANOVA, $F = 237.0$, $df=114$, $p = 0.0001$; Fig. 7). Conversely, e proportion of adult N. australis in the samples increased as the season progressed (ANOVA, =127.0, $df=114$, $p=0.0001$).This coincided with an increase in the proportion of larger sized N. ustralis in the plankton at that time (Fig. 6). Comparison of the relative proportions of size classes n the guts against that present in the plankton showed that there was generally negative selection or the smaller size classes and positive selection for adults throughout the study period (Table 5).

The ratio of stomach wet weight to fish wet weight was significantly lower in January 1990 (summer) than in the following autumn and winter (ANOVA, df=102, F= 9.0, p= 0.0001) suggesting increased feeding in these latter months.

Interannual differences

Nyctiphanes australis densities varied significantly and dramatically between the three years in which samples were taken. In 1989 N. australis density was significantly lower (mean of 0.38 individuals m^{-3}) than in 1990 (12.25 m^{-3}) and 1991 (12.79 m^{-3}) (ANOVA, F = 5.2, df = 72, p = 0.008) (Fig. 8). Similarly, N. australis biomass was two orders of magnitude lower in 1989 (0.04 mg. m^{-3}) than in 1990 (1.32 mg. m^{-3}) and 1991 (1.53 mg. m^{-3}) (ANOVA, F = 7.2, df = 72, p = 0.001). In each year there was a trend of increasing biomass through summer and autumn. In 1990 data from both the fine and coarse scale studies were available for comparison. The relatively lower abundance and biomass values reported in the coarse scale scale study are most likely due to the use of a net with a smaller mouth opening in the latter study. However, a similar trend of increasing abundance and biomass over summer and autumn mirrored that found in the fine scale study (compare Figs. 5 and 8).

Discussion

Sampling

There is a general perception that species of Nyctiphanes migrate vertically (Sheard 1953, Blackburn 1980, Williams and Fragopolou 1985). Blackburn (1980) proposed that N. australis descends to the bottom during the day and migrates to the surface at night off eastern Australia. In the present study we found no evidence for a consistent pattern of vertical migration. In fact many of our day surface hauls were equivelant to or greater than the accompanying deep haul. Similarly, O'Brien (1988) reported swarms during daytime off eastern Tasmania. Diurnal vertical migration was not found in N. simplex off California (Fiedler and Bernard 1987), and swarms were reported at the surface during daytime. It is possible that Blackburn's (1980) study was biased by the sampling strategy, which was based largely on upward vertical hauls. Hoverkamp (1989) found hat euphausiid catches from down hauls were about nine times greater than those from up hauls, uggesting that avoidance is greatly increased by upward hauls. Our conclusions are limited by the se of open nets. Nevertheless, by using surface and deep nets towed simultaneously we are onfident that we could detect gross vertical distributional trends. In the present study we found hat neither the time of day nor the depth from which samples were taken significantly affected the stimates of N. australis biomass in the region.

easonal and interannual cycles in abundance

ur results show that there is evidence for both seasonal and interannual cycles in the presence and bundance of Nyctiphanes australis off eastern Tasmania. The seasonal cycle appears to be driven y a series of events: In summer, annual intrusions of oligotrophic subtropical East Australia urrent (EAC) water flood the shelf creating an environment low in both nutrients and hytoplankton, the major food source of N. australis (Ritz et al. 1990). With the retreat of this utrient poor water and general seasonal cooling in autumn nutrients are once more available to rive production (Harris et al. 1987), hence the increase in N. australis stocks and their subsequent vailability to the fishery. Reasons for the decrease in N. australis stocks over winter, found in this nd a previous study by Ritz and Hosie (1982), are less clear. It may be, as Blackburn (1980) uggested, that some percentage of the population overwinters by descending to the seabed where hey would not be detected by plankton tows. That stomachs of bottom–dwelling tiger flathead Platycephalus richardsoni) sampled during winter in the same area were filled with krill supports his view (Hosie 1982). Other factors, such as predation during autumn may also reduce stocks urviving through to winter. The increase in numbers following winter appears to be a function of he spring phytoplankton bloom at that time (Harris et al. 1987). An increase in the relative roportion of adults to smaller size classes in both the spring and autumn blooms is noteworthy. enerally our samples were dominated by calyptopis and furcilia stages through the year. owever, the proportion of adults was significantly higher in both autumn and spring 1990. It ay be that if adult stocks do descend to the seabed during periods of low food supply then the nset of the algal blooms (or some correlate) may trigger the adults to rise into mid– and surface waters to feed.

Overlaying these seasonal cycles in abundance are interannual variations which we have shown to be at least an order of magnitude in difference. We propose that these differences are directly related to interannual variations in the regional oceanography. Harris et al (1987) proposed that the relative importance of the two major water masses – warm, stratified, nutrient poor EAC water and cool, well mixed, nutrient rich water of subantarctic origin – from year to year is determined by a combination of the local westerly wind stress and large scale oceanographic circulations often associated with El Niño / Southern Oscillation (ENSO) events. The boundary that separates these two water masses is defined as the subtropical convergence (STC), which in summer often lies in the vicinity of Maria Island (Harris et al. 1987). The position of the STC, however, shows considerable interannual variability and has been coupled with interannual variations in westerly winds (Harris et al. 1988). The Maria Island area experienced warm water temperatures and strong thermal stratification during the entire summer and autumn of 1989 resulting from the reduction in the westerly wind stress and increasing influence of subtropical EAC water. This event has been linked to the major La Niña 'Cold Event' in the southern hemisphere (Harris et al. 1991).

The interannual variability in the regional oceanography of south east Tasmanian waters has profound effects on the nutrient cycling and structure of the food chain (Harris et al. 1991). In the summer of 1988/89 Harris et al (1991) found that the increase in subtropical influence in Storm Bay ~ 55 km south of the study area, resulted in a decrease in local productivity which led to the disappearance of the large zooplankters, principally *Nyctiphanes australis*. They proposed that such large zooplankters are dependant on periods of 'new' production stemming from the influx of subantarctic waters and wind mixing.

The three years of *Nyctiphanes australis* data are consistent with the link between the changing influence of subtropical and subantarctic water, the stability of the water column (Fig. 4) and the level of *N. australis* production. It seems likely that the dominance of nutrient poor subtropical ater on the entire shelf and the strong stratification in the Maria Island area in the summer of 1989 as responsible for the disappearance of *N.australis*. It was only during late autumn when cooler aters began to intrude from the south, and partial break down of the thermocline indicated some ixing that *N. australis* began to reappear. The reduced influence of EAC water in 1990, which ominated mainly the outer shelf, and the weaker stratification, resulted in an increase in the iomass of *N. australis* either from increased production or from immigration. The dominance of ubantarctic water and the well mixed water column in the summer of 1991 resulted in even higher vels of production. Interestingly, a sudden decrease in *N. australis* biomass in the autumn of 991 coincided with an inflow of warmer tropical water at that time (compare Figs. 3 and 8), nderlining the intimate association between *N. australis* and the local hydrography. A further xample of this relationship can be found in the fine scale data, where a decrease in *N. australis* iomass coincided with an influx of EAC water in April 1990.

elationship to the fishery

NSO fluctuations are known to affect the distribution and availability of many pelagic species Sharp and Csirke 1984), including other *Trachurus* species (Smith 1985, Pearcy et al 1985, iedler and Bernard 1987). Smith (1985) reported that *T. symmetricus* in the Californian current hange their distribution during an El Niño event but could not conclude if the change was related temperature directly, or to changes in prey distributions related to temperature. Off Tasmania, lackburn (1957) found that the success of the barracouta fishery in Bass Strait was closely linked ith fluctuations in stocks of *N. australis*. In a study of the seasonal change in schooling ehaviour and vulnerability to fishing of *T. declivis* in Tasmanian waters, Williams and Pullen (in ress) found that the fishery was based on feeding schools. In that study both school size and atch rates were highest in autumn, at the time when we found the highest densities of *N. australis*. ur results indicate a close relationship between the biomass of *Nyctiphanes australis* and the vailability to the fishery of *T. declivis* off eastern Tasmania. It seems likely therefore, that changes the abundance of the former would affect *T. declivis* schooling behaviour, and consequently the mount of fish available to the fishery. We also propose that *T. declivis* are responding not only to n increase in *N. australis* biomass but also to an increase in the proportion of adult *N. australis* at this time. That positive selection of T. declivis for the larger size classes of N. australis was found (Fig. 6) supports this contention. Landings of fish over the period of this study (Fig. 9a) paralleled the abundance patterns of N. australis over the same period. No landings were made during the summer months of 1989 when N. australis abundance was negligible (Fig. 9b). The commercial catches in 1990 and 1991 also reflected the relative abundance of N. australis in those years, with more fish being landed in 1991 than 1990.

In summary, we have shown that the presence and abundance of Nyctiphanes australis in coastal waters of eastern Tasmania is associated with changes in the regional oceanography, on both seasonal and interannual scales. Due to the close association between predator and prey populations, the changing influence of the dominant water masses therefore also determines the availability of fish to the fishery. This is particularly significant during La Niña years when prey populations are largely absent. An understanding of how these interannual variations in regional oceanography affect the distribution of plankton can lead to valuable input into forecasting returns to the fishery.

Aknowledgements

We thank the skippers and crew of F.R.V. Scottsman and F. R. V. Challenger for their help during this study. We are also grateful to G. Critchley for providing hydrographic data, G. Jenkins for input into sampling design, and J. Marshall and D. Le for sorting samples. This work was partially supported by a grant from the Australian Fishing Industry Research and Development Trust Account. H. Williams, S. Nicol, G. Hosie, D. Ritz and B. Griffiths reviewed the manuscript and provided valuable suggestions.

eferences

lackburn, M. (1980) Observations on the distribution of *Nyctiphanes australis* Sars (Crustacea, Euphausiidae) in Australian waters. CSIRO Div. Fish. Oceanogr. Rep. 119.

ushing, D. H. (1982) Climate and fisheries. London, Academic press, 373 pp.

obson, A. J. (1983) An introduction to statistical modelling London, Chapman and Hall

iedler, P. C. and Bernard, H. J. (1987) Tuna aggregation and feeding near fronts observed in satellite imagery. Continental Shelf Research 7 (8) 871 - 881

ulton, J. D., Le Brasseur, R. J. (1985). Interannual shifting of the subarctic boundary and some of the biotic effects on juvenile salmonids. In: Wooster, W. S., and Fluharty, D. S. (eds.) El Niño north: Niño effects in the eastern subarctic Pacific Ocean.Washington Sea Grant Program, University of Washington Press, Seattle, p. 237-252.

arris, G. P., Nilsson, C., Clementson, L., Thomas, D. (1987). The water masses of the east coast of Tasmania: seasonal and interannual variability and the influence of phytoplankton biomass and productivity. Aust. J. Mar. Freshw. Res. 38, 569 - 590

arris, G. P., Davies, P., Nunez, M., Meyers, G. (1988). Interannual variability in climate in Tasmania and its effect on freshwater and marine fisheries. Nature. 333, 754-757

arris, G. P., Griffiths, F. B., Clementson, L. A., Lyne, V., Van der Doe, H. (1991). Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. J. Plankton Res. 13, 109-113

osie, G. (1982) *Nyctiphanes australis* G. O. Sars, in the coastal waters of S. E. Tasmania. M. Sc. Thesis, University of Tasmania. 159 pp.

overkamp, S. (1989) Avoidance of nets by *Euphausia pacifica* in Dabob Bay. Journal of Plankton Research. 11, 907–924

e Brasseur, R. J., McAllister, C. D., Fulton, J. D. and Kennedy, O. D. (1967)

Selection of a zooplankton net for coastal observations. Fisheries Research Board of Canada Technical report. No. 37, 13 pp.

Mc Gowan, J. A. (1985). El Niño 1983 in the southern Californian Bight. In: Wooster, W. S., and Fluharty, D. S. (eds.) El Niño north: Niño effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington Press, Seattle, p. 166-184

Nyan Taw and Ritz, D.A. (1979) Influence of subantarctic and subtropical oceanic water on the zooplankton and hydrology of waters adjacent to the Derwent River estuary, south-eastern Tasmania. Aust. J. Mar. Freshw. Res. 30: 179-202.

O'Brien, D.P. (1988) Surface schooling behaviour of the coastal krill *Nyctiphanes australis* (Crustacea: Euphausiacea) off Tasmania, Australia. Mar. Ecol. Prog. Ser. 12: 219-233.

Omori, M., and Ikeda, T. (1984) Methods in marine zooplankton ecology. Wiley, New York 332 pp.

Pearcy, W., Fisher, J., Brodeur, R., Johnson, S. (1985). Effects of the 1983 El Niño on coastal nekton off Oregon and Washington. In: Wooster, W. S., and Fluharty, D. S. (eds.) El Niño north: Niño effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington Press, Seattle, p. 188-204

Pearre, S. (1982). Estimating prey preference by predators: uses of various indices, and a proposal of another based on X^2. Can. J. Fish. Aquat. Sci. 39: 914-923

Ritz, D.A. and Hosie, G.W. (1982) Production of the Euphausiid *Nyctiphanes australis* in Storm Bay, south-eastern Tasmania. Mar. Biol. 68: 103-108.

Ritz, D.A., Hosie, G.W. and Kirkwood. R.J. (1990) Diet of *Nyctiphanes australis* Sars (Crustacea: Euphausiacea). Aust. J. Mar. Freshw. Res. 41: 365-374.

Sambrotto, R. N. (1985). The dependence of phytoplankton nutrient utilization on physical processes in the eastern Bering Sea area: mechanisms for yearly variation. In: Wooster, W. S., and Fluharty, D. S. (eds.) El Niño north: Niño effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington Press, Seattle, p. 268-282

harp, G. D. and Csirke, J. (1984) Proceedings of the expert consultation to examine changes in abundance and species of neritic fish resources. FAO Fish Report 291 Vol. 2, 553 pp.

mith, P. E. (1985). A case history of an anti-El Niño to El Niño transition on plankton and nekton distribution and abundances. In: Wooster, W. S., and Fluharty, D. S. (eds.) El Niño north: Niño effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program, University of Washington Press, Seattle, p. 121-142.

heard, K. (1953) Taxonomy, distribution and development of the Euphausiacea (Crustacea). B.A.N.Z.A.R.E. Rep. Ser. B, 8: 1-72

Vebb, B.F. (1976) Aspects of the biology of jack mackerel *Trachurus declivis* (Jenyns), from south-east Australian waters. Tas. Fish. Res. 10: 1-17

Villiams, H. and Pullen, G. (in press) Schooling behaviour of jack mackerel *Trachurus declivis* (Jenyns) observed in the Tasmanian purse seine fishery. Aust. J. Mar. Freshwat. Res.

Villiams. H., Pullen, G., Kucerans, G., Waterworth, C. (1987). The jack mackerel purse seine fishery in Tasmania, 1986–1987. Tech. Rep. Dep. Sea Fish., Tasm. 19: 1–32

Villiams, R. and Fragopoulu, N. (1985) Vertical distribution and nocturnal migration of *Nyctiphanes couchi* (Crustacea: Euphausiacea) in relation to the summer thermocline in the Celtic Sea. Mar. Biol. 89: 257-262

oung, J. W., Davis, T. L. O. (in press) Feeding ecology and interannual variations in diet of larval jack mackerel, *Trachurus declivis* (Pisces: Carangidae), from coastal waters of eastern Tasmania. Mar. Biol.

ar, J. H. (1984) Biostatistical analysis. 2nd Edn. Prentice Hall. Englewood Cliffs. N.J.

Table 1 : Sampling times, areas and number of samples collected off eastern Tasmania (n, number of samples; -, no samples). See Fig. 1 for positions of Riedle Bay (RB) and the transects.

	Riedle Bay			Transects		
	1989	1990	1991	1989	1990	1991
Month	n	n	n	n	n	n
Early JAN	–	1	8	6	6	6
Late JAN	–	–	–	6	6	6
FEB	–	10	–	6	6	6
MAR	–	15	–	–	6	6
APR	–	10	–	6	-	6
MAY	–	10	–	-	-	-
JUN	–	16	–	-	-	-
JUL	–	5	–	-	-	-
AUG	–	12	–	-	-	-
SEP	–	14	–	-	-	-
OCT	6	17	–	-	-	-
NOV	10	9	–	-	-	-
DEC	3	13	–	-	-	-
	19	132	8	24	24	30
	(Total n = 237)					

'able 2: Mean dry weight biomass of N. australis from different size classes

ize class	mean length (mm)	mean weight (mg)	n
(<5.0mm)	2.83	0.093	22
I (5.01 to 7.5)	6.15	0.267	29
I (7.51 to 11.0)	8.84	0.747	51
V(11.01 +)	13.38	2.458	59

able 3: Three way ANOVA of Ln (density + 1) of N. australis with season, depth and time of ay

ource	DF	F	P
ason (A)	3	3.38	0.021
pth(B)	1	1.1	0.297
el(C)	1	2.7	0.102
B	3	1.54	0.207
C	3	0.62	0.607
C	1	0.82	0.368
B.C	3	2.31	0.080
ror	113		
tal	128		

able 4: Three way ANOVA of (biomass + 1)$^{-1}$ of *N. australis* with season, depth and time of day

ource	DF	F	P
eason (A)	3	3.26	0.024
epth(B)	1	0.85	0.358
iel(C)	1	3.36	0.070
.B	3	1.15	0.332
.C	3	1.01	0.392
.C	1	0.80	0.372
.B.C	3	1.51	0.215
rror	113		
otal	128		

Table 5. *Trachurus declivis*. Pearre's Index of prey selectivity for fish of length 190-280mm LCF (<280) and 290 - 380 mm LCF (>290) preying on different size categories of *Nyctiphanes australis* during the 1990 fishing season (* p<0.05, ** p<0.01, *** p<0.001; Index ranges from -1[negative selection] to +1 [positive selection; n, number of fish examined]

	< 280 mm				> 290 mm			
Month (n)	I	II	III	IV	I	II	III	IV
an(10)	-0.22**	+0.16*	+0.06	+0.10	–	–	–	–
eb(22)	-0.65***	+0.01	+0.31***	+0.25***	-0.68***	-0.01	+0.18*	+0.33***
ar(7)	–	–	–	–	-0.22**	-0.09	+0.01	+0.31***
pr(14)	-0.34***	+0.04	+0.03	+0.06	-0.47***	+0.01	+0.08	+0.22**
ay(44)	-0.12	-0.12	+0.01	+0.18*	-0.14	-0.14*	+0.01	+0.23**
une(18)	–	–	–	–	-0.32***	-0.17*	+0.03	+0.50***

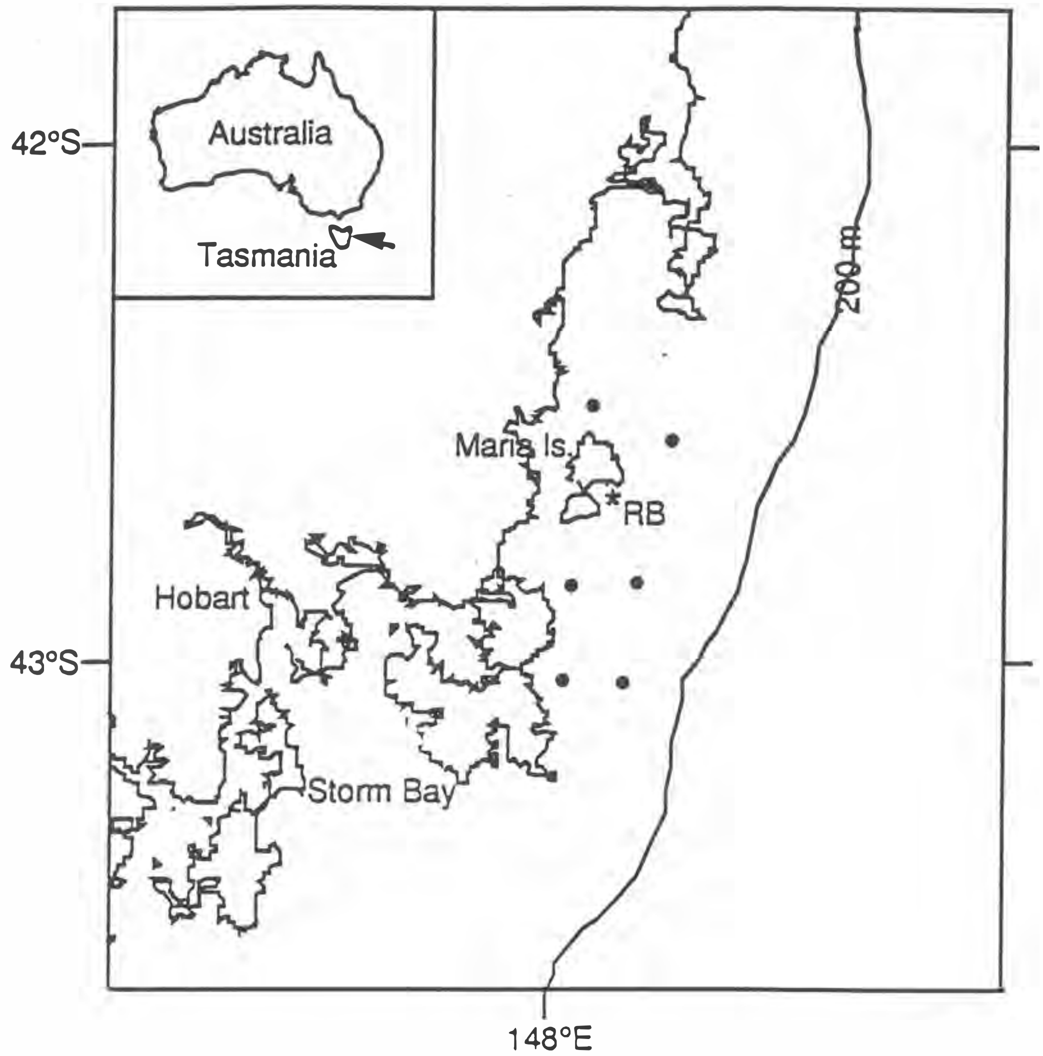


Figure 1. Location of sampling stations for Nyctiphanes australis around eastern Tasmania. RB; Riedle Bay

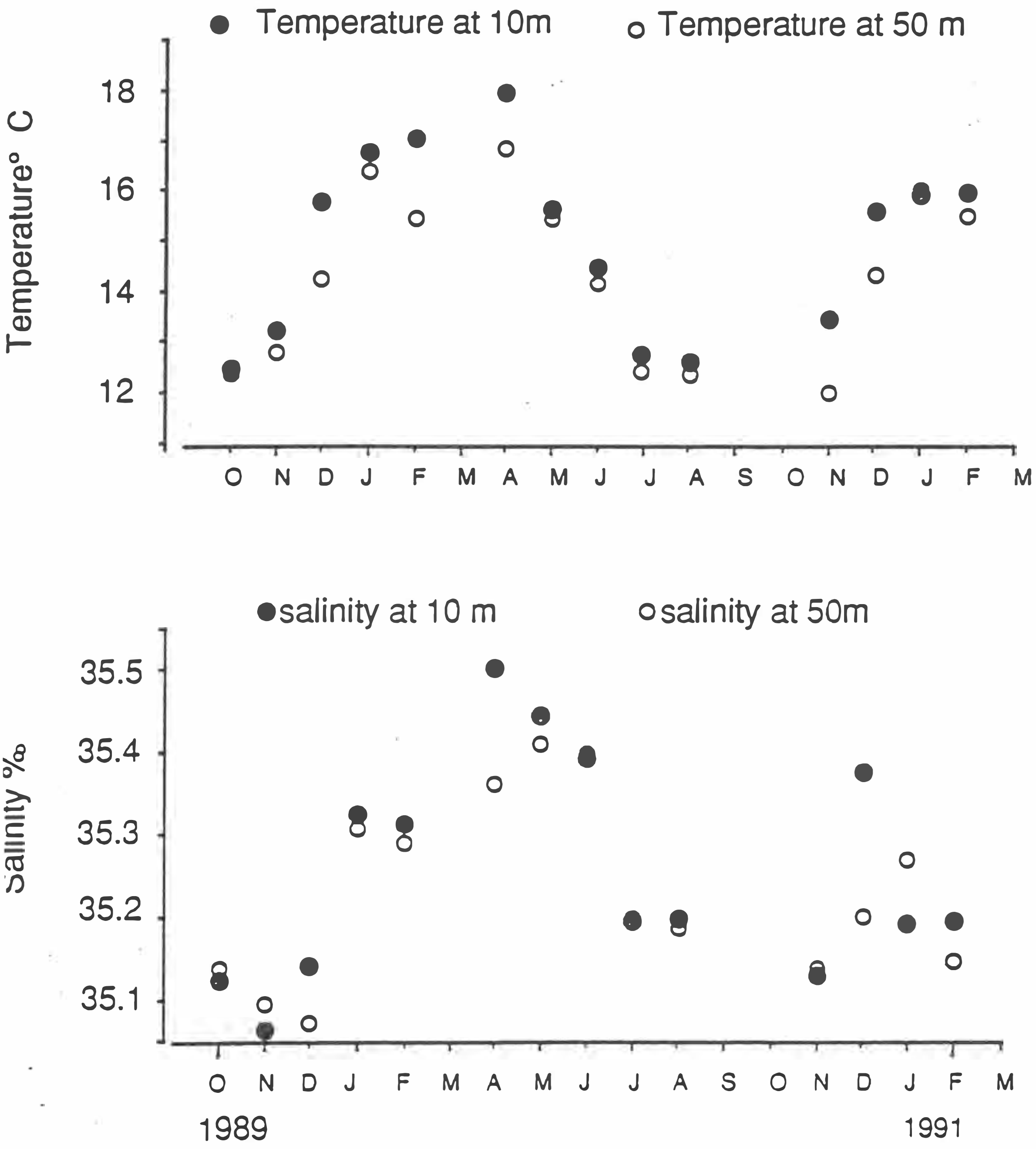


Figure 2. Monthly 10m and 50m water temperatures (°C) (a) and salinity (10^{-3}) (b) from the Maria Island monitoring station between October 1989 and February 1991

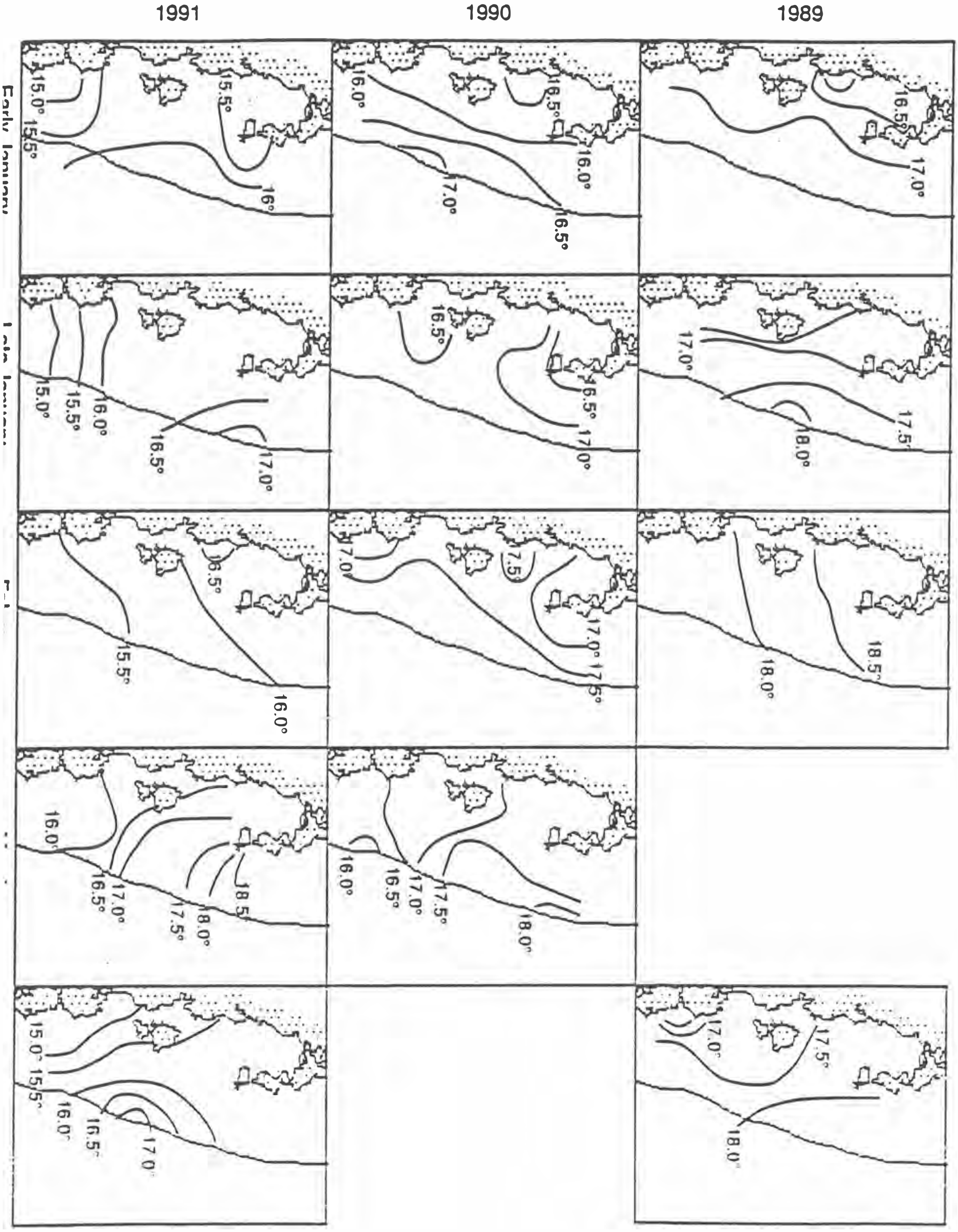


Figure 3. Distribution of sea surface temperatures in shelf waters of eastern Tasmania during summer and autumn of 1989, 1990 and 1991

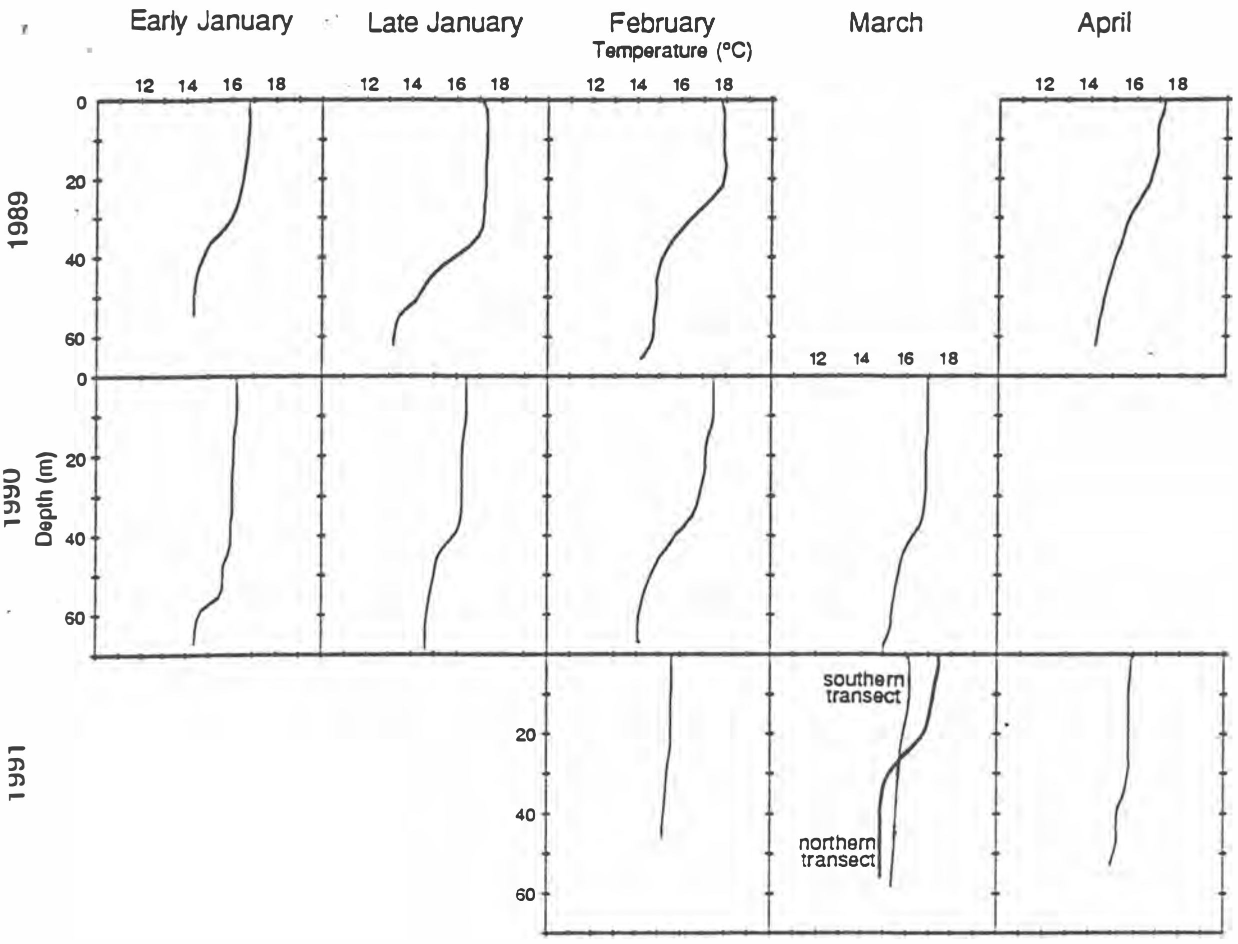


Figure 4. Vertical temperature profiles taken from the midshelf station immediatley south of Maria Island during the summer and autumn of 1989, 1990 and 1991. For March 1991 the profile from the midshelf station north of Maria Island is also presented (bold line).

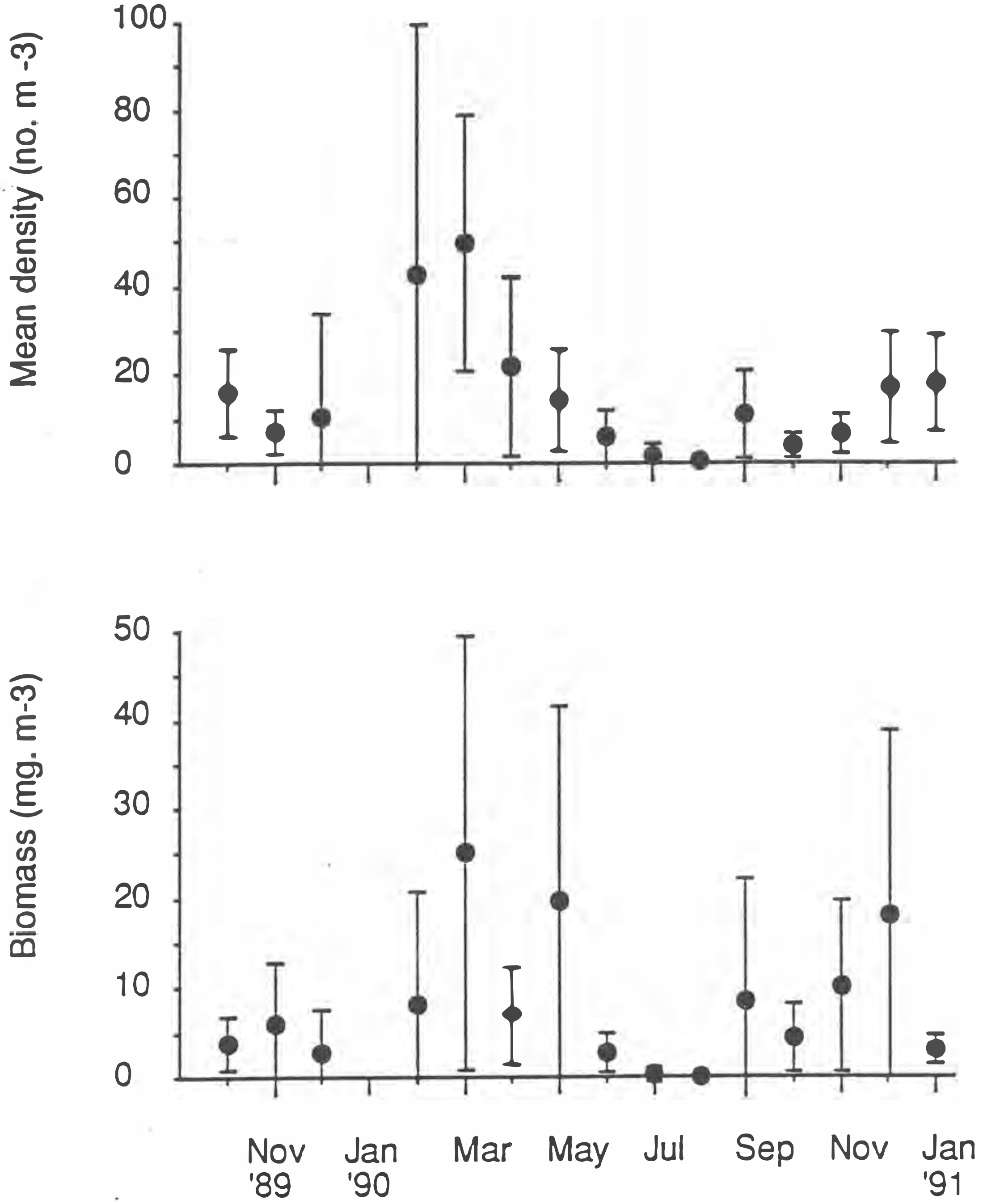


Figure 5. Nyctiphanes australis. Monthly abundance (number m^{-3}) (a) and biomass (mg. m^{-3}) (b) from Riedle Bay; means ± 95% confidence limits

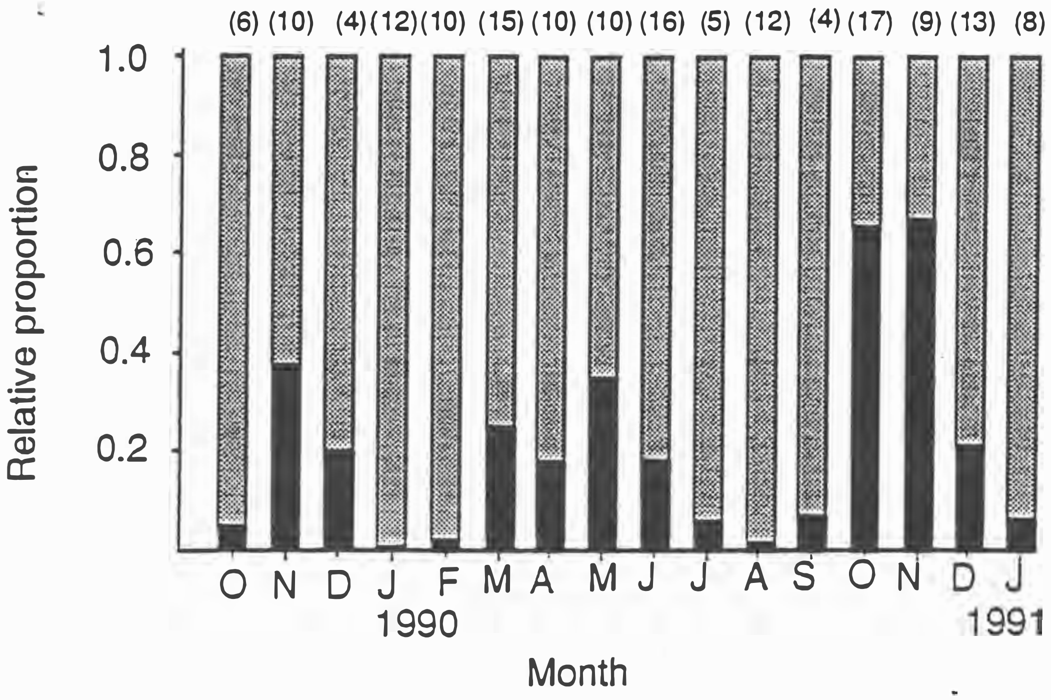


Figure 6. Nyctiphanes australis. Relative proportions of size classes between months at Riedle Bay. Shaded portions represent size classes I and II combined. Darkened portions represent size classes III and IV combined n, number of samples

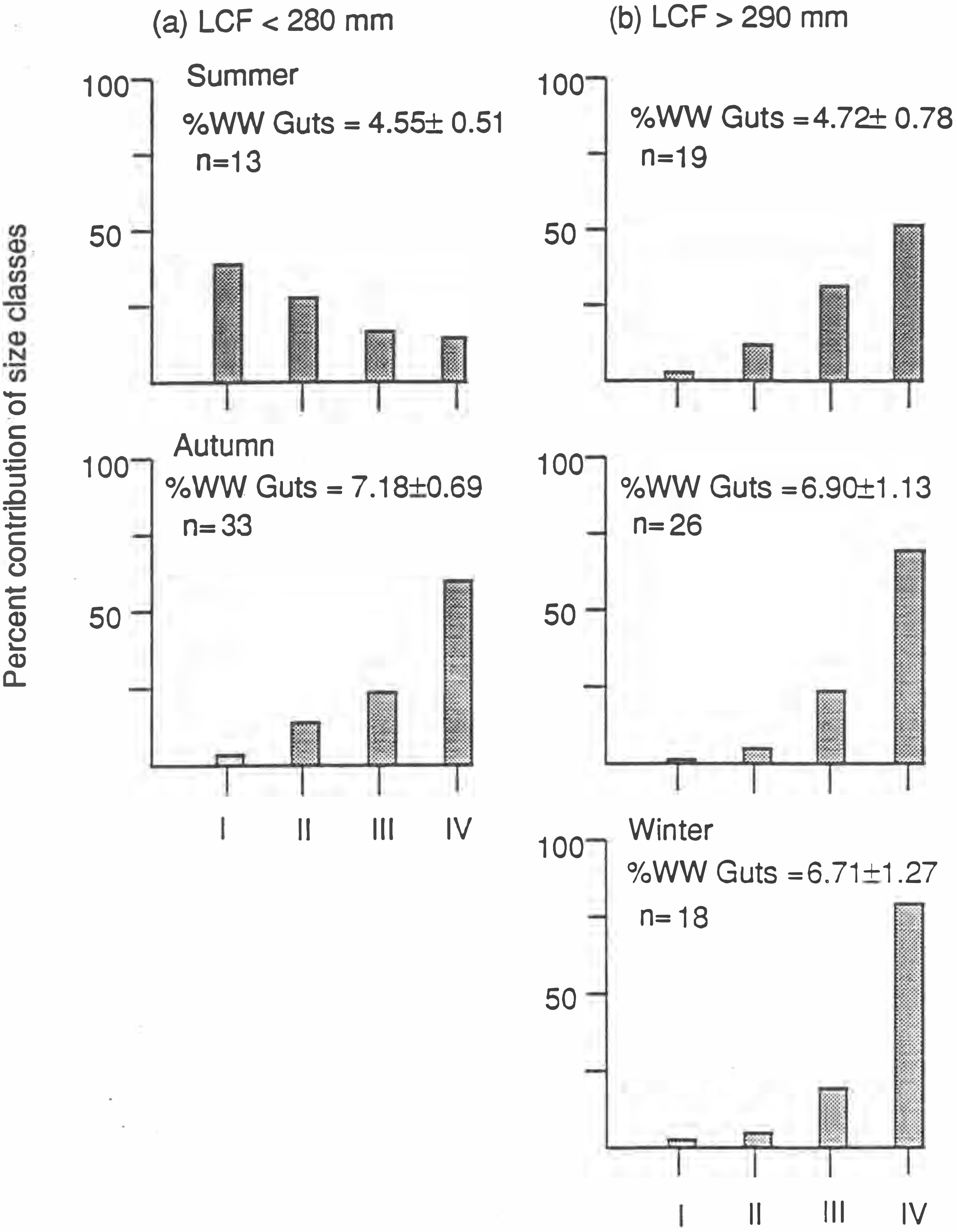


Figure 7. Nyctiphanes australis. Changes in the relative proportions of individual size classes in the stomachs of two modal classes (LCF < 280 mm, LCF > 280 mm) of Trachurus declivis in 1990

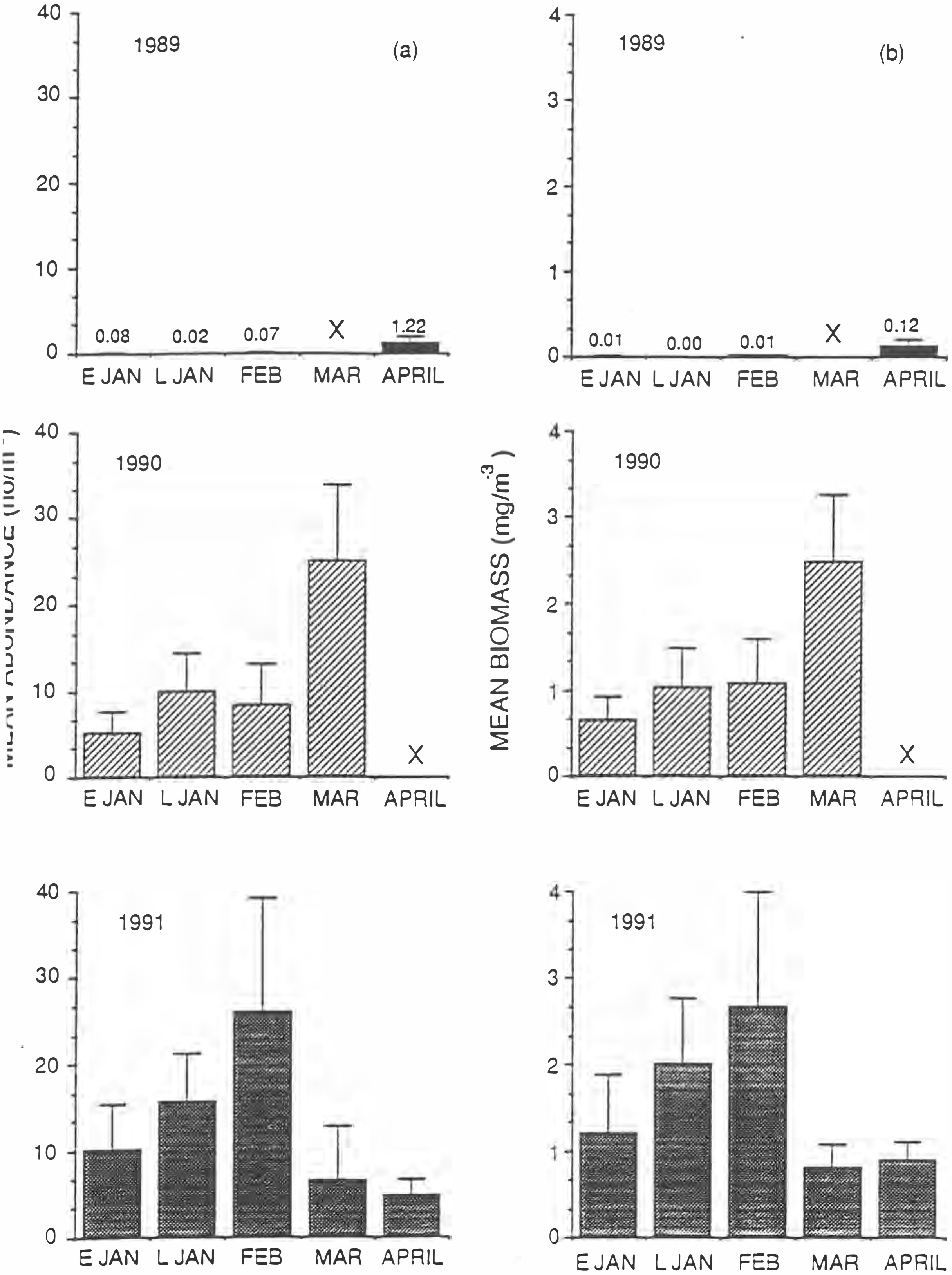


Figure 8. Nyctiphanes australis. Interannual changes in abundance (mean number. m $^{-3}$. ± SE) (a) and biomass (mean mg. m^{-3} ± SE) (b) from coarse scale sampling off eastern Tasmania in 1989, 1990 and 1991

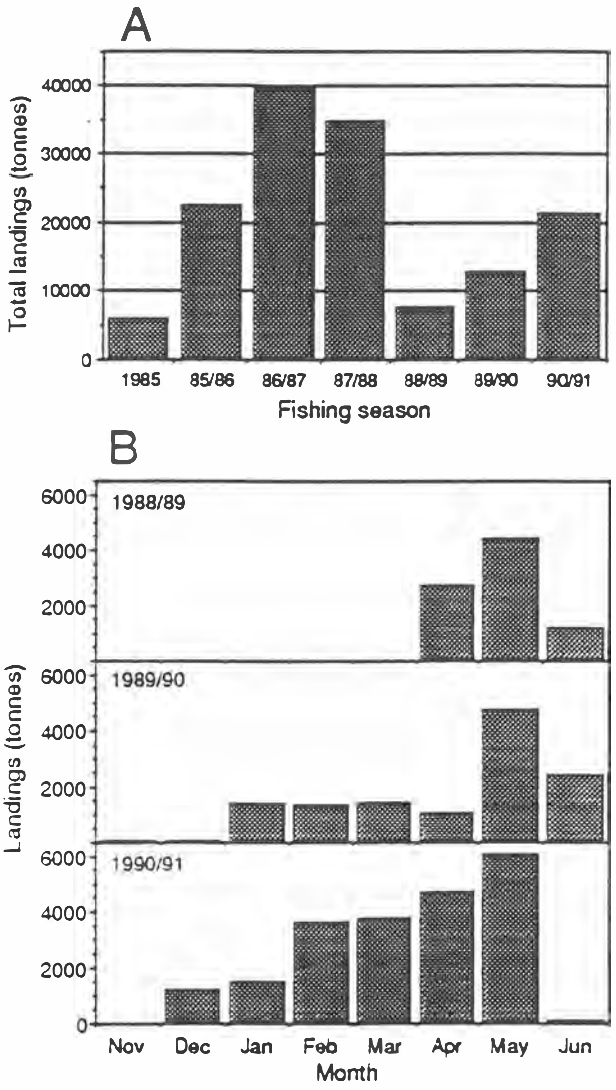


Figure 9. *Trachurus declivis*. Annual landings from the fishery between 1985 and 1991 (a) and monthly landings (b) from the fishery corresponding to the times of the study.

DOCUMENT 6

Age and growth of larval jack mackerel, *Trachurus declivis*, (Pisces: Carangidae), from eastern Tasmanian coastal waters

SUBMITTED TO AUSTRALIAN JOURNAL OF MARINE AND FRESHWATER RESEARCH

Age and growth of larval jack mackerel, *Trachurus declivis*, (Pisces: Carangidae), from eastern Tasmanian coastal waters

Alan R. Jordan

Sea Fisheries Research Laboratories, Department of Primary Industry, Fisheries and Energy,
Crayfish Point, Taroona, Tasmania 7053, Australia.

Abstract

Age and growth of the larvae of jack mackerel, *Trachurus declivis*, was determined from the examination of otolith microstructure. Larvae were collected from shelf waters of the east coast of Tasmania during January and February 1989 and January 1990. Daily increment formation was confirmed by successive sampling of a cohort of individuals, correlating the change in the number of increments with the sampling interval. Otoliths examined under the scanning electron microscope confirmed the otolith structure and increment counts discerned under the light microscope. Initial increments were shown to form at first-feeding. Larvae ranged from 3 to 25 days post first-feeding. Larvae showed exponential growth in both years with specific growth rates of 5.2% of standard length per day in 1989 and 5.4% in 1990. Absolute growth rates ranged from a minimum of 0.202 mm per day in early pre-flexion larvae to a maximum of 0.646 mm per day in post-flexion larvae. This represents a rate of growth higher than reported for other temperate perciform larvae although this may be attributable to warmer than normal water temperatures over the study area in the two years of sampling associated with a major La Niña event.

Introduction

The discovery of daily increments in the otoliths of marine fish (Panella 1971) has led to an accurate method of estimating age and growth of larval fish. Numerous studies have shown that such incremental marks form daily in larval otoliths (see reviews by Campana and Nielson 1985, Jones 1986). Counts of such increments allows population growth curves to be constructed, while a linear relationship between otolith increment width and fish size makes it possible to reconstruct growth curves of individual larvae (Mosegaard *et al.* 1988, Jenkins and Davis 1990). Estimates of growth from size at age plots have been obtained for numerous species (Methot and Kramer 1979, Bolz and Lough 1983, Jenkins 1987), and have been used to examine temporal and spatial variability in growth rates (Thomas 1986, Thresher *et al.* 1989).

Species of *Trachurus* are an important part of the pelagic fish assemblages that live off the coasts of South Africa, South America, Australia and New Zealand close to the northern edge of the subtropical convergence. While considerable work has been directed towards age and growth of clupeiod larvae (Methot and Kramer 1979, Thomas 1986, McGurk 1984) relatively few studies have measured these parameters for species of *Trachurus*. The use of daily growth increments has been reported for only one species, *Trachurus symmetricus* (Hewitt *et al.* 1985), although detailed descriptions of otolith microstructure for this species are unavailable.

Jack mackerel,*Trachurus declivis*, is a pelagic species that lives in shelf waters in southern and eastern Australia and New Zealand. A rapidly developing fishery for *T. declivis* has operated on the east coast of Tasmania since 1985, with annual landings growing to 39 000 tonnes by 1987 (Williams *et al.* 1987). However, catches in both 1989 and 1990 were dramatically reduced, their disappearance being directly attributed to interannual variability in oceanography and productivity in these years associated with a major El Niño/Southern Oscillation, or La Niña, event resulting in considerable warming of surface waters and oligotrophic conditions on the shelf (Harris *et al.* 1991). This variability in catches, common to pelagic species, emphasized the need to understand more about the early life history of the species and possible impact of such variability on larval survival.

As part of a study on the reproduction and early life history of *Trachurus declivis* on the east coast of Tasmania I examined daily growth increments in otoliths to determine age and growth of larvae. In this paper I describe the otolith microstructure of *T. declivis* larvae and validation of daily growth increments in otoliths. Estimates of growth rates and comparisons of growth trajectories are made for populations from 1989 and 1990.

Materials and Methods

Sampling Procedures

Icthyoplankton were sampled from the east coast of Tasmania at approximately fortnightly intervals between January and March 1989 and twice in January 1990 (Table 1). Samples were collected at fixed stations on 8 transects along the east coast of Tasmania from St Helens Point (Transect 1) in the north to Eaglehawk Neck (Transect 8) in the south (Fig. 1). Transects consisted of 3 stations designated as inshore (at a depth of 30-50 m), midshelf (70-100 m), and shelfbreak (1Nm inshore of the shelfbreak at an average bottom depth of 150 m).

Samples were collected with a 45 cm diameter bongo net with 500 µm mesh. Each station consisted of an oblique tow to a maximum depth of 100 m, bottom depth permitting, at a tow speed of approximately 2 knots. A temperature/depth probe and 20 kg depressor was attached to the net during each tow. At each station the net was sent to the required depth quickly, held there for 1-2 minutes and then retrieved on an oblique path. Filtered volume was estimated using calibrated flowmeters. Sampling was restricted to the hours of 0600 to 2000hrs. Samples from one net were fixed in 95% ethanol, and the other in 10% seawater formalin buffered with sodium ß glycerophosphate.

Laboratory Procedures

Trachurus declivis larvae were sorted from plankton samples in a rotatable sorting ring under a dissecting microscope and separated into three developmental stages - preflexion, flexion and postflexion. Larvae were identified on the basis of morphology and pigmentation that is remarkably similar to that described for *T. symmetricus* (Ahlstrom and Ball 1954).

Trachurus declivis is the only member of the *Trachurus* genus that is common in the study area (May and Maxwell 1986) and supports a large seasonal fishery corresponding to the months of sampling (Williams *et al.* 1987). However, several specimens of *T. murphyii* >60 cm have recently been recorded from east coast waters (Pullen *et al.* 1989). At present there is no indication that they spawn locally, although if it does contamination would be minimal due to their rarity. Several other carangid species are known to occur in the study area but only two species, the trevally, *Psuedocaranx dentex*,and pilotfish, *Naucrates ductor*, are known from more than just a few specimens (May and Maxwell 1986). The larvae have been described for both *P. dentex* (James 1976, as *Caranx georgianus*) and *N. ductor* (Sanzo 1931), and are easily separated from *T. declivis* on the basis of differences in head spination and pigmentation.

Specimens for otolith analysis were randomly selected from each sample up to a maximum of 20 larvae. For stations with more than 20 larvae, subsamples were taken in proportion to the number of individuals in each developmental stage to ensure an unbiased estimate of the age distribution of larvae. Standard length (SL; tip of snout to hypural crease or tip of notochord in preflexion larvae) was measured under a dissecting microscope with a ocular micrometer. Larvae were placed in a drop of water on a microscope cover slip and otoliths removed under cross polarized light with electrolitically sharpened tungsten needles. Otoliths were air dried and placed flat side against the coverslip and mounted in Gurr's mounting medium for microscopic examination.

Otoliths were viewed under transmitted light at 920 or 2360x magnification using a video system fitted to a compound microscope. Otolith counts and measurements were digitized using a H.E.C.

'Video Coordinate digitizer' supported by an Apple Macintosh. Specimens were examined double blind and replicated at least twice by the same reader. Approximately 6% of specimens from 1989 and 3% from 1990 were rejected. Otolith counts and measurements were made along the posterior radius of the sagitta, consistently the best line for increment counting. Counts were made between the otolith periphery and a well defined increment defined as a 'first feeding mark'. Hence, age used in the analysis of growth is defined as age post first-feeding. Total radius is defined as the distance from the centre of the focal area to the edge of the sagitta. No difference between radius measurements of two sagittae from the same fish was found (Paired t-test, $n=26$, $t=0.326$, $p>0.10$) so all counts were made on only one sagitta per fish.

In preparation for examination of internal structure, sagittae from 6 larvae between 6.2 mm and 11.21 mm were mounted whole in 5 min epoxy resin. The lateral surface of each otolith was ground to the primordium with 600 grit sand paper and 3 micron diamond paste, and polished with 0.1 micron aluminium oxide. After examination with light microscopy (LM) sagittae were decalcified with 6% EDTA at pH 8.0 for 3 min, mounted on scanning electron microscope (SEM) stubs, coated with gold and viewed in an SEM.

Otolith Validation

To determine whether increments observed in the otoliths of *Trachurus declivis* were deposited daily, we sampled cohorts of individuals and determined whether the change in number of increments was the same as the sampling interval (Campana and Nielson 1985). Larvae were sampled from T1 on the 8th January 1990 and again on the 25th January 1990. Hence, the sampling interval was known to be 17 days. Larvae from the first sampling date were measured and the number of growth increments estimated from a subsample, proportional to the number of individuals in each 0.5 mm size class. Larvae from the second date were measured and all larvae used for increment counts due to the low numbers of larvae.

Results

Otolith Microstructure

Only sagittae and lapilli were present in the otic capsules of pre-flexion larvae: asterisci were present in larvae by 6.50 mm. Growth increments were clearly visible in sagittae examined under the LM, increments consisting of an optically transparent and optically dense zone (Tanaka *et al.* 1981) (Fig. 2).

All larvae had two diffuse optically dense zones immediately adjacent to the distinct spherical primordium. The mean radius of the two increments were 6.8 µm (0.59 ±SD) and 9.4 µm (0.57 ±SD) respectively. Immediately adjacent to these increments was a faint increment with a mean radius of 10.8 µm (0.67 ±SD) that occurred in 52.9% of all larvae examined. The microstructure of the otolith differed markedly outside this zone with all larvae having a consistent, well defined increment with a mean radius of 11.9 µm (0.77 ±SD). To estimate the timing of formation of this increment, otoliths from ten late yolk sac larvae were examined. No such increment was visible on any of these otoliths. The mean radius of the otoliths was 10.8 µm. It was concluded that this increment was most likely formed close to, or at first feeding, similar to that found for other temperate species (Warlen and Chester 1985, Thresher *et al.* 1989). Beyond this first feeding increment there were clear, unambiguous increments initially with a mean increment radius of 1.3-1.5 µm, but increasing in width exponentially to the margin of the otolith. There were, however, signs of subdaily increment formation towards the edge of the otolith in some older larvae.

The microstructure of the otoliths as viewed with the LM was clarified after examination with the SEM. Firstly, both consistent diffuse increments adjacent to the primordium were visible on all otoliths examined (Fig. 3). Three larvae that had a single faint mark immediately inside the well defined first feeding mark were examined under the SEM (Fig. 3). No structure was visible within this region and hence these rings were not regarded as true daily increments and were not included in increment counts. Daily increments were clear on SEM examination, however subdaily increments were not visible, apparently as a result of less decalcification (Fig. 3). Increment counts on all three otoliths were the same under both the SEM and LM, confirming LM interpretations of increment structure.

Otolith Validation

Length frequency distributions of larvae for the first sample indicate a normally distributed population with a mean length of 4.03 mm (0.39 mm ±SD) (Fig. 4a). Two distinct cohorts were caught in the second sample taken seventeen days later, with means at 4.34 mm (0.42 mm ±SD) and 9.03 mm (1.42 mm ±SD) respectively (Fig. 4a). The distribution of ages post first-feeding clearly shows the progression of a single cohort that increased from a mode of 5 increments to a mode of 21 increments between sample periods (Fig 4b). Hence, a modal increase of 16 increments corresponds closely with the known sampling interval of 17 days. Whilst the modal age and sampling interval are not identical we feel that they support the interpretation that increments are layed down daily. While we cannot be positive that the same population was sampled, due to possible northerly or southerly advection over the 17 days, there is clear fortnightly periodicity in spawning across the entire study area (A.Jordan. unpubl data). This is supported by the presence of the cohort of small larvae caught on the second sampling date with a modal age of 7 days, exactly 14 days younger than the older cohort (Fig. 4). Hence, we are confident the cohort sampled on the two dates reflect larvae from the same spawning event and as such the results are consistent with the prediction that increments are formed daily.

Growth Rates

Growth rate and growth trajectory were estimated from 503 *Trachurus declivis* larvae (3.07-10.98 mm) in 1989 and 200 larvae (3.24-13.45 mm) in 1990. Age estimates ranged from 2 to 25 days post first-feeding. Length at age plots were first examined for larvae from both years (Fig. 5). An examination of the distribution of residuals from the linear regression shows that variance in length increases with age, therefore violating the assumption of homogenous variances (Fig. 5). When SL was transformed to logarithms the residual plots showed no increase in variance with age solving the problem of heteroscedasticity (Fig. 6). Hence larvae showed exponential growth for both years with the fitted growth trajectory accounting for 90% of the variance in length in 1989 and 96% in 1990.

There was a significant difference in the growth rates of larvae between years (5.2% SL/day vs 5.4% SL/day, ANCOVA F 1,699 = 4.25, P < .05) (Fig. 6) indicating growth was more rapid in 1990, but only slightly. The estimated length at first increment formation was slightly lower in 1989 (3.00 mm) than 1990 (3.10 mm) indicating a difference in the age or size at which the first increment is formed. Predicted absolute growth rates of *Trachurus declivis* larvae for the two years increased from a minimum 0.202 mm day^{-1} in early preflexion larvae in 1989 to a maximum of 0.646 mm day^{-1} in post flexion larvae in 1990 (Table 2).

Discussion

Distinct daily growth increments were visible in the sagittae of *Trachurus declivis* larvae. While lapilli were present in our smallest larvae, and most likely formed at the same time as the sagittae, their small size and corresponding narrow increment widths meant sagittae were consistently more reliable for age estimates.

Initial increment formation may occur prior to hatching, at hatching, and at the onset of first feeding (Brothers *et al.* 1976, McGurk 1984). In this study, sagittae from late yolk-sac larvae had a mean radius similar to the radius of the first clear increment found in older larvae. This well defined increment was absent in all yolk-sac larvae examined. It was thus assumed that this increment was deposited at first feeding. A number of species are known to deposit the first distinctive daily increment at first feeding (McGurk 1984, Rice *et al.* 1985, Warlen and Chester 1985, Thresher *et al.* 1989), including the carangid *Trachurus symmetricus* (Hewitt *et al.* 1985) which begin to feed at an approximate size of 3.10 mm. This is remarkably similar to the size at first increment formation (3.00 mm in 1989 and 3.10 mm in 1990) estimated from the growth trajectory for *T. declivis*, and further supports the conclusion that daily increment formation begins at first feeding.

Examination of otoliths under the SEM has been used to confirm otolith structure (Bolz and Lough 1983, Jenkins and Davis 1990) and to compare increments counts obtained by LM (Campana and Nielson 1982, Ratdke and Dean 1982). It is also a useful technique when examining check marks because they etch more deeply, making them easily distinguishable from surrounding increments (Campana and Nielson 1985). The structure of the two diffuse increments observed in the focal area of *Trachurus declivis* otoliths under the LM clearly differed from the well defined first feeding mark when examined under the SEM. These 'checks' clearly reflect events in the pre-feeding life history and while one check most likely corresponds to the check formed at hatch, similar to that found in a number of other species (Bolz and Lough 1983, Rice *et al.* 1985, Thresher *et al.* 1989), it is unclear at what stage the second check is formed. However, this is in contrast to *T. symmetricus* where no increments were visible in the focal area of otoliths formed prior to first feeding (Hewitt *et al.* 1985). The faint rings observed under the LM just inside the first feeding mark in a proportion of larvae are similar to those observed prior to deposition of the first distinctive ring in a number of species (Bolz and Lough 1983, Jenkins 1987). They were not visible under the SEM and were not regarded as true daily increments.

Age may be underestimated in larvae where increment width is approximately 0.5 μm or less (Campana 1984) which is near the resolution limits of the LM. This is unlikely to be a source of bias in *Trachurus declivis* as the narrowest increments were 0.7 μm apart, with most being much larger. This was further supported through examination under the SEM which can resolve even the narrowest daily increments (Campana *et al.* 1987), and confirmed the structure of the increments as seen under the LM. Subdaily increments may introduce another bias in age estimation (Campana and Nielson 1985), but SEM examination confirmed the LM interpretation as subdaily increments were poorly etched compared to the daily increments.

Exponential growth trajectories have been identified for a number of temperate species (Bolz and Lough 1983, Jenkins 1987). The exponential growth trajectory of *Trachurus declivis* larvae indicates that growth is slow for the first two weeks but increases rapidly, remaining exponential until at least 25 days after first feeding. This is similar to that found for *T. symmetricus* larvae where growth trajectory for larvae < 15 post first feeding was exponential (Thielacker 1978). Although there is no indication that growth rate declined late in larval life, such changes have been documented in other perciform species and often relate to the juvenile phase associated with settlement (Victor 1986) or estuarine recruitment (Warlen and Chester 1985). The life history or habitat of juvenile *T. declivis* is unknown.

Growth rates of *Trachurus declivis* larvae appear to be comparable to those of other temperate species although direct comparisons are difficult due to morphological differences and variability in growth trajectories (Methot and Kramer 1979, Warlen and Chester 1985, Warlen 1988). However, the mean growth rate of *T. declivis* larvae <15 days (0.27 mm day^{-1} in 1989 and 0.29 mm day^{-1} in 1990) was almost twice that found for *T. symmetricus* (ca. 0.16 mm day^{-1}) of the same age (Hewitt *et al.* 1985).

While growth rates between the two years were found to be significantly different, the difference of 0.2% SL per day is unlikely to be biologically significant. While decreased growth rate leads to a longer larval phase and subsequent greater cumulative mortality (Shepherd and Cushing 1980) it is unlikely that growth rate differences observed would have a significant mortality effect. The comparison of 1989 and 1990 larval growth rates is of interest due to the variability in oceanography and productivity observed in south-east Tasmanian waters in these years. The productivity of these waters is determined by the local westerly wind stress and the relative position of nutrient poor subtropical and nutrient rich subantarctic water in the area (Harris *et al.* 1987). The summer spawning period of 1989 was characterized by decreased westerly wind stress and increased subtropical influence resulting in considerable warming of surface waters. Maximum summer temperatures in Storm Bay, immediately south east of our study area rose by 2.5°C between 1986 and 1989 (Harris *et al.*1991). This event appears to be driven by an El Niño/Southern Oscillation (ENSO) event, or La Niña in the southern hemisphere (Harris *et al.* 1991). These conditions led to a decrease in productivity on the shelf resulting in the elimination of all large zooplankters, and the dominance of small copepods (Harris *et al.* 1991), which are less affected by levels of production as they can switch from herbivory to omnivory (Cushing 1989). This shift in production and community structure is similar to that experienced in other waters affected by ENSO events (Fulton and LeBrasseur 1985, Smith 1985). As food abundance and water temperature are seen as the major factors controlling larval growth, the impact of warmer water temperatures and decreased production in 1989 and 1990 would be expected to be reflected in growth rates of *Trachurus declivis* larvae.

Despite the summer of 1989 being characterised as a warm year, continued subtropical influence in 1990 meant that water temperatures were only slightly lower in that year. Mean 10m temperature at stations used for otolith analysis was 17.0°C in 1989, compared to 16.9°C in 1990. Shelf waters did not become significantly warmer in 1989 until late February, well after most spawning and larval growth had taken place (A. Jordan unpubl data). While it is unlikely that such a small difference in temperature would be reflected in growth rates, the warmer waters of both years may have had a positive effect on growth.

The decrease in production and change in the plankton composition in shelf waters in 1989 and 1990 was reflected in the diet of *Trachurus declivis* larvae (Young and Davis 1992). While small copepods were dominant in the diet, reflecting their presence in the plankton, prey numbers were low in both years suggesting a decrease in copepod production also occurred (Young and Davis 1992). While there was no evidence that *T. declivis* larvae had an impact on prey densities, it is possible that low prey numbers had a negative effect on growth. The higher prey numbers in 1990 (Young and Davis 1992) may account for the higher growth rates in that year. This is supported by Devonald (1983) found a good correspondence between prey availability and the condition of mackerel, *T. symmetricus*, larvae in Californian waters. In the offshore oligotrophic part of their spawning habitat *T. symmetricus* were in worse condition than those in more productive inshore waters (Theilacker 1986) and were reflected in low growth rates in offshore larvae (Hewitt *et al.* 1985). While a density dependent reduction in growth rate through competition for food has been found in larvae from tropical waters (Jenkins *et al.* 1991), studies from temperate waters suggest that larvae do not impact on their prey (Cushing 1983, Jenkins 1987). Our results indicate that despite the low prey abundance, *T. declivis* showed rapid growth in 1989 and 1990, and may have resulted from the warmer water temperatures associated with the La Niña event in those years.

Acknowledgements

I am grateful to G. Pullen, J. Marshall, G. Jenkins, and the captain and crew of the F. R. V. Challenger for assistance in the collection of samples. Special thanks to J. Marshall for assistance in laboratory. I thank G. Jenkins for the discussions which helped guide this work. The manuscript benefited from the useful suggestions made by G. Jenkins, H. Williams and G. Pullen. This work was supported by a grant from the Australian Fishing Industry Research and Development Trust Account (DFT2Z).

References

Ahlstrom, E. H., and Ball, O. P. (1954). Description of eggs and larvae of jack mackerel (*Trachurus symmetricus*) and distribution and abundance of larvae in 1950 and 1951. *US Fish and Wildlife Service Fishery Bulletin* **97** (56), 209-45.

Bolz, G. R., and Lough, R. G. (1983). Growth of larval Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, on Georges Bank, spring 1981. *US National Marine Fisheries Service Bulletin* **81**, 827-36.

Brothers, E. B., Mathews, C. P., and Lasker, R. (1976). Daily growth increments in otoliths from larval and adult fishes. *US National Marine Fisheries Service Bulletin* 74, 1-8.

Campana, S. E. (1984). Microstructural growth patterns in the otoliths of larval and juvenile starry flounder *Platichthys stellatus*. *Canadian Journal of Zoology* **62**, 1507-12.

Campana, S. E., and Nielson, J. D. (1982). Daily growth increments in otoliths of starry flounder (*Platichthys stellatus*) and the influence of some environmental variables in their production. *Canadian Journal of Fisheries and Aquatic Sciences* **39**, 937-42.

Campana, S. E., and Nielson, J. D. (1985). Microstructure of fish otoliths. *Canadian Journal of Fisheries and Aquatic Sciences* **42**, 1014-32.

Campana, S. E., Gagne, J. A., and Munro, J. (1987). Otolith microstructure of larval herring (*Clupea harengus*): Image or reality. *Canadian Journal of Fisheries and Aquatic Sciences* **44**, 1922-29.

Cushing, D. H. (1983). Are fish larvae too dilute to affect the density of their prey? *Journal of Plankton Research* **5**, 847-54.

Cushing, D. H. (1989). A difference in structure between ecosystems in strongly stratified waters and those that are only weakly stratified. *Journal of Plankton Research* **11**, 1-13.

Devonald, K. F. (1983). Evaluation of the feeding success of first-feeding jack mackerel larvae off southern California, and some contributing factors. Ph.D. Thesis, University of California, Scripps Institute of Oceanography, 227 p.

Fulton, J. D., and LeBrasseur, R. J. (1985). Interannual shifting of the subantarctic boundary and some of the biotic effects on juvenile salmonids. In W.S. Wooster and D.L.

Fluharty, (eds), El Niño north: Niño effects in the eastern subarctic Pacific Ocean, pp. 237-47. Washington Sea Grant Program, University Washington, Seattle.

Harris, G. P., Nilsson, C., Clementson, L. A., and Thomas, D. (1987). The water masses of the east coast of Tasmania: seasonal and interannual variability and the influence on phytoplankton biomass and productivity. *Australian Journal of Marine and Freshwater. Research* **38**, 569-90.

Harris, G. P., Griffiths, F. B., Clementson, L. A., Lyne, V., and Van der Doe, H. (1991). Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. *Journal of Plankton Research* **13**, 109-31.

Hewitt, R. P., Theilacker, G. H., and Lo, N. C. H. (1985). Causes of mortality in young jack mackerel. *Marine Ecological Progress Series* **26**, 1-10.

James, G. D. (1976). Eggs and larvae of the trevally *Caranx georgianus* (Teleostei: Carangidae). *New Zealand Journal of Marine and Freshwater Research* **10**, 301-10.

Jenkins, G. P. (1987). Age and growth of co-occurring larvae of two flounder species, *Rhombosolea tapirina* and *Ammotretis rostratus*. *Marine Biology (Berlin)* **95**, 157-66.

Jenkins, G. P., and Davis, T. L. O. (1990). Age, growth rate, and growth trajectory, determined from otolith microstructure of southern bluefin tuna, *Thunnus maccoyii*, larvae. *Marine Ecological Progress Series* **63**, 93-104.

Jenkins, G. P., Young, J. W., and Davis, T. L. O. (1991). Density dependence of larval growth of a marine fish, the southern bluefin tuna, *Thunnus maccoyii*. *Canadian Journal of Fisheries and Aquatic Sciences* **48**, 1358-63.

Jones, C. (1986). Determining age of larval fish with the otolith increment technique. *US National Marine Fisheries Service Bulletin* **84**, 91-103.

McGurk, M. D. (1984). Ring deposition in the otoliths of larval Pacific herring, *Clupea harengus pallasi*. *US National Marine Fisheries Service Bulletin* **82**, 113-20.

May, J. L., and Maxwell, J. G. H. (1986). Field guide to trawl fish from temperate waters of Australia. CSIRO, Hobart. pp 216-22.

Methot, R. D.Jr, and Kramer, D. (1979). Growth of northern anchovy, *Engraulis mordax*, larvae in the sea. *US National Marine Fisheries Service Bulletin* **77**, 413-23.

Mosegaard, H.,Svedand, H., and Taberman, K. (1988). Uncoupling of somatic and otolith growth rates in Atlantic char (*Salvelinus alpinus*) as an effect of differences in temperature response. *Canadian Journal of Fisheries and Aquatic Sciences* **45**, 1514-24.

Panella, G. (1971). Fish otoliths: daily growth layers and periodical patterns. *Science* (Wash. D.C.). **173**, 1124-27.

Pullen, G., Williams, H., and Last, P. (1989). South American fish found off Tasmania. *Australian Fisheries* **48** (6), pp. 35.

Rice, J. A., Crowder, L. B., and Binkowski, F. P. (1985). Evaluating otolith analysis for bloater *Coregonus hoyi*: do otoliths ring true? *Transations of the American Fisheries Society* **114**, 532-39.

Sanzo, L. (1931). Uova stadi embrionali e post-embrionali di *Naucrates ductor. L. Mem. R. Com. Talassogr. Ital.* 185.

Shepherd, J. G., and Cushing, D. H. (1980). A mechanism for density-dependant survival of larval fish as the basis of a stock-recruitment relationship. *Journal du Conseil, Conseil International pour l'Exploration de la Mer* **39**, 160-67.

Smith, P. E. (1985). A case history of an anti-El Niño to El Niño transition on plankton and nekton distribution and abundances. In W.S. Wooster and D.L. Fluharty, (eds), El Niño north: Niño effects in the eastern subarctic Pacific Ocean, pp. 121-42. Washington Sea Grant Program, University of Washington, Seattle.

Tanaka, K., Mugiya, Y., and Yamada, J. (1981). Effects of photoperiod and feeding on daily growth patterns in otoliths of juvenile *Tilapia niclotica. US National Marine Fisheries Service Bulletin* **79**, 459-65.

Theilacker, G. H. (1978). Effect of starvation on the histological and morphological characteristics of jack mackerel, *Trachurus symmetricus*, larvae. *US National Marine Fisheries Service Bulletin* **76**, 403-14.

Theilacker, G. H. (1985). Starvation-induced mortality of young sea-caught jack mackerel, *Trachurus symmetricus*, determined with histological and morphological methods. *US*

National Marine Fisheries Service Bulletin **84**, 1-17.

Thomas, R. M. (1986). Growth of larval pelagic fish in the south-east Atlantic from daily growth rings in 1982/83 and 1983/84. *South African Journal of Marine Science* **4**, 61-77.

Thresher, R. E., Bruce, B. D., Furlani, D. M., and Gunn, J. S. (1989). Distribution, advection and growth of larvae of the southern temperate gadoid, *Macruronus novaezelandiae* (Teleostei: Merlucciidae), in Australian coastal waters. *US National Marine Fisheries Service Bulletin* **87**, 29-48.

Victor, B. C. (1986). Delayed metamorphosis with reduced larval growth in a coral reef fish (*Thalassoma bifasciatum*). *Canadian Journal of Fisheries and Aquatic Sciences* **43**, 1208-13.

Warlen, S. M. (1988). Age and growth of larval gulf menhaden, *Brevoortia patronus*, in the northern Gulf of Mexico. *US National Marine Fisheries Service Bulletin* **86**, 77-90.

Warlen, S. M., and Chester, A. J. (1985). Age, growth, and distribution of larval spot, *Leiostomus xanthurus*, off North Carolina. *US National Marine Fisheries Service Bulletin* **83**, 587-99.

Williams, H., Pullen, G., Kucerans, G., and Waterworth, C. (1987). The jack mackerel purse seine fishery in Tasmania,1986-1987.*Tech Rep.Mar. Lab Dep Sea Fish (Tasm)* **19**.

Young, J. W., and Davis. T. L. O. (1992). Feeding ecology, and interannual variations in diet of larval jack mackerel, *Trachurus declivis* (Pisces: Carangidae) from coastal waters of eastern Tasmania. *Marine Biology (Berlin)***110**, in press.

Table 1. - Summary of sampling dates in 1989 and 1990 and number of *Trachurus declivis* larvae used for otolith examination.

Cruise	Date	No. analyzed
89-1	11-14 January 1989	290
89-2	23-26 January 1989	165
89-3	27 February - 2 March 1989	48
90-2	5-8 January 1990	62
90-3	22-22 January 1990	138

Table 2. - Predicted absolute growth rates (mm day^{-1}) of *Trachurus declivis* larvae at various ages from first feeding in 1989 and 1990.

Age (days)	1989	1990
5	0.202	0.220
10	0.262	0.287
15	0.340	0.376
20	0.441	0.492
25	0.572	0.646

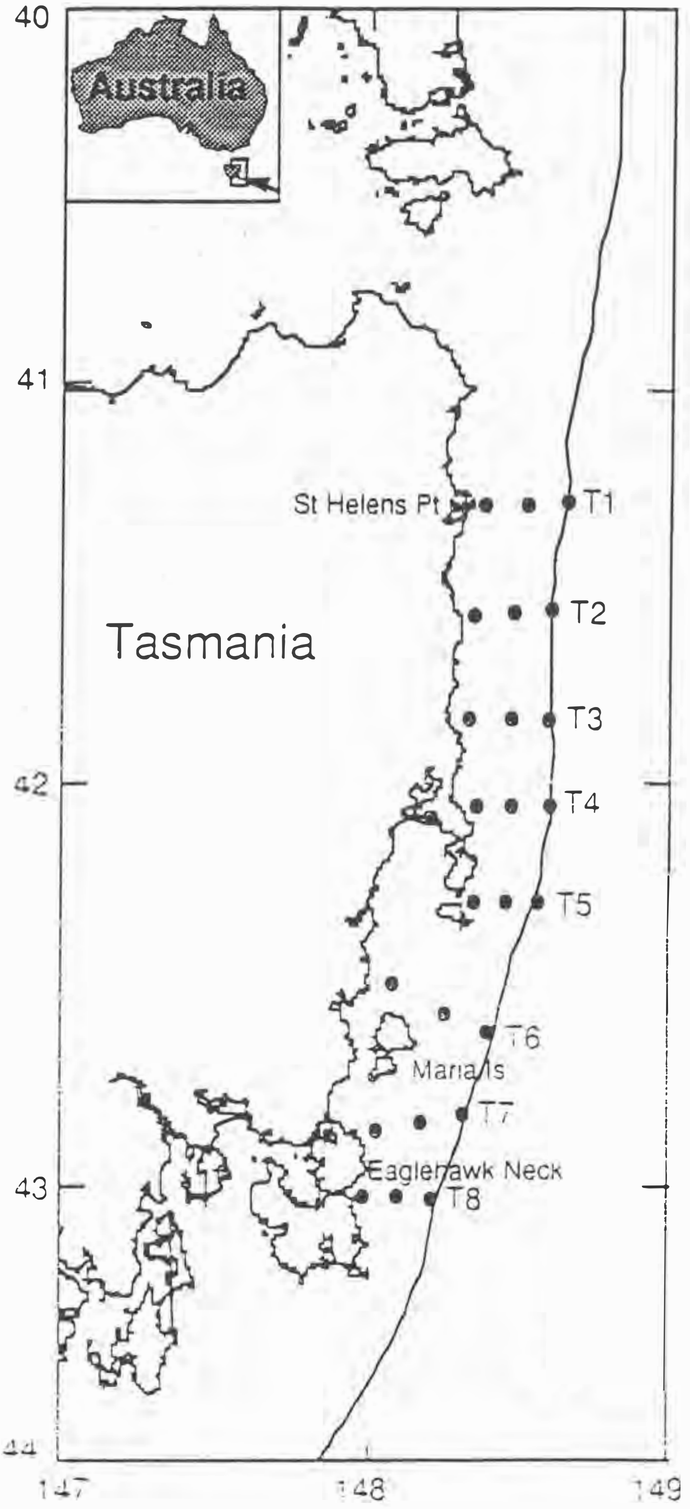


Figure 1. Location of sampling stations for *Trachurus declivis* larvae on the east coast of Tasmania, Australia.

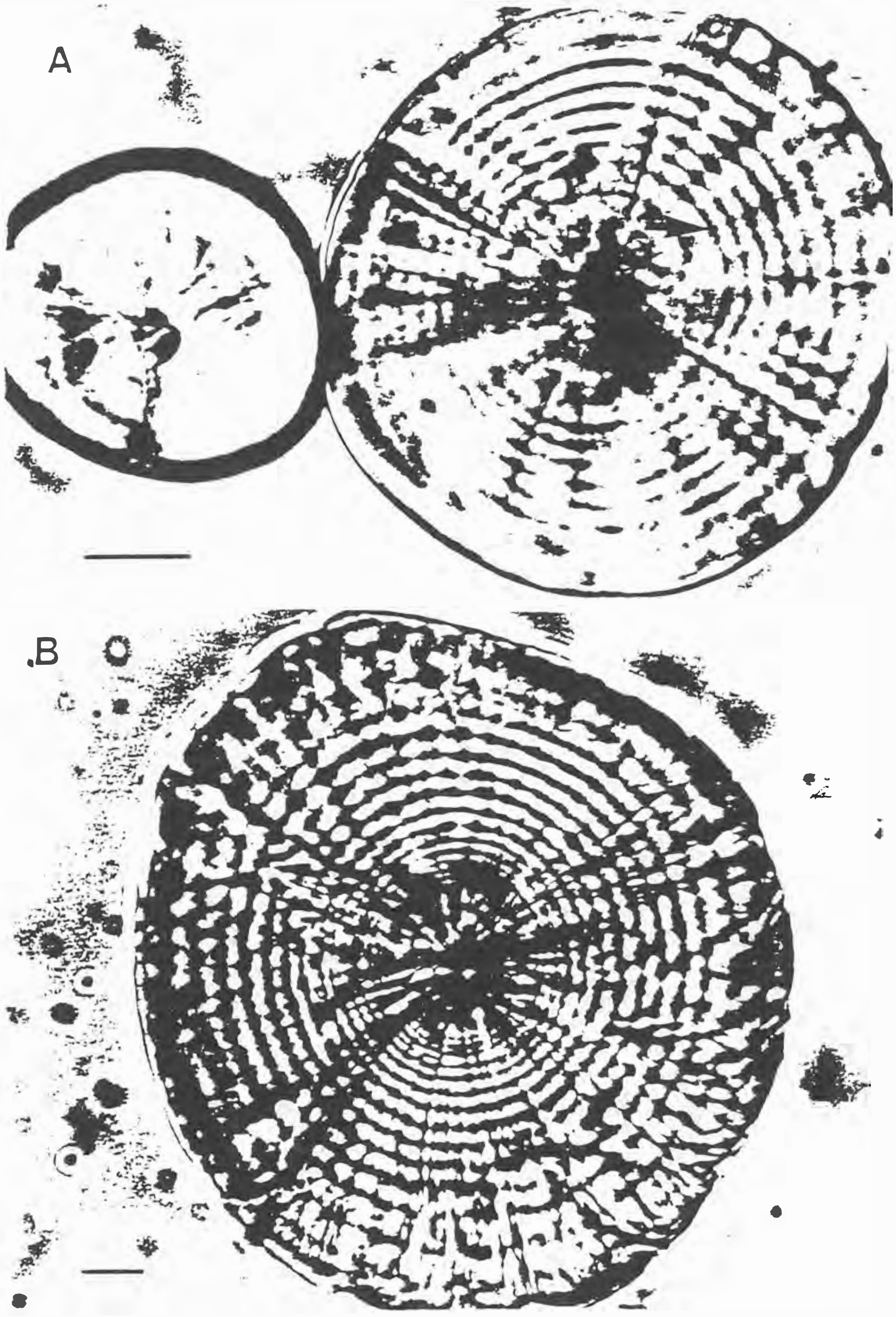


Figure 2. Light micrographs of *Trachurus declivis* otoliths. A. Sagittae and lapillus from a 5.31 mm larvae. Arrowhead indicates the distinct first-feeding increment. B. Sagittae from a 7.06 mm larvae estimated to be 15 days post-first feeding. Growth increments appear as pairs of wide incremental and narrow discontinuous bands. Bars = 10 um

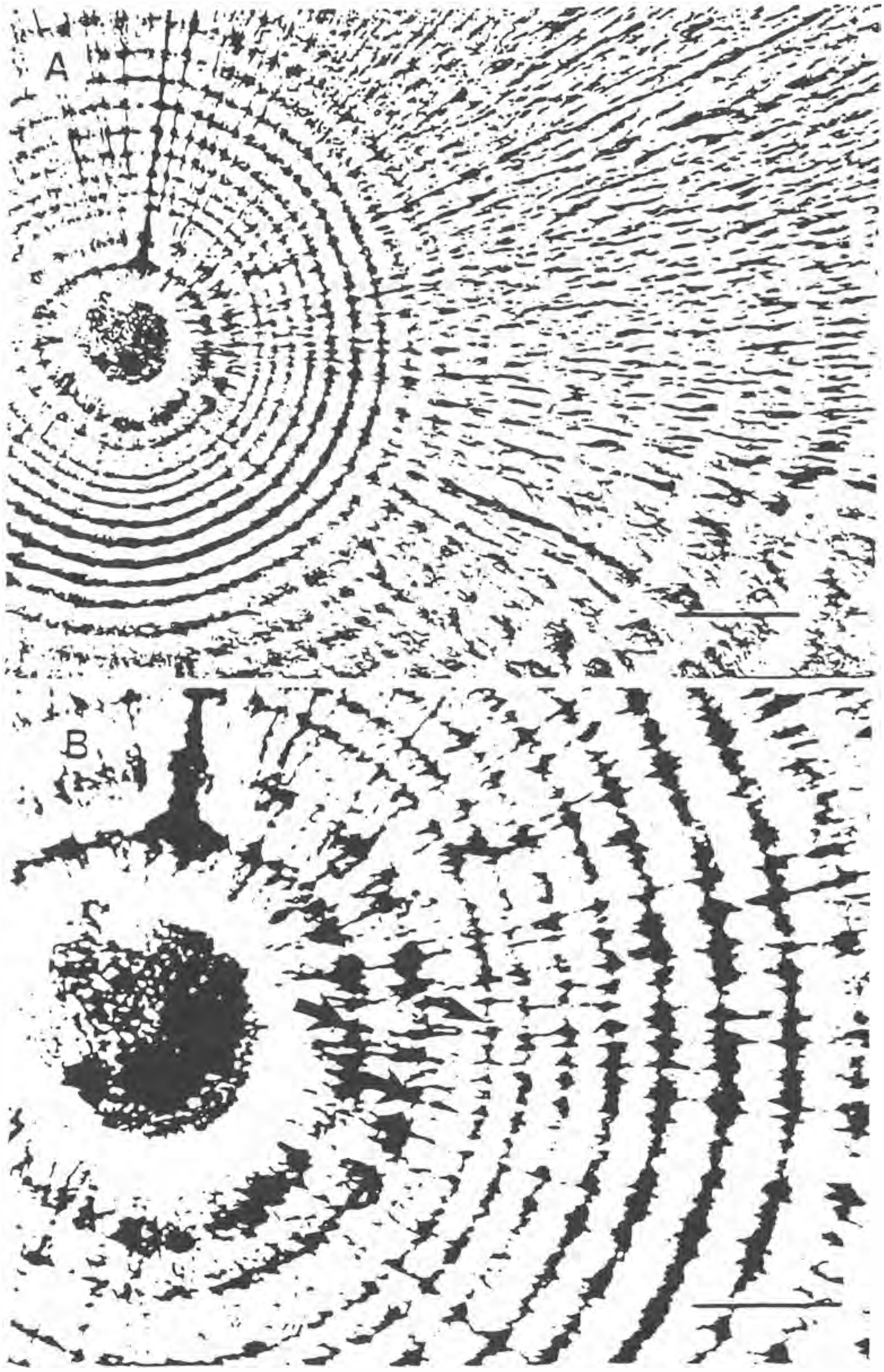


Figure 3. Scanning electron micrographs of otoliths. A. Sagittae from a 8.38 mm larvae showing microstructure of growth increments. Bar = 10 um. B. Central region of sagittae from the same larvae showing the difference between the structure of the two diffuse increments in the core region of the otolith (large arrow heads) immediately interior to the distinct first feeding increment (small arrow head). Bar = 5 um.

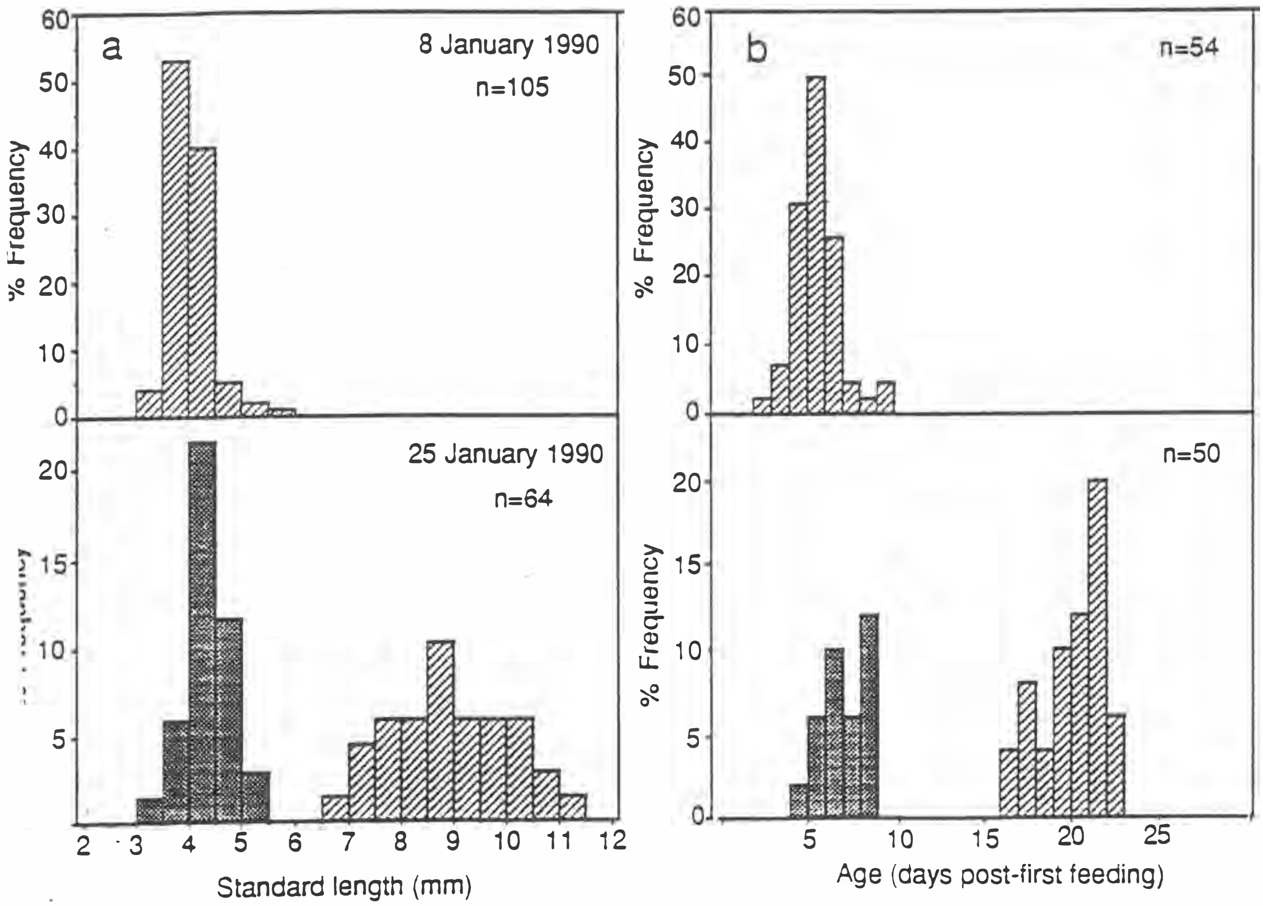


Figure 4. (a) Size frequency distribution of larval *Trachurus declivis* collected from T1 on two sampling dates in January 1990. (b). Age frequency distribution for subsample of larvae from populations in 4a.

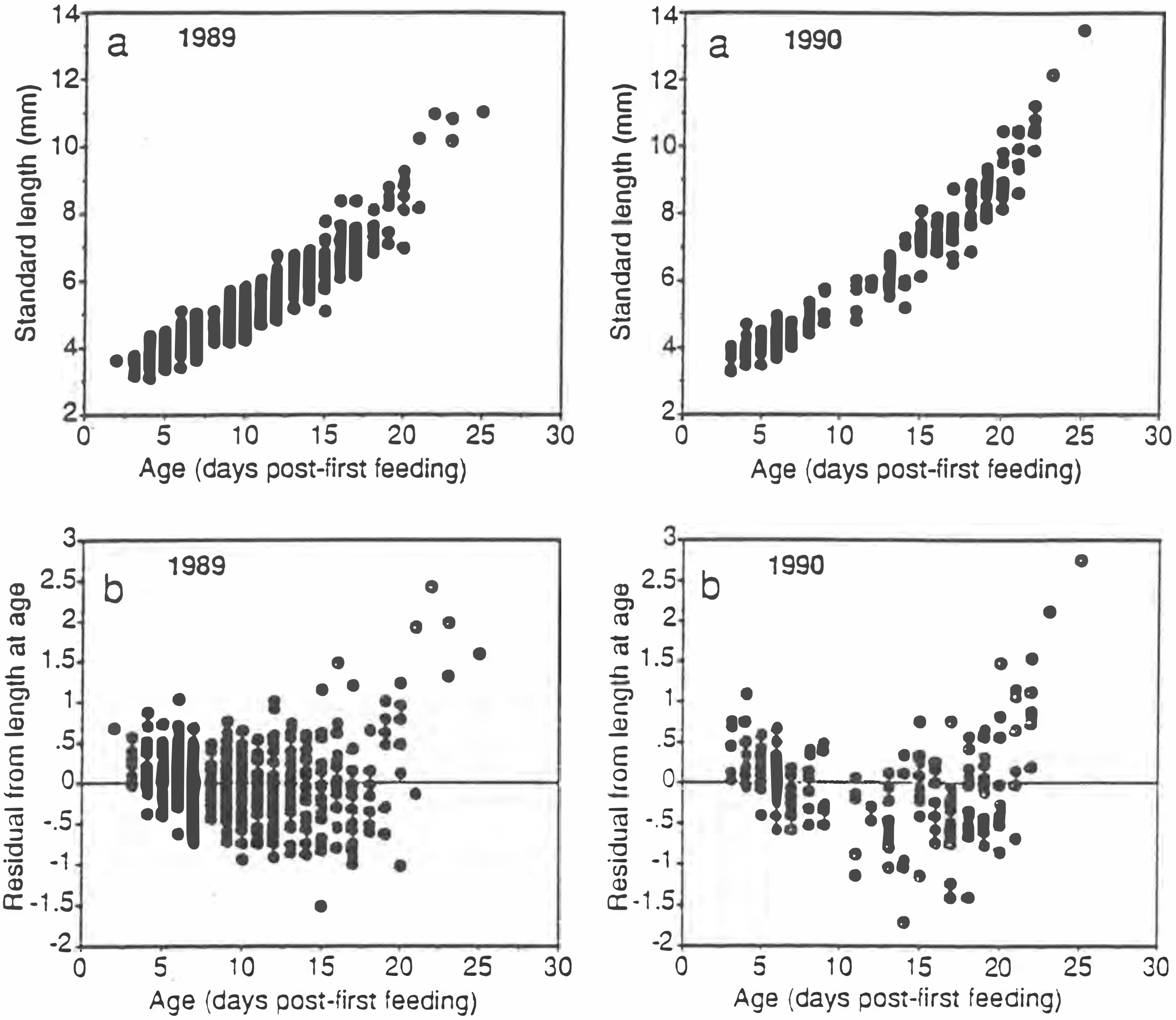


Figure 5. (a). Relationship between standard length and estimated age (days post-first feeding) for larvae collected in 1989 and 1990.
(b). Distribution of residuals from the semi-log regression of standard length against age (days post-first feeding) for larvae in 1989 and 1990 shown in 5a. Distributions show increasing variance in length with age.

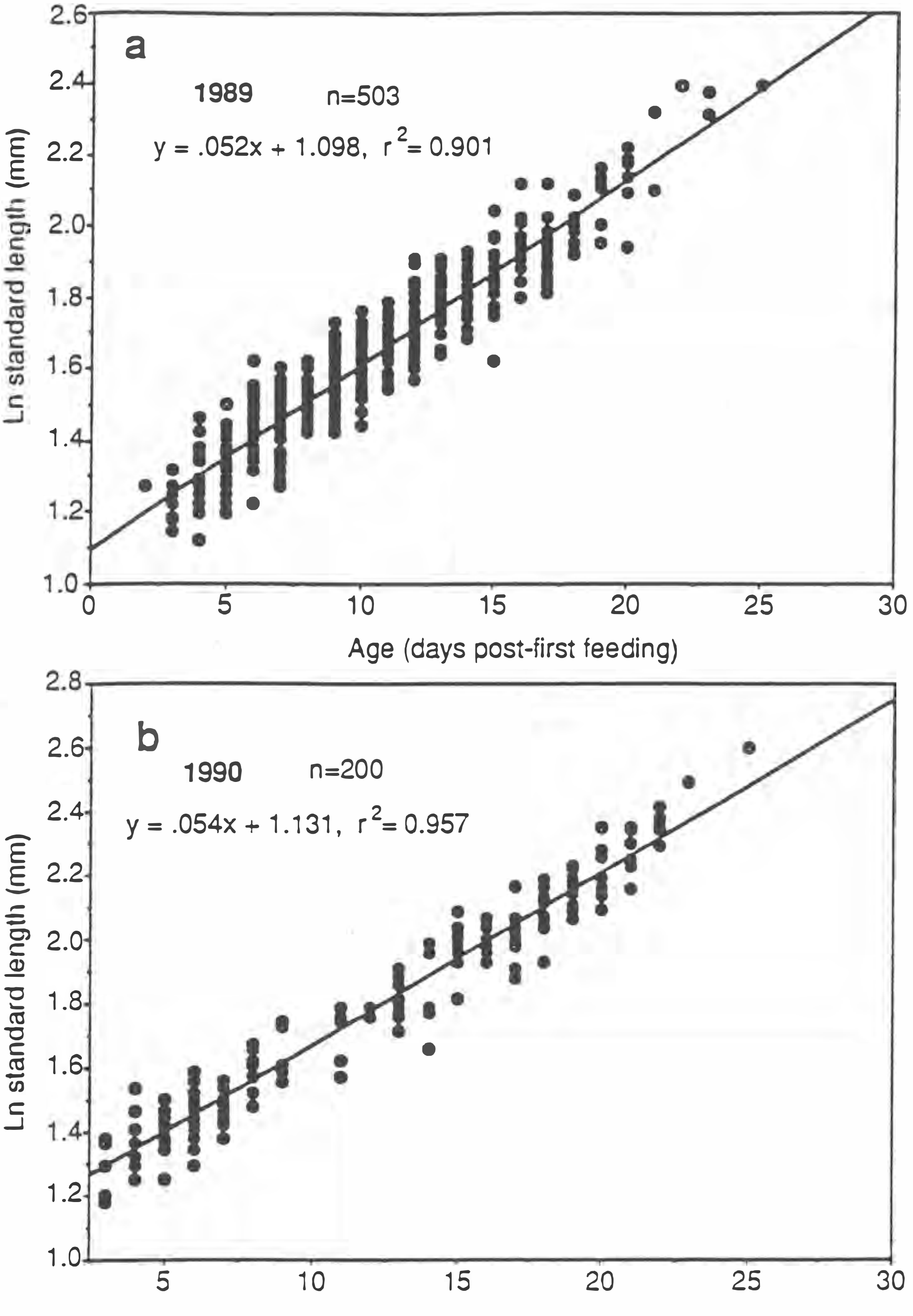


Figure 6. Regressions of ln standard length against age (days post-first feeding) for Trachurus declivis larvae collected in (a) 1989 and (b) 1990. Differences in the slopes of the regressions are significant at $p< 0.05$.

DOCUMENT 7

Reproductive biology and sexual maturity of jack mackerel, *Trachurus declivis*, in eastern Tasmanian waters

TO BE SUBMITTED TO AUSTRALIAN JOURNAL OF
MARINE AND FRESHWATER RESEARCH

Reproductive biology and sexual maturity of jack mackerel, *Trachurus declivis* (Jenyns) in eastern Tasmanian waters.

J. Marshall, G. Pullen, and A. Jordan

Sea Fisheries Research Laboratories, Department of Primary Industry, Crayfish Point, Taroona,
Tasmania 7053, Australia.

Abstract

The reproductive biology of jack mackerel, *Trachurus declivis*, was determined from fish sampled during the spawning season of 1987 and 1991 from commercial purse seine catches and research trawling. Histological, microscopic and macroscopic techniques were used to examine the ovaries of *T. declivis*. Half of the adult fish were sexually mature (stage 3) at 31.5 cm FL and all fish were mature by 37.0 cm FL. Oocyte development and pre-ovulatory atresia is similar to other species of the same genus. Oocyte diameter size-frequency showed a polymodal distribution, indicative of serial spawning. Atresia was present in all oocyte stages studied, with their occurrence increasing with increasing stage of development. Despite sampling during the spawning season, post-ovulatory follicles were not found, possibly due to rapid reabsorption or spawning fish not being vulnerable to the sampling gear.

Introduction

Jack mackerel, *Trachurus declivis*, supports a substantial fishery in south east Tasmanian waters with landings peaking at almost 40,000 tonnes in the 1986/87 season (Williams et al. 1987). The fishery is based around large seasonal surface and sub-surface schools that appear on the shelf on the east coast of Tasmania between November and May (Williams et al. 1987). Schools are targeted by purse seine vessels operating predominantly in inshore waters.

Reproductive biology and oocyte development have been studied in several *Trachurus* species, namely *Trachurus symmetricus* (MacGregor 1976), *Trachurus trachurus* (Macer 1974, Hecht 1990), *Trachurus murphyi* (Kaiser 1973, Andrianov 1985) and *Trachurus japonicus* (Chigirinskiy 1970). These studies found *Trachurus* species to be serial spawners, except Kaiser (1973) who reported a single spawning habit for *T. murphyi* in Chilian waters.

The results detailed here are part of an ongoing program investigating the biology of *Trachurus declivis* in east coast Tasmanian waters. In this paper we present data on oocyte development, size at sexual maturity, spawning habit, and atresia in *T. declivis*.. The implications of the reproductive biology in the application of the egg production method to this species are considered.

Methods

Sampling regime

Specimens were collected from the commercial purse seine fishery and the Fisheries Research Vessel 'Challenger' using demersal trawl fishing gear. Most fish were caught on the east coast of Tasmania (Fig 1), between November 1987 and January 1991. A maximum of 20 fish were sampled at random from each commercial or research catches for histological purposes, and up to 50 fish from the commercial fishery for length frequencies. The fork length of each fish was measured to the nearest centimetre below. Fish were sexed and the macroscopic gonad stage was determined using criteria modified from Blackburn and Gartner (1954), as in Table 1. One or both ovaries were fixed for a minimum of 2 weeks in 10% formalin in sea water buffered with 4% ß-glycerophosphate.

Length at maturity

Length at first sexual maturity ($LD_{0.50}$) was defined as the fork length (FL) at which 50 % of females, collected over the spawning season, were mature. Ovaries were considered mature if their most advanced oocytes were yolked or ripe (the equivalent of stage 3 or greater). Only fish sub-sampled from the commercial catch during the known spawning season , December to March (A. Jordan, unpubl. data), were used for the analysis. Confidence limits for proportions were calculated for the data (Zar 1984. p378), then fitted with a logistic curve in GENSTAT using a 'logit link function'. The $LD_{0.50}$, $LD_{0.25}$ and $LD_{0.75}$ was calculated with 99% confidence limits

Histology

Sections of ovary 5mm thick were placed in plastic cassettes and soaked in 70% ethanol plus 10% glycerol for a minimum of 3 days before being processed. A Tissue-Tek Vacuum Infiltration Processor was used on an ethanol, toluene, and Paraplast-Plus based process (Drury *et al.* 1973). The sections of material were blocked in paraffin wax, cut at 6 µm and stained in Harris' haemotoxylin and eosin (H&E), or a one-solution triacid stain (Steedman 1970).

In many studies, no significant differences in oocyte frequency distribution has been found between right and left ovaries (West 1990, Laroche and Richardson 1980, DeMartini and Fountain 1981). However average oocyte size may vary along the length of the ovary (West 1990). To test for differences of oocyte size within the ovary, 5 to 10 sections from each of 3 ovaries were used for comparison. No significant difference in average oocyte size was found between transverse section in the ovaries (ANOVA: Ovary 1, F=2.64, df=(4,35), p>0.05; Ovary 2, F=3.29, df=(7,71), p>0.05; Ovary 3, F=2.858, df=(7,72), p>0.05). Therefore, random transverse sections were taken for all gonads used histologically and microscopically.

For assigning histological oocyte developmental stages we used terminology defined by Yamamoto (1956) and staging criteria from West (1990) . Details of oocyte staging are presented in Table 1. Only oocytes that were sectioned through the nucleus were included in the oocyte diameter measurements.

West (1990) and Wallace et al. (1987) in reviewing oocyte development in teleosts found classification of the most advanced type of oocyte will present an accurate indication of gonad development. This procedure was used for histological gonad staging.

Atretic follicles were identified from the descriptions of Hunter and Macewicz (1980, 1985a). Atretic gonads were noted as a positive/negative occurrence. Proportions of ovaries at maturity stages 2, 3, and 4 that had atretic eggs were calculated as a percentage. Atresia in ovaries at stages 1, 5, and 6 were not analysed due to small numbers of gonads collected.

Atretic oocytes were distinguished from atretic post-ovulatory follicles by the occurrence of cuboidal hypertrophic granulosa cells (Hunter and Macewicz 1985a), rather than columnar follicle cell in a convoluted structure which are found in the former (Hunter and Goldberg 1980).

Size-frequency distributions

Size-frequency distributions of oocytes from stages 2 to 5 were obtained by teasing apart an ovarian lamellae and examining the oocytes in water under a stereo microscope using transmitted light and brightfield illumination. The ovarian lamellae was removed from a 1 cm transverse section of the gonad. Oocyte diameter was measured as the maximum diameter of the oocyte on a random orientation. Whole oocytes were classified according to Davis and West (1991), as in Table 1.

Results

Length at maturity

Ovaries were considered mature if the the oocytes had entered vitellogenesis (stage 3). A logistic curve fitted to the portion of mature females (Fig 2) gave a $LD_{0.50}$ value of 31.5cm (99% CL 31.0 to 32.0cm). $LD_{0.25}$ and $LD_{0.75}$ were calculated as 29.6 (99%CL 29.1 - 29.9) and 33.4 (99%CL

33.0 - 34.0) respectively. All females greater than 37.0 cm FL were mature with the smallest fish in vitellogenesis being 23.4 cm FL.

Histological ovarian development

Jack mackerel have gonads typical of a multiple spawning fish, with asynchronous oocyte development, ie. oocytes in many stages of development occurring simultaneously in reproductively active ovaries (Wallace and Selman 1981).

Oocytes less than 35 µm constitute the reservoir of oocytes that are present year round in active as well as non-active ovaries. The following descriptions refer to the oocyte stage rather than the gonadal stage as in Table 1. Ovarian development was similar to that of other serial spawning fish as described by Wallace and Selman (1981), West (1990), Hunter and Macewicz (1980).

No chromatin nucleolar cells were noted in the single juvenile fish examined(FL= 14cm), whose ovary consisted of ovigerous folds (lamella) with a well developed blood supply. No sections showing migration of the nucleus towards the periphery were observed. Very few jack mackerel at stage 6 have ever been sampled in the fishery, therefore no histological information is available for this stage. The final stages of oocyte maturation are often difficult to follow in histological material because of the shrinkage and distortion of cells during processing and the loss of oocytes from the ovarian follicle during handling. Histological development of jack mackerel ovaries are described in figure 3.

Occurrence of atresia

Pre-ovulatory atretic oocytes in jack mackerel can be recognised by their irregular cell shape, break down of the granulosa, hypertrophy of the cuboidal cells (theca) around the periphery, and degradation of the interior inclusions (Hunter and Macewicz 1985a), possibly by phagocytosis (Davis et al 1977) (Fig. 3f).

Gonads with atretic oocytes were noted in all ovarian maturity stages studied, with higher occurrence in the later stages (Table 2). Within the gonad, the percentage of atretic oocytes increased with increasing stage of development. In stage 2 and 4 gonads atresia occurred predominantly in the most developed oocytes, where as in stage 3, atresia was noted to mostly occur as advanced reabsorption of yolked oocytes. As the cells were not viable, the gonad has still been classified as stage 3. No post-ovulatory follicles were noted in any gonads.

Ovarian Maturation

The size frequency distribution of oocytes in ovaries shows the developmental sequence of maturation (Fig. 4). Oocyte diameters clearly show polymodal distribution, with peaks corresponding to size ranges shown in the macroscopic stages (Table 3) with some overlap between the stages. The occurrence of all oocyte stages present in stage 5 (ripe) ovaries represents asynchronous oocyte development indicating that *T. declivis* is is a serial spawner. However it is not possible to predict the number of spawnings from modes in the size frequency distribution (Hunter and Goldberg 1980).

DISCUSSION

Length at maturity

The smallest *T. declivis* that contained yolked oocytes (stage 3) was 23.4 cm FL, similar to Webbs (1976) results of 24.0-24.9 cm TL. Stevens (1984) using a similar but purely macroscopic criteria (stage 3) estimated *T. declivis* from the Great Australian Bight attains sexual maturity at lengths of 16-18 cm FL. Fish from this region are known to be a different stock from those in east coast Tasmanian waters (Lindholm and Maxwell 1988).

The $LD_{0.50}$ of 31.45 cm FL does not correspond with Webbs (1976) statement that the majority of fish above 27 cm TL are mature. Webb (1976) used a criteria of all fish at macroscopic stage 2 and above being sexually mature, which may have lowered his mean maturity estimates. Vitellogenesis (stage 3) is a more accurate and frequently used indication of sexual maturity (DiMartini and Fountain 1980, Hecht 1990, Andrianov 1985), and as such, we feel our estimates are a closer estimation of size of sexual maturity.

The $LD_{0.25}$ and $LD_{0.75}$ values (29.55 cm FL and 33.41 cm FL) indicates a broad range of sizes which at or over sexual maturity occurs. Variation in body size at first sexual maturity is a feature common to serial spawners and fishes in general (Nikolskii 1969). Although the logistic curve has provided tight 99% confidence limits around the $L_{0.50}$ value, there is significant residual deviance which indicates binomial error. There are two possible upward biases for this error. One being the discontinuity of the data due to restrictions in the sampling regime, and the other is the ability of mature fish to rapidly reabsorb the gonad through atresia and hence appear to be immature.

Sampling bias may occur as fish for this analysis were sampled exclusively from the commercial fishery. Williams et al (1987) reports that the mean length of fish caught by the fishery decreases markedly during the spawning season, postulating that this results from mature fish moving out onto the shelf break to spawn reducing their vulnerability to the fishery. However, the presence of mature fish in the fishery at this time suggests that there may be some movement of fish between the shelf break spawning area and inshore waters during the spawning season. Hecht (1990) suggested *T. trachurus capensis* also moves to the shelf break to spawn. Andrianov (1985) noted a marked decrease in commercial catches of spawning or ripe fish of *T. murphyi* during the spawning season, suggesting there is migration of the spawning population away from the fishery at this time.

Estimates of length at maturity for other *Trachurus* species vary considerably. Hecht (1990) estimates an $LD_{0.50}$ of 32.0 cm TL for *T. trachurus capensis* , stating that all fish were mature by 36.0 cm TL. Kerstan (1985) estimates the $LD_{0.50}$ for *T. trachurus* at 25.4 cm TL, however, he does not state the criteria used to determine maturity. Andrianov (1985) reports that more than 50% of female *T. murphyi* are mature at 39-42cm FL.

Ovarian development

Histologically, the process of oocyte development in *T. declivis* ovaries is similar to other *Trachurus* species such as *T. murphyi* (Andrianov 1985) and *T. trachurus* (Macer 1974). The presence of oocytes at different growth phases in single histological sections confirms the asynchronous nature of oocyte development.

Peaks of oocyte diameters do not correlate closely to histologically recognisable stages of oocytes, but do coincide with visual whole oocyte staging. Davis (1982) found that histologically sectioned oocytes were on average 13% smaller than formalin preserved oocytes. It is recommended that macroscopic gonodal staging is used in conjunction with histology to verify staging techniques.

Atresia

The function of reabsorption of residual oocytes after spawning is to remove unwanted material, however the reason for pre-ovulatory degradation is not well understood (Macer 1974), but may be related to environmental and dietary factors (Hunter and Macewicz 1985a).

In *T. declivis* pre-ovulatory atresia was most common in oocytes with advanced yolk formation (stage 4), but less advanced oocytes were also affected. Other authors have found that atresia is more common in yolked than unyolked oocytes (Hunter and Macewicz 1985a). These results are similar to that for *T. trachurus* (Macer 1974), which also showed variability between oocyte batches and stages. Hunter and Macewicz (1985a) found food ration, level of energy reserves, timing of the reproductive cycle and perhaps certain environmental conditions such as temperature and daylength affect the atresia rate in *Engraulis mordax*, another serial spawner. Given sufficient food after starvation, atresia stopped, maturation and vitellogenesis returned, and a reproductively active ovary was rapidly reformed (Hunter and Macewicz 1985a). Incidence of spawning in females with atretic ovaries would be expected to be low during the spawning season and high at the end of the spawning season (Hunter and Macewicz 1985a).

Gonads with both atretic and viable advanced stage 4 oocytes have been noted in *T.declivis*, although it is not known what proportion of the developing oocytes will reach ovulation. Atresia occurred predominantly in yolked (stage 4) oocytes of *T. declivis* gonads, which may indicate greater sensitivity at this developmental stage to changing environmental factors. *T. declivis* showed atresia in oocytes from stage 2 gonads, which may infer that the gonads are able to be reabsorbed at any developmental stage. However, Macer (1974) found that atresia only occured in yolked oocytes of *T. trachurus*

Hunter and Macewicz (1985a) have defined that to obtain a quantitative assessment of oocyte atresia, it is necessary to sample throughout the spawning season from a range of size classes as seasonal, biological and environmental factors influence rates of atresia. While it has not been possible using the present incomplete data to make these assessments in *T. declivis*, we feel it is important to study the implications of atresia,. The affect of atresia on fecundity may be under estimated since the duration of atretic stages is short and small standing stocks of atretic oocytes could be an indication of a high loss rate over the entire season (Hunter and Macewicz 1985a).

Post-ovulatory follicles have been shown to be rapidly reabsorbed in a number of temperate species, including *E. mordax* which reabsorb post-ovulatory follicles to a form that are indistinguishable from atretic follicles within 48 hours (Hunter and Goldberg 1980). No structures which could positively be identified as post-ovulatory follicles were noted in *T.declivis*. Several factors could be influencing these results. Firstly, as fish are thought to spawn on the shelf break, as suggested by Williams et al. (1987) it is likely that post-ovulatory follicles are reabsorbed by the time the fish are vulnerable to the inshore commercial fleet. However, the reduced vulnerability of spawning fish to the fishery would also result in reduced incidence of post-ovulatory follicles. Research trawling on the shelf break may also undersample the spawning population as jack mackerel are able to avoid trawl gear at normal trawl speeds (3.0 kts) (Jones 1990), the speed used in this study.

Secondly, a relatively small portion of the oocytes are released at any one time suggesting that unless gonads are sampled frequently the probability of observing post-ovulatory follicles is low (Macer 1974). The lack of post-ovulatory follicles appears to be common in other *Trachurus* species. Both Macer (1974) and Andrianov (1985) found empty follicles to be scarce in *T. trachurus* and *T. murphyi* respectively, resulting from rapid resorption of follicles, low frequency of samples and reduced availability of spawning fish.

Reproductive strategy

Similar oocyte diameter distributions as described for *T. declivis*, indicative of serial spawning, have been described for other species of *Trachurus* including *T. trachurus* (Macer 1974, Hecht 1990), *T. japonicus* (Chigirinskiy 1970) and *T.symmetricus* (MacGregor 1976). Kaiser (1973) reported a single spawning habit for *T. murphyi* in Chilian waters but more recently Andrianov (1985) has found the same species to have a prolonged spawning season on the Peruvian shelf, possibly spawning in batches, but no evidence of clear polymodal size composition in oocyte diameter.

Neither the spawning frequency nor the number of egg batches spawned each season have been determined for any *Trachurus* species. Estimates of spawning frequency require either the determination of the percentage occurrence of postovulatory follicles or the incidence of females with hydrated oocytes (Hunter and Macewicz 1985b). Neither stage could be adequately sampled n *T. declivis* due to low vulnerability of spawning fish, as previously discussed.

dentifying the oocytes which are potentially capable of release in a current season causes roblems in estimating annual fecundity for serial spawning fish . One approach by Macer (1974) as been to estimate the number of yolked (Stage 4) oocytes in each batch. But it is not possible to stimate the number of batches in one season from the number of size-frequency modes of oocytes lready present in the gonad, as new batches of oocytes are continually being recruited through ogenesis. Also, batch fecundity can vary in different age classes and throughout the season Parrish et al. 1986), and pre-ovulatory atresia could create a substantial difference between otential and actual fecundity (Macer 1974, Hunter and Macewicz 1985). Hence, to determine nual fecundity in *T. declivis* estimates of batch fecundity, spawning frequency and rates of resia are required, all of which have proven impossible given the current problems involved in mpling the spawning population.

Acknowledgements

We thank people in the Tasmanian Division of Sea Fisheries who assisted in this project including H. Williams, G. Kucerans, C. Waterworth and P. Machin. We thank the captain and crew of the FRV Challenger for assistance in this study. Thanks also to the purse seine skipper and crews for their help . D. Ratkowski and H. Williams provided assistance with statistics. Special thanks to G. West for his encouragement and assistance with the interpretation of the histological material. The funds for this study were provided by the Fishing Industry Research Development Council (FIRDC), grant number (DFT2Z).

References

Andrianov, D. P. (1985). Study on the reproduction of Peruvian scad, *Trachurus murphyi*, (Carangidae), of the Peruvian Shelf. *Journal of Ichthyology* (English translation of *Voprosy Ikhtiologii*) **25(2)**, 32-40.

Blackburn, M., and Gartner, P. E. (1954). Populations of barracouta, *Thysites atun* (Euphrasen), in Australian waters. *Australian Journal of Marine and Freshwater Research* **5**, 411-68.

Chigirinskiy, A. I. (1970). The nature of oogenesis and fecundity in the Japanese horsemackerel (*Trachurus japonicus*). *Journal of Ichthyology* (English translation of *Voprosy Ikhtiologii*) **10**, 755-60.

Davis, T. L. O. (1977). Reproductive biology of the freshwater catfish, *Tandanus tandanus* Mitchell, in the Gwydir River, Australia II. Gonodal cycle and fecundity. *Australian Journal of Marine and Freshwater Research* **28**, 159-69.

Davis, T. L. O. (1982). Maturity and sexuality of barramundi, *Lates calcarifer* (Bloch), in the Northern Territory and south-eastern Gulf of Carpentaria. *Australian Journal of Marine and Freshwater Research* **33**, 529-45.

Davis, T. L. O., and West, G. J. (In press) Maturation, reproductive seasonality, fecundity and spawning frequency in *Lutjanus vittus* (Quoy and Gaimard) from the North West Shelf of Australia. *U.S. National Marine Fisheries Service Fishery Bulletin*

DiMartini, E. E., and Fountain, R. K. (1981). Ovarian cycling frequency and batch fecundity in the Queenfish, *Seriphus politus*: attributes representative of serial spawning fishes. *U.S. National Marine Fisheries Service Fishery Bulletin.* **79**, 547-60.

Drury, R. A. B., and Wallington, A. E. (1973) Carleton's histological technique.(4th edition). Oxford University Press, New York.

Hecht, T. (1990). On the life history of cape horse mackerel *Trachurus trachurus capensis* off the South-east coast of South Africa. S. Afr. J. Mar. Sci. **9**, 317-326.

Hunter, J. R., and Goldberg, S. R. (1980). Spawning incidence and batch fecundity in northern anchovy, *Engraulis mordax. U.S. National Marine Fisheries Service Fishery Bulletin.* **77**, 641-652.

Hunter, J. R., and Macewicz, B. J. (1980). Sexual maturity, batch fecundity, spawning frequency and temporal pattern of spawning for the northern anchovy, *Engraulis mordax*, during the 1979 season. *CalCOFI Report* **21**, 139-149.

Hunter, J. R., and Macewicz, B. J. (1985a). Rates of atresia in the ovary of captive and wild northern anchovy, *Engraulis mordax. U.S. National Marine Fisheries Service Fishery Bulletin* **83**, 119-136.

Hunter, J. R., and Macewicz, B. J. (1985b). Measurement of spawning frequency in multiple spawning fishes. In Lasker, R (Ed) 1985. An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy *Engraulis mordax*. NOAA *Technical Report* No NMFS-36, 79-94.

Jones, J. B. (1990). Jack mackerels (*Trachurus* spp.) in New Zealand waters. *New Zealand Fisheries Technical Report*. **23**, 28p.

Kaiser, C. E. (1973). Gonodal maturation and fecundity of the horse mackerel, (*Trachurus murphyi*), off the coast of Chile. *Transactions, American Fishery Society* **102**, 101-108.

Kerstan, M. (1985). Age, growth, maturity, and mortality estimates of horse mackerel (*Trachurus trachurus*) from the waters west of Great Britain and Ireland in 1984. *Arch. Fisch. Wiss.* **36**, 115-154.

Laroche, J. L., and Richardson, S. L. (1980). Reproduction of the northern anchovy, *Engraulis mordax*, off Oregon and Washington. *U.S. National Marine Fisheries Service Fishery Bulletin* **78**, 603-18.

Lindholm, R. and Maxwell, J. G. H. (1988). Stock separation of jack mackerel *Trachurus declivis* (Jenyns, 1841) and yellowtail *T. novaezealandiae* (Richardson, 1843) in southern Australian waters, using principle components analysis. *CSIRO Marine Laboratories Report* 189,

Macer, C. T. (1974). The reproductive biology of the horse mackerel *Trachurus trachurus* (L.) in the North Sea and English Channel. *Journal of Fish Biology* **6**, 415-438.

MacGregor, J. S. (1976). Ovarian development and fecundity of five species of Californian current fishes. *CalCOFI Report* **18**, 181-188.

Nikolskii, G. V. (1969). Theory of fish population dynamics as the biological background for the rational exploitation and management of fishery resources. Oliver & Boyd. Edinb, 323p.

Parrish, R. H., Mallicoate, D. L., and Klingbeil, R. A. (1986). Age dependent fecundity, number of spawnings per year, sex ratio, and maturation stages in northern anchovy, *Engraulis mordax.U.S. National Marine Fisheries Service Fishery Bulletin*.**83**(3), 503-517.

Steedman, H. F. (1970). A one-solution triacid general stain which differentiates oxygenated from non-oxygenated red blood corpuscles. *Stain Technology* **45(6)**, 247-252.

Stevens, J. D., Hausfeld, H. F., and Davenport, S. R. (1984). Observations on the biology, distribution and abundance of *Trachurus declivis*, *Sardinops neopilchardus*, and *Scomber australasicus* in the Great Australian Bight. *CSIRO Marine Laboratories Report* **164**, 1-27.

Wallace , R. A., and Selman, K. (1981). Cellular and dynamic aspects of oocyte growth in teleosts. *American Zoologist* **21**, 325-43.

Wallace, R. A., Selman, K., Greeley, M. S. Jr., Begovac, P. C., Lin, Y-W., McPherson, R., and Petrino, T. R. (1987). Current status of oocyte growth. In 'International Symposium on Reproductive Physiology of Fish'. (Eds D. R. Idler, L. W. Crim and J. M. Walsh.) pp. 167-77. (Memorial University of Newfoundland: St Johns.)

Webb, B. F. (1976). Aspects of the biology of jack mackerel *Trachurus declivis* (Jenyns) from south east Australian waters. *Tasmanian Fisheries Research* **10**, 1-14.

West, G. (1990). Methods of assessing ovarian development in fishes: A review. *Australian Journal of Marine and Freshwater Research* **41**, 199-222.

Williams, H., Pullen, G., Kucerans, G., and Waterworth, C. (1987). The jack mackerel purse seine fishery in Tasmania, 1986-87. *Technical Report of the Marine Laboratories, Department of Sea Fisheries (Tasmania)* **19**, 32p.

Yamamoto, K. (1956). Studies on the formation of fish eggs. Annual cycle in the development of the ovarian eggs of flounder, *Liopsetta obscura*.. *Journal of the Faculty of Science, Hokkaido University, Series VI, Zoology* **12**, 362-73.

Zar , J. H. (1984). Biostatistical analysis (2nd Ed) Prentice -Hall, Inc., Englewood Cliffs, New Jersey. 718pp.

Table 1. Microscopic, macroscopic and histological staging criteria used for *Trachurus declivis*

Stage	Category	Microscopic Histological[a]	Macroscopic Ovary[b]	Microscopic Oocyte[c]
1.	Virgin	Chromatin nucleolar Clear spherical nucleus surrounded by a thin layer of cytoplasm. No nucleolus visible	Small strap with rounded edge, less than 3/4 of body cavity. Pink, firm texture.	Unyolked Spherical transparent bodies.
2.	Maturing virgins	Perinucleolar Thick homogeneous cytoplasm around a light nucleus containing few to many peripheral nucleoli. Yolk vesicle may be apparent.	Virgin - at least 3/4 of body length, pink and glassy. Recovering - as long as body cavity, bloodshot and flabby at posterior.	
3.	Developing	Yolk vesicle formation Yolk vesicles apparent in cytoplasm increasing in size and number with development. Zona radiata thickens, stains pink with H&E.	Almost length of body cavity, opaque and becoming yellow. Ova not discernible.	Partially Yolked Some granular nuclear material visible becoming darker with increased size but not opaque.
4.	Late Developing	Yolk granular stage Evenly distributed and uniform appearance of yolk vesicles, oil vesicles and eosinophilic yolk granules in cytoplasm. Peripheral nucleolus around a distinct nuclear membrane. Aggregation of oil vesicles in late stage.	Full length of body cavity, opaque and yellowish pink. Ova discrete.	Yolked Opaque bodies. Yolk surrounded by a translucent vitelline boarder.
5.	Ripe	Nuclear migration & Yolk Fusion Coalescence of yolk granules to form uniform 'plates'. Migration of nucleus to periphery of cytoplasm, visible nuclear material,and dissolution of nuclear membrane.	Full length of body cavity and swollen occupying all available space. Ovary and ova becoming transparent.	Nuclear migration Parts of oocyte become translucent as yolk coalesces. Ripe Large translucent bodies.
6.	Running Ripe	(Pre)Ovulation Hydration of cell, uniform pink staining yolk. String like appearance of thecal cells.	Eggs express with slight pressure. Ovary pinkish, clear and granular.	
7.	Spent	Spent Occurrence of recent post-ovulatory follicles.	Slack and bloodshot. Few residual oocytes present.	

---

[a] adapted from West (1990)
[b] adapted from Blackburn and Gartner (1954)
[c] adapted from Davis and West (in press)

Table 2; Incidence of atresia within and between gonads

Stage	% Atretic gonads	% Atretic oocytes	Predominant atretic stage	No. gonads examined
2	57.0	5.17 ± 1.99	2 (100%)	7
3	61.5	9.40 ± 1.74	3 (20%) 4 (80%)	9
4	64.7	10.13 ± 2.16	4 (100%)	24

Table 3; Mean oocyte diameter in mm

Stage	Mean	+/-SD	Range
Unyolked	0.075	0.036	0.02 - 0.24
Yolk visible	0.235	0.051	0.16 - 0.38
Yolked	0.544	0.117	0.28 - 0.74
Migratory nucleus	0.871	0.050	0.74 - 0.98

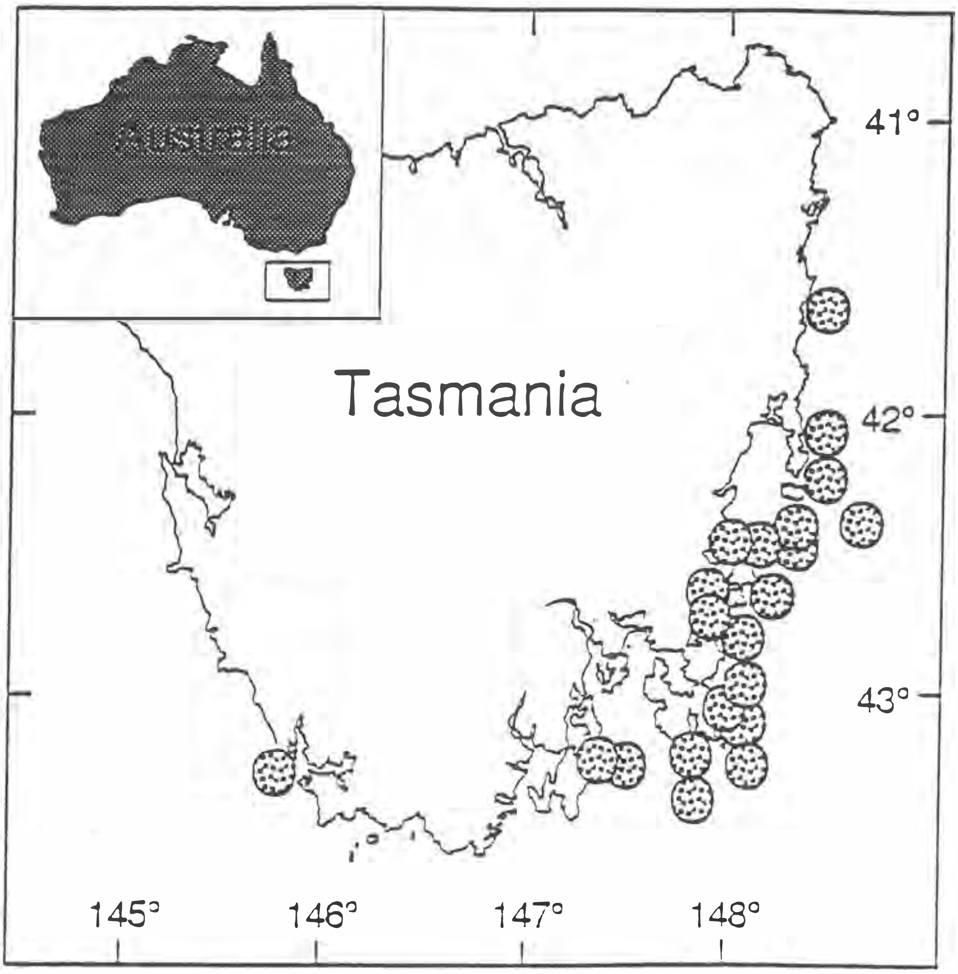


Figure 1. Study area. Circles show distribution of catches subsampled for analysis

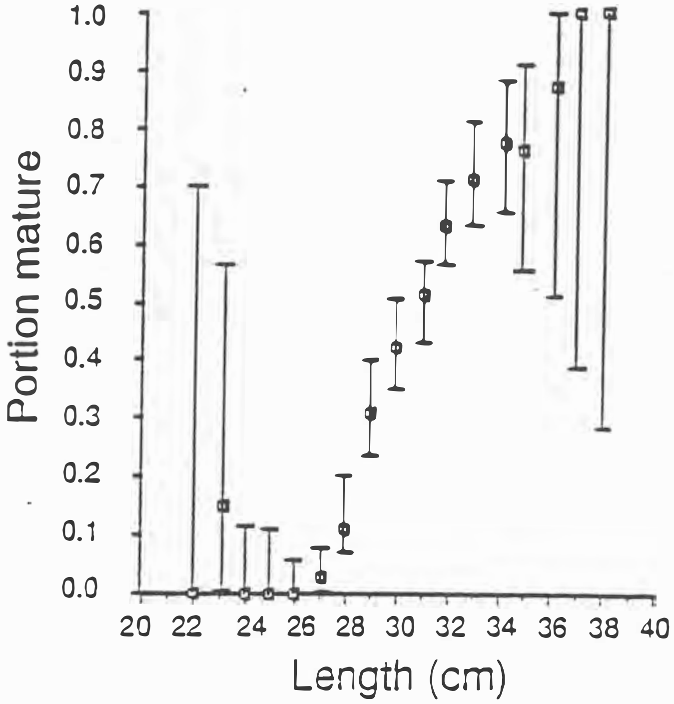


Figure 2. Proportion of mature females by 1 cm length classes (± 95% CL) for data collected at the height of the spawning season

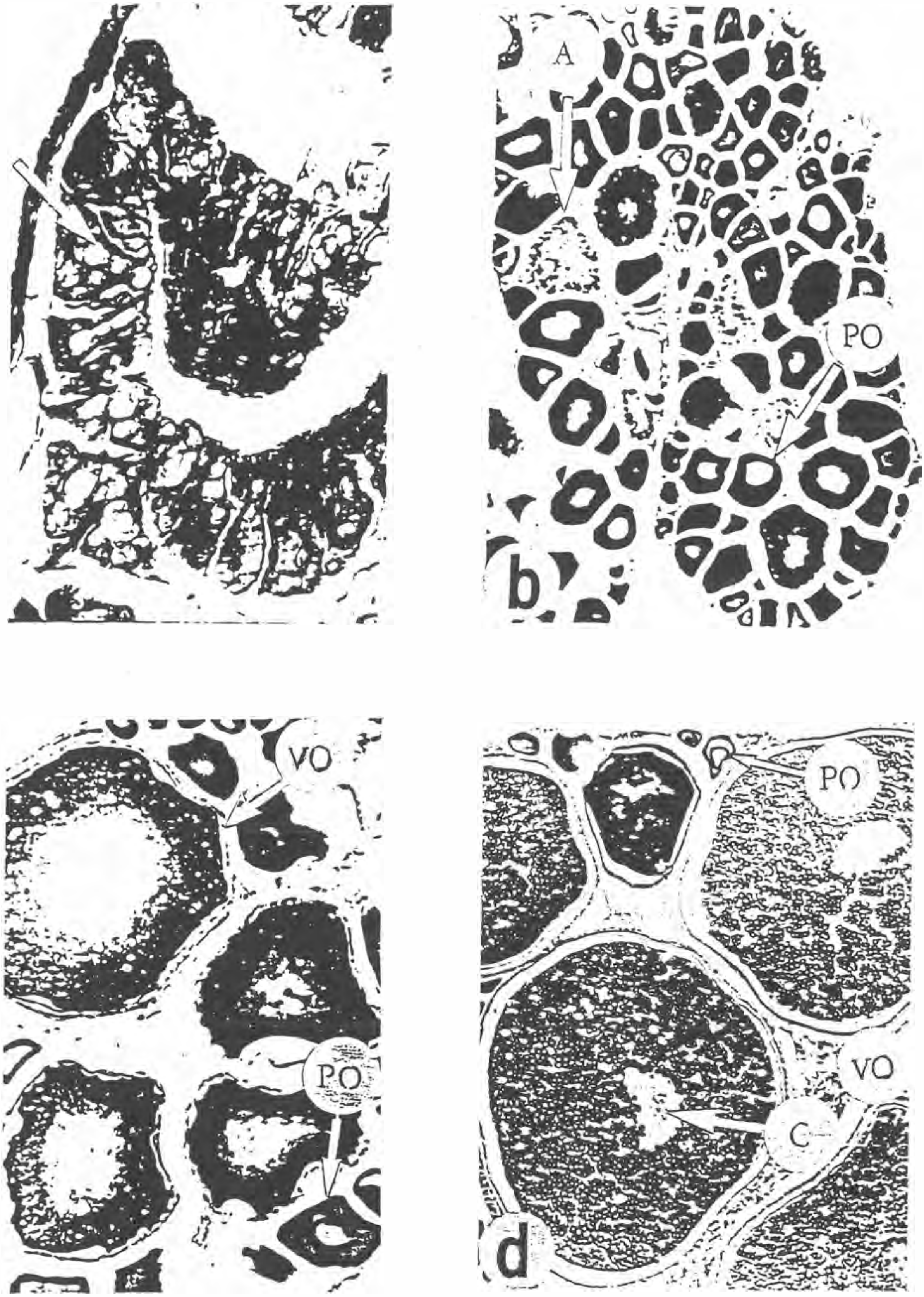


Figure 3. Microphotographs showing the development of oocytes.

(a) Stage 1 - Chromatin nucleolus; White spherical chromatin nucleolar bodies (O) are surrounded by small dense dark staining blood vessels. A thin layer of cytoplasm, not apparent in the photo, surrounds the nucleus.

(b) Stage 2 - Perinucleolar: The healthy pre-vitellogenic oocyte (PO) shows an oval nucleus with few peripheral nucleolii. The cytoplasm stains a dense uniform dark purple with (H&E). Micro villi may give the cytoplasm a granular appearence. Oocyte diameter 35 - 85 µm. Atresia may also occur in perinucleolar oocytes (A)

(c) Stage 3 - Yolk vesicle formation: The vitellogenic oocyte (VO) shows an increase in size and number of peripheral nucleolii in the nucleus. Vesicles appear within hte cytoplasm and the zona radiata bradens to a wide pink band with H&E. Oocyte diameter ranges from 100 to 130 µm. much larger than th perinucleolar oocyte (PO)

(d) Stage 4 - Yolk granular stage: eosinophplic yolk granules are uniform in size and consistancy in the cytoplasm of the yolk granular oocyte (VO) Lampbrush chromosomes (C) are visable as evenly dispersed rods throught eh centre of the nucleus. Oocyte diameter 250-480 µm.

(e) Stage 5: Nuclear migration and yolk fusion: the nuclear membrane has dissolved, releasing the nuclear material and the yolk granules or lipid droplets have coalesced to form yolk plates (YP) The irregular shape of the outer membrane is an artifact of processing.

(f) Atresia: a freshly atretic oocyte (Aa) has large cuboidal cells around the periphery, whereas an older atretic oocyte (Ab) shows little differentiation of the peripheral cells from the phagocytosed interior .

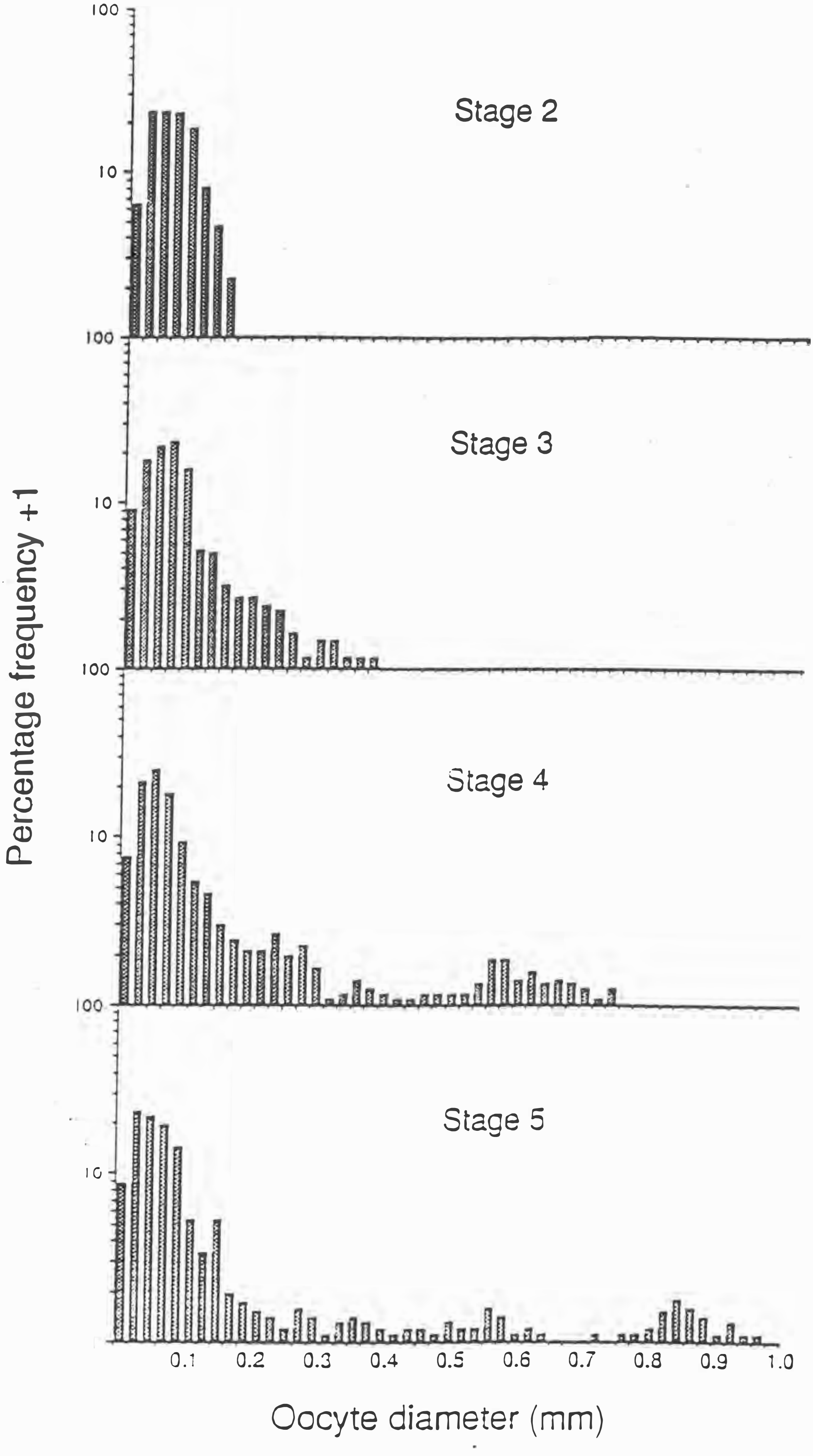


Figure 4. Oocyte frequency distribution and gonadal stage by 0.02 mm intervals in ovaries representing the development sequence of maturation

DOCUMENT 8

Schooling behaviour of jack mackerel, *Trachurus declivis* (Jenyns), observed in the Tasmanian purse seine fishery

SUBMITTED TO AUSTRALIAN JOURNAL OF MARINE
AND FRESHWATER RESEARCH

Schooling behaviour of jack mackerel, *Trachurus declivis* (Jenyns), observed in the Tasmanian purse seine fishery

Howel Williams and Grant Pullen

Sea Fisheries Research Laboratories, Department of Primary Industry, Fisheries and Energy,
Crayfish Point, Taroona, Tasmania, 7053.

bstract

e seasonal, lunar and diurnal changes in schooling of jack mackerel was examined using gbook information collected from an industrial fishery off the east coast of Tasmania between 85 and 1989. In addition the size composition of individuals within schools was examined.

hool size increased significantly from spring to autumn. The ratio between surface and bsurface schools encountered by the fishery also changed seasonally. Surface schools edominated during summer, whilst subsurface schools were targetted more frequently in tumn. The fishery is predominantly a day fishery and no lunar effects on catch rates or fishing tensity were detected.

tches are mainly comprised of jack mackerel although redbait (*Emmelichthys nitidus* chardson) and blue mackerel (*Scomber australasicus* Cuvier) are a significant by-catch. In mmer, schools are almost exclusively composed of jack mackerel whilst in other seasons mixed hools are found. The availability of schools to the fishery appears to be closely related to the ailability of feed. Jack mackerel school by length and a strong correlation between the mean size redbait and jack mackerel in mixed schools was found.

Introduction

Jack mackerel, *Trachurus declivis* (Jenyns), is an abundant neritic pelagic fish occurring throughout the coastal waters of southern Australia and New Zealand. In Australia, the species is restricted to southern waters from Shark Bay in Western Australia around to the mid New South Wales coast. Within this range there are at least two stocks, one occurring in the Great Australian Bight and the other in eastern Australian waters (Richardson 1982; Stevens and Hausfeld 1982; Lindholm and Maxwell 1988). Whilst the species is widely distributed, the greatest abundance of surface schooling fish in eastern Australian waters is found in Tasmanian coastal waters between 40°S and 44°S (Williams 1981).

Large surface schools occur seasonally; in the coastal waters off New South Wales jack mackerel form surface schools in spring and summer (Williams 1981), whilst off Tasmania, schools occur during summer and autumn (Williams et al. 1987). Although surface schools are not apparent during winter off eastern Tasmania, jack mackerel are taken in demersal trawls (Blaber and Bulman 1987; Williams, 1989).

The occurrence of large surface schools, particularly those off Tasmania, has attracted much speculation on the potential for a significant fishery (Blackburn and Tubb 1950; Hynd and Robins 1967). Until recently in Australia, the species was only lightly exploited, principally as a baitfish fishery. Reported annual catches in Tasmania prior to the early 1970s were less than 5 tonnes (additional quantities were taken by rock lobster fishermen to use as bait but were not reported). In 1972 an attempt was made to base an industrial fishery for fish meal on the resource off the east coast of Tasmania. That venture achieved total landings of 6 200 tonnes caught by purse seine in eight months. The venture failed for reasons not directly related to the resource (lack of markets and problems with producing fish protein concentrate) (Williams et al 1989).

A second attempt to found an industrial fishery was made in 1985. That venture proved successful and exhibited rapid growth in landings. In 1985 the then Tasmanian Department of Sea Fisheries commenced research to monitor the fishery and assess the potential yield of the resource. By the end of the third fishing year in 1987 annual landings had grown to 41,000 tonnes. Management, in form of quotas and a Total Allowable Catch was imposed by the Tasmanian Government at that e to restrain the growth of the fishery (Williams, 1987).

source assessments of jack mackerel have been attempted using fishery independent methods, ically aerial survey techniques (Hynd and Robins 1967; Williams 1981). Those studies imated the biomass of fish within an area by summing the tonnage of fish seen in surface ools. This method assumes that all schools within an area at a given time are visible. For ools to be visible they must be formed in close proximity to the sea surface. This assumption been brought into question by acoustic surveys that have demonstrated that jack mackerel are o present as subsurface schools (Wolfe 1971; Wolfe 1976). This factor may introduce a nificant bias in aerial assessment methods.

understanding of the schooling behaviour of jack mackerel and the implications that this aviour will have on assessment techniques is essential to any future assessments. The aim of paper is to examine data on schooling behaviour that has been collected from the fishing fleet ween 1985 and 1989 in order to provide a better understanding of the seasonal, lunar and rnal changes in schooling. In addition the biological characteristics of schools were examined as re the species associations within schools.

thods

term 'fishing year' used in this paper refers to the annual period of active commercial fishing, t is from September to the following June.

hing logbook reports

tailed information on a set-by-set basis (a set being one fishing operation - a shot and haul of a se seine net) was recorded in the fishing logbooks. The information recorded included type of ool (surface or subsurface formed), the estimated percentage of the school caught, the method which the school was located, the size of the catch and its species composition. The logbook been described in detail by Williams (1986). The logbook information used in this study was recorded during the period from February 1985 to July 1989. The range of the fishery during that period is shown in Figure 1.

Computer entries of logbook returns were checked for errors with validation programs. The time of fishing and the duration of fishing trips were checked against the reported departure and return times. The total catch for the trip was compared with the sum of the catches for all sets made during the fishing trip. An independent check of trip landings was made by comparing the reported landing against processor records.

School size by month - It was assumed that any one set would not capture more than one school of fish. This assumption is generally true of the fishery, where individual schools are pursued. Individual school sizes were calculated by dividing the estimated catch from a set, by the estimated proportion of the school caught by the set. The mean school size by month for each fishing year was then calculated.

Estimates of the proportion of a school caught and estimates of quantities captured at sea are not precise measurements and will vary depending upon the skill and knowledge of the skippers recording the information. For the purpose of this analysis these data have been averaged over the fleet and over each month. The overall accuracy of the catch data was assessed by calculating the difference between the estimated catches and landed catches.

Number of sets per hour and nictimeral differences - The time at the start of sets recorded in the logbooks was standardised to Eastern Standard Time (EST). The number of sets in hourly intervals was summed for each season (spring, summer and autumn) of fishing and was also pooled over all seasons. The frequency of sets by hourly interval was then calculated. The seasonal frequency of sets was also calculated by day (0700-1859 hours) and night (1900-0659 hours). The significance of any differences between day and night set frequency by season was then tested with a c^2 test.

School type targetted and method of location by month - The number of sets made on surface or sub-surface schools was calculated for each month of each fishing year and for each month for all fishing years pooled.

umber of sets and catch sizes by moon phase - The influence of lunar cycles was investigated by ouping sets into four phases of the lunar month. The four phases were the new moon, first nsition, full moon and second transition. The new and full moon phases are of nine days ration each and correspond to the period of four days preceding and following the day of the full new moon. The first and second transitional phases vary between 5 to 6 days duration.

e analysis was restricted to data from the three complete fishing years (1985/86, 1986/87 and 87/88). The total catch (C) and the number of vessels at sea fishing (V) for each fishing day re calculated. From these data the catch per vessel at sea fishing was calculated (C/V). Data for ch fishing day were then grouped into moon phases, seasons and fishing years. A three-factor alysis of variance (ANOVA) was applied to the catch, vessels fishing and catch per vessel hing data. The factors used were fishing year, season and moon phase.

e means of vessels fishing per day, total catch and catch per vessel fishing per day were lculated for each moon phase, season and fishing year and for each season over the three fishing ars combined.

tch composition - The species composition of individual catches was not consistently recorded all fishers and this information is typically difficult to estimate in a reduction fishery where the ch is not sorted before processing (MacCall 1984). Only data from one skipper with a consistent ord of reporting catch composition was used for the purpose of the analysis. Even so the ormation is likely to be biased as there is a tendency to not record low proportions of by-catch cies in individual sets. This factor should lead to underestimates of the contribution of by-catch cies to landings. The data are useful, however, in establishing broad seasonal trends in changes species composition in the fishery.

ngth frequency of catches

ngths of fish were measured at sea from random samples of individual catches. At sea sampling s conducted throughout each fishing year. The length to tail fork (FL) of between 50 and 100 ed fish were measured to the nearest centimetre. Additional random samples were collected at sea from individual sets and returned to the laboratory, for detailed biological examination. Fish from these samples were measured (FL) to the nearest millimetre.

Results

The number of sets recorded by the logbooks by month for each fishing year is given in Table 1. The total catch (of all species pooled) by month and fishing year is given in Table 2.

Total monthly landings ranged from 77 tonnes to 9 973 tonnes. Fishing generally began between September and November, and continued through to May/June in the following year. In the first three complete fishing years, catches gradually increased through the year to a peak in April/May. In April 1988, catches slumped and although good catches were made in May and June no further landings were made until April of the following year. The 1988/89 fishing year lasted only three months, at much reduced monthly landings. The effects of severe inter-annual variability is apparent from these data. The probable causes of this variability are discussed elsewhere (Pullen et al.,1989; Harris et al. 1991).

School size by month

Estimated landings compared well to actual landings. Over the period of the study the mean estimated landings recorded by fishers was 103% of actual landings (SE = 0.3%).

Estimates of individual school sizes ranged from 2 to 1,850 tonnes. The overall mean being 82 tonnes (±2.6 tonne SE). The mean school size by month is shown in Figure 2. At the beginning of the fishing year mean school size was approximately 60 tonnes. Throughout the summer months, mean school size remained relatively constant, but increased during autumn, reaching maximum mean sizes of around 120 tonnes of fish per school.

t should be noted that the sample of schools used in this analysis were those selected for fishing nd may not be representative of the range of school sizes occurring at any time. Sampling will be biased as a result of fishers selecting for schools of a size closest to the carrying capacity of the hing vessel. The carrying capacity of vessels in the fleet ranged from 120 to 400 tonnes. The ssels of 120 tonne carrying capacity accounted for approximately 60% of all landings.

spring and summer, when school sizes are typically small the largest schools available will be hed. Towards the end of the fishing year the size of available schools may exceed the carrying pacity of vessels and fishers will tend to either select smaller schools or attempt to catch portions large schools. The effects of these biases will be to over-estimate mean school size at the ginning of the fishing year and under-estimate it at the end. The actual trend in size of schools ring the fishing year is likely to be more pronounced than that presented here.

umber of sets per hour and nictimeral differences

e number of sets by hourly interval for all fishing years, and for spring, summer and autumn shown in Figure 3. It is apparent from this figure, that sets are made more frequently during day in all seasons. The results of the c^2 test for homogeneity between day and night set quencies are given in Table 3. For all seasons and all data pooled there were significant ferences between day and night fishing (P<<0.001).

ring summer, there was a marked peak in hourly set frequency corresponding to sunrise.

hool type targetted and method of location by month

e monthly proportion of surface/subsurface schools captured are given in Figure 4. The jority (69%) of all sets were made on surface schools. Early in the fishing year subsurface iools are the most frequently fished school type, as the season progresses surface schools come prominent whilst late in the season subsurface schools are increasingly targetted.

e ratio of surface to subsurface schools captured, given in Figure 4, does not necessarily resent changes in schooling behaviour of the jack mackerel population. The sampling on which ratio of school types captured is based is subject to bias, being fishery dependent. The hniques used for locating surface school and subsurface schools differ greatly in their iciency. As information on the location and size of surface schools is more readily available than t for subsurface schools, fishers are more likely to make sets on surface schools.

Searching for surface schools is relatively cheap and effective as a large area can be covered by a single aerial spotter; large areas may also be searched by look-outs on fishing vessels. Subsurface schools must be detected by sonar, the effective range of which is quite limited when compared to visual searches.

Number of sets and catch sizes by moon phase

The results of the three factor ANOVA on daily catch, vessels fishing and catch per vessel fishing are given in Table 4, the means and standard errors of vessels fishing per day, total catch and catch per vessel fishing per day are shown in Figure 5.

Moon phase alone was not a significant factor for any of the statistics tested. Fishing year was a significant factor for daily catch and the number of vessels fishing. Season was a significant factor for daily catch, number of vessels fishing and catch per vessel fishing.

Season and moon phase were significant factors for the daily catch per vessel fishing. Fishing year and season were significant factors for both the daily number of vessels fishing and catch per vessel fishing. No clear relationship between moon phase and either fishing activity (number of vessels fishing or daily catches) or vulnerability (catch per vessel fishing per day) was apparent.

Catch composition

The mean monthly species compositions of schools are given in Figure 6. Jack mackerel usually account for more that 80% of the fish making up the schools captured in all months of the fishery, and may comprise 100% of schools in summer. Redbait (*Emmelichthys nitidus* Richardson) is caught in most months and is the most significant by-catch species, with a range in contribution of 0-30% of school composition. In tonnage the most significant landings of this species occur at the end of the fishing year.

Blue mackerel (*Scomber australasicus* Cuvier) is the other significant by-catch species. This species is caught during the summer and autumn months as the fish move inshore from oceanic waters into coastal water, (Last *et al.* 1983), and so become vulnerable to the fishery. It becomes a jor by-catch in early autumn, with up to 20% of the catch being attributable to this species arch-April).

ngth frequency of catches

e length compositions of individual schools were examined to determine whether fish associated schools on the basis of cohort or by length. Freon (1984), suggested three criteria for termining the basis of associations forming schools. These were;

i) if the variation in length composition increases with increasing mean length the fish are associating by cohort,

ii) if there is no relationship between the variation in length composition and mean length the fish are freely associating, and

iii) if the variation in length composition remains constant with increasing mean length the fish are associating by length.

e mean length (L_m) and standard error of variation in length (SE_l) for each school were plotted, d the results are shown in Figure 7. A linear regression fitted to this data yielded

$$SE_l = 0{\cdot}0802 + 0{\cdot}0049\ L_m \qquad (r = 0{\cdot}137,\ n = 94,\ 0{\cdot}2>P>0{\cdot}1).$$

F test of the significance of the slope gave $0{\cdot}2>P>0{\cdot}1$ indicating that the slope was not nificantly different from 0. This relationship conforms to Freon's criteria iii) above and refore suggests that fish are schooling by length.

rrelation of interspecific length in schools

rther evidence of schooling by length was found in the relationship of mean length of jack ckerel (L_j) and redbait (L_r) occurring in the same schools (Figure 8). Linear regression analysis these data yielded;

$$L_r = -1{\cdot}0942 + 0{\cdot}8334\ L_j \qquad (r = 0{\cdot}77,\ n = 16,\ P<<0{\cdot}001).$$

A strong correlation exists between the mean size of these species when found together. This correlation is unusual, given that schooling of jack mackerel is probably by length. That is, the regression line does not follow unity but rather the mean size of redbait is proportionally smaller than that for jack mackerel found in the same school.

Discussion

In this study we have examined the schooling behaviour of jack mackerel from information provided in fishing returns from the Tasmanian purse seine fishery. In addition the pattern of association of fish within schools (both intra- and inter-specific) was examined. Previous assessments of jack mackerel biomass have been based on aerial surveys of surface schooling (Hynd and Robins 1967; Williams 1981). In the present study we have found that subsurface schooling is an important alternative school type that occurs throughout the fishing year. The previous surveys would, therefore, underestimate the abundance of fish by disregarding the portion of the population occurring in subsurface schools. The degree of underestimation may vary seasonally (the ratio of surface schools to subsurface schools captured varies throughout the fishing year) and will also be subject to inter-annual variability. We believe that the ratio is likely to be biased in favour of surface schooling due to sampling (that is fishing skippers will tend to take the schools that are easiest to find and capture). Given that it is not possible to accurately estimate past ratios of surface to subsurface schools it is not possible to correct the previous assessments.

Future resource assessments will need to take account of schooling behaviour. For example, it may be desirable to conduct hydroacoustic surveys simultaneously with aerial surveys so that a measure of the number and size of surface and subsurface schools can be made. Alternatively, hydroacoustic surveys alone may be used to estimate the abundance of both surface and subsurface schools. This latter technique is currently being investigated by the authors.

Changes in school size and school type (surface/subsurface) have direct consequences on the vulnerability of jack mackerel to purse seining. At the beginning of the fishing year, subsurface hools predominate, and searching is conducted by fishing vessels using sonar. During this riod a fishing vessels time at sea is divided between searching and fishing. As the fishing year ogresses the incidence of surface schooling increases and aerial spotting becomes more widely ed. Aerial spotting can cover an area more efficiently than sonar, resulting in an increase in the ficiency with which surface schools are found. In addition fishing vessels spend less time arching (as they are being directed to locations by aerial spotters) and consequently vessels have re fishing time available.

tch rates are influenced by the vulnerability of schools, the varying proportion of time spent by fishing fleet in searching and fishing, the seasonal changes in school size and the seasonal anges in searching efficiency. It is difficult to separate or compensate for these factors and thus it not possible to use catch rates as an index of abundance (catches will not increase in direct portion to fishing effort).

hooling

e data presented here demonstrate a definite bias toward day fishing in the commercial fishery. servations by the authors indicate that schools form in the water column around dawn and tend vards the surface immediately after dawn. Surface schools tend to persist during daylight on ercast days, whilst on sunny days schools go down. There is also a tendency for surface ools to form in the last few hours of daylight.

e schools of jack mackerel encountered during this study are likely to have been formed dominantly for feeding/foraging. Feeding in surface waters normally takes place during the day untov 1969; Stevens et al. 1984; Webb 1976). The fish taken by the commercial fishery in smanian waters are usually gorged with the euphausid 'krill', *Nyctiphanes australis* Sars (with mach contents comprising up to 13 % of somatic weight) (Pullen unpubl. data). During 1989 1 1990, extensive ichthyoplankton sampling over the eastern Tasmanian fishing grounds during nmer and early autumn, found very low abundances of krill (Pullen et al. 1989; Jordan pers. nm.). The availability of fish to the commercial fishery during these fishing years was very tricted with few surface schools being sighted by aerial spotters. Whilst schooling in coastal waters was not occurring, jack mackerel were caught in demersal trawls conducted on the continental shelf adjacent to the fishing grounds (Williams 1989). The presence of significant quantities of adults in these waters could also be inferred from the presence and abundance of preflexion larvae on the shelf (Pullen et al. 1989).

These features suggest that the distribution and abundance of krill has a major influence on the formation of schools in Tasmanian coastal waters. In turn, the availability of schools in coastal waters determines the success of the commercial fishing year. The factors which determine the inter-annual variability in the productivity of southeastern Tasmanian shelf waters has been studied by Harris et al. (1991). That study suggested that major changes in krill abundance were caused by the effect of a La Niña 'cold event' on the zooplankton community. It is likely that the association between krill abundance and schooling of jack mackerel is important on the intra-annual as well as the inter-annual scale.

The results obtained in this study from the analysis of moon phase on fishing activity and catches do not conform with the findings of other studies. Williams (1981) found that the degree of day-time formation of surface school and thus the visibility of fish to aerial spotters were highest during the new moon to first transitional phases. Webb (1977) found that catch rates were highest during the same period. Our data show no lunar influences affecting fish vulnerability. Data presented here demonstrate that most fish are caught by day and it is understandable that lunar effects on day fishing would be small. In addition the preference of jack mackerel for feeding by day suggests that the degree of luminosity given by the moon will have little influence on foraging behaviour at night.

Composition of schools

Whilst school size of *T. declivis* changes significantly during the year, the variation in length of fish within a school bears no relation to increasing school size. There is also no correlation between variation of length within schools and mean length. These two factors suggest that *T. declivis* individuals associate by length, rather than by cohort (Freon 1984).

idence for active sorting by length within schools composed of single species has been found by cher et al. (1985) in the herring *Clupea harengus* and the mackerel *Scomber scombrus*. Their dy found that individual fish changed neighbours frequently but that they were choosing to nain longer next to fish of similar size. In these schools, sorting was suggested to be active, her than passively determined by a mechanism such as cruising speed. In the present study, ive sorting may well explain the similarity in length of fish from single species schools, and the ilarity in lengths of fish of the same species within multispecies schools.

e correlation between the mean length of co-occurring *T. declivis* and *E. nitidus* found in this dy, suggests a more complex process however, as the mean lengths of either species are not nilar. This is contrary to the condition seen in schools of similar species such as *Sardinella*, ere association may be due to length similarities rather than species groups (Freon 1984). It is ssible that school structure plays some part in explaining this difference. For instance *T. declivis* d *E. nitidus* may occur in discrete parts of a school, rather than mingling randomly. If this were e then cruising speed may explain the correlation in mean lengths between the species. That is, gle species schools of similar cruising speed would be more likely to remain in close proximity. he species are mixed within a school then a more complex mechanism than sorting by length is uired. Field observations of schooling behaviour would be required to resolve this problem.

knowledgments

e gratefully acknowledge the skippers and crew of the purse seiners and the spotters for their operation with this work. We also thank Gweido Kucerans and Carl Waterworth for their istance. This study was assisted by a grant from the Fishing Industry Research Trust Account RTA 85/77).

References

Blaber, S. J. M. and Bulman, C. M. (1987). Diets of fishes of the upper continental slope of eastern Tasmania: content, calorific values, dietary overlap and trophic relationships. *Mar. Biol.* **95**, 345-56.

Blackburn, M. and Tubb, J. A. (1950). Measures of abundance of certain pelagic fish in some south-eastern Australian waters. *CSIRO Aust. Bull.* **251**.

Freon, P. (1984). La varibilité des tailles individuelles à l'interieur des cohorts et des bancs de poisson. 1re partie: Observations et interpretations. *Oceanologica Acta* **7**(4), 457-68.

Harris, G. P., Griffiths, F. B., Clementson,. Lyne, V. and Van der Doe, H. (1991). Seasonal and interannual variability in physical processes, nutrient cycling and the structure of the food chain in Tasmanian shelf waters. *J. Plankton Res.* **13**, 109-31.

Hynd, J. S. and Robins, J. P. (1967). Tasmanian tuna survey report of first operational period. *CSIRO Div. of Fish. and Oceanog. Tech. Pap.* **22**.

Last, P. R., Scott, E. O. G. and Talbot, F. H. (1983). *Fishes of Tasmania*. Hobart, Tas. Fish. Dev. Auth.

MacCall, A. D. (1984). Report of the working group on resources study and monitoring. In 'Reports of the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources' (Eds. Csirke, J. and Sharp, G. D.). *FAO Fish. Rep.* **291**(1), 9-39.

indholm, R. and Maxwell, J. G. H. (1988). Stock separation of jack mackerel *Trachurus declivis* (Jenyns, 1841), and yellowtail *T. novaezealandiae* (Richardson, 1843) in southern Australian waters using Principal Component Analysis. *CSIRO Mar. Labs. Rep.* **189**.

itcher, T. J., Magurran, A. E. and Edwards, J. I. (1985). Schooling mackerel and herring choose neighbours of similar size. *Mar. Biol.* **86**, 319-22.

llen, G., Jenkins, G. and Williams, H. (1989). Where are they? *Fishing Today.* **2**(1), 31.

:hardson, B. J. (1982). Geographical distribution of electrophoretically detected protein variation in Australian commercial fishes. I. Jack mackerel, (*Trachurus declivis*, Jenyns). *Aust. J.Mar. Freshw. Res.* **33**, 917-26.

untov, V. P. (1969). Some features of the ecology of pelagic fishes in the Great Australian Bight. *Probl. Ichthyol.* **9**, 801-9.

:vens, J. D. and Hausfeld, H. F. (1982). Age determination and mortality estimates on an unexploited population of jack mackerel *Trachurus declivis* (Jenyns, 1841) from southeast Australia. *CSIRO Mar. Labs. Rep.* **148**.

:vens, J. D., Hausfeld, H. F. and Davenport, S. R. (1984). Observations on the biology, distribution and abundance of *Trachurus declivis*, *Sardinops neopilchardus* and *Scomber australasicus* in the Great Australian Bight. *CSIRO Mar. Labs. Rep.* **164**.

:bb, B. F. (1976). Aspects of the biology of jack mackerel *Trachurus declivis*, (Jenyns) from south-east Australian waters. *Tas. Fish. Res.* **10**, 1-14.

:bb, B. F. (1977). Moon's influence on shoaling pelagic fish species. *Aust. Fish.* September, 8-11.

lliams, H. (1986). Collection and storage of data in the trawl, purse seine and drop-line fisheries. *Tech. Rep. Mar. Lab. Dep. Sea Fish. (Tasm.).* **8**.

lliams, H., Kirkwood, R., Pullen, G. and Kucerans, I. G. (1986). The jack mackerel purse seine fishery in Tasmania, 1985-86. *Tech. Rep. Mar. Lab. Dep. Sea Fish. (Tasm.).* **13**.

lliams, H., Pullen, G., Kucerans, G. and Waterworth, C. (1987). The jack mackerel purse seine fishery in Tasmania, 1986-87. *Tech. Rep. Mar. Lab. Dep. Sea Fish. (Tasm.).* **19**

Williams, H. (1987). Mackerel plan allows fishing by both big and small boats. *FINTAS* 10(4), 44-7.

Williams, H. (1989). Jack mackerel go walkabout. *Fishing Today* **2**(1), 31-2.

Williams, K. (1981). Aerial survey of pelagic fish resources off South East Australia 1973-1977. *CSIRO Div. of Fish. and Ocean. Rep.* **130**.

Wolfe, D. C. (1971). Pelagic fish survey. 1. Seasonal availability of fish schools in in-shore waters. *Tas. Fish. Res.* **5**, 2-11.

Wolfe, D. C. (1976). Pelagic fish survey. 2. Fish schools in off-shore waters. *Tas. Fish. Res.* **10**, 13-25.

ble 1 Number of sets by month in each fishing year

			Fishing year		
nth	1985	1985/86	1986/87	1987/88	1988/89
ptember		8	5		
tober		27	26		
vember		159	116	58	
cember		49	75	98	
uary		66	121	137	
bruary		63	147	114	
rch	20	92	119	119	
ril	33	156	155	104	41
y	74	59	106	161	67
e	14		3	64	19
tal	141	679	873	855	127

Table 2 Total catch (tonnes) by month in each fishing year

Month	Fishing year 1985	1985/86	1986/87	1987/88	1988/89
September		135	77		
October		505	178		
November		2996	3233	1674	
December		1793	2840	4126	
January		1925	4767	5073	
February		2202	6452	4254	
March	596	2853	5056	4793	
April	1544	7040	9973	4051	2826
May	3630	3718	9069	9117	4862
June	230		196	4827	1177
Total	6000	23167	41841	37915	8865

ble 3 c^2 test for homogeneity between day and night set frequencies

ason	n	c^2	df	P
ring	306	60.4	1	<<0.001
mmer	1040	284.5	1	<<0.001
tumn	1289	478.1	1	<<0.001
oled	2635	814.5	1	<<0.001

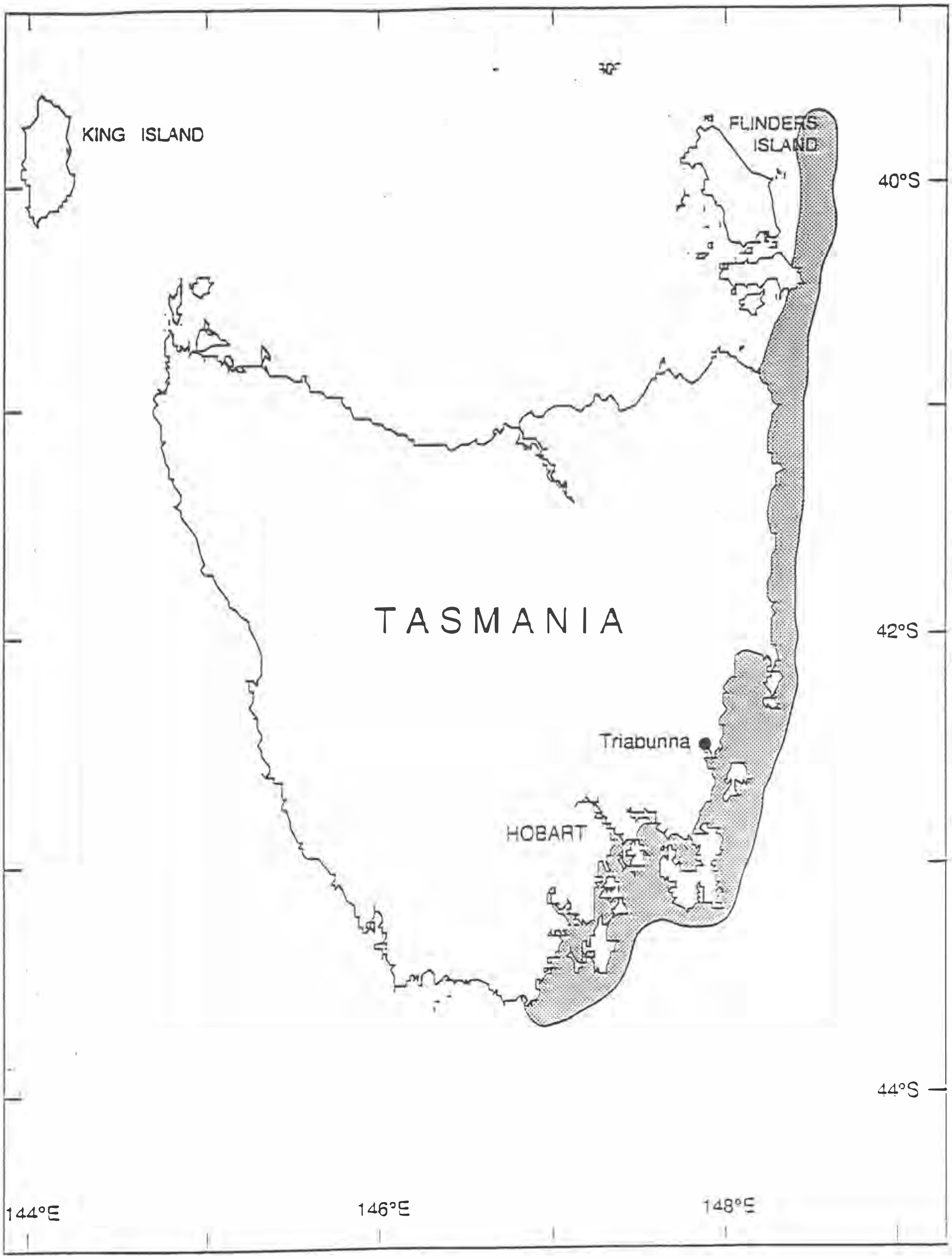
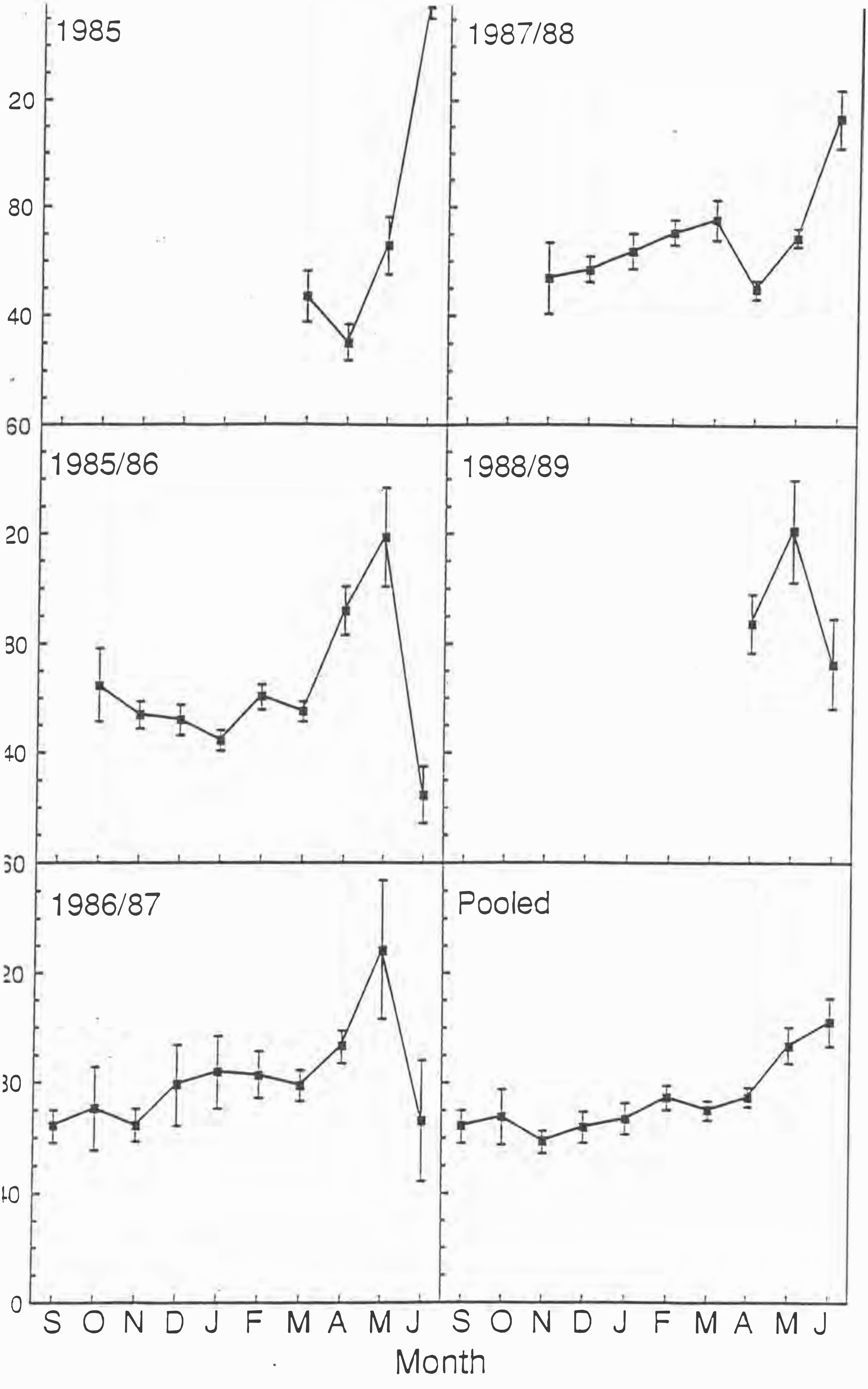


Figure 1. The range of the jack mackerel fishery during the period February 1985 to July 1989.



igure 2. Mean school size by month for each fishing year and pooled over the period March 1985 to June 1989. Vertical bars represent 1 SE.

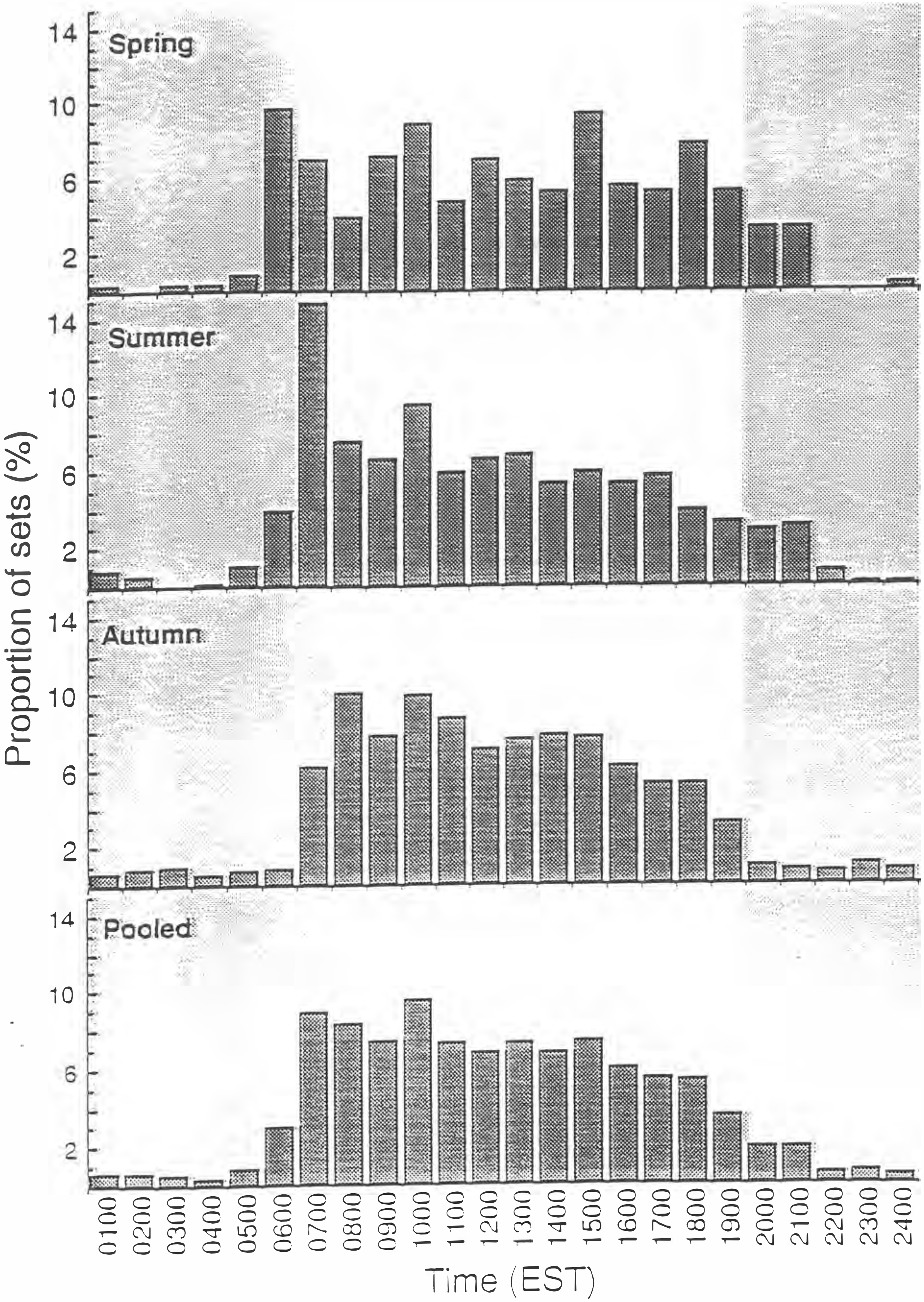
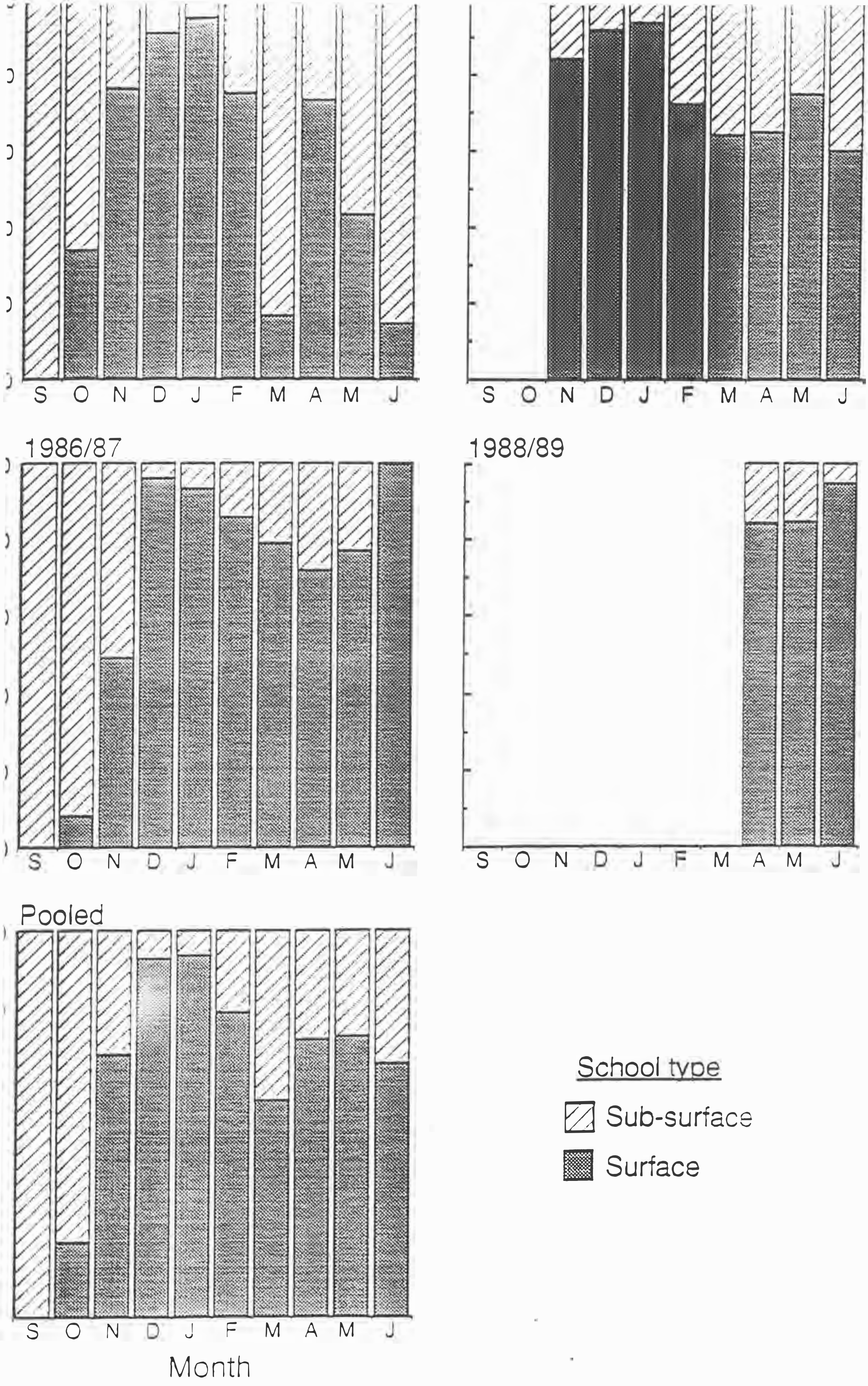


Figure 3. Number of sets per hour by season and pooled over the period March 1985 to June 1989.



ure 4. Proportion of surface/subsurface schools captured by month for each fishing year and for the period March 1985 to June 1989.

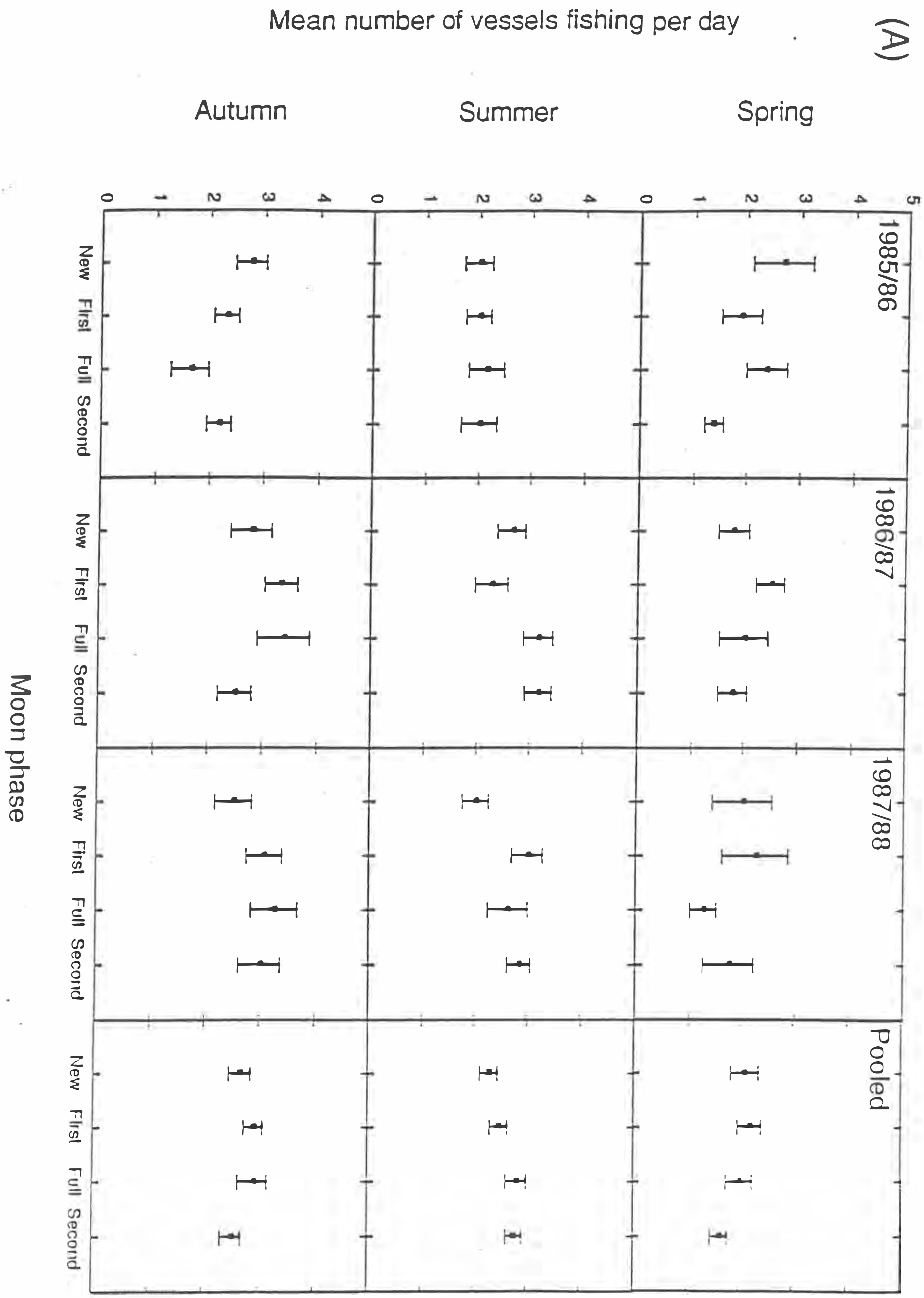
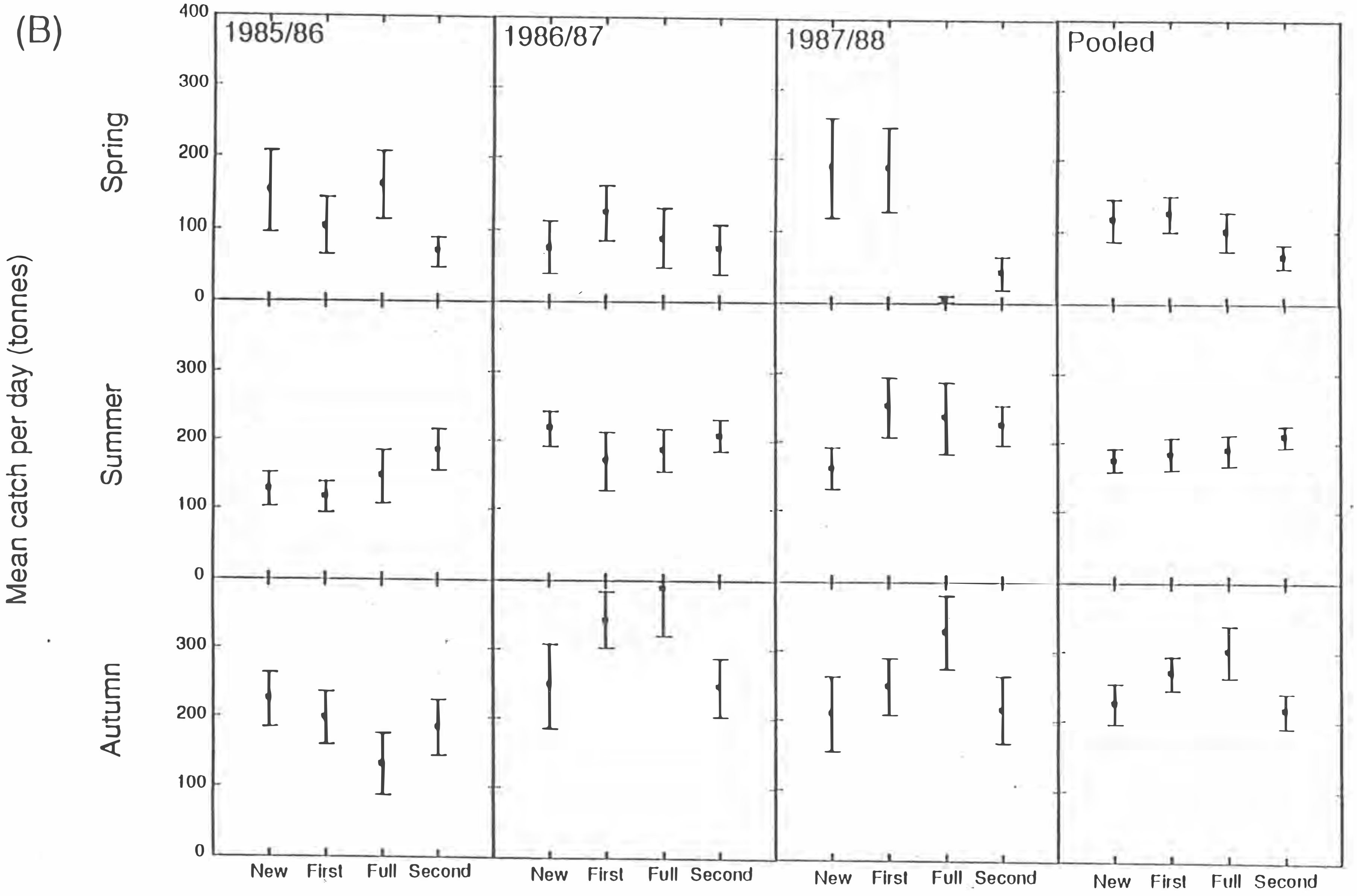
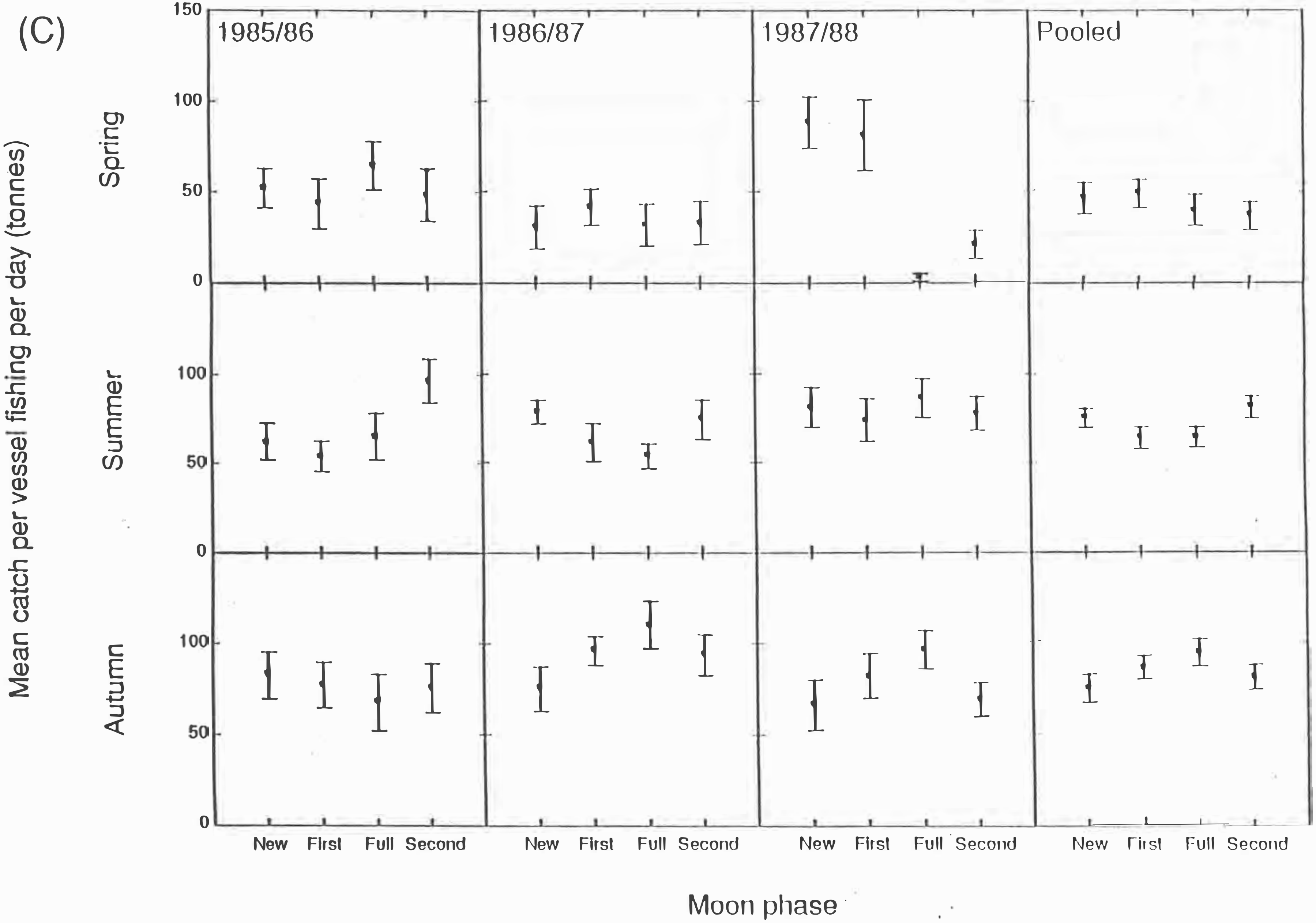


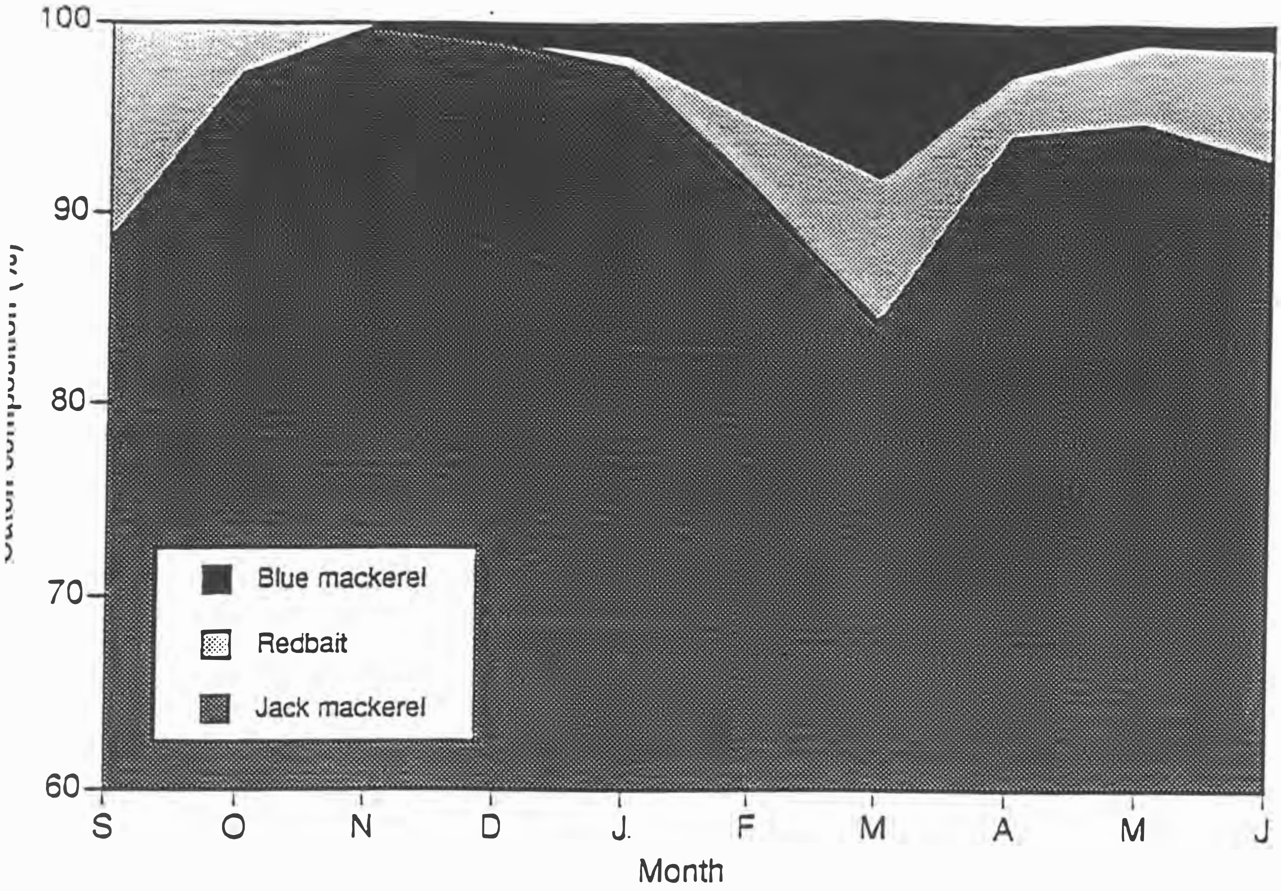
Figure 5. Mean number of vessels fishing per day (A), the mean total catch per day (B) and the mean catch vessel fishing per day (C) by moon phase for each season and fishing year and for the period March 1985 to May 1989 pooled.


(B)
Mean catch per day (tonnes)
Spring
Summer
Autumn
1985/86
1986/87
1987/88
Pooled
400
300
200
100
0
New
First
Full
Second

(C)



1985/86
1986/87
1987/88
Pooled
Spring
Summer
Autumn
150
100
50
0
Mean catch per vessel fishing per day (tonnes)
New
First
Full
Second
Moon phase



igure 6. Mean monthly species composition of schools during the period March 1985 to June 1989.

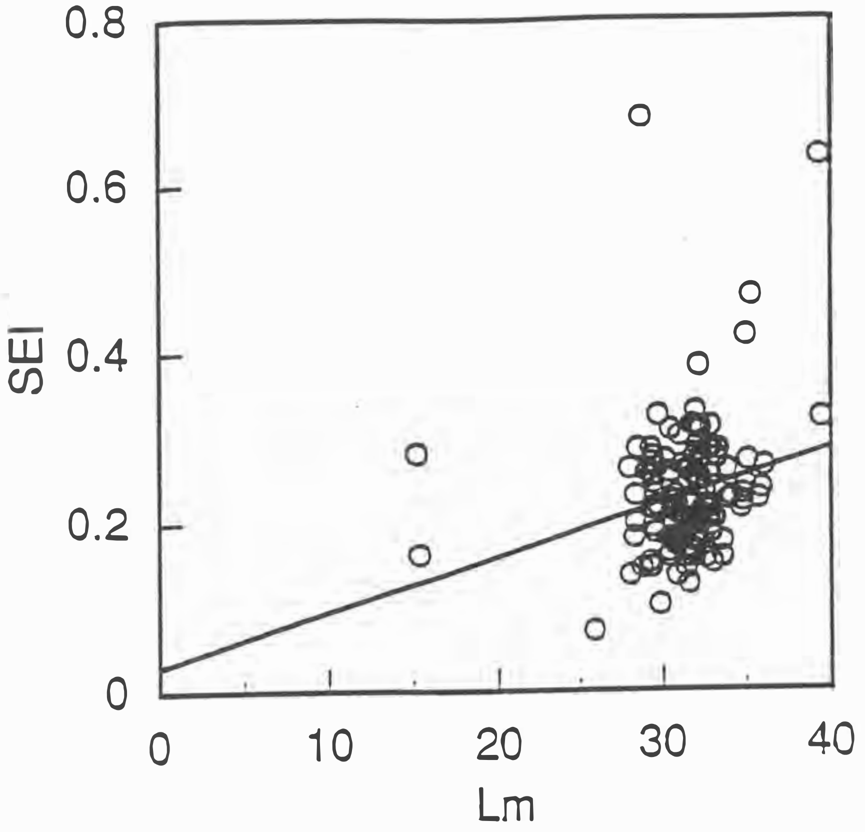
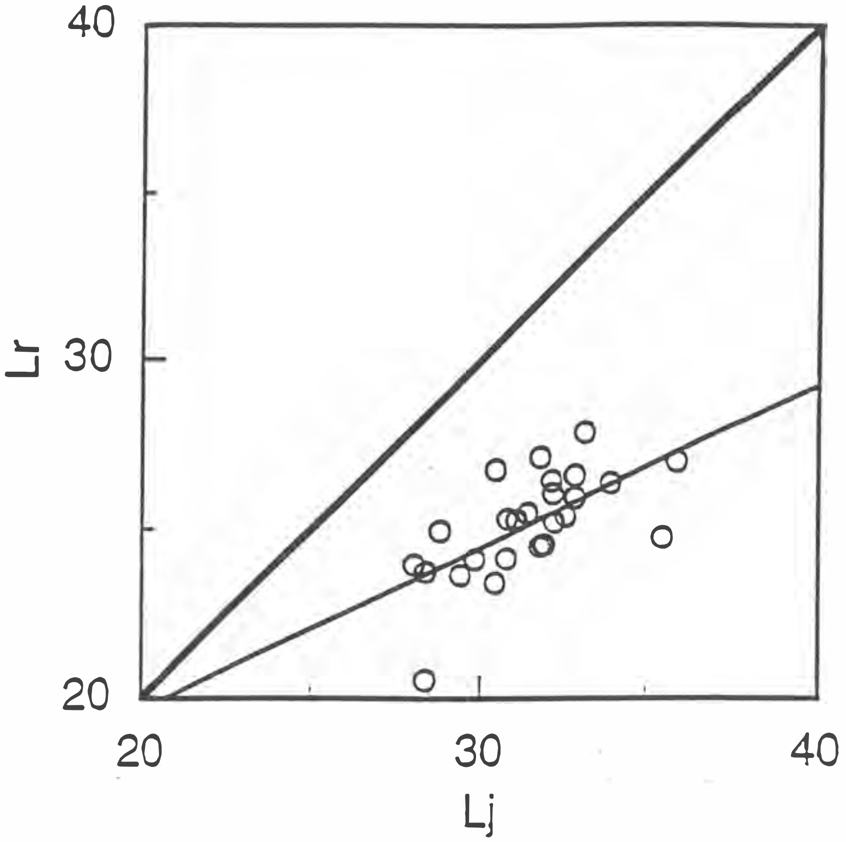


Figure 7. The relationship between mean length within schools of *Trachurus declivis* (L_m) and standard error (SE_l). The fitted line represents a linear regression of the data.



ure 8. The relationship between mean length within schools of co-occurring *Trachurus declivis* (L_j) and *Emmelichthys nitidus* (L_r). The solid line represents a linear regression of the data. the dotted line represents unity between the respective lengths.

DOCUMENT 9

Catalogue of ichthyoplankton station details

INTERNAL REPORT

Catalogue of stations details sampled during this study.

					Depth (m)		Temp (T°C)			Water
Cruise	Stat	Date	Lat	Long	Water	Tow	Surface	10 m	Time	Vol (m^3)
179	1A	5/12/88	4251	14758	48		15.8		1515	
179	1B	5/12/88	4545	14810	80	75	15.4		1630	37
179	1C	6/12/88	4237	14826	130	100	15.0		850	61
179	2A	9/12/88	4224	14801	37		15.9		915	
179	2B	6/12/88	4231	14816	90		15.8		1135	46
179	3A	6/12/88	4218	14820	70		15.2		1335	38
179	3B	6/12/88	4214	14824	70		15.3		1425	34
179	3C	7/12/88	4204	14837	150	100	15.3		1255	41
179	4A	7/12/88	4204	14837	47		15.7		1516	20
179	4B	7/12/88	4154	14829	83		15.9		1415	35
179	5B	7/12/88	4143	14827	70		15.8		1650	102
179	5C	7/12/88	4136	14834			17.7		1753	36
179	6A	7/12/88	4126	14821	35		15.7		2000	1
179	6B	7/12/88	4129	14826	90		16.1		1930	38
189	1	11/1/89	4059	14824	37	29	14.8	14.7	608	113
189	2	11/1/89	4054	14832	80	43	16.9	16.9	726	100
189	3	11/1/89	4052	14845	150	80	16.8	16.8	840	155
189	4	11/1/89	4051	14849	730	77	16.9	16.9	921	146
189	5	11/1/89	4015	14844	1130	83	17.6	17.5	1240	130
189	6	11/1/89	4117	14838	145	81	17.2	17.2	1352	129
189	7	11/1/89	4118	14830	112	52	16	15.9	1517	129
189	8	11/1/89	4119	14822	92	48	15.3	15	1637	120
189	9	12/1/89	4134	14820	47	16	15.5	15.4	811	123
189	10	12/1/89	4134	14828	98	82	16.1	15.9	926	122
189	11	12/1/89	4134	14835	170	94	17	17	1055	112
189	14	12/1/89	4149	14835	126	88	17.1	17.1	1350	111
189	15	12/1/89	4149	14827	76	39	15.7	16.1	1458	108
189	16	12/1/89	4149	14819	39	16	16	16	1615	110
189	17	13/1/89	4202	14819	54	25	16.2	16.2	649	123
189	18	13/1/89	4202	14829	87	42	16.4	16.4	806	128
189	19	13/1/89	4204	14837	140	79	17.3	17.3	902	134
189	20	13/1/89	4205	14843	1450	64	17.3	17.3	958	140
189	21	13/1/89	4214	14840	1258	55	17.1	17.2	1129	159
189	22	13/1/89	4216	14834	140	61	17.1	17.1	1219	127
189	23	13/1/89	4217	14827	107	72	17.1	17.1	1305	141
189	24	13/1/89	4218	14822	86	41	16.6	16.4	1350	126
189	25	13/1/89	4230	14803	40	12	15.9	15.4	1631	111
189	26	14/1/89	4233	14816	85	47	17.4	17.3	615	130
189	27	14/1/89	4237	14826	160	79	17	17	728	140
189	28	14/1/89	4239	14833	1600	76	17	17	820	131
189	29	14/1/89	4243	14831	1600	89	17	17	911	128
189	30	14/1/89	4246	14820	130	68	17.5	17.4	1027	154
189	31	14/1/89	4248	14811	94	49	16.8	16.6	1136	163
189	32	14/1/89	4251	14800	65	33	16.8	16.5	1250	144
189	33	14/1/89	4302	14818	970	64	17.4	17.4	1503	134
189	34	14/1/89	4302	14814	135	76	17.3	17.1	1542	140
189	35	14/1/89	4302	14806	97	79	17.5	17.4	1644	131
189	36	14/1/89	4302	14759	74	40	16.7	16.5	1745	149
189	37	14/1/89	4315	14805	190	80	16	16	1929	126
189	38	15/1/89	4317	14749	120	96	15.9	15.4	532	108
189	39	15/1/89	4313	14735	65	33	16.3	16.1	722	106
190	5	26/1/89	411448	1484397	932	79	18	17.9	834	128
190	6	26/1/89	411701	1483810	136	86	18	18	742	112
190	7	26/1/89	411789	1483002	107	88	18	18	645	114
190	8	26/1/89	411901	1482199	42	20	16.8	15.4	552	105
190	13	25/1/89	414901	1484095	1049	76	18.5	18.4	1210	117
190	14	25/1/89	414903	1483503	138	74	18.4	18.4	1255	125
190	15	25/1/89	414903	1482687	76	53	18.2	18.2	1356	118
190	16	25/1/89	414905	1481900	47	40	17.4	17.3	1453	107
190	21	25/1/89	421388	1483996	1173	68	18.3	18.2	848	136
190	22	25/1/89	421594	1483418	127	55	17.7	17.6	750	136
190	23	25/1/89	421699	1482700	99	62	17.7	17.7	654	125

Cruise	Stat	Date	Lat	Long	Depth (m)		Temp (T°C)		Time	Water
					Water	Tow	Surface	10 m	(EST)	Vol (m^3)
190	24	25/1/89	421802	1482200	76	59	17.4	17.4	606	148
190	25	24/1/89	423010	1480302	30	22	16.8	16.3	1427	110
190	26	24/1/89	423308	1481601	90	67	17.4	17	1256	138
190	27	24/1/89	423680	1482525	124	71	18.1	17.8	1135	133
190	29	24/1/89	424300	1483100	1500	64	17.7	17.6	1023	134
190	30	24/1/89	424641	1482180	170	71	17.3	17.1	859	149
190	31	23/1/89	424903	1481014	92	73	16.6	16.1	1407	159
190	31	23/1/89	424903	1481014	92	61	16.6	16.1	1437	122
190	31	23/1/89	424903	1481014	90	27			1507	211
190	31	23/1/89	424903	1481014	92	21			1533	29
190	31	23/1/89	424903	1481014	92	8			1555	105
190	31	23/1/89	424903	1481014	92	2			1620	111
190	31	24/1/89	424803	1481104	93	62	17.3	17.3	728	140
190	32	24/1/89	425408	1475497	63	43	16.3	16.2	545	291
190	40	24/1/89	424919	1480480	74	51	16.3	16.3	632	127
190	41	24/1/89	424903	1481014	98	58	17.3	17.3	810	133
190	42	24/1/89	424463	1482654	700	77	17.9	17.7	943	133
193	6	2/3/89	411633	1483940	170	77	20.6	19.7	955	135
193	7	2/3/89	411791	1482989	110	60	19.4	19.4	825	127
193	8	2/3/89	411791	1482292	57	29	17.2	17.5	730	139
193	9	2/3/89	413368	1482045	42	19	16.9	18	1320	118
193	10	2/3/89	413390	1482814	92	68	18.8	17.7	1205	117
193	11	1/3/89	413403	1483548		56	20.6	20.6	1700	150
193	14	1/3/89	414905	1483554	130	59	20.5	20.5	1445	147
193	15	1/3/89	414904	1482688	75	50	19.5	19.6	1340	162
193	16	1/3/89	414911	1481903	40	11	17.6	17.5	1240	155
193	17	1/3/89	420203	1482025	58	35	17.9	19.9	1047	116
193	18	1/3/89	420289	1482977	84	58	18.3	18.3	943	122
193	19	1/3/89	420360	1483726	130	54	18.8	18.9	842	153
193	22	28/2/89	421575	1483367	130	54	18	18.5	1803	163
193	23	28/2/89	421703	1482700	94	67	18.1	18.4	1710	137
193	24	28/2/89	421757	1482029	70	40	18.2	18.3	1620	136
193	25	28/2/89	423044	1480417	36	11	18.6	18.3	1350	134
193	26	28/2/89	423246	1481586	85	41	18.2	17.9	1233	101
193	27	28/2/89	423670	1482569		49	17.9	17.9	1120	112
193	30	28/2/89	424586	1482200	140	51	18	18.1	955	122
193	31	28/2/89	424814	1481100	93	65	17.8	17.8	840	116
193	32	28/2/89	425100	1480000	47	11	17.8	17.8	715	89
193	34	27/2/89	430097	1481413	175	76	18	17.9	1640	106
193	35	27/2/89	430190	1480622	96	59	17.9	17.9	1745	110
193	36	27/2/89	430217	1475993	76	33	17.7	17.6	1830	132
197	22	5/4/89	421585	1483410	140	60	18.3	18.3	1440	109
197	23	5/4/89	421687	1482703	99	67	18.4	18.3	1350	120
197	24	5/4/89	421748	1481986	60	38	17.2	17.2	1255	129
197	25	5/4/89	423000	1480300	34	17	17.8	17.6	1035	95
197	26	5/4/89	423306	1481614	90	63	17.9	17.9	910	112
197	27	5/4/89	423708	1482663	150	58	18.1	18.1	755	101
197	30	4/4/89	424600	1482164	130	56	18	18	1545	98
197	31	4/4/89	424784	1481047	84	63	17.2	16.9	1450	135
197	32	4/4/89	425200	1480047	50	43	17.3	16.9	1335	94
197	34	4/4/89	430149	1481506	140	50	17.8	17.7	1050	131
197	35	4/4/89	430236	1480652	98	63	17.8	17.7	1155	123
197	36	4/4/89	430195	1475848	66	42	16.5	16.5	915	110
198	6	12/4/89	411907	1483788	140	44	18.2	18.1	1720	142
198	7	12/4/89	411898	1483000	108	41	17.9	17.9	1630	146
198	8	12/4/89	412000	1482326	40	16	17.6	17.6	1530	114
198	9	12/4/89	413543	1482041		40	17.8	17.6	1300	46
198	10	12/4/89	413417	1482849	98	58	18.3	18.2	1210	135
198	11	12/4/89	413434	1483662	150	64	18.3	18.3	1120	101
198	14	12/4/89	414884	1483530		52	18.4	18.4	920	108
198	15	12/4/89	414944	1482687	74	54	18.1	18.1	825	140
198	16	12/4/89	414879	1481922	43	39	17.5	17.6	735	131
198	17	11/4/89	420292	1482162	59	48	17.7	17.7	755	1276
198	18	11/4/89	420178	1482874	84	52	18.1	18.1	855	112

Cruise	Stat	Date	Lat	Long	Depth (m) Water	Tow	Temp (T°C) Surface	10 m	Time (EST)	Water Vol (m^3)
198	19	11/4/89	420386	1483662	130	73	19	19	1000	105
215	6	14/11/89	4117	14840	179	42	14.7		1307	151
215	7	14/11/89	4118	14830	108	69	15.1	14.4	1511	155
215	25	15/11/89	4240	14827	48	35	14.5	13.9	1453	133
215	26	15/11/89	4238	14816	89	57	13.8	13.5	1346	147
215	27	15/11/89	4231	14806	217	68	14.2	13.9	1146	144
217	6	12/12/89	4120	14838	297	64	16.9	16.8	1828	150
217	7	12/12/89	4119	14830	109	52	16.4	15.6	1918	154
217	8	12/12/89	4119	14822	53	45	14.7	13.7	2014	95
217	9	12/12/89	4134	14820	33	24	14.7	13.9	1427	112
217	10	12/12/89	4134	14828	100	64	15	14.6	1527	144
217	11	12/12/89	4134	14835	144	51	16.9	16.6	1630	4666
217	15	12/12/89	4149	14827	75	63	15.3	15.1	1135	138
217	16	12/12/89	4149	14819	47	30	14.8	14.5	1236	138
217	17	13/12/89	4200	14820	52	21	14.4	14.2	843	116
217	18	13/12/89	4202	14829	87	68	15.7	15.8	947	113
217	19	13/12/89	4203	14837	135	74	16	16	1055	124
217	22	13/12/89	4216	14833	125	63	16.4	15.5	1240	178
217	23	13/12/89	4217	14827	101	15	15.7	15.5	1330	56
217	24	13/12/89	4218	14822	83	37	15.3	14.8	1410	139
217	25	13/12/89	4230	14803	39	19	15.9	15.6	1636	121
217	26	14/12/89	4233	14815	82	66	15.5	15	815	130
217	27	14/12/89	4238	14826	127	92	15.5	15.6	945	128
217	31	14/12/89	4248	14811	102	77	15	15.2	1200	131
217	32	14/12/89	4251	14800	65	50	14.7	14.5	1324	125
218	6	8/1/90	4119	14838	150	70	16.8	16.9	910	87
218	7	8/1/90	4119	14830	100	65	16.5	16.7	800	154
218	8	8/1/90	4119	14822	40	22	16.4	16.2	650	132
218	9	8/1/90	4134	14821	40	19	16.5	16.1	1310	138
218	10	8/1/90	4134	14828	100	81	16.7	16.3	1215	121
218	11	8/1/90	4134	14835	130	70	16.5	16.5	1120	149
218	14	7/1/90	4149	14835	132	64	16.8	16.6	1610	177
218	15	7/1/90	4149	14827	75	51	17	16.7	1720	159
218	16	7/1/90	4149	14819	45	22	16.6	16	1930	106
218	17	7/1/90	4202	14819	45	24	16.5	16	1345	115
218	18	7/1/90	4202	14829	86	67	16.9	16.7	1225	165
218	19	7/1/90	4204	14837	130	77	16.3	16.1	1115	133
218	22	7/1/90	4216	14833	130	67	16.5	16.3	915	147
218	23	7/1/90	4217	14827	100	78	16.4	16.4	750	156
218	24	7/1/90	4217	14823	69	48	15.9	16	655	145
218	25	6/1/90	4230	14801	29	8	16.8	16.2	1615	103
218	26	6/1/90	4233	14816	90	51	16.2	16.1	1410	208
218	27	6/1/90	4237	14826	170	75	16.7	16.7	1215	176
218	30	6/1/90	4246	14822	130	68	17	16.7	1045	191
218	31	6/1/90	4247	14811	88	68	16.2	16.3	850	155
218	32	6/1/90	4251	14800	60	34	15.6	15.8	700	154
218	34	5/1/90	4302	14814	138	71	16.9	16.1	1640	159
218	35	5/1/90	4302	14806	96	71	16.4	16	1725	180
218	36	5/1/90	4302	14759	65	67	15.9	15.9	1830	152
219	6	25/1/90	4149	14838	180	62	17.7	17.8	855	196
219	7	25/1/90	4118	14830	115	65	17.4	17.6	750	203
219	8	24/1/90	4119	14822	50	0	16.8	0	1930	134
219	9	24/1/90	4134	14820	35	23	17.3	16.8	1730	130
219	10	25/1/90	4134	14828	105	0	17.5	0	1215	166
219	11	25/1/90	4134	14835	140	72	17.5	17.6	1115	154
219	14	25/1/90	4149	14835	130	87	17.9	17.7	1515	151
219	15	25/1/90	4149	14827	80	62	16.8	16.6	1415	147
219	16	24/1/90	4149	14819	45	20	16.8	16.7	1505	114
219	17	24/1/90	4202	14819	45	21	16.4	16.5	1245	125
219	18	24/1/90	4202	14829	85	72	17.4	17.2	1125	130
219	19	24/1/90	4204	14837	140	80	17.5	17.4	1015	136
219	22	24/1/90	4216	14833	140	79	16.9	17.6	750	3577

Cruise	Stat	Date	Lat	Long	Depth (m)		Temp (T°C)		Time	Water
					Water	Tow	Surface	10 m	(EST)	Vol (m^3)
219	23	24/1/90	4217	14827	100	78	16.6	16.7	655	142
219	24	24/1/90	4217	14823	84	68	16.4	16.6	610	157
219	25	23/1/90	4230	14804	40	17	17.4	16.5	1440	151
219	26	23/1/90	4233	14816	90	69	17	16.7	1305	153
219	27	23/1/90	4237	14826	130	78	17.4	17.1	1135	2305
219	28	23/1/90	4239	14833	400	75	17.2	16.8	1035	143
219	30	23/1/90	4245	14822	135	71	17	17	900	161
219	31	23/1/90	4248	14811	100	71	16.4	16.4	750	162
219	32	23/1/90	4251	14800	68	54	16.3	16.5	630	158
219	34	1/22/90	4301	14814	135	68	16.9	0	1435	166
219	35	1/22/90	4302	14806	96	59	16.7	16	1535	174
219	36	1/22/90	4302	14759	76	57	16.9	16.2	1625	160
221	25	15/2/90	4230	14804	42	24	17.9	17.2	1724	157
221	26	15/2/90	4234	14816	88	68	17.3	17.3	1537	164
221	30	15/2/90	4246	14821	118	67	17.9	17.7	1325	613
221	31	14/2/90	4249	14811	93	50	18	0	1702	65
221	32	14/2/90	4251	14859	51		17.4	0	1857	358
221	34	15/2/90	4302	14814	152		17.7	17.6	1050	98
221	35	15/2/90	4302	14806	98		0	0	946	4549
221	36	15/2/90	4302	14759	71		16.6	0	854	66
221	42	15/2/90	4232	14810	64	53	17.4	17.4	1634	4486
222	9	20/2/90	4134	14821	47	17	17.8	16.9	1918	114
222	10	20/2/90	4134	14828	100	68	18	18.4	1820	32
222	11	20/2/90	4134	14835	135	72	18	17.6	1712	4508
222	14	20/2/90	4149	14835	130	65	17.9	17.5	1515	650
222	15	21/2/90	4149	14822	76	62	17.6	17.6	900	4576
222	16	21/2/90	4149	14819	45	33	17.2	17.4	805	657
222	17	20/2/90	4202	14820	53	32	17.1	17	1252	74
222	18	20/2/90	4202	14829	87	54	17.7	17.6	1157	157
222	19	20/2/90	4204	14837	241	57	18	17.8	1100	4547
222	22	20/2/90	4216	14834	305	58	17.5	17.5	930	585
222	23	20/2/90	4217	14828	104	67	16.9	17.1	850	157
222	24	20/2/90	4218	14822	83	33	16.9	16.9	805	4614
222	43	19/2/90	4226	14808	49	11	16.8	16.4	1720	570
222	44	19/2/90	4219	14813	32	27	16.9	16.8	1816	109
222	101	21/2/90	4240	14809	42	14	16.7	16.7	1455	
222	102	21/2/90	4241	14808	60	32	16.9	16.7	1518	
222	103	21/2/90	4241	14807	44	34	16.8	16.6	1540	
222	104	2/22/90	4241	14806	33		16.8		835	
224	6	13/3/90	4119	14837	190	67	18.8	18.6	1745	
224	7	13/3/90	4119	14830	107	62	18.3	18.7	1645	
224	8	13/3/90	4119	14822	49	33	17.9	17.7	1545	
224	9	13/3/90	4134	14820	30	24	17.6	17.4	1350	
224	10	13/3/90	4134	14828	98	57	17.7	17.3	1250	
224	11	13/3/90	4134	14836	140	74	18.7	18.6	1145	
224	14	13/3/90	4149	14835	150	63	18.6	18.7	930	
224	15	13/3/90	4149	14827	76	56	18.5	18.5	825	
224	16	13/3/90	4149	14819	43	29	17	17.1	720	
224	17	14/3/90	4201	14819	45	40	17	17	855	
224	18	14/3/90	4202	14829	84	57	18.4	18.4	1010	
224	19	14/3/90	4204	14837	140	70	18.7	18.8	1110	
224	22	14/3/90	4116	14849	150	105	18.5	18.3	1245	
224	23	14/3/90	4217	14827	95		17.1		1345	
224	24	14/3/90	4218	14822	79		17.1		1435	
224	25	14/3/90	4230	14803	37	17	17.1	17.1	805	
224	26	15/3/90	4233	14816	88	47	17.7	17.7	935	
224	27	15/3/90	4237	14826	150	70	17.6	17.7	1100	
224	30	15/3/90	4246	14822	200	77	19.9	16.9	1220	
224	31	15/3/90	4246	14821	94	76	16.9	16.9	1345	
224	32	15/3/90	4215	14800	61	47	16.7	16.7	1520	
224	34	16/3/90	4302	14815	154	58	16	16.2	920	
224	35	16/3/90	4302	14806	94	55	16.1	16.2	815	
224	36	16/3/90	4302	14759	67	36	16.3	16.6	725	

					Depth (m)		Temp (T°C)		Time	Water
Cruise	Stat	Date	Lat	Long	Water	Tow	Surface	10 m	(EST)	Vol (m^3)
225	201	21/3/90	4256	14800	23		16.5		922	
225	202	21/3/90	4303	14757	32		16.5		1023	
225	203	21/3/90	4307	14758	26		16.8		1106	
225	204	21/3/90	4308	14758			16.7		1125	
225	205	21/3/90	4311	14758	20		16.8		1221	
225	206	21/3/90	4308	14753	13		17		1406	
225	207	21/3/90	4310	14752	23		16.8		1420	
225	208	21/3/90	4312	14752	20		16.7		1450	
225	209	21/3/90	4306	14742			17.2		1645	
225	210	22/3/90	4306	14743			17.3		725	
225	211	22/3/90	4306	14733	36		16.6		840	
225	212	22/3/90	4305	14723	15		16.7		940	
226	300	4/4/90	4339	14849	45		15.2		730	
226	301	4/4/90	4339	14641	60		15.4		805	
226	302	4/4/90	4337	14634	67		15.5		850	
226	303	4/4/90	4336	14627	64		15.7		935	
226	304	4/4/90	4335	14621	39		15.8		1005	
226	305	4/4/90	4335	14609	57		15.8		1115	
226	306	4/4/90	4334	14601	45		16.4		1210	
226	307	4/4/90	4325	14555	35		16.4		1330	
226	308	4/4/90	4321	14556	33		16.6		1405	
226	309	4/4/90	4320	14558	34		16		1430	
226	310	5/4/90	4319	14557	18		15.4		840	
226	311	5/4/90	4318	14556	14		15.4		900	
226	312	5/4/90			40		16.2		1410	
226	313	5/4/90	4333	14601	65		16.7		1530	
226	314	5/4/90	4335	14617	30		16.2		1700	
247	31	19/12/90	4259	14810	100	56	15.3	15.4	945	
247	32	19/12/90	4254	14757	57	45	14.7	14.8	810	
247	35	19/12/90	4304	14805	100	82	15.1	14.6	1035	
247	36	19/12/90	4304	14800	80	44	14.7	13.9	1115	
248	6	5/1/91	4118	14836	137		16.2		1625	178
248	7	5/1/91	4118	14830	113		16.2		1540	130
248	8	5/1/91	4118	14823			16.2		1445	164
248	9	5/1/91	4134	14821	45		15.6		1255	196
248	10	5/1/91	4134	14828	94		16		1210	207
248	11	5/1/91	4134	14835	138		16.3		1125	158
248	14	5/1/91	4147	14834	125		16.2		950	160
248	15	5/1/91	4147	14827	74		15.8		845	141
248	16	5/1/91	4147	14818	40		15.1		745	162
248	17	4/1/91	4201	14819	45		15.3		1515	183
248	18	4/1/91	4203	14828	88		16		1415	161
248	19	4/1/91	4203	14836	130		16.3		1320	201
248	22	4/1/91	4215	14833	123		16.1		1145	135
248	23	4/1/91	4216	14826	100		15.8		1050	150
248	24	4/1/91	4217	14820	70		15.2		950	190
248	26	3/1/91	4238	14813	89		16.1		1550	203
248	27	3/1/91	4237	14824	117		15.9		1430	107
248	30	3/1/91	4245	14821	125		16.1		1255	122
248	31	3/1/91	4248	14811	94		15.5		1140	161
248	32	3/1/91	4252	14800	66		15.5		1015	176
248	34	3/1/91	4300	14814	150		15.5		815	140
248	35	3/1/91	4301	14806			15.5		705	4670
248	36	3/1/91	4301	14754	70		14.8		600	57
249	6	23/1/91	4118	14838	170		16.8		845	87
249	7	23/1/91	4118	14829	90		16.7		750	103
249	8	23/1/91	4118	14823			16.2		640	106
249	9	23/1/91	4133	14821	48		16.7		1315	103
249	10	23/1/91	4134	14828	100		16.1		1220	109
249	11	23/1/91	4133	14835	143		17.1		1127	
249	14	22/1/91	4146	14834	134		17.5		1530	104
249	15	22/1/91	4147	14826	74		16.9		1430	103

Cruise	Stat	Date	Lat	Long	Depth (m) Water	Tow	Temp (T°C) Surface	10 m	Time (EST)	Water Vol (m^3)
249	16	22/1/91	4148	14818	38		16.7		1325	105
249	17	22/1/91	4201	14819	50		16.5		1135	102
249	18	22/1/91	4202	14828	87		16.5		1030	86
249	19	22/1/91	4203	14836	150		17		930	91
249	22	22/1/91	4214	14833	121		17		745	107
249	23	22/1/91	4217	14827	98		16.4		650	97
249	24	22/1/91	4216	14822	73		16.3		550	124
249	50	22/1/91	4304	14715	20		17.2		1206	106
250	25	29/1/91	4230	14803	40		17		1230	151
250	26	29/1/91	4232	14817	88		16.4		1345	151
250	27	30/1/91	4240	14824	180		16.4		930	122
250	30	30/1/91	4246	14820	118		16.3		1200	147
250	31	30/1/91	4248	14811	94		16.3		1315	94
250	32	30/1/91	4251	14800	66		15.8		1445	90
250	34	31/1/91	4301	14810	102		15.4		940	114
250	35	31/1/91	4301	14806	96		15		855	106
250	36	31/1/91	4301	14759	75		15.2		800	97
250	51	29/1/91	4236	14812	89		16.4		1530	144
250	52	29/1/91	4240	14808	51		16.7		1600	121
250	53	30/1/91	4240	14813	93		16.1		820	160
250	54	30/1/91	4247	14815	101		17.4		1240	111
250	55	30/1/91	4250	14805	78		16.3		1405	97
252	6	20/2/91	4119	14839	113		17.8		1130	154
252	7	20/2/91	4118	14839	103		16.6		1100	172
252	8	20/2/91	4118	14834	49		16.5		1000	181
252	9	20/2/91	4134	14820	45		16.2		840	147
252	10	20/2/91	4133	14826	90		16.3		800	138
252	11	20/2/91	4134	14835	193		16.9		1300	181
252	14	20/2/91	4149	14834	118		16.5		1510	179
252	15	18/2/91	4150	14826	71		16.4		1530	168
252	16	19/2/91	4149	14819	45		16.6		1630	156
252	17	18/2/91	4202	14820	51		16.5		1345	199
252	18	18/2/91	4208	14827	87		16.2		1245	193
252	19	20/2/91	4202	14836	119		16.4		1655	173
252	22	21/2/91	4215	14833	114		15.8		820	2823
252	23	21/2/91	4216	14826	97		15.9		905	135
252	24	19/2/91	4218	14820	72		16.2		1115	149
252	25	21/2/91	4231	1482	36		17.1		1200	194
252	60	21/2/91	4224	14814	56		16.2		1030	186
252	61	21/2/91	4228	14807	43		16.7		1125	146
253	26	26/2/91	4236	14814	86		15.8		1415	149
253	31	27/2/91	4248	14809	85		15.5		1700	135
253	32	28/2/91	4252	14759	55		15.6		1100	157
253	35	28/2/91	4257	14806	89		15.4		910	133
253	36	28/2/91	4258	14801	71		15.5		1005	182
253	64	26/2/91	4239	14813	90		16.2		1500	130
253	65	26/2/91	4240	14810	78		16.4		1530	102
253	66	26/2/91	4242	14805	68		16.8		1610	
253	67	27/2/91	4240	14814	80		16.4		1120	
253	68	27/2/91	4240	14811	82		16.2		1530	130
253	69	27/2/91	4240	14811	82		16.2		1530	
253	100	27/2/91	4240	14812	88		15.9		1210	217
253	101	27/2/91	4240	14812	88		15.9		1230	188
253	102	27/2/91	4240	14812	88		15.9		1250	140
253	103	27/2/91	4240	14812	88		15.9		1310	138
253	104	27/2/91	4240	14812	88		15.9		1330	138
253	105	27/2/91	4240	14812	88		15.9		1355	160
253	106	27/2/91	4240	14812	88		15.9		1420	155
253	107	27/2/91	4240	14818	103		15.7		1440	148
254	25	18/3/91	4232	14802	44		16.5		1320	135
254	26	18/3/91	4239	14817	102		17.4		1500	119
254	31	3/19/91	4251	14808	90		16		935	102

Cruise	Stat	Date	Lat	Long	Depth (m)		Temp (T°C)		Time	Water
					Water	Tow	Surface	10 m	(EST)	Vol (m^3)
254	32	19/3/91	4254	14802	52		16		1320	141
254	35	19/3/91	4302	14803			15.7		1115	121
254	36	19/3/91	4301	14758	65		15.8		1200	128
254	70	18/3/91	4241	14813	91		17.5		1550	129
254	71	18/3/91	4241	14810	77		16.9		1615	140
254	72	18/3/91	4241	14807	52		16.2		1700	117
254	73	19/3/91	4243	14805	65		16.1		820	117
254	74	19/3/91	4255	14807	91		16		1015	124
254	75	20/3/91	4225	14822	97		18.7		1130	156
254	76	20/3/91	4220	14822	74		18.8		1220	136
254	80	20/3/91	4218	14821	73		19		1300	
256	25	8/4/91	4232	14805	40		15.7		1405	107
256	26	8/4/91	4236	14814	85		15.8		1530	110
256	30	9/4/91	4244	14821	300		17.4		900	280
256	31	9/4/91	4249	14811	93		15.8		1040	109
256	32	9/4/91	4252	14759	55		15		1640	
256	35	9/4/91	4302	14805	94		14.9		1240	183
256	36	9/4/91	4302	14759	70		14.7		1340	113
256	42	9/4/91	4253	14803	79		15.5		1550	109
256	43	9/4/91	4302	14802	83		14.8		1415	109
258	25	6/5/91	4231	14806	51		14.3		1250	132
258	26	6/5/91	4233	14816	90		14.4		1350	116
258	27	6/5/91	4235	14827	140		14		1500	101
258	31	7/5/91	4248	14811	94		14.1		1225	155
258	32	7/5/91	4251	14800	65		14.2		1340	139
258	35	7/5/91	4302	14806	95		13.4		1600	157
258	36	8/5/91	4302	14759	72		13.1		1630	164
258	L1	7/5/91	4253	14801	65		13.9		1420	
258	M1	8/5/91	4308	14801			13.1		1530	
258	R1	7/5/91	4241	14808	50		13.9		820	
258	R2	9/5/91	4240	14807	30		13.9		915	
258	R3	9/5/91	4240	14807	28		13.9		1000	
258	R4	9/5/91	4253	14801			13.9		1010	
258	R5	9/5/91	4237	14809	49		14.2		1135	

6. ORIGINAL GRANT APPLICATION

Fishing Industry Research Committee

Application for Funding - 1988-89

1. **Title of proposal:** Jack mackerel resource assessment in south eastern Australian waters.

2. **Name of Applicant:** Department of Sea Fisheries, Tasmania (DSF)

3. **Department, division or section:** Fisheries Division, Pelagic Fisheries Section.

4. **Proposal:**

This proposal aims to develop methods for estimating the size of the jack mackerel resource using fishery-independent techniques. This information will be used to develop relative indices of abundance which will become the basis for calculating annual total allowable catch (TAC) for the jack mackerel fishery.

The primary methods to be used will be sonar and aerial survey techniques. Sonar surveys will involve regular transect sampling aimed at developing a hydroacoustic index of abundance. The aerial surveys will take advantage of the aerial census data currently being collected by the DSF. This information is collected from the spotters by a logbook, but is not currently being analysed due to staffing shortages.

Inter-annual variability in the jack mackerel resource will be assessed by relating the baselines formed from the hydroacoustic, and aerial surveys to sea temperature. Sea temperature data will be derived from routine hydrographic surveys and by sea surface temperature images provided by the CSIRO Division of Fisheries. In this way a qualitative understanding of the effects of sea temperature on adult distribution will be gained.

The project will utilize the research vessel *Challenger* to conduct transects on a fortnightly basis through the summer and autumn on the east coast of Tasmania. A Simrad SQ 270 sonar will be used to map school abundance on these transects. Routine ichthyoplankton and hydrographic stations will also be sampled on the transects. Associated with the transects will be mid-water and bottom trawling to sample and identify targets.

There is a paucity of information on adult abundance, distribution, spawning areas and the early life history of jack mackerel. This project would substantially add to our knowledge in these areas whilst providing information of direct relevance to the management and development of the fishery.

5. **Name of persons responsible for program:**

Name	Kim Evans, B.Sc.(Hons.) Acting Assistant Director - Fisheries	Dr Howel Williams R.O.I.C. Pelagic Fisheries Section
Address	Dept Sea Fisheries, Tasmania GPO Box 619F Hobart 7001	Dept Sea Fisheries, Tasmania GPO Box 619F Hobart 7001
Telephone	(002) 30 6632	(002) 27 8867
Facsimile	(002) 23 1539	(002) 278 025

6. **Qualifications of staff to be employed on program:**

	% on this project
H. Williams, B.Sc.(Hons.) Ph.D	(10%)
C. Waterworth, Technical Officer	(10%)
Research Officer to be appointed	(100%).
Technical Officer to be appointed	(100%).

Objectives:

(a) develop indices of abundance for jack mackerel to enable appropriate annual TACs to be set,
(b) describe and assess the potential for variability in jack mackerel stocks caused by environmental factors, and
(c) collect data on the breeding behaviour and early life history of jack mackerel.

Justification, including practical application:

Background:

The jack mackerel fishery is a new and developing fishery, for which there has only been two full seasons of fishing. Even so it has grown dramatically from an unexploited resource in 1984 to the largest single species fishery in Australia at present in terms of landed weight. In the last season, landings of 42,000 tonnes were valued at approximately $4 million. The principal product is fish meal, which is of value both as a replacement for imported stock feeds and as a source of feed for the developing Tasmanian salmonid aquaculture industry. Several new markets are developing for mackerel (notably baitfish, canning and export for human consumption), and their development will greatly increase the value of the fishery.

The strong growth in landings has occurred because of the increasing participation of vessels and processors in the fishery. Whereas in 1985 the fishery was based around one processor and three vessels, the fishery now supports three major processors and ten vessels with an existing potential capacity in excess of 85,000 tonnes per annum.

With funding from FIRTA and the DSF a joint program has been developed to monitor catch data and collect basic biological information from the exploited population. However no assessment has been made of the population size or the existence of inter-annual variability.

Last year Tasmania sought to introduce planned development of this fishery through an Offshore Constitutional Settlement (OCS) giving Tasmania management responsibility. The developmental pressure has become intense with a potential for serious overcapitalisation occuring. This OCS was opposed on the grounds that the fishery was still developing and that the question of stock size and distribution had not been resolved.

As the OCS negotiations were unsuccessful, and because of concern that overcapitalisation may occur, the Tasmanian Government implemented a management plan for Tasmanian waters where 99.6% of the catches are made. The objective of this plan is to reduce the risk of overcapitalisation and protect the fish stocks. Management will be effected by setting annual TAC's and allocating quota to fishermen.

Under the new management plan it will not be possible to set TAC's in the short term that will optimise economic value and harvest rates due to the lack of resource assessments. This will require management to take a speculative course in setting annual TAC's. The joint FIRTA/DSF resource monitoring program will be maintained as the core research program for this fishery by the DSF. This program, although of great value in collecting data from the early development period of the fishery, is only of real value in the long term. The present time series data from this program is currently of little value to an assessment of resource size for two reasons. Firstly, this is because the program has only run for two full seasons and therefore the data is too sparce to be useful, and secondly the data is fishery based and is therefore biased to the existing fishing grounds and by fishing effort.

No information is available on stock size or on what might be a realistic TAC. It should be possible however to use the TAC as a long term research tool by sending pulses of effort through the stock by changing the annual TAC and monitoring the biological effects under the existing monitoring program. This would be a long term research program and the interpretation of the results would be complicated by the large scale fluctuations in population size that are characteristic of pelagic fish populations. This would have the effect of introducing so much background noise to population parameters that the effects of pulsed effort may be impossible to detect with the current fishery based research program. This type of research would have little chance of success in isolation of resource estimates derived by fishery-independent means.

The proposed program is aimed at estimating the abundance of the population by fishery-independent techniques. This would remove several of the constraints that hamper population analysis in the existing program, and particularly it will be independent of fishing area and intensity. This program will also aim to identify and quantify those factors that cause fluctuations in the population. A better understanding of the relationship between abundance and TAC will be attained and this will allow the fishery to develop to the optimal level of capacity in a shorter period of time.

Need for resource assessment:

Temperate pelagic fisheries such as the jack mackerel commonly exhibit year class failures and changes in adult distribution due to the effects of sporadic or cyclic changes in their habitats. Typically these perturbations are detected by changes in sea temperature and their effects are often complex. Where adult distribution is changed then abundance of fish in traditional fishing grounds may be low or nonexistant. Spawning in abnormal years may be affected as spawning grounds may not be accessible due to adverse temperature conditions. In addition the effects of adverse temperature on larval survival (through changes to the timing and magnitude of primary productivity and thus food availability) will be the main determinant of recruitment for the ensuing year class. If this effect is not detected then the recruiting year class may be overfished.

These phenomena have been detected in other temperate fisheries and are recognised as major determinants of abundance. For example, pelagic fisheries in Japan have fluctuated markedly as a result of changes to warm water currents, whilst both the sardine fishery in America and the anchovy fishery off South America have been dramatically affected by El Niño events. Environmental changes rather than fishing pressure have become the primary concern of management strategies in these fisheries.

Fisheries consultants Dr. John Gulland, Prof. Carl Walters and Dr. Ray Hillborn who visited Australia recently have emphasised the problems of using conventional fisheries orientated methods for assessing such fisheries. They see the need for fisheries-independent methods for resource assessment. Dr. Ray Hilborn, who was employed as consultant to the DSF for five months suggested that priorities in the research strategy should be the formulation of methods for assessing abundance.

Because the size of the jack mackerel resource may vary it is not appropriate to set a TAC that remains static from year to year. The DSF's aim is to develop a method to routinely assess the population and calculate an index of abundance to be used each year as the basis for setting the size of the TAC. It is hoped that this may also account for future compensations in the TAC to accommodate variable recruitment. It is anticipated that if the development of the techniques described here are successful then resource assessments of jack mackerel will be continued by the DSF after FIRTA funding ceases.

Need for fundamental breeding information:

There is very little known about the early life history of jack mackerel or of its breeding behaviour. These aspects of the species biology are of great importance in understanding many aspects of the population's dynamics. Basic information is impossible to collect from the fishery as no fish in ripe or running ripe condition have been sampled to date. Our data suggests that the breeding fish leave the fishing grounds to spawn (probably at the shelf break) and return when they are in a spent condition. However there is only scarce data relating to the

probable spawning sites and the early life history stages of larval jack mackerel; whilst data on the behaviour of spawning fish, their fecundity and the relationship of spawning fish to the inshore populations is virtually nonexistant.
Data of direct relevance to these questions could be collected in parallel to the other work described here with little extra effort. This opportunistic sampling of larvae and adults in breeding condition would greatly add to our understanding of the biology of this species.

Location(s) of operations:

Department of Sea Fisheries Laboratories, Taroona
Fisheries research vessel *Challenger* off the east and north east coast of Tasmania.

Proposal in detail:

a) Plan of Operation

1. Method of procedure-

Field work will be carried out predominantly during the summer and autumn months when jack mackerel school up into surface and shallow sub-surface aggregations. During each year of the project, the Department's research vessel *Challenger* will be utilized to carry out sonar transects off the Tasmanian east coast. The transects will cover areas both within and outside the fishing grounds, and will run from the coast out to the shelf break.

The number of schools encountered perpendicular to the vessel's course along each transect will be counted. It is not known yet whether this method will allow fish schools to be scaled by size. However this is not central to the analysis as the information on average school size is available from the fishery. Observations on schooling behaviour by day and by season will be recorded. A hard copy of the sonar image will be printed by plotter to produce a permanent record and also to allow measurements and accurate counts to be made.

Spatial autocorrelation will be used to determine packing rates of schools per unit area and interaction between schools. It may also be used to examine interaction between schools of different species if species identification becomes possible with experience. The hydroacoustic method of producing an index of abundance will be assessed for its suitability on jack mackerel.

Regular ichthyoplankton and hydrographic stations will be conducted along the transects. Ichthyoplankton tows will be made using 500μm plankton nets and the samples preserved for later analysis. Temperature profiles will be made using temperature/depth probes (and associated software and hardware) at each station. The nets, probes, flowmeters and ancillary deck gear for this equipment will be supplied by the DSF.

Target trawling on the transects and at the shelf break will be carried out. The DSF has recently purchased and tested a pelagic trawl net and net sonde, and techniques for mid-water trawling with this equipment have been developed. Catches from these trawls will be used to identify sonar targets and the fish caught will be analysed to determine breeding condition. Gonad samples will be taken and histological examination of the ovaries made.

Development of a data base for existing and future returns from the aerial spotters logbook will give information on the abundance of surface schools from the beginning of the 1986-87 fishing season. Subsequent analysis should yield information on abundance as a function of spotting effort. Spotting data is also available for areas outside traditional fishing grounds.

The distribution of adult fish detected by both hydroacoustic and aerial survey techniques will be mapped and analysed. This data and the temperature data gained from the temperature profiles and the sea surface temperature images will be examined for correlations.

2. Facilities available-

- (a) office and laboratory space at the Taroona Marine Laboratories of the DSF.
- (b) dedicated sea time on the *Challenger* and use of associated equipment (plankton/trawl nets, net sonde, etc).
- (c) dedicated use of the Simrad SQ270 sonar* and temperature/depth probes with associated microcomputer.
- (d) administrative support, library services.
- (e) unrestricted use of the Departments in-house computing facilities and peripherals.
- (f) access to SST images purchased by the DSF from CSIRO Division of Fisheries.
- (g) unresticted access to the purse seine data base including catch and biological data.

* It should be noted that the Simrad SQ270 was aquired specifically for this type of project. The unit was purchasd and installed in 1987 with funding from Rural Credits and the DSF.

b) Supporting Data

1. Previous work in this or related fields-

Hydroacoustic surveys have been used by many countries to assess fish populations. Sonar mapping has been used in both South and North America to assess anchovy populations. In South America routine surveys from commercial vessels are used to measure fish abundance at the begining of each season (EUREKA surveys). Similar techniques using research vessels have been used in the U.S.A. for most of the pelagic fish resources off the west coast of North America.

11. Commencement and completion dates:

Commencement date 1 July 1988

Completion date 30 June 1991

12. Funds requested.

Total funds requested.

Item	1988-89 $	1989-90 $	1991-91 $
Total salaries	57 715	60 586	62 725
Total operating expenses	7 500	6 800	6 800
Total travelling expenses	7 278	7 278	7 278
Total capital items	27 300		
Estimated income	0	0	0
Gross Total Cost	**99 793**	**74 664**	**76 803**

The assets of FIRTA program 85/77, "Resource monitoring of the jack mackerel purse seining fishery in south eastern Australia" include a Wild M5A stereo microscope. This program terminates in June 1988 and the equipment will then be returned to FIRTA. As the proposed program outlined here also requires a similar item, it is suggested that if a transfer could be made to this program then the Capital grant requested above could be reduced by $6 500, with a total request for 1988/89 of $93 293.

See Annex A for detail

. Funds to be provided by the applicant or sought from other sources:

Funds provided by applicant

m	1988-89 $	1989-90 $	1991-91 $
tal salaries	4 512	4 674	4 790
tal operating expenses	159 100	163 800	167 500
tal travelling expenses	209	209	209
tal capital items	144 200		
imated income	0	0	0
oss total cost	**308 021**	**168 683**	**172 499**

See Annex B for detail

. Cooperating agencies:

Specific advice on currents and the sea temperature flux around Tasmania will be sought from Dr Graham Harris of the CSIRO Division of Fisheries Research (DFR). Dr Ron Thresher and Dr John Gunn (also of CSIRO-DFR) will be consulted on information arising from the analysis of the Southern Program larval collection, particullarly taxonomic and aging techniques.

Scientific advice will be sought at Demersal and Pelagic Fisheries Research Group meetings.

. Is similar work being undertaken in Australia:

No work of a similar nature is being undertaken in Australia. However research on jack mackerel of interest to the proposal is being carried out. This research includes;

- ongoing monitoring program of the jack mackerel fishery by the DSF,
- parasite marker research by the University of Queensland and
- an analysis of the distribution of mitochondrial DNA in jack mackerel populations by the University of Tasmania.

The CSIRO-DFR has a taxonomically important larval collection aquired during the Southern Program. Some cooperative work between the DSF and CSIRO-DFR has been undertaken to recover Carangid larvae from this collection. Taxonomic and aging techniques developed in the future by the CSIRO-DFR will be of central importance to the analysis of the larval samples to be collected by the methods described in this proposal.

. Publication of results:

The results of the program will be presented to FIRC in the prescribed progress reports and in the project final report. The results and progress will be presented yearly at DSF research reviews. Progress will also be reported in the DSF Technical Report series.

The results will also be written up in manuscripts for submission to scientific journals for publication.

Some of the results will also be presented at annual meetings of the Demersal and Pelagic Fisheries Research Group, Australian Marine Science Association, and the Australian Society for Fish Biology.

Annex A. Details of funds sought.

Budget item	1988/89 $	1989/90 $	1990/91 $
1. Salaries			
Research Officer	25 395	27 102	28 310
Technical Officer	19 325	19 842	20 292
Sea going Allowances (120 seadays, payed as overtime and is subject to payroll tax and workers comp.)	6 811	7 150	7 403
Payroll tax (6%, including sea going)	3 092	3 246	3 360
Workers compensation (6% due to seagoing staff)	3 092	3 246	3 360
Sub-total	**57 715**	**60 586**	**62 725**
2. Operating expenses			
Consumable equipment and maintenance of gear	4 500	4 500	4 500
Wet weather gear, film development etc.	1 500	800	800
Software development	1 000	1 000	1 000
Purchase of monographs	500	500	500
Sub-total	**7 500**	**6 800**	**6 800**
3. Travelling expenses			
Sea victualing allowance	2 088	2 088	2 088
Personal allowances (2 trips for 5 days)	990	990	990
Air fares (2 return trips Sydney) [DPFRG and Conference attendance]	1 200	1 200	1 200
Vehicle running costs	3 000	3 000	3 000
Sub-total	**7 278**	**7 278**	**7 278**
4. Capital items			
Motor vehicle (Ford utility)	10 800		
Dissecting microscope	6 500		
Simrad sonar plotter (installed)	10 000		
Sub-total	**27 300**		
Estimated income.	0	0	0
Gross Total Cost	**99 793**	**74 664**	**76 803**

nex B. Details of funds provided by applicant.

lget item	1988/89 $	1989/90 $	1990/91 $
Salaries			
Research Officer 10%	2 710	2 831	2 900
Technical Officer 10%	1 802	1 843	1 890
Sub-total	**4 512**	**4 674**	**4 790**
Operating expenses			
Boat time: 60 days *Challenger* per year (@$1 100 per day)	66 000	66 000	66 000
Sea surface temperature data	4 000	4 000	4 000
Office, administrative and laboratory services. [Based on multiplier of 1.8 x total salries]	88 600	92 900	96 100
Publishing and page charges	500	900	1 400
Sub-total	**159 100**	**163 800**	**167 500**
Travelling expenses			
Sea victualing allowance	209	209	209
Sub-total	**209**	**209**	**209**
Capital items			
Sonar and transducer	120 000		
Submersible data loggers, reader and deck gear	22 000		
Plankton nets, flow meter and deck gear	2 200		
Sub-total	**144 200**		
oss Total Cost	**308 021**	**168 683**	**172 499**