ISSN 1441-8487

FISHERY ASSESSMENT REPORT

TASMANIAN ABALONE FISHERY

2001

Compiled by David Tarbath, Kate Hodgson, Craig Mundy and Malcolm Haddon

June 2002

National Library of Australia Cataloguing-in-Publication Entry:

Tarbath, David Bruce, 1955-
Fishery assessment report : Tasmanian abalone fishery.

Bibliography.
Includes index.
ISBN 0 7246 4770 8.

1. Abalones - Tasmania. I. Tarbath, D. B. (David Bruce), 1955- . II. Tasmanian Aquaculture and Fisheries Institute. Marine Research Laboratories. (Series : Technical report series (Tasmanian Aquaculture and Fisheries Institute)).

338.37243209946

This assessment of the Tasmanian abalone resource uses input from the abalone fishery assessment working group (AbFAWG). Membership of the AbFAWG during the period covered by this assessment was :

Assoc. Prof. Malcolm Haddon	Program Leader, Wild Fisheries Program, Tasmanian Aquaculture and Fisheries Institute, (Chair)
Dr. Craig Mundy	Section Leader, Abalone Research and Assessment Section
Grant Pullen	Principal Fisheries Management Officer, Department of Primary Industry, Water and Environment
Dean Lisson	President, Tasmanian Abalone Council
John Hoult	Tasmanian Abalone Council
Rob Royle	Chairman, Quota Holder Sub-Council
Allen Hansen	Chairman, Processor Sub-Council
Nigel Wallace	Chairman, Diver Sub-Council
Greg Woodham	Treasurer, Tasmanian Abalone Council
Kate Hodgson	Research Assistant, Resource Modelling Section, Tasmanian Aquaculture and Fisheries Institute
David Tarbath	Research Fellow, Abalone Section, Tasmanian Aquaculture and Fisheries Institute

At the AbFAWG meeting on 28 March 2002, Scott McKibben attended in place of John Hoult, and Dr. Howel Williams attended as an observer.

This report was compiled by D. Tarbath, K. Hodgson, C. Mundy and M. Haddon, TAFI Marine Research Laboratories, PO BOX 252-49, Hobart, TAS 7001, Australia. E-mail: David.Tarbath@utas.edu.au.
Ph. (03) 6227 7277, Fax (03) 6227 8035
Published by the Marine Research Laboratories, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania 2002.

Abalone Fishery Assessment: 2001

Executive summary

The 2001 Abalone Fishery Assessment was based primarily on commercial catch-effort statistics and size-composition data from the Tasmanian fishery for blacklip abalone (*Haliotis rubra*) and greenlip abalone (*H. laevigata*). Commercial catch-effort statistics were derived from data supplied by the Tasmanian Department of Primary Industry, Water and Environment. This was based upon catch dockets provided by licensed divers. Catch-rates were derived from the catch-effort statistics and annual variation in catch-rate was interpreted as a relative index of abalone abundance. The size-composition data were mostly collected by TAFI research staff, but some data were obtained directly from divers. Changes in size-composition from commercial catch samples are used to assess variation in levels of fishing mortality across years.

In 2000, the Tasmanian blacklip abalone fishery was divided into separate Eastern and Western zones, and the greenlip fishery was managed separately. The purpose of zoning was to manage the distribution of effort and protect the more accessible areas from high fishing pressure and consequent over-exploitation. In 2001, an additional blacklip zone was created in the north of the State to promote fishing in an area that was considered relatively under-exploited. The Northern Zone extends from the Arthur River in the west to the Musselroe River in the east and includes the Bass Strait islands. The Eastern Zone extends from the Musselroe River to Whale Head in the south, and the Western Zone from Whale Head to the Arthur River. The greenlip fishery takes place in the north of Tasmania and the Bass Strait islands.

Each zone was given a fixed total allowable catch (TAC): the Eastern Zone set at 1120 tonnes, the Western Zone at 1260 tonnes and the Northern Zone at 280 tonnes. The greenlip fishery operated with a TAC of 140 tonnes. In 2001 therefore, the state-wide abalone catch was 2800 tonnes.

There are two important features in this assessment. The first concerns the status of stocks in the Eastern Zone, which saw a substantial decline in abalone stocks on the east and south-east coasts. The second was that Western Zone stocks are also showing signs of depletion.

In the Eastern Zone, catch-rates continued to fall throughout the fishery. In spite of increases in diver efficiency over the past decade, catch-rates fell to levels comparable to those of the 1980’s when the fishery was extensively depleted.

The Eastern Zone fishery was mostly dependent upon abalone that had grown through the size-limit within the previous year. In some areas, these new recruits were absent from the catch, which was consistent with low levels of larval settlement in the mid 1990's. Larger abalone, those with two or three years growth above legal size, were either absent from catches or present only in low numbers. Combined with the falling catch-rates, the manner in which the size-structure of the commercial catch altered through time indicates that fishing mortality has been too high. If these trends continued in 2002, appropriate management control options might include further quota cuts and/or size-limit increases to those introduced for the 2002 season.

Areas of reef that in earlier years have produced substantial quantities of abalone are no longer productive (e.g. Blocks 28, 29 and 30). These reefs have failed to recover, which may be because divers have persistently removed any stock build up in these areas. At current levels of effort these blocks are unlikely to recover. Specific management controls for these blocks could include complete closure or seasonal closures. To prevent the redirection of even the small amount of effort that continues to be imposed on these blocks, such closures should only be introduced in concert with an equivalent reduction in TAC for the zone from which they derive.

In 2002, the TAC for the Eastern Zone was reduced from 1120 tonnes to 857.5 tonnes and the minimum size limit was increased from 132 mm to 136 mm. We were unable to determine whether the 262.5 tonne reduction in TAC was appropriate for the current level of stocks in the Eastern Zone but both of these measures were designed to reduce fishing mortality in an effort to stabilize stock levels and possibly allow them to recover.

In the Western Zone, continued catch-rate declines, particularly in the blocks accessible to trailer-borne craft, indicated that abundance has fallen. There are aspects of the Western Zone fishery that make catch-rates unreliable indicators of stock abundance, suggesting that it may be falling faster than the catch rates. We were unable to collect sufficient catch-sampling data to judge whether size-composition was stable. Catch-rates in Blocks 6, 9 and 12 have fallen considerably over recent years and options to limit stock depletion need to be considered to spread effort into more remote areas before local depletions force a diversion of effort.

The Northern Zone fishery operated successfully in 2001, although effort was distributed in a manner rather different from that predicted from past catches. The catch taken from the North West was at relatively high levels, and in comparison, the catch from King Island negligible. Market forces appeared to be directing effort to the North West. Catch rates in Block 5 dropped markedly in 2001 and if this trend continued then the stocks in that area are likely to become depleted. Management options to redistribute effort from this area include imposing limits on the annual catch in some or all of the northern regions.

Greenlip catch-rates appear to have stabilised or improved in all regions except King Island. Lower catch-rates in this area may be associated more with the high size-limit applied in 2001 rather than stock depletion.

The overall catch of recreational divers was still relatively minor, but was mostly directed to the east and southeast coasts. These coincided with areas where levels of depletion by commercial divers were greatest. While the commercial fishery is carefully scrutinised and tightly regulated, there are no corresponding checks and controls within the recreational fishery apart from a daily catch-limit and size-limits. In particular, there are no means to monitor the quantity of catch, and from where it is taken. This undermines the integrity of the process of establishing safe levels of catch and setting a TAC. As the recreational catch is largely derived from the stressed portions of the Eastern Zone, we require more precise information about the size of the recreational abalone catch and distribution of effort.

Fishery Assessment techniques

It was noted in the 2000 Assessment that Eastern Zone stocks were reduced compared with previous years. With hindsight, it is now apparent that the extent of this reduction was greater than anticipated. It may have been better appreciated with a different approach to assess changes in catch-rates. Consequently this report briefly reviews the usage of catch-rates as a performance indicator as well as the two supplementary performance indicators - egg production and size composition.

In the past, abalone fishery researchers around the world have thought that changes in catch per unit effort (CPUE) were poor indicators of relative stock abundance. This view derived from the knowledge that divers could maintain high catch-rates, whilst steadily reducing stock levels, by successively depleting areas of high abundance. The aggregating behaviour of abalone also contributed to high catch-rates at falling stock levels because divers could target abalone aggregations.

The decline in the Eastern Zone occurred following high levels of fishing pressure over the past four years. Because stocks are now at reduced levels through most of the Eastern Zone, divers are far less able to move to areas of greater abundance when their catch-rates fall. With the possible exception of some deeper reefs, all areas with viable stocks are fished hard and in some areas, reefs are fished almost daily. The confounding effect upon catch-rates caused by divers depleting successive reefs no longer applies. This high level of fishing pressure across the Eastern Zone also means that large aggregations of legal-size abalone are uncommon, and that divers are collecting individual abalone rather than large abalone aggregations. Consequently, in the Eastern Zone fishery, changes in CPUE are now likely to better reflect changes in abundance than they do elsewhere.

In other parts of the Tasmanian fishery where fishing mortality is lower than in the Eastern Zone and where legal-size abalone are harvested from dense patches, catch-rate trends may be less than optimal indicators of abundance. Sustained falls in catch-rate should be interpreted as stock depletion, but this may be out of proportion to the stock decline because of the conditions under which the abalone are taken. Such trends should be given serious consideration as the stock decline may be much greater than indicated by the fall in catch-rates, for the reasons of serial depletion and aggregating behaviour of abalone described above.

Past assessments of the Tasmanian abalone fishery have relied heavily upon comparing current catch and catch-rates with those from two reference periods – the first from 1979 to 1982 when catches were at peak levels, and the second from 1992 to 1995 when the catch was reduced following high levels of depletion, and stocks were rebuilding. This comparative method was developed for and is extensively described in the initial Abalone Fishery Management Plan. However, because of the dynamic nature of the fishery, the above two periods are a compromise, and are not the most appropriate reference periods for some blocks, particularly in the west. This problem combined with additional complications such as improvements in diver efficiency and the steady attrition of abalone producing reefs, indicate comparisons with the above reference periods may mask the magnitude of changes and produce ambiguous messages about the health of the fishery. They may be adequate indicators of fishery performance when stocks are rebuilding, but they fail to give appropriate levels of warning when the fishery is declining.

It is proposed that we review our reliance on comparisons of catches and catch-rates against reference periods, and instead consider using ten year trends in catch and catch-rate. Other techniques such as catch-rate frequency distributions may also be used. Trend assessment needs to be done in conjunction with catch size-composition and an understanding of the conditions experienced by divers who operate in the fishery. Past attempts by researchers to use catch and catch-rate trends to monitor stock abundance of abalone failed because the trends were reviewed on too large a spatial scale. Such trends were driven by factors additional to changes in abundance (e.g. weather conditions, market preferences), which produced information that conflicted with that derived from comparison with the two reference periods. We now have a better awareness of the effects of local factors upon catch-rates. Combining this with information about the size-structure of abalone, and the fact that catches are reported at the sub-block level, we are able to interpret catch-rate trends with greater confidence particularly in the Eastern Zone.

Levels of egg production (the second performance indicator) are yet to be used as a widespread assessment tool in abalone fisheries. Some of the stock collapses in abalone fisheries in other parts of the world have been correlated with low levels of egg production. However, the connection between egg production and recruitment to the fishery, while intuitively appealing, is mathematically improbable. Additional factors such as fertilisation success, larval mortality, larval supply and juvenile mortality are highly variable and likely to decouple any relationship between egg production and recruitment. Stock-recruitment relationships in abalone fisheries as in most fisheries are obscure and extremely difficult to determine. It is unlikely that maintaining levels of egg production alone would ensure a sustainable fishery.

An alternative indicator could be derived from one of the objectives of the management plan - to ensure that abalone are allowed to grow to a size where they have had two breeding seasons through the use of appropriate size-limits. In parts of the Tasmanian fishery where abalone growth is such that the gap between the size at onset of maturity and the size-limit approximates two or more year's growth (especially the northern part of the state), stock levels were historically relatively stable. If this measure were formally adopted, the fishery performance indicator would be derived from both growth rates and median size-at-maturity, from a number of sites within an assessed region.

The third performance indicator (change in size-composition of the catch) is an important stock assessment tool. A reduction in modal size in conjunction with falling catch-rates is a clear indication of depletion. To be of most use, we require this data be resolved to a small spatial scale i.e. sub-block level. It is only since 2000, when divers first started reporting catches at the level of sub-block, that we have been able to review changes in size-composition in a meaningful way.

In summary, the major findings of the assessment were:

- Depletion of stocks continued throughout the Eastern Zone at levels greater than previously considered in spite of a quota reduction from 1190 to 1120 tonnes in 2000 (associated with the introduction of the Northern Zone).

- Catch-rates in the Eastern Zone were comparable with those from the late 1980's when the fishery was extensively depleted and have continued to be at this low level during the first quarter of the 2002 fishing year.

- The size-composition of catch samples indicates that the Eastern Zone fishery is dependent upon abalone that have recently grown through the size-limit. Under these circumstances there is no standing crop to act as a buffer to accommodate poor levels of larval recruitment that may have occurred in previous years.

- Areas of reef on the east coast that formerly produced significant quantities of abalone are now no longer productive.

- Western Zone catch-rates have fallen. In the more accessible blocks, catch-rates have fallen for a second successive year. Because of the nature of the fishery, catch-rates as an index of abundance may under-estimate the degree of stock reduction in this area.

- Changes in the frequency distribution of catch-rates indicated that Western Zone stocks were depleted in Blocks 6, 9 and 12 and suggest some measure of protection will be required in these blocks.

- The reduction of size-limit and development of the Northern Zone fishery has progressed satisfactorily. However, blacklip stocks in the northwest are currently being exploited at greater rates than are considered sustainable. This suggests that the catch needs to be reduced and either transferred to King Island or removed from the TAC.

- Levels of blacklip catch and catch-rate from the Furneaux Group and the North East region of the Northern Zone indicate a healthy fishery.

- The greenlip fishery is stable in all areas other than King Island. The low catch-rates at King Island may be associated more with the high size-limit rather than depletion. The distribution of catch was managed successfully in 2001.

- The level of recreational catch appropriate for the east and southeast coasts must be considered to prevent divers impacting on depleted stocks. A means of monitoring this fishery is recommended.

Table of Contents

1. Introduction

1.1 Abalone Biology

1.1.1 Distribution and habitat

Abalone are marine archaeogastropods that inhabit rocky substrata sub-tidally and feed on macro-algae. Two species are fished commercially in Tasmania: the blacklip abalone, *Haliotis rubra* Leach, and the greenlip abalone, *Haliotis laevigata* Donovan. Blacklip abalone occur throughout southern Australia and are fished commercially in Tasmania, Victoria, South Australia, New South Wales and Western Australia (Shepherd, 1973; Harrison, 1983; Prince and Shepherd, 1992). Blacklip abalone live at depths ranging from 0 to at least 50 m, although abundances are highest between 0 to 15 m depth in most areas. Greenlip abalone occupy a more limited distribution and are only fished commercially in Tasmania, Victoria, South Australia and Western Australia. Within its distribution greenlip abalone are constrained to areas of strong tidal flow. The species occurs at depths ranging from 0 to 30 metres.

1.1.2 Reproduction

The sexes are separate, and external fertilisation of gametes occurs by synchronous broadcast spawning of eggs and sperm into the water column. Whilst individual abalone can produce million of gametes each reproductive season (Shepherd, Godoy and Clarke, 1992), fertilisation success is influenced by the distance between spawning adults. Highest rates of fertilisation are achieved when male and female adults are within 2 metres of each other. Experimental studies of greenlip abalone have demonstrated that fertilisation success is less than 5 % at separations greater than 16 metres (Babcock and Keesing, 1999).

Reproduction of blacklip abalone is reported to occur at different times of the year in different places, although in southern Tasmania spawning intensity is maximal in late winter and early spring, with minor spawning throughout much of the rest of the year (Nash, Sellers, Talbot, Cawthorn and Ford, 1994). Spawning of greenlip abalone appears to be epidemic, occurring over a period of 2-3 days in late spring/early summer (Rodda, Keesing and Foureur, 1997). There is also evidence that greenlip abalone aggregate before and during spawning, possibly as an adaptive response to maximise fertilisation success (Shepherd, 1986).

Abalone eggs are lecithotrophic, so there is no feeding during the planktonic larval phase, although Manahan and Jaeckle (1997) have demonstrated significant absorption of dissolved organic nutrients through the integument. The larval phase is temperature-dependent but short (a few days) compared with that of species that have planktotrophic larvae (eg., oysters and fish), which can have a planktonic larval duration of several weeks.

Abalone larvae settle preferentially on crustose coralline algae (McShane, 1996). Chemical cues for settlement include gamma-aminobutyric acid (GABA), a constituent of coralline algae (Morse, Hooker, Jensen and Duncan, 1979), the mucous grazing trails of conspecific abalone (Seki and Kan-no, 1981) and the bacteria that grow on the surfaces of coralline algae.

1.1.3 Feeding

Small abalone feed on coralline algae until a few millimetres shell length, then feed for the rest of their lives on macro-algae. Preferred food species of *H. rubra* have been identified using gut analysis (Foale and Day, 1992) and laboratory trials (Fleming, 1995a; Fleming, 1995b). In southern Australia *H. rubra* primarily feeds on fleshy red macro-algae, although a variety of brown algal species are also eaten.

Abalone feed on either attached or drift algae. The relative importance of these two dietary components apparently depends on availability, which in turn depends on the degree of wave action and the species composition of algae growing where the abalone are living (Shepherd, 1973).

1.1.4 Growth and size

Growth rates have been estimated using both mark-recapture and direct ageing methods. Most mark-recapture studies have been of abalone larger than about 60 mm, and the data fitted by various methods to the von Bertalanffy growth function. When abalone smaller than ~60 mm have been tagged it has been shown that growth rate (in absolute terms, such as mm/yr) is maximal at a size greater than zero (Nash, 1995), indicating that the age-length relationship is sigmoidal. The use of the von Bertalanffy growth function is therefore not useful for fitting growth data when small sizes are included; these data may be fitted to sigmoidal growth functions (e.g. Gompertz, Schnute).

Worthington et al. (1995) have fitted New South Wales *H. rubra* mark-recapture data to several growth functions using the computer program GROTAG. Growth rates of small (10-60 mm) *H. rubra* have been measured by modal progression analysis (Nash, unpublished data).

Following the work of Prince et al. (1988b), who demonstrated the deposition of one shell layer per year, direct ageing of *H. rubra* was widely used to assess growth rates in the Tasmanian abalone fishery (Nash, 1992; Nash *et al.*, 1994). Nash (1994b) provided additional evidence of one growth ring per year in both adult and juvenile *H. rubra* in southern Tasmania. More recent work supports the assumption of annual growth rings in young blacklip abalone from the northern part of the west coast, and at two sites on the east coast – one in the north and the other on Maria Island (Tarbath, 1999).

Work involving a series of small scale mark-recapture studies to corroborate some of the growth estimates from ageing is underway in the north of the State. Additional growth studies are ongoing on parts of the West Coast, and more are planned for the East Coast.

Growth rates vary greatly between areas, although there is a trend towards faster growth and larger maximum size from north to south in Tasmanian waters (James, 1981; Nash, 1992; Nash *et al.*, 1994; Tarbath, 1999).

Maximum age of *H. rubra* is probably at least 20 years. This is difficult to estimate from mark-recapture data because blacklip abalone can live for several years with no growth; thus, age-at-95%-of-L_∞, which is sometimes used to estimate longevity, is therefore of little use. Direct ageing using shell growth rings suggests a maximum age of about 25 years (Nash, 1992; Nash *et al.*, 1994)

1.1.5 Age and size at maturity

Size at maturity varies considerably around the State (Tarbath, Haddon and Mundy, 2001a; Tarbath and Officer, 2001). Size at maturity tends to increase from north to south, although there is considerable variation at small spatial scales. There is some evidence that maturation is related primarily to age, not size (Nash, 1990).

1.1.6 Stock structure

Prince et al. (1987; 1988a) have postulated that *H. rubra* larvae may disperse no more than tens or hundreds of metres from the natal source, although the evidence is not conclusive (Sasaki and Shepherd, 1995). Even if the conclusions of Prince et al. are not generally correct, it is very likely that larval dispersal is no more than a few kilometres. Adult movement is at least as extensive as that postulated by Prince et al. for the planktonic larval phase (Nash, 1995); movements of tagged blacklip abalone have been recorded over distances of between 300 and 500 metres (Nash, 1995; Tarbath, 1999).

Population genetic studies do not convincingly support the limited dispersal hypothesis, nor do they preclude it. Using enzyme electrophoresis, Brown (1991) found that measures of genetic distance between sites in southern Australia (including Tasmania) suggest an isolation-by-distance model, although significant genetic heterogeneity was found over small spatial scales (<3 km). Some of the four possible population/larval dispersal scenarios listed by Brown to explain this do not include limited larval dispersal. Population genetic studies of this sort are unable to discriminate between these scenarios (Brown, 1991).

Using mitochondrial DNA methods, Barrett (1989) found little genetic variation between sites extending from northern to southern Tasmania, and suggested that gene flow may be sufficient to maintain a homogeneous distribution of mitochondrial DNA genotypes throughout Tasmanian waters.

A recent genetic study using microsatellite analysis has found no evidence for differentiation among blacklip populations of abalone in Tasmania (Elliott, Bartlett, Evans, Haddon and Officer, 2002).

1.2 Fishery background

1.2.1 Commercial fishery

The Tasmanian abalone fishery has been reviewed by Harrison (1983) and Prince and Shepherd (1992). Abalone have been exploited commercially in Tasmania since the mid-1960s. Management measures introduced for the fishery (size limits, limited entry, total allowable catch, area restrictions, etc.) have been summarised by Nash (1994a; 1996).

A minimum size limit was first introduced in 1962. It has been changed several times to reflect perceptions of the condition of the fishery and in recent years, investigations of size at onset of sexual maturity. A state-wide increase from 127 to 132 mm occurred in 1987, followed in 1990 by a further increase to 140 mm in the west and south-west (between Wild Wave River and Whale Head). More recent changes include increases in size limit for greenlip abalone to maintain adequate levels of egg production (Officer, 1999).

Entry to the fishery was limited in 1969 to the number of divers in the fishery in 1968 (120). A further five licences were created for the Furneaux Group in 1972 to provide employment opportunities for the islanders. The catch increased steadily since the commercial fishery began, peaking in 1984 before a total allowable catch (TAC) and individual transferable quotas (ITQs) were introduced in 1985. Each of the 120 mainland Tasmanian divers were allocated 28 units of quota, and the five Furneaux divers 20 units. Each unit was equivalent to 1.1 tonnes of abalone (live weight). The Furneaux divers were each granted an additional eight quota units in 1990, giving a total of 3,500 units in the entire Tasmanian abalone fishery.

Because of concerns about declining abalone abundance, the TAC was reduced in each of the four years following the introduction of quotas until, in 1989, a quota unit was equivalent to 600 kg live weight of abalone (a reduction of 45 percent over four years). The TAC (for blacklip and greenlip abalone combined) remained at 2,100 tonnes from 1989 to 1996. Between 1997 and 1999, the TAC was set at 2520 tonnes.

A recurring feature of previous stock assessments has been high catch-rates of large abalone on the West Coast, suggesting that blacklip abalone abundance is relatively high and fishing pressure is low.

In 1999, it was decided that the West Coast could sustain a higher level of fishing, and that the East Coast and greenlip catches should be reduced. The size-limit for greenlip was increased from 132 to 140 mm in the North West, and from 140 to 150 mm in all other greenlip-producing areas.

In 2000, the blacklip abalone fishery was divided into Eastern and Western zones, and the greenlip fishery managed separately. Each zone and the greenlip fishery were allocated a separate TAC. A regional TAC of 1400 tonnes was set for the western part of the Tasmanian coast between Port Sorell in the north and Whale Head in the south (subsequently known as the Western Zone). The TAC of the remaining part of the blacklip fishery (the Eastern Zone) was set at 1190 tonnes. Catch from the greenlip abalone fishery was reduced to 140 tonnes and size-limits set at 145 mm in the North East and Furneaux Group, 155 mm at King Island and 140mm in the North West. The TAC for the entire abalone fishery was 2730 tonnes.

In 2001, a new zone for blacklip abalone was created, comprising the northern parts of the Eastern and Western Zones between the Musselroe River and the Arthur River. The size-limit for the Northern Zone was set at 132 mm between the Arthur River and Woolnorth Point, and from there eastward at 127 mm. The TAC was set at 280 tonnes. The Western Zone TAC was reduced to 1260 tonnes from the previous year and the Eastern Zone 1120 tonnes. The greenlip TAC remained at 140 tonnes. The TAC for the entire abalone fishery was 2800 tonnes.

As a measure to control effort in the greenlip fishery on the more accessible coasts, and to force divers to fish remote areas, a series of caps were placed on three of the four greenlip regions. In the North East, catches were capped at 30 tonnes, in the North West 40 tonnes, and the Furneaux Group 42 tonnes. The remainder were to be taken from King Island. Small catch overruns occurred in the three capped zones.

Within the Furneaux Group, the Franklin Sound greenlip fishery (Block 35) operated only between 1 April and 30 September. This measure was adopted in 2000 to protect this part of the fishery, and has been implemented ever since.

An additional measure to control catches in the most productive part of the Eastern Zone blacklip fishery, sub-blocks 13C, D, and E, was introduced in 2001. A series of quarterly caps of 75 tonnes were implemented, such that when catches reached the limit, that part of the fishery was to be closed. Closures subsequently occurred in August, and again in October.

1.2.2 Recreational fishery

Recreational divers who hold a fishing licence (recreational abalone) may harvest abalone. This licence is obtainable for a fee, and allows a daily catch limit of ten abalone of legal size. There are also possession limits of 20 abalone per person holding a recreational abalone licence and 5 abalone per person for those who do not hold recreational or commercial abalone licences. Size-limits for recreational fishers are 132 mm for blacklip (State wide), and 145 mm for greenlip in all areas except the North West, where it is 140 mm.

Recreational fishing licences endorsed for abalone are issued on an annual basis for the period 1 November to 31 October. There is no limit on the number of recreational abalone divers. Surveys of recreational fishing have been undertaken by the Department of Primary Industry and Fisheries (Lyle, 2000).

1.3 Impact of the Fishery on the Marine Environment

Abalone are prised from rock surfaces individually by divers using a knife-like tool. There is a negligible deleterious effect of this fishing method on the habitat.

Because of the ecological interactions that occur between abalone and other organisms in their environment (competition and predation), it is almost certain that reductions in abalone abundance caused by fishing have a corresponding effect on the ecosystem which may alter the habitat in some way. It has not been established, however, that these changes are deleterious to the environment, or whether they fall outside the range of habitat variation that occurs in response to fluctuations in environmental factors not related to or caused by abalone fishing.

2. Management Objectives and Strategies

The Review of the Management Plan of the Tasmanian Abalone Fishery (2001) specifies management objectives and strategies under several headings. These objectives are listed below. The strategies employed to achieve these objectives are also listed where they are relevant to the stock assessment.

2.1 Maintain Biomass and Recruitment

Objectives

- To maintain fish stocks at sustainable levels by constraining the catch and size of individual abalone taken by the commercial and non-commercial abalone sectors. In particular, to ensure that:

    a) abalone are harvested at sustainable levels, and,

    b) biomass and egg production do not decrease below the chosen proportion of pre-fishing egg production and that reasonable levels of egg production are maintained in all regions of the fishery.

- To allow abalone to grow to a size where they have had two breeding seasons through the use of appropriate size limits.

Strategies

- Limit the catch of the commercial sector and restrict catching potential of the non-commercial sector.

- To prohibit the taking of abalone at a size below which the fish have not had adequate opportunity to reproduce through the enforcement of minimum legal sizes, whilst ensuring that the minimum size limits reflect differences in both growth rates and harvesting rates around Tasmania.

2.2 Sustaining Yield and Economic Return

Objectives

- To take abalone at or above a size likely to result in the best use of the yield from the fishery.
- To protect abalone below the minimum legal size.
- To maintain economic returns by restricting the level of catch and the number of participants in the commercial fishery.

Strategies

- To prohibit the taking of abalone below the minimum legal size limits.
- Restricting the number of divers in the fishery and limiting their catches within the Total Allowable Catch.

2.3 Commercial Fishing Interactions

Objective

- To separate the activities of abalone divers from those of other commercial divers and the rock lobster fishery, and to limit the harvesting of seaweeds until there is a better understanding of the ecological implications of such a harvest.

2.4 Access to Fish Stocks by Non-Commercial Fishers

Objectives

- To provide reasonable access to abalone stocks for recreational fishers and Aboriginal people.
- To restrict the daily catch of recreational fishers such that it is not a cover for illegal fishing.

2.5 Marine Farming Interactions

Objective

- To enable both the farming of abalone and the harvesting of wild stocks to co-exist without one posing a threat to the other.

2.6 Environmental Interactions

Objectives

- To maintain the marine ecosystems upon which Tasmania's abalone stocks depend and minimise the impact of other fisheries on the ecosystems.
- To maintain a robust abalone stock around Tasmania.

Strategies

- Set the TAC for the commercial abalone quota fishery at a conservative level, thereby minimising the impact of population declines on the ecosystems.
- Establish a series of Marine Resources Protected Areas so that representative Tasmanian marine ecosystems are reserved under a no-take policy.
- Set minimum legal size limits to reduce the potential for local depletion and disruption of community structure.

2.7 Enforcement

Objectives

- To prevent the combined take of abalone by licensed commercial and recreational divers, Aboriginal people and unauthorised persons from exceeding the sustainable productivity of the Tasmanian abalone stocks.
- To prevent recreational divers, Aboriginal people and unauthorised persons from selling abalone.
- To prevent unauthorised persons from taking and possessing abalone.
- To prevent any person from possessing commercial quantities of abalone without suitable documentation.

2.8 Cost Recovery and Return to the Community

Objectives

- To recover the Government's operating costs for the abalone fishery (commercial and recreational) from the participants through the fees agreed in the Abalone Deeds of Agreement, and licence fees from holders of abalone quota, commercial abalone divers and recreational licences.
- To recover a proportion of the resource rent generated by the commercial abalone fishery through the fees agreed in the Abalone Deeds of Agreement and licence fees from holders of abalone quota licences.

2.9 Quality Assurance

Objectives

- To maintain the high level of quality assurance for abalone.
- To promote best practice in the handling and processing of marine resources for human consumption.

3. Performance Indicators and Trigger Points`

There are three performance indicators currently specified in The Tasmanian Abalone Fishery Revised Policy Paper (2000): changes in catch-rate and catch, egg production and size composition.

Changes in catch and catch-rate may reflect changes in the abundance of abalone. Catch and catch-rate trigger points (specific changes in catch or catch-rates compared with particular reference years) were described in the Draft Tasmanian Abalone Fishery Policy Document (Anonymous, 1997). The regions used in relation to trigger points were the statistical blocks and regions currently used for the reporting of abalone fishing activity (Fig. 1).

It was noted in the previous Stock Assessment Report (Officer, 1999b) that in many parts of the State, 1997/98 catch and catch-rates were outside the levels specified by trigger points. The use of a single reference year did not make allowances for inter-annual variability, and differences were heightened when the reference year was unusually high or low.

It was subsequently proposed that the use of arbitrary levels of change be abandoned in favour of a careful consideration of all catches and catch-rates with respect to those from reference periods.

The first reference period adopted the average of 1992 to 1995. These years represent a period when fishing pressure was at a low level, and the fishery is assumed to have been in healthy state.

Because of increases in TAC, current catch levels are correspondingly higher than in the 1992-95 reference period, and comparisons may reflect little apart from the change in TAC. Current catch and catch-rates are therefore also compared with the average of a second reference period: 1979 to 1982. This period was prior to the introduction of a TAC, and catches unfettered by management restrictions, were amongst the highest in the history of the fishery.

Current catch-rates will almost inevitably be higher than those from the 1979 to 1982 period. Divers' work practises have changed so that they now operate much more efficiently, and divers can now land more abalone per unit of effort. A review of the effects of improving diver efficiency upon catch rates is included in Appendix 5.

Monitoring abalone stocks by assessing levels of egg production is the second performance indicator described by the management plan. Unfortunately, it has never been determined at what level egg production should be maintained, or how egg production is related to abundance. Intuitively, some level of egg production is required to maintain an abalone population. However, the development of eggs from within the gonad to recruitment of the mature animal to the fishery is an enormously complex process. Even at post-settlement stages, there is little evidence to relate abundance to future levels of recruitment to the fishery (McShane, 1996).

Nash (1992) has stressed the importance of reliable site-specific estimates of natural mortality in egg-per-recruit analyses, and discounts the value of such analyses where variations in natural mortality are not accounted for. The other parameters used in per-recruit analyses (growth, size at 50% maturity, size-fecundity relationship) vary widely, both spatially and with stock density (Breen, 1992; Nash, 1992). Generally per-recruit analyses rely on assumptions of population equilibrium that are unlikely to be fully satisfied. Egg-per-recruit reference points are at best suggestions rather than indicators of future recruitment levels (Shepherd, Guzmán del Próo, Turrubiates-Morales, Belmar, Baker and Sluczanowski, 1991; Breen, 1992; McShane, 1995).

The third performance indicator, gathering data about the size composition of commercial catches, has resumed in 1998 after a break of several years. The intention is to detect any change in the size composition caused by fishing affecting the size-structure of the available abalone stock. Between 1998 and mid 2000, catch sampling was done by divers who took photos of samples taken from their catch. These photos were processed using image enhancement software, and the lengths of the abalone measured. In 2001, the photographic program was replaced by a new program using research staff to measure samples of divers’ catches at fish processing factories.

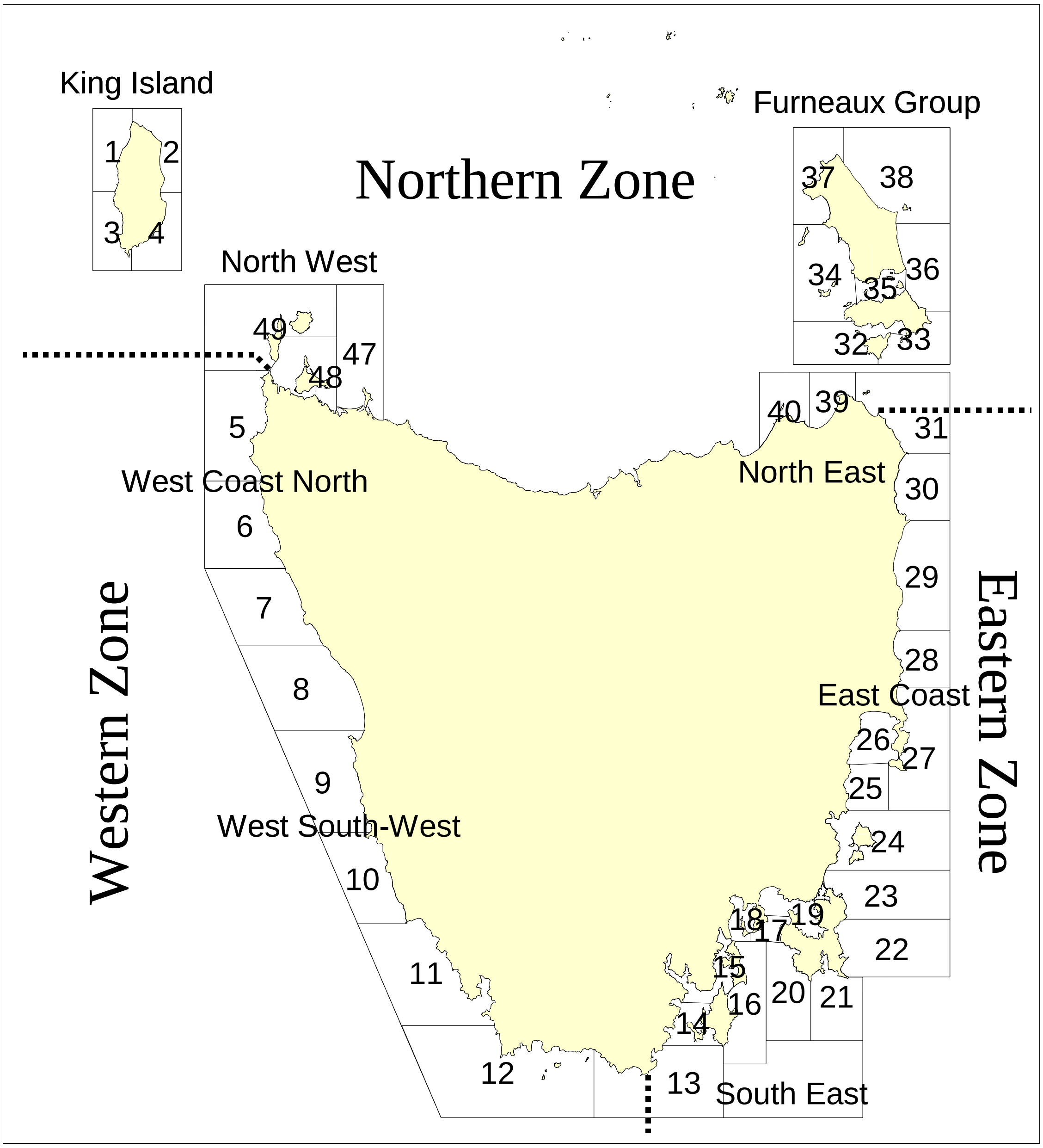


Fig. 1. Statistical blocks, regions and zones used in the Tasmanian abalone fishery. Statistical blocks are commonly grouped for analysis into eight regions: King Island (blocks 1 to 4), West Coast North (blocks 5 and 6), West South West (blocks 7 to12), South East (blocks 13 to 21), East Coast (blocks 22 to 29), North East (blocks 30, 31, 39, 40), the Furneaux Group (blocks 32 to 38) and the North West (blocks 47 to 49). While statistical blocks and regions are fixed, zones and zone boundaries may change. Zone boundaries are shown as dotted lines.

4. Previous Assessments

Using data on the size composition of the catch to assess the impact of fishing, Witherspoon (1975) demonstrated a reduction in size composition of the catch between 1968 and 1975 in two selected statistical fishing blocks.

Harrison (1983) carried out surplus production analyses of Tasmanian abalone populations to provide estimates of sustainable yields and optimum levels of fishing effort. He concluded that catches for 1980-81 exceeded the long-term sustainable yield in most areas. It is noted that the catch for 1983 and 1984 exceeded the 1981 catch. The validity of surplus production analysis relies on the assumption that catch-rates may be used as an index of abundance. This assumption has been questioned because of the aggregating behaviour of abalone, the targeting of these aggregations by divers, and the catch-rate threshold of individual divers, who will move to another site rather than continue fishing at a site when the catch-rate drops below this threshold (Prince, 1987; Prince, 1989; Breen, 1992).

Prince and Shepherd (1992) demonstrated that catch per unit effort (CPUE) becomes an increasingly sensitive index of abundance as fishing mortality increases. In collaboration with Philip Sluczanowski of the South Australian Fisheries Department, Prince prepared a computer model of an abalone population, called AbaSim. The model could be used by fishers, fisheries researchers and managers to explore the effects of different rates of exploitation, TAC levels and size limits on the age composition of the stock, its biomass, and rate of recovery after depletion. As an educational tool it is very useful, but it does not necessarily portray the status and dynamics of the Tasmanian abalone fishery.

More recent assessments used some of the evidence that was used in previous years and provided explicit documentation of the evidence used in the assessment process (Nash, 1996; Officer, 1997; Officer, 1999b, Tarbath, 2001 #1139, Tarbath, 2001 #1144). These fishery assessments were based on evidence derived from:

- commercial catch/effort/catch-rate statistics,
- commercial catch-at-length (market-measuring) data,
- yield- and egg-per-recruit analyses,
- size-composition of research diver population samples
- median size at sexual maturity
- changes in time taken to collect research samples
- strip transect estimates of abundance (at sites sampled on several occasions), and
- trends (or changes) in age composition (obtained from repeated population surveys at selected sites, using shell growth rings as an index of age).

Prior to the 2000 assessment, a steady increase in catch-rate was noted in most areas , accompanied by a change in the geographical distribution of catch and fishing effort. In the 2000 assessment, major catch-rate declines were noted on the East Coast and South East, as well as the more accessible West Coast blocks. The catch-rate declines prompted an interim assessment of the East Coast (Tarbath *et al.*, 2001a), which found widespread stock declines on the more accessible coastlines, and recommended an increase in size-limit to maintain recruitment.

4.1 Yield-Per-Recruit And Egg-Per-Recruit Analyses

Yield-per-recruit analyses have been carried out for blacklip abalone (Nash *et al.*, 1994, unpublished data) to determine the combinations of minimum size limit and fishing pressure that maximise the yield per recruit from the resource. Officer (1999a) undertook similar analyses for greenlip abalone. This latter study was the basis for raising size limits in some greenlip fishing regions to ensure that adequate egg production would be maintained.

Greenlip size-limits were raised in the North West in 2001, for the 2002 fishing year. In 2001, levels of fishing mortality in the region rose higher than anticipated by Officer, and to maintain sufficient levels of egg production, the size-limit was raised 5 mm to 145 mm.

A comparison of egg production levels with those of fished abalone stocks elsewhere has been used to indicate the risk of recruitment failure. Nash (1992) and Nash et al. (1994) used egg-per-recruit analysis to estimate current levels of egg production of blacklip abalone relative to virgin stock egg production at several sites around Tasmania. These analyses indicated that levels of egg production over a broad spatial sale were relatively high (> 40 percent of virgin stock egg production) and provide little cause for concern that recruitment failure is imminent for blacklip abalone (Koslow, 1992).

4.2 Fishery-Independent Estimates Of Abundance

Earlier work by the Abalone Assessment Section using strip transects did not show any significant changes in abundance. Moreover, because abalone generally live in aggregations it is difficult to obtain accurate and precise estimates of abundance or density. Highly variable numbers of abalone in low population density areas require that excessive numbers of replicates be done to achieve an acceptable level of sensitivity. Furthermore, abalone move in response to disturbance (Nash *et al.*, 1994) and re-aggregate after stock density has been reduced by fishing (McShane and Smith, 1989; Nash *et al.*, 1994). This movement further complicates abundance estimation. For these reasons Tasmanian transect survey work lapsed.

During the last few years however, Victorian researchers have adopted a different approach to transect surveys, and are able to detect relatively small changes in abundance while maintaining realistic costs. An evaluation of methods for assessing the abundance of blacklip abalone in Victoria found transect surveys to be the best of five methods assessed (Gorfine, Hart and Callan, 1996; Hart and Gorfine, 1997; Hart, Gorfine and Callan, 1997). The study concluded that including methods to evaluate the spatial distribution of abalone would enhance results.

A three year FRDC funded study of fishery independent assessment methods commenced in Tasmania in 2002.

4.3 Commercial Catch Sampling Data

The collection of commercial abalone catch-at-length data through the market-measuring program lapsed in 1995. Analyses of size-composition data undertaken to 1996 (Nash, 1996) concluded that:

- Sampling has been uneven around the State, and to some extent reflects the contribution of each statistical block to the total catch. The most extensive sampling has been from blocks 9 on the West Coast, 13 and 14 in the South East, and 23, 24 and 27 on the East Coast.

- There was a reduction in the size composition of the catch between 1984 and 1995 in most areas, but in none of the areas did this approach knife-edge fishing (in which case the fishery would be composed primarily of recruits through the size limit). This reduction in size composition may reflect either a true reduction in size composition or an increase in selective targeting of smaller abalone (which the market generally prefers), or a combination of the two factors. This may be resolved using length-frequency data gathered by research personnel; these data should represent true size composition.

- Size composition trends must be viewed in combination with catch-rate trends if there is to be any chance of a useful assessment of the stocks using commercial size-composition data. This is because the average size of fish in the catch may increase at high levels of fishing pressure if recruitment rates are declining. The slight decline in size composition of the catch, coupled with the (increasing or stable) catch-rate trends in most statistical blocks, provides no evidence of either growth overfishing or recruitment overfishing.

- The market measuring data to 1995 provided no evidence that the Tasmanian abalone stocks were in a state of either growth overfishing or recruitment overfishing.

Historically, catch sampling was undertaken on a large spatial scale i.e. at block level because the source of catches could only be reported in terms of statistical blocks. With the development of a photographic catch-sampling program in 1998, where the divers collected samples from their own catches, and returned photos with details about the exact location of the catch, the information available from catch-sampling was greatly improved.

The photographic catch-sampling program lapsed in 2000, both because of insufficient participation in the program by divers, and because extracting length data from the photos was a costly process. The program was replaced by a new catch-sampling program where research staff visit fish processing factories and measure samples from divers catches. This method works satisfactorily in the South East, where research staff are located. A part-time catch-sampler has recently started measuring catches in the North West.

5. Assessment Methods

5.1 Commercial Catch-Effort Statistics

Like its predecessors, the 2001 assessment is based principally on an analysis of trends in the catch and catch-rate of the commercial fishery. These data were obtained from dockets submitted by divers when landing catches. Catch and effort were reported by statistical block (Fig. 1) on these dockets. Catch and effort were estimated by block when the catch occurs over multiple blocks or days. Catch-rates for the main statistical blocks and regions were calculated for each diver-day by dividing the catch (in kilograms) by diving effort (in hours) to yield catch per unit of effort (CPUE) in kg/hour. Annual catch-rates are the geometric means of catch-rates, grouped by year. Catch-rate trends over the last ten years were reviewed. This period (1992 – 2001) was used because we are reasonably certain that diver efficiency remained constant over this period, and that the time spent collecting abalone is a constant unit of effort for each diver.

5.2 Commercial Catch Sampling Data

Size-composition of samples from an earlier market measuring program (1984 to 1995) has been included in previous assessments. These were of limited use, because the scale on which it was reported was large (i.e. by statistical block). The size of abalone varies across small spatial scales and consequently, catch-sampling data from a single block may contain samples of small abalone and samples of large abalone, each caught in different locations. More specifically, samples from areas subject to heavy fishing pressure where abalone are caught before they grow large were mixed with those from lightly fished areas, containing many larger abalone. This prevents reasonable interpretation of changes in size composition from data collected prior to the photographic catch-sampling program. Viewing these size-compositions gave the misleading impression that the catch included good quantities of larger abalone, whereas in the more heavily fished sub-blocks, large abalone are scarce. These size-compositions are no longer included in the report.

Data from the photographic catch-sampling program can be resolved to a much smaller spatial scale. Divers usually described from exactly where on the coast the catch was taken, and they would also include the block number, and in 2000, the sub-block number.

A recent examination of data from this program shows that in many cases, the divers were confused about which sub-block, and in some cases, which block they were fishing. This factor introduces error, not only into the catch-sampling data, but into the catch and effort data. The regions where most of the confusion arises is in Blocks 13 and 14, and 27 and 28. This uncertainty in block boundaries is being addressed by DPIWE through the production of new updated maps.

Currently, catch-sampling data are collected by TAFI researchers who visit factories and measure samples of abalone from divers' catches. This data can be resolved to sub-block level by using details reported by divers on their catch returns.

Previous assessments used size-composition data provided by Tasmania's largest abalone processor: Tasmanian Seafoods Pty Ltd. These data described the proportion of factory production made up of large abalone. It was recently observed that divers sort their west coast catches, selling the smaller abalone to live-market buyers at a higher price, but passing on the bulk of the catch (the larger abalone) to canneries. This means that Tasmanian Seafoods' data no longer accurately reflects changes in size-composition of the west coast catch, and thus can no longer be used.

5.3 Recreational Fishing Surveys

The recreational catch reported in this assessment was derived from the preliminary results of recreational fishing surveys undertaken by the Department of Primary Industry and Fisheries (J. Lyle, pers. comm.). These surveys used a combination of diary and recall methods to obtain estimates of the recreational fishing catch in Tasmania. We also report the number of recreational diving licenses issued each season.

6. Fishery Assessment: 2001

The Tasmanian Abalone Management Plan specifies that fishery performance will be examined and measured using three approaches: reviewing changes in catch and catch-rate, maintaining adequate levels of egg-production, and monitoring size-composition of the commercial catch (Anonymous, 2000).

This assessment is largely dependent upon the first approach, changes in catch and catch-rate. Monitoring levels of egg production is a difficult process, particularly because it requires sound estimates of rates of mortality due to natural causes and fishing. Although mortality research has been undertaken in previous years in Tasmania (Nash, 1992; Nash *et al.*, 1994; Officer, 1999a; Tarbath, 1999), the mortality estimates of blacklip abalone are contentious – hence estimates of egg production for this species may be unreliable. Monitoring size-composition of the commercial catch requires an adequate time series of small spatial-scale data: this is the first assessment for which this data has become available.

6.1 Review of catch and catch-rates

This review of catch and catch-rates is in two parts: the first deals with blacklip abalone catches, the second covers the greenlip fishery.

This stock assessment compares the 2001 catch and catch-rates against the average catch and catch-rates of two reference periods: 1979 to 1982 and 1992 to 1995. The significance of any change is considered with respect to the quantity of abalone coming from the region or block, its catch history, changes in market demands, management closures and size-limits changes.

There have been a series of size-limit increases, particularly after the first reference period, but also in the greenlip fishery in recent years, which may affect landed weights. For example, abalone of shell-length 132 mm (the size-limit applied in 1987) typically weigh between 10% and 15% more than abalone of 127 mm shell-length (the size-limit in the early part of the fishery). When comparing catch between years it should be noted that a catch of the same weight may now contain fewer abalone.

6.1.1 Blacklip Fishery Assessment - evaluation of catch and catch-rates with reference to historical catches.

Blacklip abalone - Catch reference points: Regions

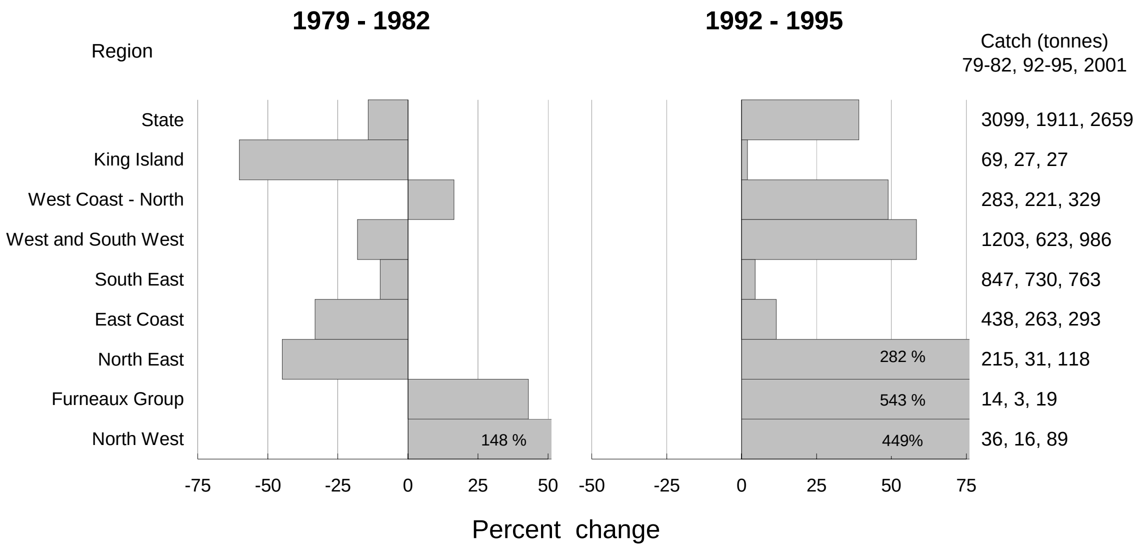


Fig. 2. The 2001 blacklip abalone catch (tonnes) by region, including the State, expressed as percent change from the average catch-rates of the periods 1979-82 and 1992-95. The left-hand charts show the change in catch compared with the average catch of 1979-82, and the right-hand chart compares the catch with that of 1992-95 average. The average catches for 1979-82, 1992-95 and 2001 are shown on the right-hand side of the chart.

- The state blacklip abalone catch is 2659 tonnes landed weight, about halfway between the high catches of the early reference period (3099 tonnes average landed weight), and the low catches of the second reference period (1911 tonnes average landed weight).

- Despite the decreased size-limit in the Northern Zone, there has been no increased catch from King Island (Fig. 2).

- In the West Coast – North and the North West regions, there have been significant increases in catch compared with those from *both* reference periods. Because catch is now distributed by zone, and the State TAC has increased, it is not surprising that catches are greater than those of 1992-95. It is surprising, however, to see that recent catches are greater than those from the early reference period, when catches were supposedly at their peak (Fig. 2). However, closer examination of the catch history shows that peak catches for much of the west coast and the north of the state generally occurred slightly later, between 1983 and 1987 (Appendices 7 and 8). The 2001 catches were below those levels.

- Catches were greatly increased from those blocks within the Northern Zone: Blocks 49, 5, most of the Furneaux Group blocks (Blocks 32 to 38) and Blocks 39 and 40 in the North East. In the first two blocks, this is due to a combination of the implementation of the Northern Zone with its smaller size-limit, and ease of access to plentiful stocks. Significantly, there has been no such increase from blocks 36 and 37, where the size-limit is still too large (Fig. 3).

- In the Western Zone, increased catch in Block 6 is related to increased diver activity in the region because of fishing in the adjacent Northern Zone, and processor preferences for abalone caught at 132-mm instead of the 140-mm size-limit prevailing further south. There has been a corresponding decrease in catch from Blocks 7 and 8. Catches from Blocks 10, 11 and 12 are approaching or equivalent to those from the 1979-82 reference period (Fig. 3).

- In the South East, the dominance of Block 13 tended to mask the fall in catch in the rest of the region. The catch in sub-Blocks 13C, D and E was capped, and consequently there was transfer of effort from Block 13 to Blocks 14 and 16 which is reflected in increased catches there. Catches from other blocks (Blocks 14 to 22) were generally below those of the reference periods (Fig. 3).

- On the East Coast, catches were at levels below those of the two reference periods in Blocks 22, 27 and 28. These blocks are historically significant contributors to the East Coast catch, and their failure to produce in 2001 is alarming. In particular, Block 28 seems to be following the pattern established by Block 30. Maria Island and Mercury Passage (Block 24) maintained high catch-levels. Increased catches in Blocks 26 and 29 are not significant as the totals are low, and reflect the efforts of several divers fishing neglected patches of abalone rather than increased abundance within those blocks. Block 31 again produced high levels of catch (Fig. 3).

Blacklip abalone - Catch reference points: Blocks

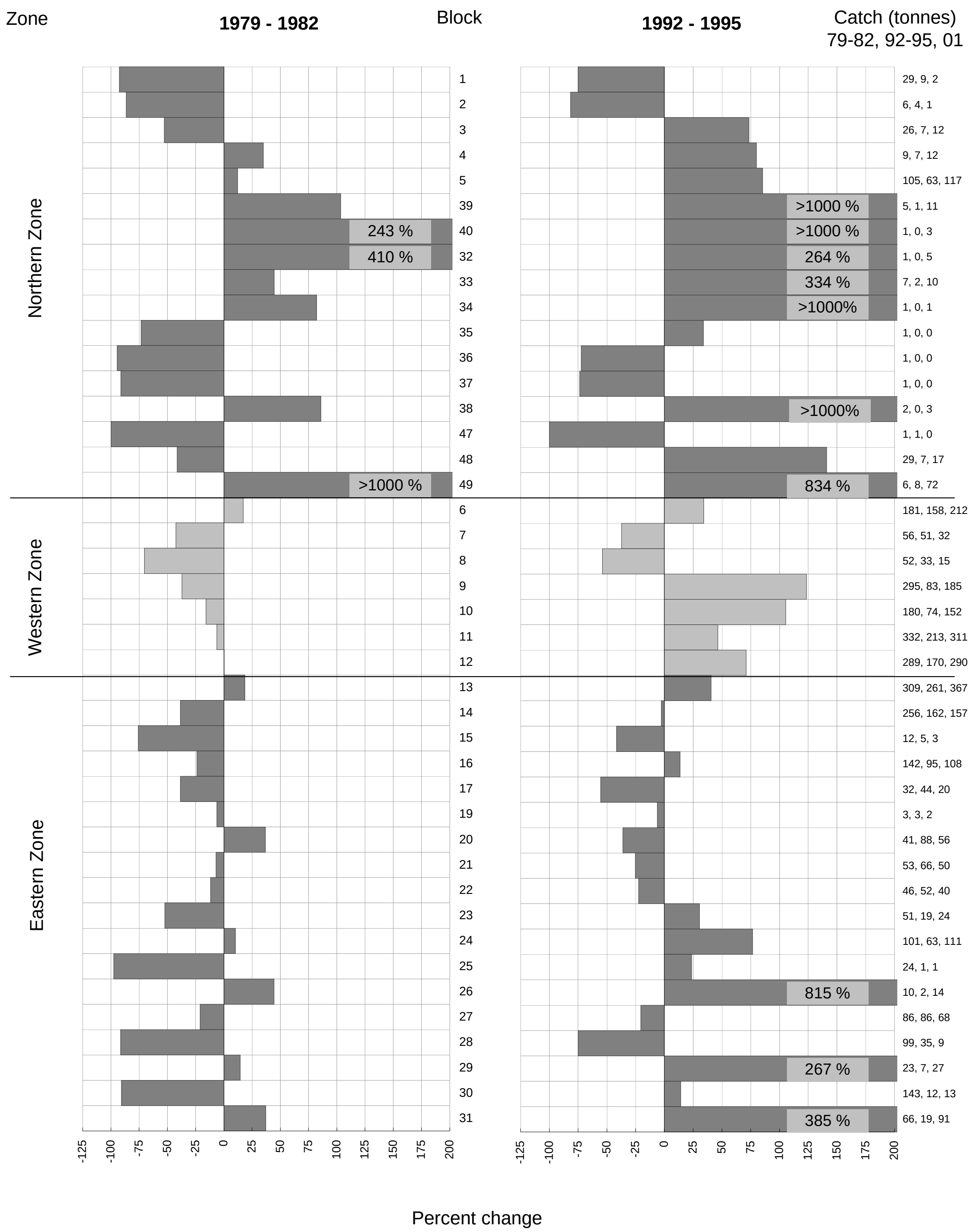


Fig. 3. The 2001 blacklip abalone catch by block, sorted by zone, showing the deviation of the 2001 catch from two reference periods in the history of the fishery. The left-hand chart shows the change in catch compared with the average catch of 1979-82, and the right-hand chart compares the catch with that of 1992-95 average. The blocks (shown in the column between the two charts) are grouped by region (shown on the left-hand side of the page). The average catch in tonnes for the periods 1979-82 and 1992-95 and the 2001 catch are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated. Note that the zones are not perfectly represented by block boundaries and consequently the closest boundaries were used in this diagram.

Blacklip abalone - CPUE reference points: Regions

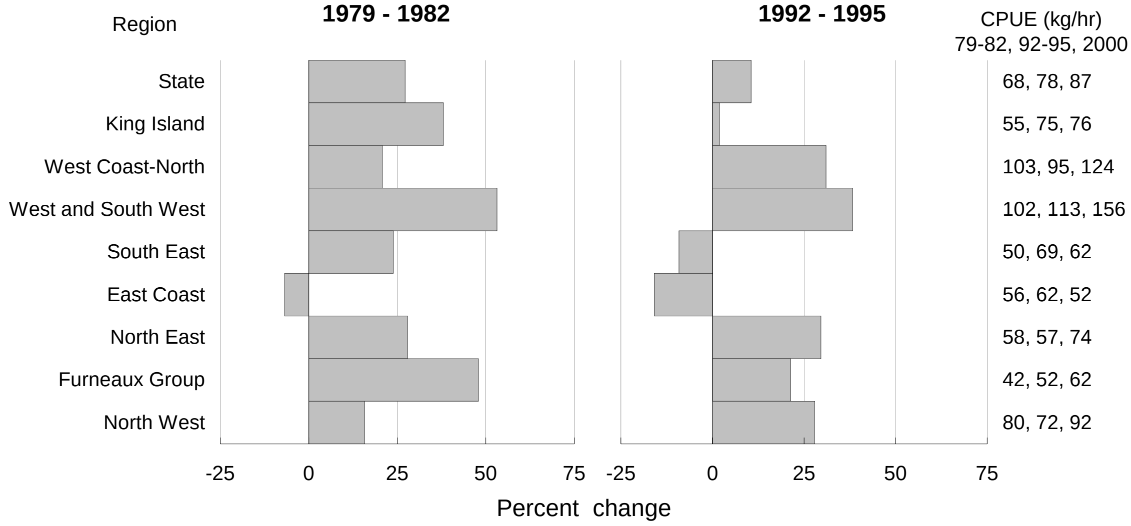


Fig. 4. The 2001 catch-rates (kilograms per hour) by region, including the State, expressed as percent change from the average catch-rates of the periods 1979-82 and 1992-95. The left-hand charts show the change in catch-rate compared with the average catch-rate of 1979-82, and the right-hand chart compares the catch-rate with that of 1992-95 average. The average catch-rates for 1979-82, 1992-95 and 2001 are shown on the right-hand side of the chart. Historical catch-rates from King Island, the Furneaux Group and North West Tasmania are calculated using effort data which includes a significant component of effort from greenlip abalone catches. Following the separation of greenlip from the rest of the fishery in 2000, it has only recently become possible to separate blacklip effort (hours spent diving) from greenlip effort. In some regions (particularly the Furneaux Group, and King Island), the major part of the annual blacklip catch has for many years been caught as a by-catch of greenlip fishing operations, and the information shown in Fig. 4 may not reflect the reality of blacklip abalone fishing in those areas.

For the first time, catch-rates have fallen below catch-rates of the two reference periods (Fig. 4). The catch rates for the South East are 9 percent lower than those of 1992-95 but 24 percent higher than those of 1979-82. Catch-rates on the East Coast are 16 percent and 7 percent less than those of the two respective reference periods. This means that in spite of improvements in efficiency made by divers enabling them to land more abalone per hour (better handling methods such as drop-lines, improved gear and technological developments such as GPS, dive computers, and improved wetsuit design), they are now landing abalone at lower rates. Note that for the first time, the original CPUE triggers of the 1997 Draft Management Plan would have been fired in response to the reduction in South-East and East Coast catch-rates. Catch-rates in abalone fisheries are recognised as not being particularly sensitive indicators of fishery performance. Therefore, the seriousness of this decline must be seen as an indication that this stock is now significantly depleted.

Catch-rates in all other regions, apart from King Island, are higher than the two reference periods. How much of this is due to improved diving and handling techniques, and how much is due to increase in abundance is not known. Catch rates show only a marginal improvement over those from the 1992-95 reference period. However, it has been reported by divers that blacklip abalone are plentiful at King Island and the King Island blacklip fishery is in not in decline.

Blacklip abalone - CPUE reference points: Blocks

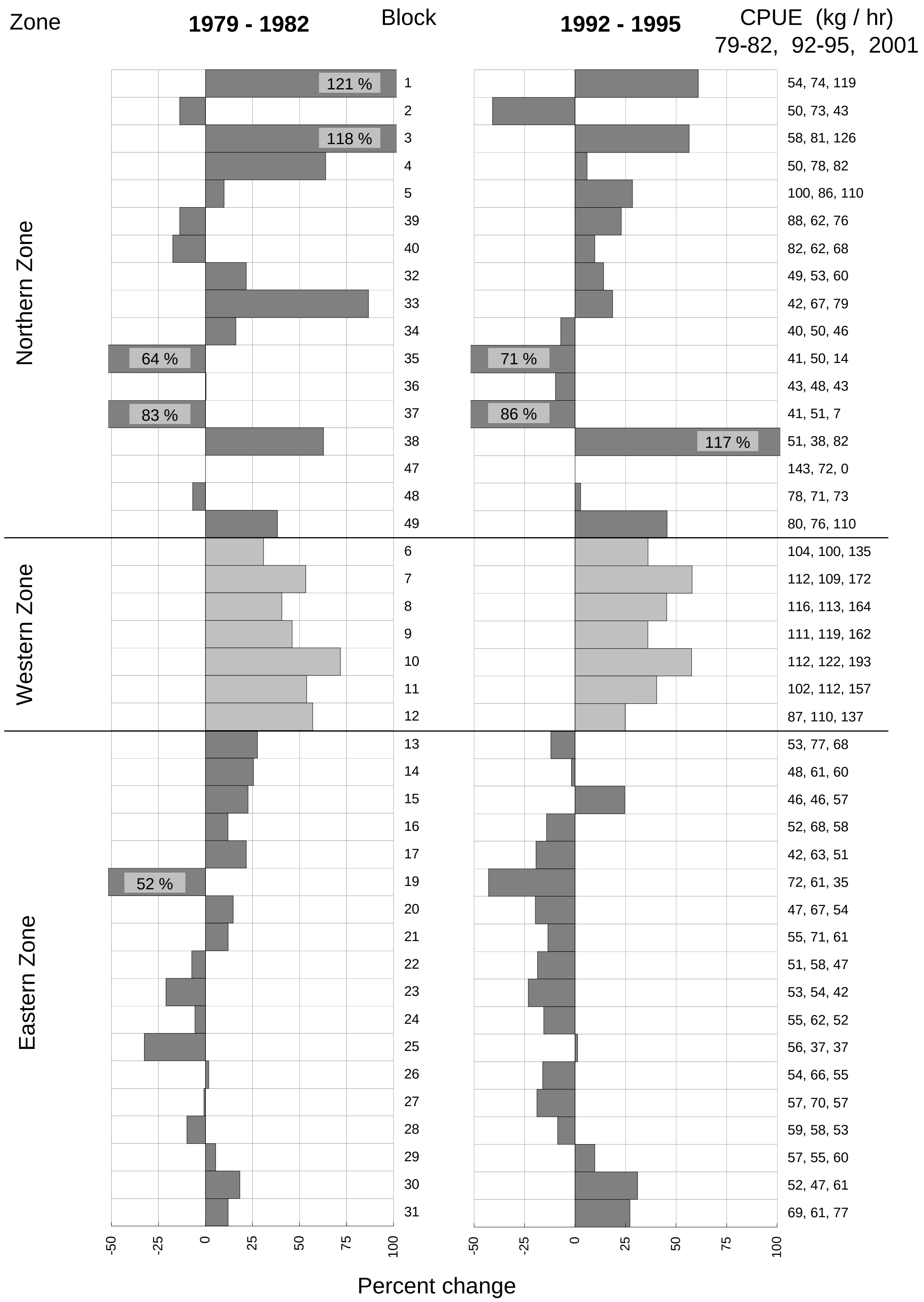


Fig. 5. 2001 catch per unit effort (CPUE) by block, expressed as percent change from the average catch-rates of the reference periods 1979-82 and 1992-95. Catch-rates from the Northern Zone are calculated using effort data which includes a significant component of effort from greenlip abalone catches prior to 2000.

The following points are noted with respect to changes in blacklip catch-rate compared with the reference periods (Fig. 5):

- Most of the Eastern Zone blocks showed catch-rates lower than those from the 1992-95 reference period. Block 19 was much lower, but that block is a minor contributor to the fishery.

- Blocks 30, 31 and 15 reported higher catch-rates than the 1992-95 reference period. Of these, only Bock 31 contributes a significant amount of catch, and in conjunction with information from other sources (trends in catch and catch-rate, Section 6.4.3) it can be concluded that stocks were at healthy levels in 2001. That catch-rates were relatively high in Block 30 is misleading: abalone stocks have collapsed here, and the high catch-rates are due to a few divers targeting isolated remnant populations. Levels of catch in Block 15 fluctuate and it is not a significant contributor to the fishery.

- In the Western Zone, catch-rates were relatively high compared with those from the 1992-95 reference period. However, the difference was least in Blocks 6, 9 and 12, all of which are relatively accessible to divers in trailer-borne boats and are consequently exposed to high levels of effort.

- In the Northern Zone, only Blocks 5 and 49 had significant levels of catch. Catch-rates in these blocks were above those of the 1992-95 reference period. Catch-rates from Blocks 35, 35 and 37 should be disregarded as catches were inconsequential.

6.1.2 Blacklip abalone: commercial catch distribution

The statistical blocks for the abalone fishery are shown in Fig. 1. To illustrate changes in the distribution of the catch around the State since 1975, the catch from each of the regions is shown for blacklip abalone in Fig. 6 to Fig. 9. The upper graph in each of these figures shows the catch in absolute terms (tonnes) and the lower graph shows the catch from each of these regions as a proportion of the total annual catch.

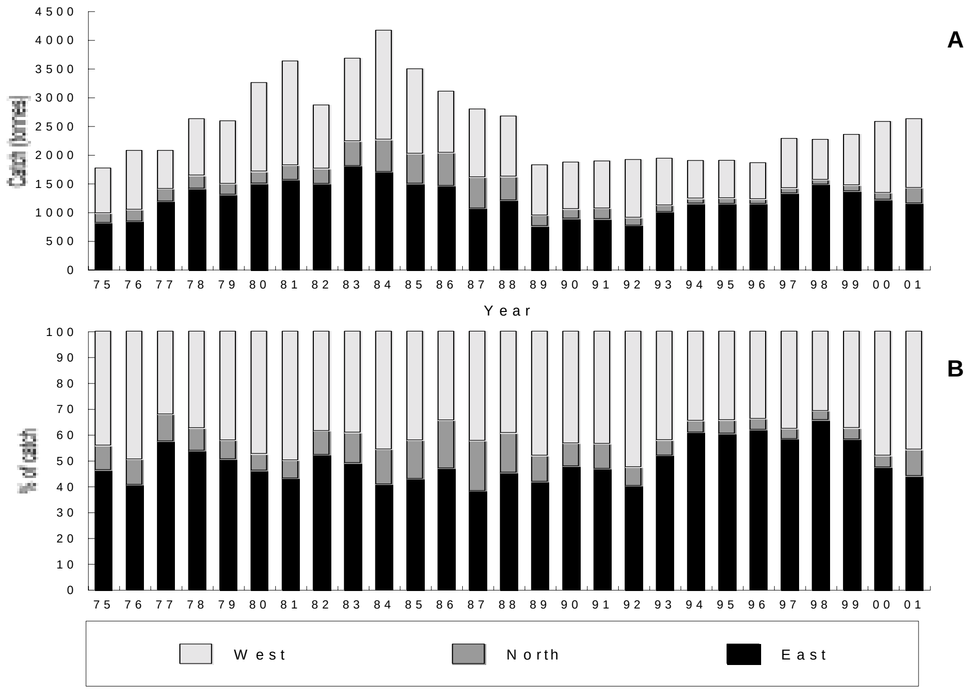


Fig. 6. The catch of blacklip abalone from an approximation of the three blacklip zones in Tasmania, by year from 1975 to 2001. The Eastern Zone was calculated from the sum of blacklip catches in Blocks 13 to 31 (the Northern Zone includes part of Block 31 and the Western Zone part of Block 13), the Northern Zone calculated from blacklip catches in Blocks 1 to 4, 5 (the Western Zone includes part of Block 5), 32 to 57 (part of Block 31in the Northen Zone was omitted), and the Western Zone from Blocks 6 to 12 (parts of Blocks 5 and 13 omitted).

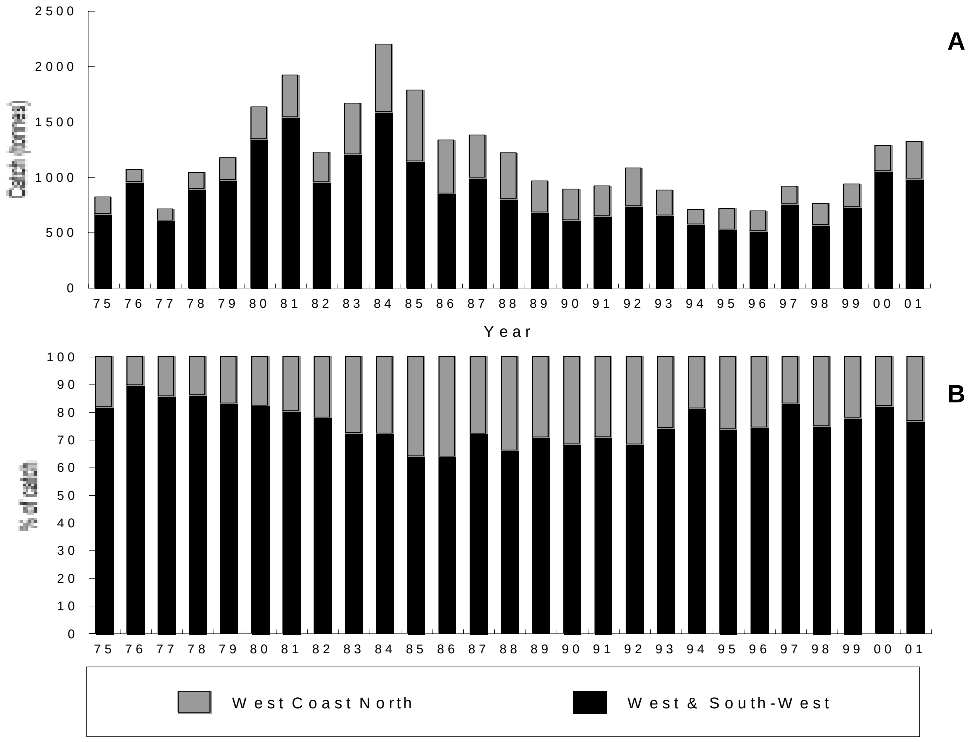


Fig. 7. The catch of blacklip abalone from the west of Tasmania, by year from 1975 to 2001. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total blacklip catch.

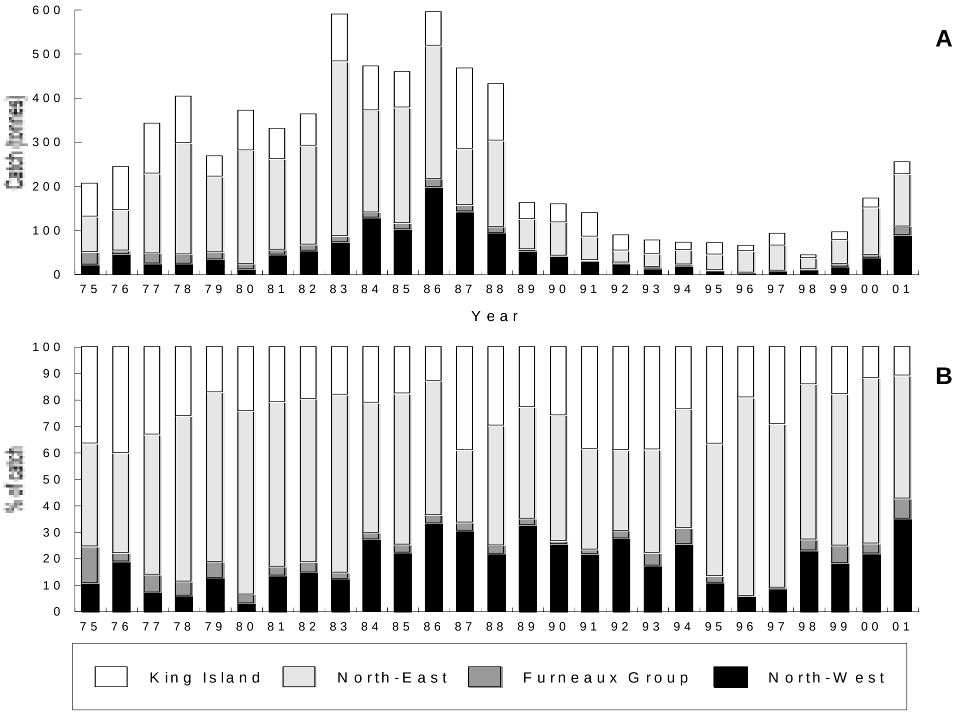


Fig. 8. The catch of blacklip abalone from the north of Tasmania, by year from 1975 to 2001. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total blacklip catch in that region.

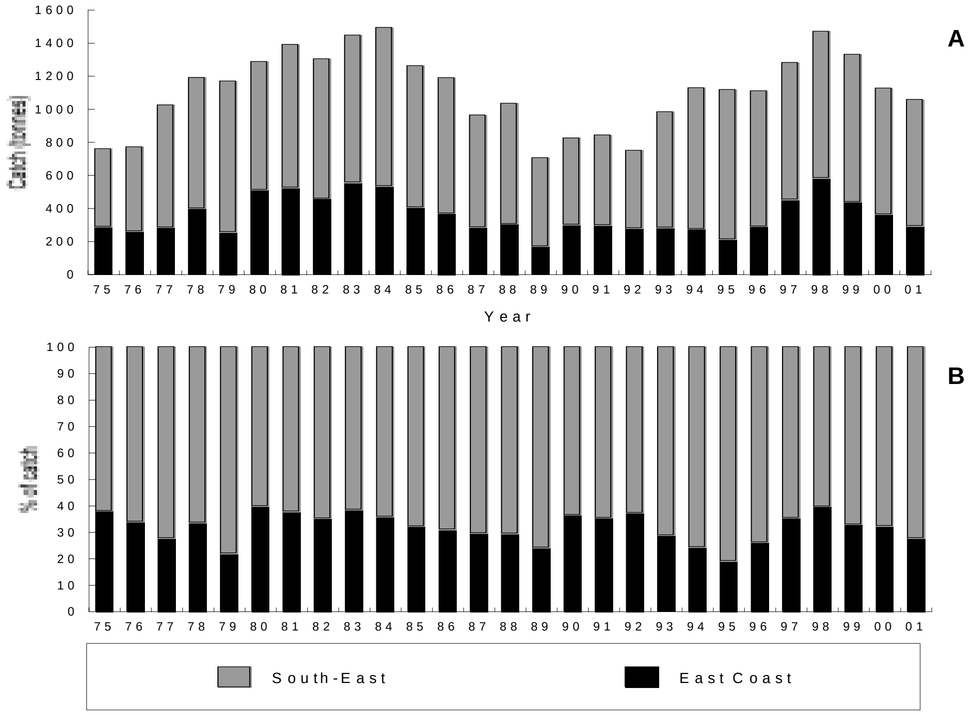


Fig. 9. The catch of blacklip abalone from the east and southeast of Tasmania, by year from 1975 to 2001. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total blacklip catch.

The following points are noted with reference to Figs. 6 to 9:

- Between 1993 to 1999 the East Coast and South East produced the greatest proportion of the catch, reaching a peak in 1998 when 60 percent of the total Tasmanian abalone catch was taken here (Fig. 6). Following the introduction of zones in 2000, the West Coast produced increasingly greater proportions of the catch.

- Catches from the East Coast have declined (Fig. 9), and are now mid-range in the 26 year period.

- There has been a small increase in catch from the north of the State (Fig. 6), most of that coming from the North East in Block 31 (Fig. 8).

6.2 Greenlip Fishery Assessment: 2001

6.2.1 Evaluation of catch and catch-rate with reference to previous years

For the sake of applying uniform processes to the assessment of both the blacklip and greenlip fisheries, the greenlip abalone fishery catch information for 2001 is evaluated here against the same two reference periods applied to the blacklip fishery. However, this method of assessment is not particularly appropriate for the greenlip fishery. Following management changes to the greenlip fishery, divers changed their fishing practises in a variety of ways. Changes in catch and catch-rate are therefore less likely to reflect changes in abundance than in the blacklip fishery, and are more likely to reflect the management changes recently introduced to the fishery.

During the period 1995-1999, strong market demand put greenlip stocks under pressure. A number of processors, mostly in the north of the State and offshore islands, supplied a premium product (i.e. large abalone) alive to markets in Sydney, for which they received a higher price than the blacklip beach price. Because greenlip stocks are limited, there was competition between divers and processors for the resource, and the stocks were fished at levels higher than could be sustained.

A series of management initiatives aimed at transferring effort from vulnerable stocks were introduced from 1998. The most important control was implementation of a separate greenlip fishery, with its own TAC in 2000. In 2001, catches in three of the four greenlip regions were capped to drive effort to King Island, where catches were perceived to be relatively under exploited.

The effect of partitioning the greenlip fishery meant that the major players in the greenlip fishery who had developed infrastructure, markets and fishing practises to specialise in that fishery, had to obtain quota from other quota holders to maintain their share of the fishery and stay in business. It also meant that some of the major processors who also happened to hold many quota units effectively controlled access to a considerable part of the greenlip fishery. Many divers who previously caught greenlip now catch less than they used to, and other divers who had never caught greenlip now catch large quantities.

These management changes, especially the introduction of area-specific caps, increased the degree of competition among participants of the fishery, a result of which was changes in catch and catch-rates that had little to do with abalone abundance. As well, changes in level of catch compared with the reference periods reflect the implementation of closures, and not necessarily changes in abundance.

Following partitioning of the greenlip fishery from the blacklip fishery, access to the fishery was controlled by allocation of greenlip quota. Each of the 3500 quota units contained a portion of greenlip quota (40 kilograms per unit) as well as portions for each of the blacklip zones. In 2001 the greenlip quota was 5% by weight of the quota unit.

Greenlip abalone – regional catch

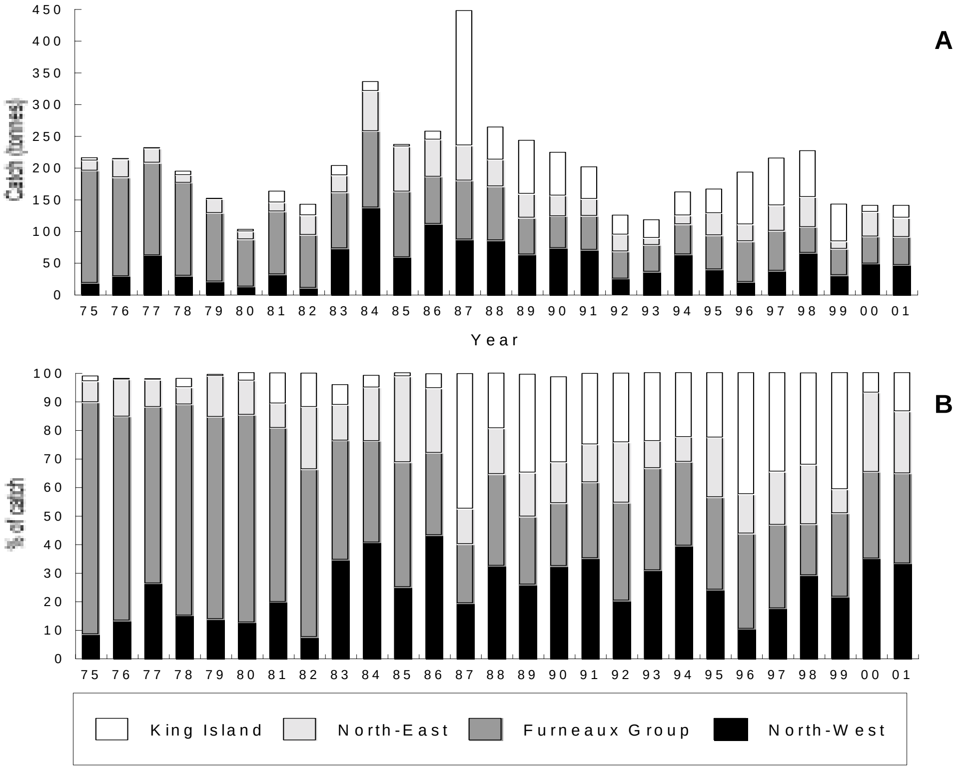


Fig. 10. The catch of greenlip abalone from the four main greenlip-producing regions of Tasmania, by year from 1975 to 2001. King Island includes blocks 1-4. North East includes blocks 30, 31, 39 and 40. The Furneaux Group includes blocks 32-38. North West includes blocks 5, 6, 47, 48 and 49. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total greenlip catch. Proportions do not sum to 100 % in some years due to minor catches in other blocks or misreported catches in areas that do not produce greenlip abalone**.**

Greenlip abalone – Catch reference points: Regions

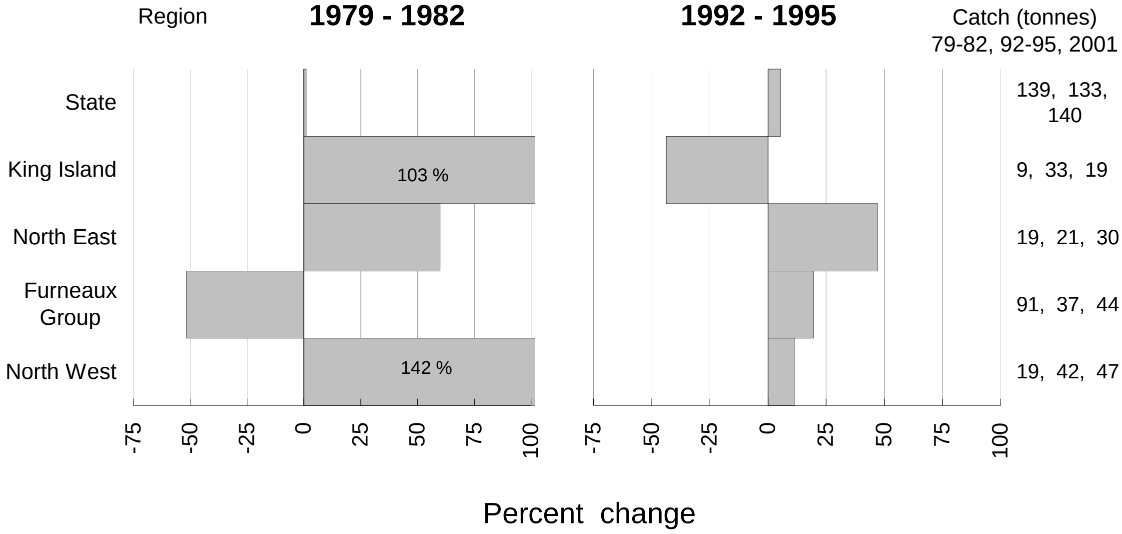


Fig. 11. The 2001 greenlip catches by region, showing the differences between catches in 2001 and the average of those from the 1979-82 and 1992-95 reference periods. The average catch (tonnes) for the periods 1979-82 and 1992-95 and the 2001 catch are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

Greenlip abalone – CPUE reference points: Regions

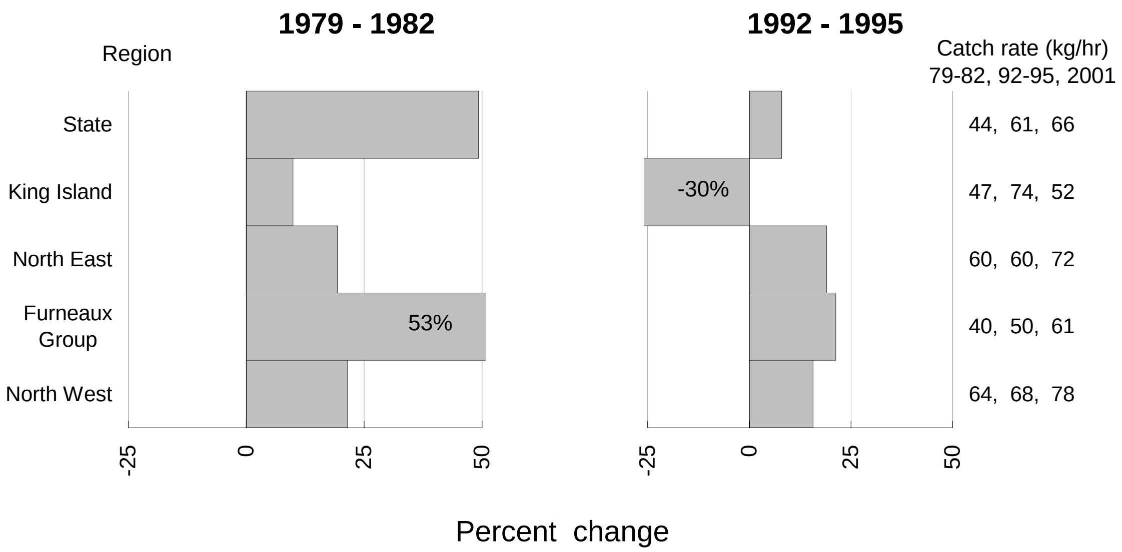


Fig. 12. The 2001 greenlip catch-rates by region, showing the differences between catch-rates in 2001 and the average of those from the 1979-82 and 1992-95 reference periods. The average catch-rate (kilograms per hour) for the periods 1979-82 and 1992-95 and the 2001 catch-rate are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

Greenlip abalone – Catch reference points: Blocks

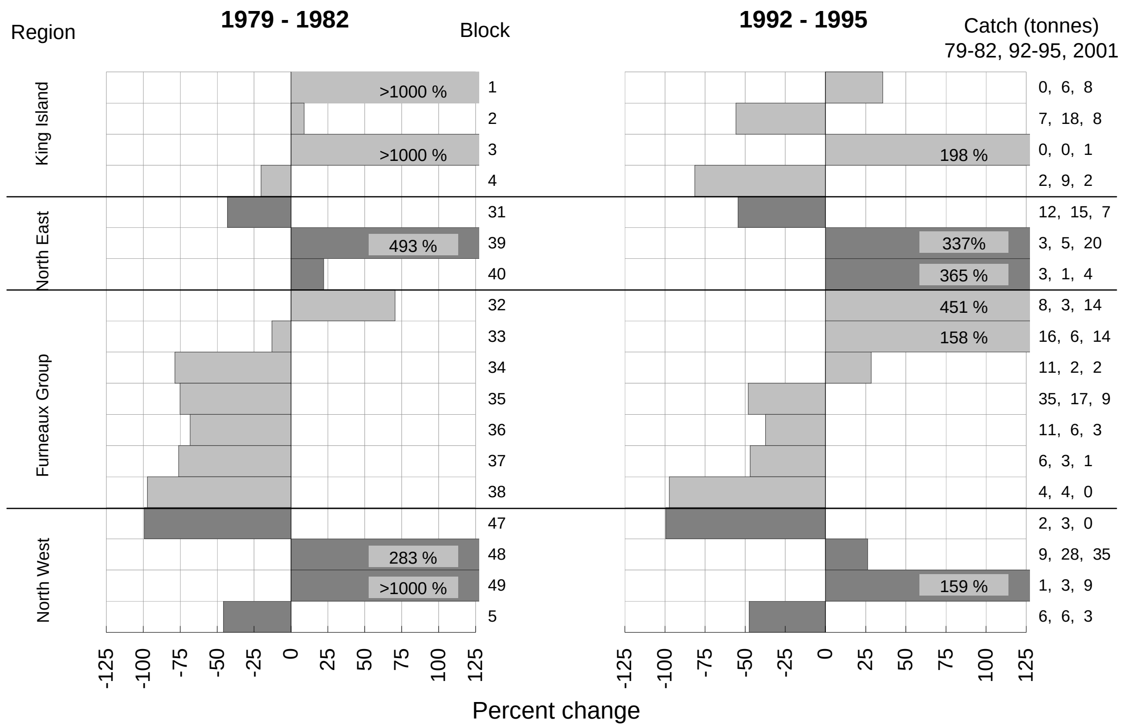


Fig. 13. The 2001 greenlip catches by block, showing the differences between catches in 2001 and the average of those from the 1979-82 and 1992-95 reference periods. The blocks (shown in the column between the two charts) are grouped by region (shown on the left-hand side of the page). The average catch (tonnes) for the periods 1979-82 and 1992-95 and the 2001 catch are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

The following points are noted with reference to Fig. 13 and Fig. 14:

- Catch-rates from King Island are lower than during the second reference period. It seems that greenlip populations are yet to fully recover from high levels of depletion between 1996 and 1999. In addition, the imposition of the 155-mm size-limit made fishing areas where abalone grow at slower rates unproductive. Recent fishing has focussed on a few faster growing populations where the comparatively high level of effort causes low catch-rates. Catch-rates should improve following the reduction of the size-limit to 150 mm in 2002, which will make fishing other stocks more viable, and will spread effort from the more heavily fished areas.

- In 2001, the Furneaux Group greenlip fishery was focussed in the south, and little catch was taken from the more northern blocks. Blocks 32 and 33 are accessible to divers launching small boats from the north-east corner of the Tasmanian mainland. Motherships also fished the southern part of the Furneaux Group where they could fish both greenlip and Northern Zone blacklip. The Franklin Sound fishery (Block 35) was fished predominately by one diver, and when the Furneaux Group was eventually closed in September, the catch was less than 50% of its 20 tonne cap. The northern blocks only received sporadic attention, mainly from local divers.

Greenlip abalone – CPUE reference points: Blocks

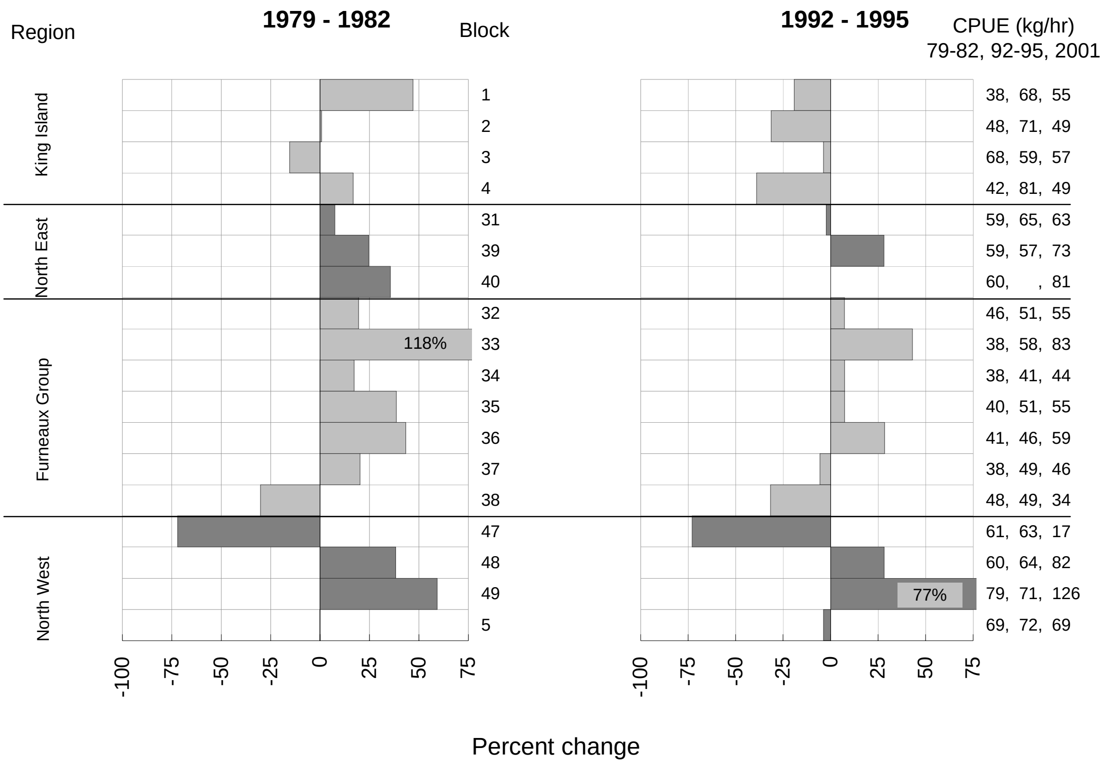


Fig. 14. The 2001 greenlip catch-rates by block, showing the differences between catch-rates in 2001 and the average of those from the 1979-82 and 1992-95 reference periods. The blocks (shown in the column between the two charts) are grouped by region (shown on the left-hand side of the page). The average catch-rate (kilograms per hour) for the periods 1979-82 and 1992-95 and the 2001 catch-rate are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

- The North West was a popular region for divers to work. They had good access to blacklip from both Western and Northern Zones, and to greenlip. The increase in greenlip catch came from Block 48, where Black Reef produced some large catches and the Petrels and eastern side of Hunter Island performed consistently. The fishery was closed in early September after reaching its local cap.

6.3 Change In 2001 Catch Compared With 2000 Catch

To highlight recent differences in distribution of catch within blocks that contributed most to the fishery, the 2001 catch was plotted against the 2000 catch. If no change had occurred in the distribution of catch, all the blocks would have been positioned on the diagonal line of equivalence. Thus the position of each block relative to that line indicates the degree of variation of catch compared with the previous year. If the position of the block is above the line, then the catch is greater than might be expected; if below the line then the catch is less than expected.

In the blacklip fishery (Fig. 15), Block 13 contributed the most catch in both years, but because it was capped in 2001, contributed less than might be expected. The catch from Blocks 14, 16 and 24 was higher than expected, and made up the loss from Block 13. In the Western Zone, the catch from Blocks 6 and 12 was greater than expected. There were significant increases in catch in Blocks 5 and 49 due to diversion of effort to the north of the state caused by the development of the Northern Zone,.

In the greenlip fishery (Fig. 16), there was an extensive redistribution of effort. Blocks 48, 39, 32 and 33 all had increased levels of catch, while Blocks 35, 31, 40 and 5 had substantial falls in catch.

6.3.1 Blacklip fishery

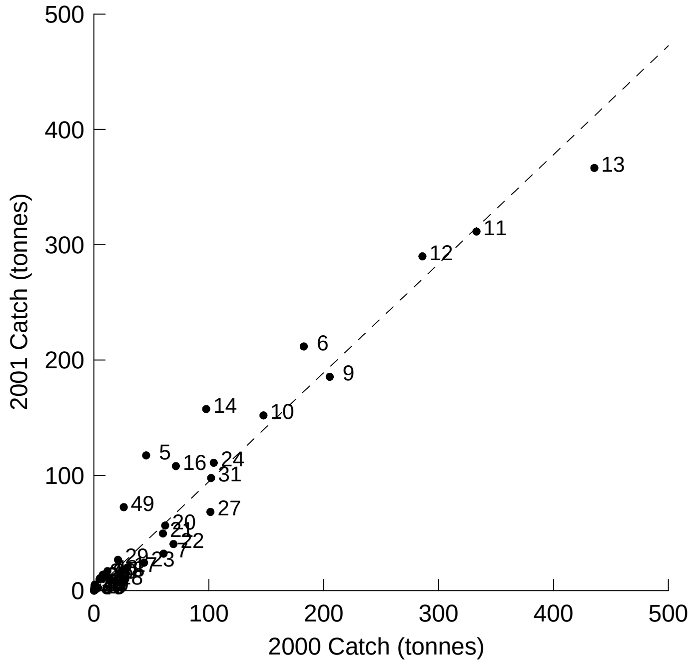


Fig. 15. Differences in catch between years, by block, within the blacklip fishery, showing 2001 catch by block plotted against 2000 catch, relative to the TAC adjustment between the two years shown by the dotted line.

6.3.2 Greenlip Fishery

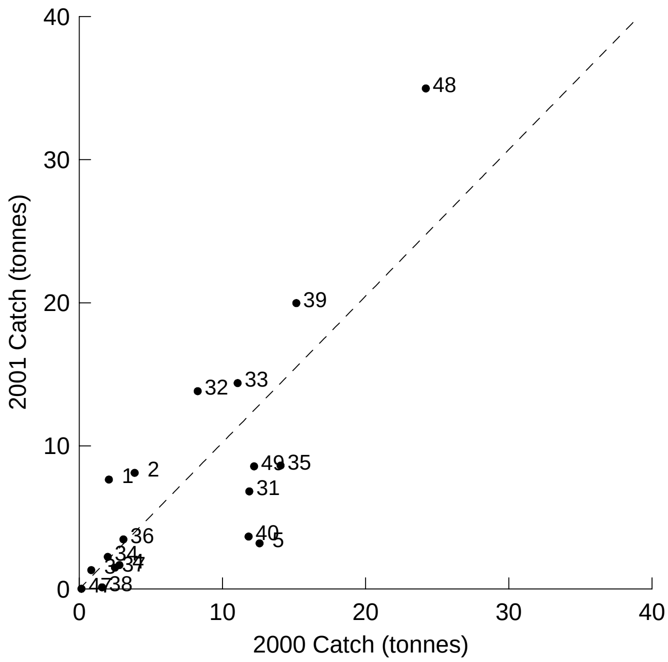


Fig. 16. Differences in catch between years, by block, within the greenlip fishery, showing 2001 catch by block plotted against 2000 catch. The expected catch is indicated by the position of the dotted line.

6.4 Blacklip And Greenlip Abalone: Ten Year Trends In Catch And Catch-Rate

This year we have attempted to display trends in catch and catch-rates in a clearer manner, by limiting the range of catch information to the recent past. A ten year period is used because we believe effort was relatively constant between 1992 and 2001. Discussions with divers suggested that they mostly use the same methods and types of equipment now that they were using ten years ago (i.e. we think divers operate at the same level of efficiency now as they did then). This makes comparison of changes in catch-rate over the period more valid, and they may more accurately reflect changes in abundance, rather than improvements in abalone handling techniques.

The ten year charts differ from similar charts in Appendices 7 and 8 in two respects. Firstly, the ten year charts show the total catch for each species, not the combined catch and the greenlip catch. Secondly, the annual catch-rates are derived from geometric means and not arithmetic means. Usually, there is little difference between the arithmetic and geometric means, but when catch-rate distributions become skewed to the right, the geometric mean is the lower of the two i.e. it is less influenced by small numbers of high catch-rates. Catch-rates in blocks where greenlip are fished are derived from effort data for both species, since it has not been possible to separate effort for each species until 2000.

We initially standardized 1992-2001 catch-rates by block using general linear models optimized for three regions within the fishery, using the variables year, month, diver and boat. In the north, blacklip or greenlip catch was also included. In most blocks, the standardized catch-rates closely followed the geometric mean. However, in blocks with highly variable catches and low numbers of diver days, there were variations between standardized catch-rates and the geometric mean. In these blocks, the standardized catch-rates fluctuated greatly; too few data points resulted in unrealistic effects being attributed to the predictor variables. Rather than standardizing catch-rates for part of the fishery, and using geometric means for blocks where there were too few data, we chose to use a uniform approach and used geometric means for all blocks.

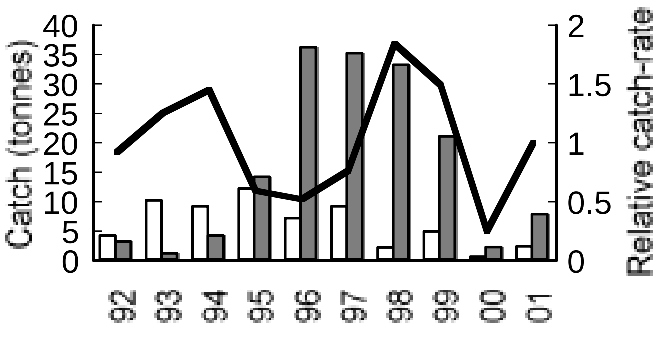
We used relative catch-rates instead of absolute values, not only to remove ambiguity caused by comparison of absolute values from dissimilar parts of the fishery, but also so that blocks within each zone mostly share a common axis and consequently trends are not magnified or diminished in any way by the arbitrary selection of the range of values on the independent axis.

The blocks are grouped by region, and the regions by zone. Note that the zone boundaries pass through blocks, so there will be some overlap between blocks in adjacent zones.

The comments adjacent to each block have in part been provided by a small number of people. These were usually divers who were identified from catch returns because they regularly fished particular areas and were subsequently contacted and asked to supply information about their catches and perceptions of stock abundance.

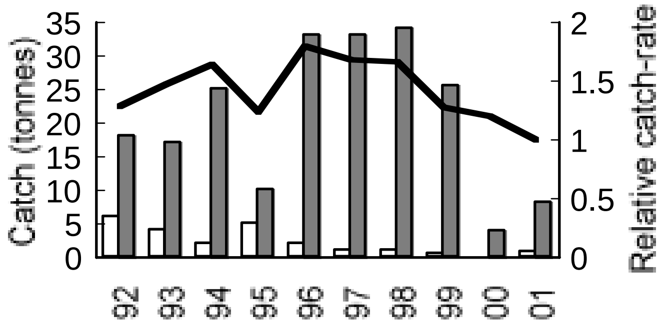
Catch-rates are shown as a black line, blacklip catch as unfilled columns and greenlip catch as shaded columns.

6.4.1 Northern Zone and Greenlip fishery



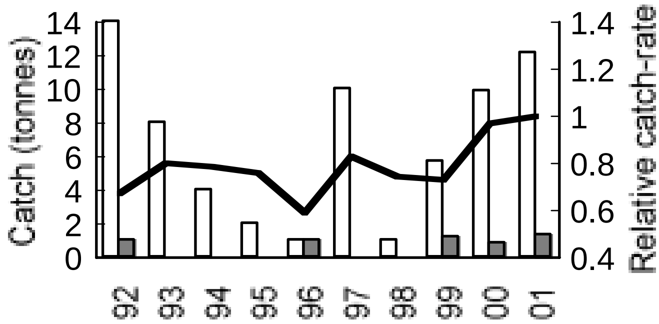
Block 1:

Generally on King Island (Blocks 1 to 4) catches and catch-rates are unstable, probably due more to changing divers and size-limits rather than falling stock levels. However, in some areas, greenlip have yet to recover from heavy fishing between 1996 and 1999.



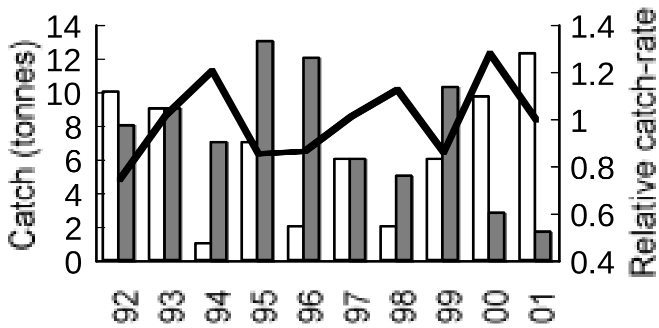
Block 2:

Almost 19 tonnes of greenlip were taken from King Island in 2001. While this is well down on previous years, it is locally considered that stock levels will not yet support significantly greater levels of catch.



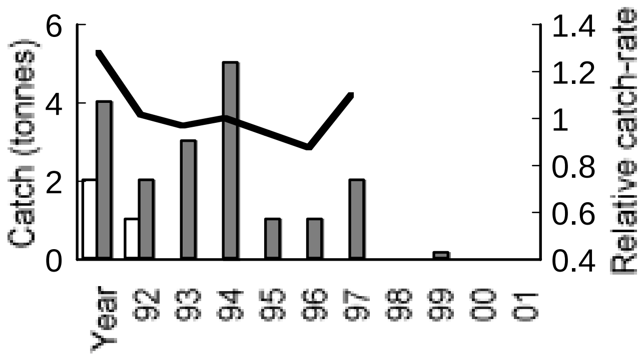
Block 3:

Blacklip catches are relatively low, but divers report that they are particularly abundant, and catch-rates support this. The 5-mm size-limit reduction appears to be adequate to give good access to stocks here.



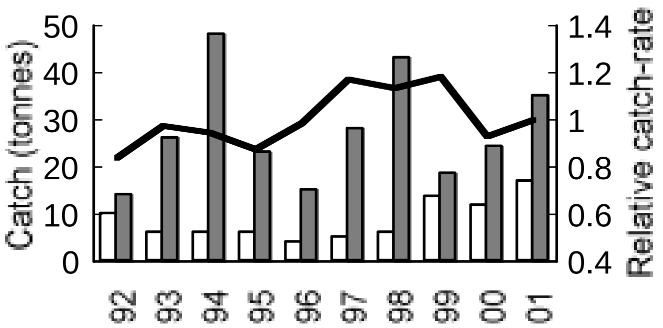
Block 4:

Catch-rates in this block reflect wildly fluctuating levels of catch and changes in target species rather than abundance.



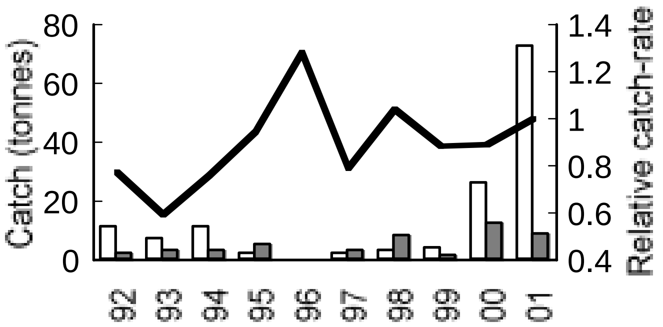
Block 47:

Has not been fished seriously for several years, divers devoting attention to more westward blocks.



Block 48:

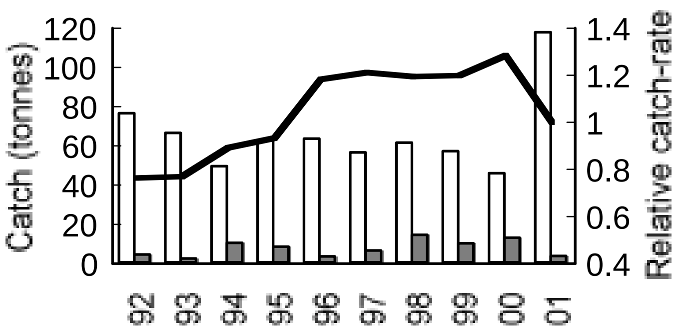
Produced good catches of greenlip, particularly from Black Reef. The more remote areas also consistently provided good catches.



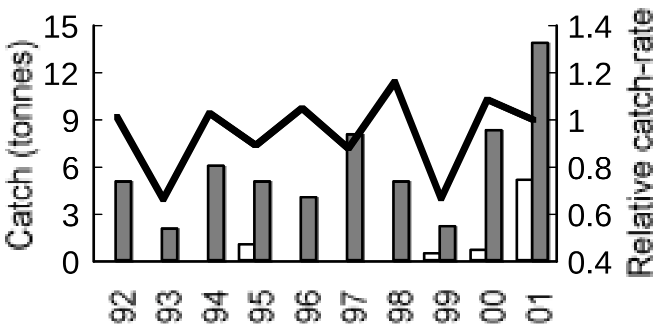
Block 49:

Most of the blacklip catch came from sub-block 49C, divers landing catch at Woolnorth, although some good catches also came from Three Hummock Island and the northern part of Hunter Island earlier in the year.

Block 5:

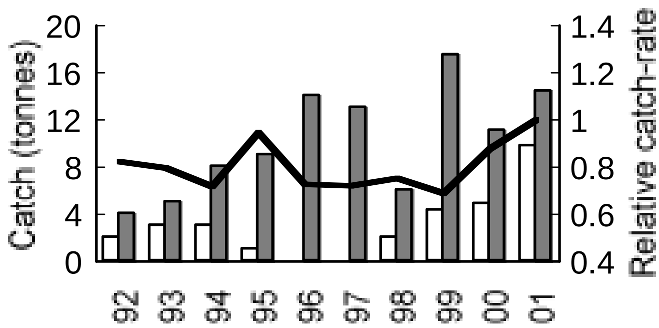


Although some fishing was done from Woolnorth, most divers chose to work from Bluff Hill Point, and consequently the catch was predominately taken from between the Arthur River and Green Point. Catch-rates have fallen, partly as a response to a big increase in effort associated with implementation of the Northern Zone, and partly due to an influx of divers unfamiliar with the coast.



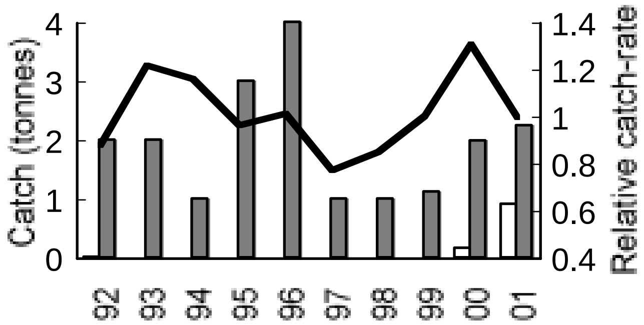
Block 32:

Although some good catches of blacklip were landed, this is predominately a greenlip fishery, where blacklip are a by-catch.

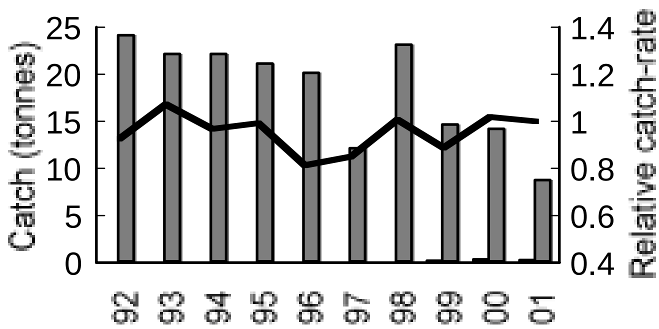


Block 33:

Most divers targeted greenlip, but increasing quantities of blacklip were landed.

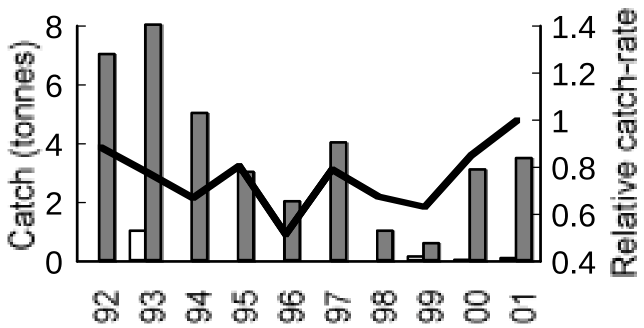


Block 34:



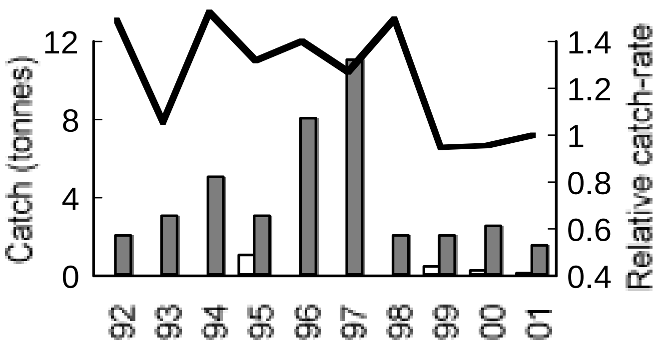
Block 35:

Fished mostly by one diver, greenlip catches fell well below the 20 tonne cap. This fishery operates for just 6 months from 1 April, and the attention of most divers was focussed in the south of the Furneaux Group.

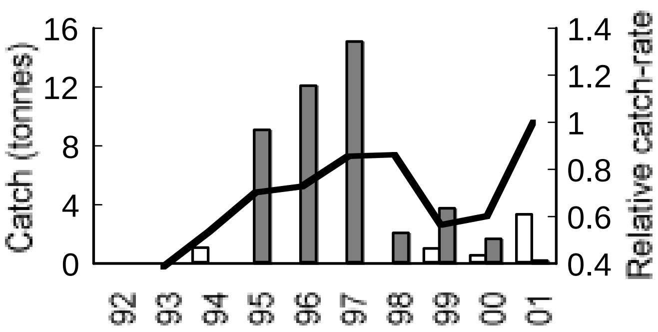


Block 36:

Blocks 36-38 received little attention from greenlip fishers, because they were landing adequate catches from Blocks 32 and 33.

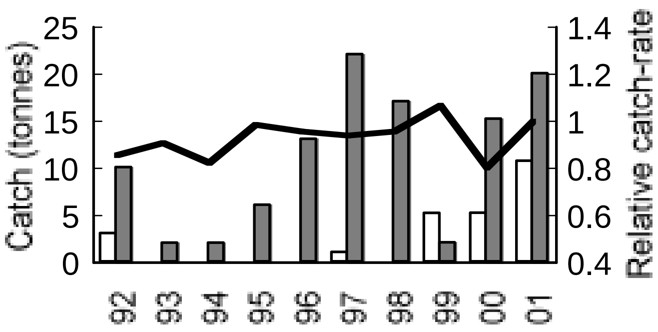


Block 37:



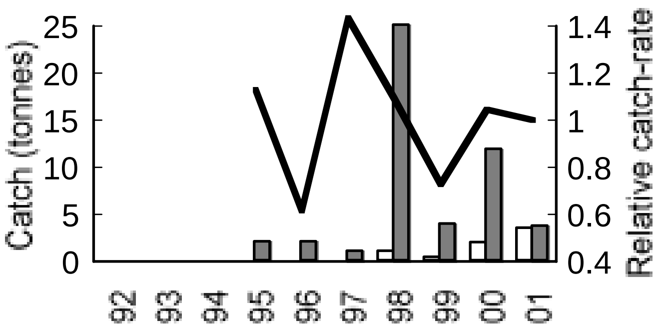
Block 38:

Higher catch-rate reflects renewed interest in blacklip following opening of Northern Zone at a reduced size-limit.



Block 39:

This block produced good catches of both blacklip and greenlip abalone. Big catches in this region depend upon divers finding reef that has been unfished for many years: recovery is usually slow and annual catch is inconsistent.

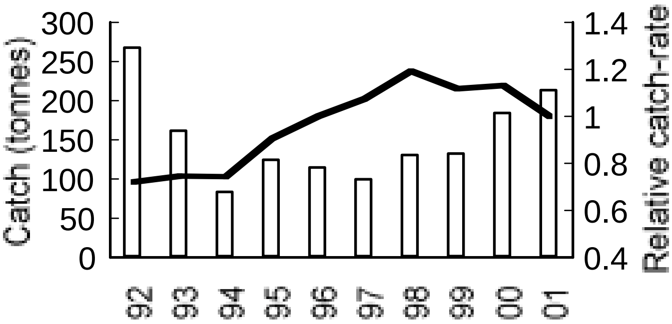


Block 40:

Greenlip stocks have not recovered from depletion of earlier years. The blacklip catch comes mostly from Waterhouse Island.

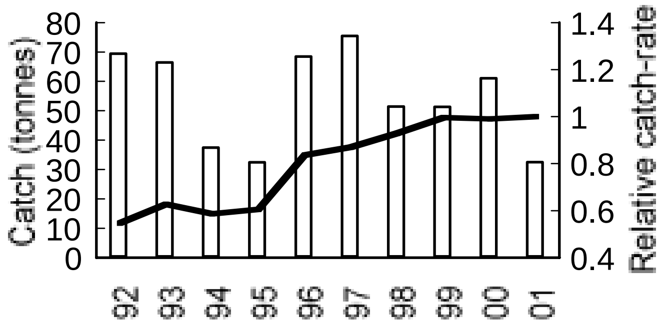
6.4.2 Western Zone

Throughout the Western Zone, catch-rates have fallen in response to increased levels of catch in 2000 and 2001.



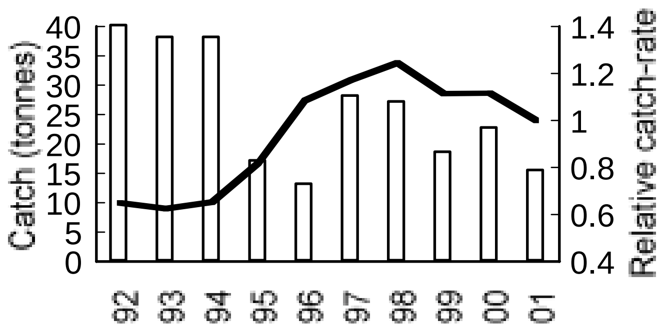
Block 6:

Catch-rates are falling, due in part to an influx of divers who came to the area to fish the Northern Zone and are unfamiliar with the coast, and in part to the extra catch taken over the last two years. Effort was transferred here from other parts of the Western Zone because buyers wanted fish caught at 132 mm size-limit.

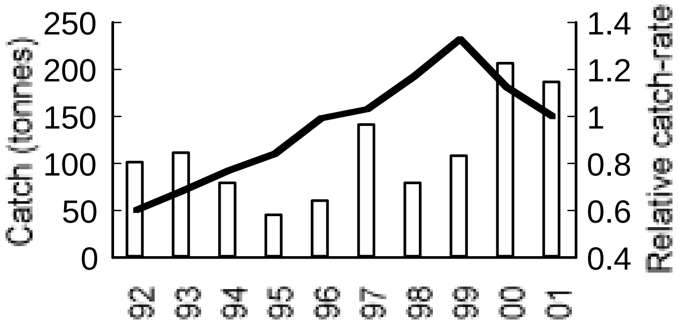


Block 7:

Effort shifted from Blocks 7 and 8 to Block 6 so that divers would have a better chance of fishing the Northern Zone should suitable conditions arise, and because buyers wanted smaller abalone.

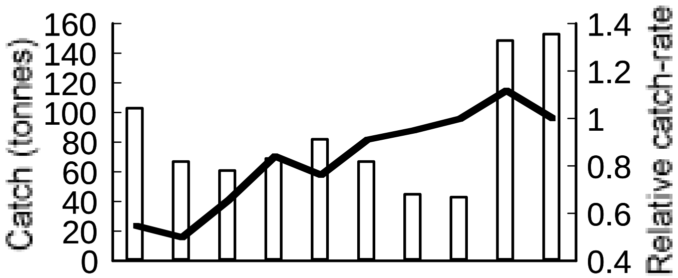


Block 8:



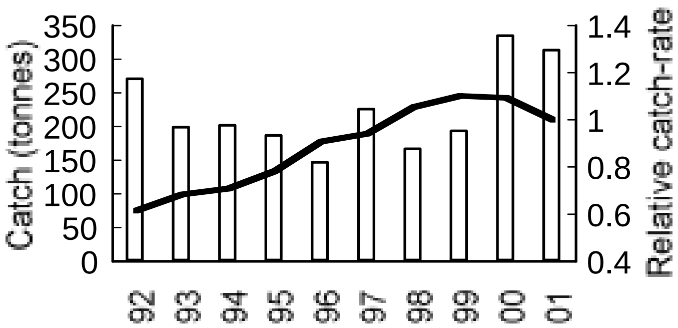
Block 9:

This block receives a lot of attention from divers fishing from trailer-boats. Catch-rates have fallen for the second successive year, and combined with a falling catch in 2001, indicate falling abundance.



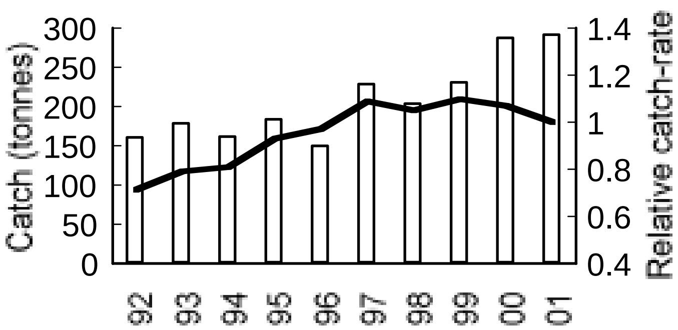
Block 10:

Although catch-rates are falling in Blocks 10, divers are optimistic that stock levels are satisfactory here and there is no significant stock decline. Catches have risen by over 300% since 1998.



Block 11:

The magnitude of the catch from this block is second only to Block 13. Catches remained high but catch-rates fell.

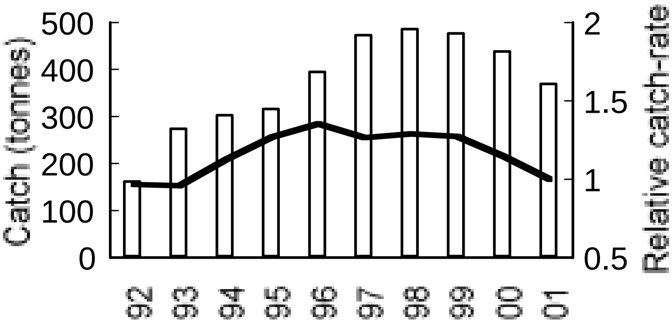


Block 12:

The eastern parts of this block are exposed to high levels of effort from trailer-boat divers who preferentially fish the area for the live-fish market. Catch-rates are falling slowly, and are at the lowest for five years. Catches have increased steadily since 1992.

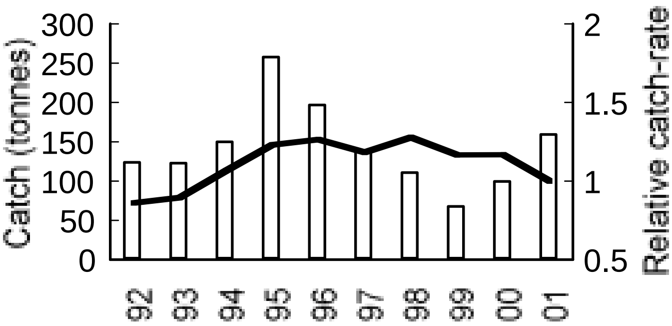
6.4.3 Eastern Zone

All blocks show a fall in catch-rates indicative of stock depletion.



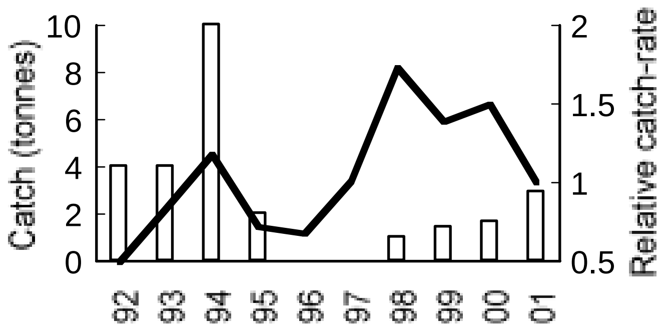
Block 13:

The catch from those parts of Block 13 that are in the Eastern Zone was limited by management controls in 2001. Catch-rates have fallen for the second successive year, indicative of falling stock levels.



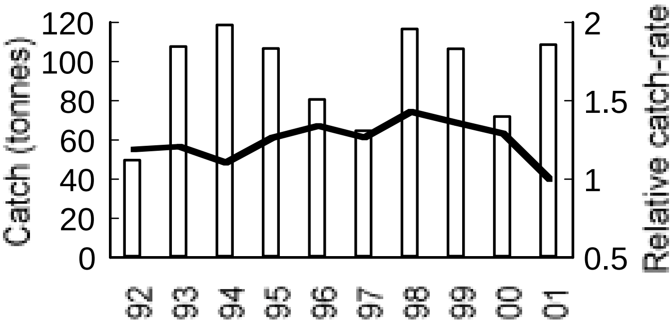
Block 14:

Following closure of Block 13, divers chose to fish in adjacent Block 14. While some good catches were taken from the Friars in sub-block 14E, the remainder of the Block was fished at low catch-rates, indicative of low stock levels.



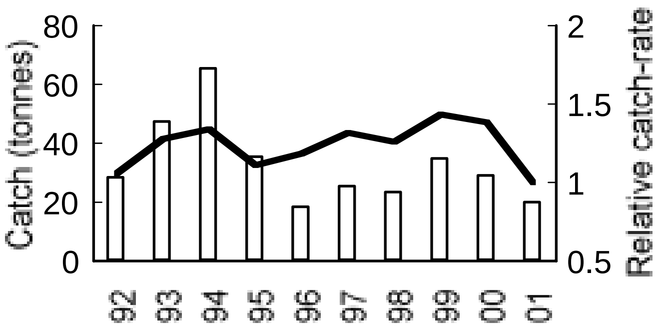
Block 15:

Fluctuating catch-rates probably reflect irregular effort more than abundance.



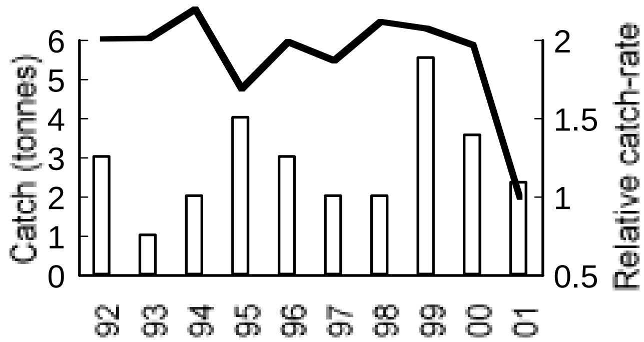
Block 16:

Together with Block 14, this block carried much of the transfer of effort when Block 13 was closed. Reasonable catches were taken from south of Mangana Bluff, but for the most part, catch-rates were low, indicative of low stock levels.

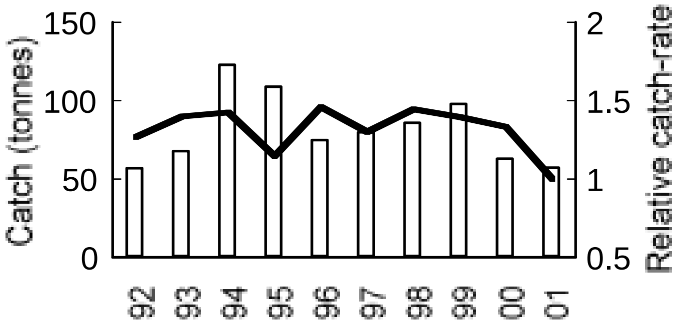


Block 17:

Comparatively little catch was taken here in 2001, and in conjunction with catch-rates falling for the second successive year, must be indicative of dwindling stock levels.

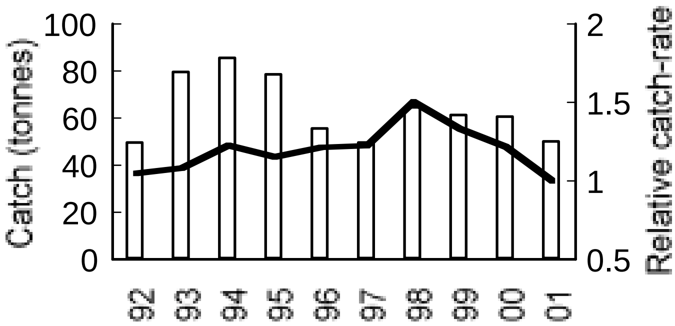


Block 19:



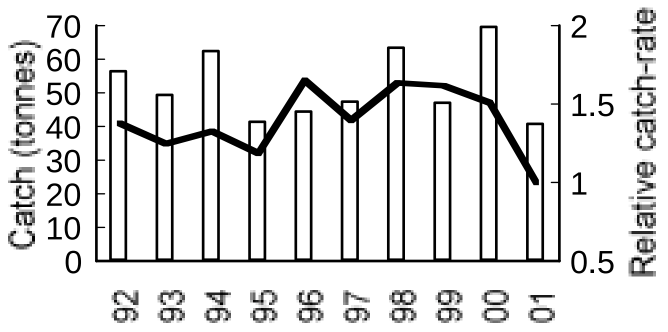
Block 20:

Catch and catch-rates for this part of Storm Bay have been falling for several years now, which can only be reasonably interpreted as falling stock levels.



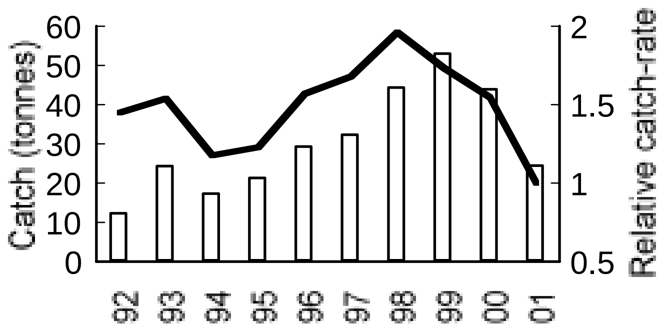
Block 21:

Catch-rates here have fallen sharply for the past four years, at reducing levels of catch, indicating falling stock levels.



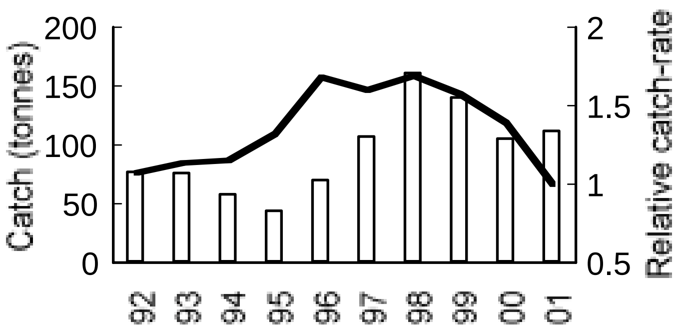
Block 22:

Historically, catch and catch-rates have always fluctuated here. However, the latest catch-rate decline is severe, and in conjunction with lower catches, must indicate low stock levels.



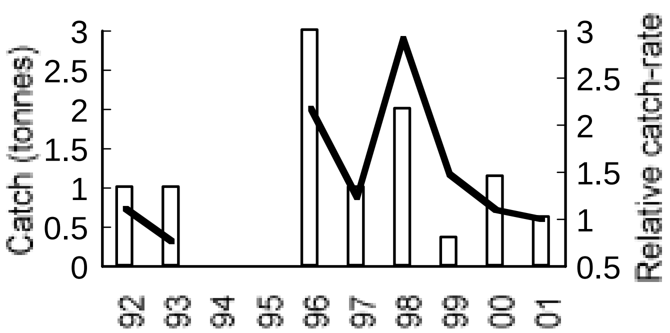
Block 23:

Divers report low stock levels in this block, supported by falling catch and catch-rates for a number of years.

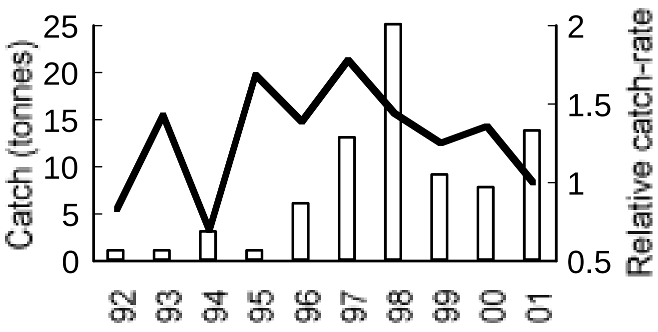


Block 24:

Catch-rates here are falling sharply. Some divers attempted to transfer their operations from the Actaeons to Maria Island. However, they found stock levels much lower here, and returned south.

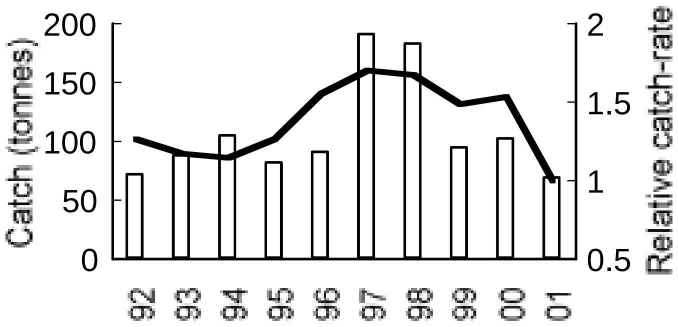


Block 25:



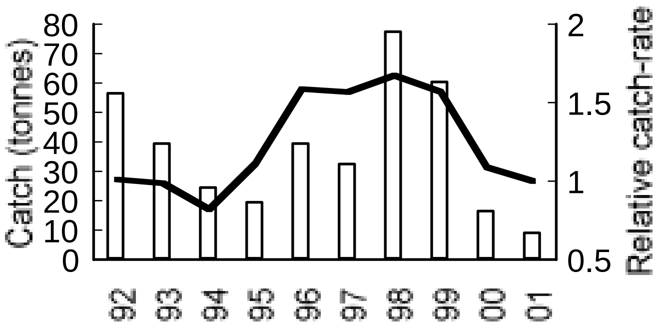
Block 26:

Catches rose this year, as divers moved here from nearby blocks. Few divers found worthwhile catches, and in the last quarter of the year, catch-rates were very low.



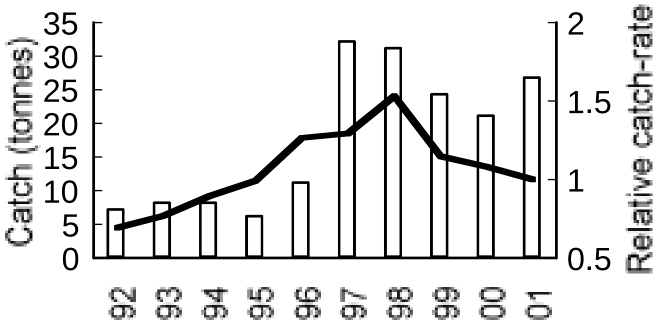
Block 27:

This block performed poorly in 2001. Divers reported low stock levels north of Wineglass Bay and moved elsewhere. Reasonable catch-rates were maintained in the more remote southern part of the Peninsula, or by diving in deeper water.



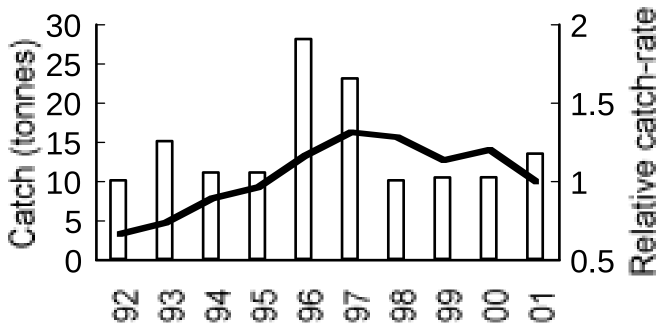
Block 28:

This block appears to be going out of production, in a manner similar to Block 30. Divers report that reefs that formerly held good quantities of abalone are now no longer productive. Divers occasionally experienced good catch rates while fishing in the shallows at Seymour, but otherwise stock levels were low.



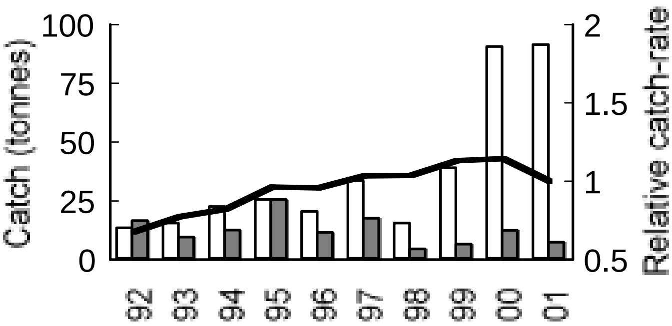
Block 29:

Moderate levels of catch came from the northern part of the block, but were poor elsewhere.



Block 30:

Divers experienced reasonable catch-rates here, either by diving in very deep water, or by fishing a few isolated patches where abalone are abundant. Otherwise, this block continues to under perform its long-term 74 tonne average catch.



Block 31:

For the second successive year, catches were at high levels. Some of this catch occurred in the Northern Zone at a smaller size. Note however that catch-rates fell. That this occurred in the last quarter of the year indicates that the reserve of stocks from years of low fishing mortality is being rapidly depleted and future fishing may depend upon recruits, at lower levels of catch and catch-rate.

6.4.4 Summary – trends in catch and catch-rate

Eastern Zone:

Without exception, blocks in the Eastern Zone have performed poorly compared with recent years. Falling catch-rates combined with reduced catches can only indicate that stock levels are depleted.

The best performing areas were the Actaeons (sub-blocks 13C, 13D and 13E), Block 31 and the Friars and adjacent coast (sub-blocks 14E and 16A). In this last area, some of the catch attributed to the Friars is rumoured to have come from the Western Zone; if this is true then the situation here is worse than reported.

Western Zone:

The remote Blocks 10 and 11 performed well again this year. However, in view of falling catch-rates, stock levels must be considered at risk. Catch-rates and catches are falling in the more accessible blocks as stock levels are being steadily depleted.

Northern Zone:

Stock levels in all regions remain high. Blocks 5 and 49 contributed two thirds of the catch, which is more than expected from the TAFI analysis of predicted sustainable catches. King Island contributed much less than expected. Much of the Furneaux Group remains un-fishable because the size-limit is too high. Size-limits between Musselroe Point and Waterhouse Island seem to be appropriate for economical fishing while giving adequate protection to stocks.

Greenlip fishery:

King Island stocks are yet to recover from earlier high levels of depletion. Stocks in other regions appear to be copacetic with acceptable catch-rates and moderate levels of catch. Note that the premium product for the live market are abalone larger than 500 gram, or 160 mm shell-length. Divers who supply this market fish to a much larger size-limit, and consequently their catch-rates may have no bearing on abundance of legal-size abalone.

6.5 Commercial catch sampling data

The measurement of abalone caught commercially recommenced in 1998, after falling into abeyance for several years. In 2001, over 62,000 abalone from 727 samples were measured, from a total of 8077 fishing events (diver-days). We now have monthly length data from several of the more heavily fished sub-blocks for two or more years, enabling an accurate assessment of changes in size-structure of stocks.

Size-composition of samples by sub-block for the past four years are provided in Appendix 6. We show sub-blocks only where enough data has been collected, or some feature of the sub-block makes it particularly noteworthy. We have insufficient samples from the greenlip fishery, King Island or the Furneaux Group to produce size-composition charts.

The number of abalone measured and the number of days sampled is shown in the top right hand corner of each month’s chart. Where the number sampled divided by diver days is between 15 and 30, it indicates that the size-composition data was derived from photographs of diver’s catches (only about 25 abalone would fit within the frame of the photograph and not all could be measured). Where the number sampled dived by diver days is approximately 100, the catch was sampled by TAFI researchers.

The horizontal axis shows size-class of the abalone measured, grouped in 5-mm increments. For clarity, labels are shown only for every second size-class, and only for the last chart each year. Each size class except the first includes abalone of the size indicated by the size-class label, and up to 5 mm below. Thus the 140-mm size-class includes abalone of sizes between 136 mm and 140 mm. The 130-mm size-class includes all abalone up to and including 130 mm.

The charts are grouped by year, and listed sequentially by month. Comparisons within a sub-block can be made between each year. Where there are sufficient samples, comparisons can also be made within a year.

There are few samples from Block 5, and these were included mostly to compare size-structure with samples from further south (Block 9) and to the north in Block 49. Block 5 samples were modal at the 140-mm size-class during most months, and illustrate the small size of abalone from this part of the West Coast. Note that some samples feature larger abalone, which shows the variable size-range of abalone within the sub-blocks.

Generally, size-composition of samples form Blocks 9 and 11 tend to be modal at size-classes between 150 and 170 mm, though some samples showed smaller abalone. Further east, the catch from sub-block 12D is highly variable in size, probably because the sub-block covers such an extensive length of coast.

Comparison between years in sub-blocks 13D and 13E illustrates the recent and rapid transformation of the Eastern Zone fishery to one that is dependent upon recruits. Between 1998 and 2001, catches featured progressively smaller abalone, until in 2001, over half the catch is of abalone smaller than 140 mm. This is because depletion has been so extensive, and fishing mortality so high that abalone now no longer get the opportunity to grow large. Most of the other blocks in the South East feature larger abalone than in Block 13, but generally there is a decrease in modal size during the four years.

On the East Coast, from Block 22 to Block 31, there is a northward decrease in modal size, and in most cases, the modal size is mostly reduced from previous years.

At Maria Island (Block 24), there is little evidence of recruits in the last part of 2001, particularly from sub-blocks 24D and 24E. This may be due to sample error or delayed onset of seasonal growth, but we came to the same conclusion (independent of catch sampling) when undertaking field surveys for the 2001 East Coast assessment (Tarbath *et al.*, 2001a). The December 2001 samples from sub-block 24D shows some smaller abalone.

We have a limited number of samples from the Northern Zone taken at the 127-mm size-limit. Sub-block 31B contains samples caught at both the 127-mm and 132-mm size-limits in 2001 (the boundary passes through the sub-block). The other sub-blocks show the generally small size of abalone in the region, with isolated catches of larger fish.

The most important conclusion to be drawn from the size-composition information is that abalone are being caught at smaller sizes in the East and South East as fishing mortality increases. The depletion of larger animals is visible as a shift downwards of the modal size class. The fishery is becoming increasingly dependent on recruits, which increases the level of risk within the fishery. There will be a decrease in egg-production, and the absolute number of animals needed to be taken to obtain the TAC is increased. Overall, this indicates that fishing mortality (the total proportion of animals taken) is increasing. Given that the Eastern Zone TAC was reduced in 2001, an increase in fishing mortality is a clear sign of stock depletion.

6.6 East Coast Assessment

Following a request from the Tasmanian Abalone Council (TAC) for information about the status of East Coast abalone stocks, an extensive study of populations on the section of coast between Blocks 22 and 29 was undertaken by TAFI researchers. Information about size at sexual maturity, population size-composition, and gross changes in sampling time was collected and presented as a report to industry (Tarbath *et al.*, 2001a).

Samples were collected at 35 sites. Information from these sites was compared with that gained from these and other sites in previous years to highlight any biological changes that might have occurred as a result of fishing. Of particular interest were changes that might indicate reduced recruitment, both to the fishery as pre-recruits (next year's crop) and to the population generally in terms of potential for ongoing sustainability.

At each site, two years of growth was projected onto the median size at which abalone become sexually mature. The Management Plan for the fishery includes a stated objective that to maintain biomass and recruitment, abalone shall be allowed to grow to a size where they have had two breeding seasons prior to recruitment to the fishery. By comparing the projected size at two years beyond sexual maturity with the current 132-mm size-limit, the adequacy of the size-limit in meeting the management objective was assessed.

The report concluded:

- Size-limits on the East Coast are too small to adequately support the Management Plan objective "to allow abalone to grow to a size where they have had two breeding seasons…"

- The East Coast fishery is largely dependent upon annual recruitment for most of the catch.

- At the majority of sites sampled, the relative abundance and rates of collection of pre-recruits and juveniles were sufficiently high to suggest that the fishery would continue to supply adequate levels of catch in the short term, although catch-rates may be reduced.

- On the east coast of Maria Island and on parts of the coast between Wineglass Bay and Bicheno, relative abundance and rates of collection of pre-recruits and juveniles are particularly low, and may not sustain present levels of fishing.

- By increasing size-limits in line with average projected sizes the Management Plan objective for East Coast stocks north of Eaglehawk Neck will be achieved. However stocks to the south which grow to a larger size will be less adequately protected. Because of variation in growth, some populations will inevitably be over-protected, while others will receive insufficient protection.

The Eastern Zone TAC for 2002 was subsequently reduced from 1,120 tonnes to 857.5 tonnes, and the size-limit for the zone was increased from 132 mm to 136 mm, to be reviewed at the end of 2002 with a further minimum size increase planned.

6.7 Effect of local closures

In 2001, fishery managers made extensive use of closures of parts of the fishery to conserve stocks at risk of localised depletion. In particular, once prescribed limits were met, both the greenlip fishery on mainland Tasmania and the Furneaux Group, and the parts of Block 13 within the Eastern Zone were closed.

The closures of sub-blocks 13C, 13D and 13E caused effort to shift to surrounding blocks. However, while the 2001 catch in Block 13 was down about 57 tonnes on the previous year's catch, the catch attributed to Blocks 14 and 16 rose by almost 100 tonnes as they absorbed effort from the East Coast as well as Block 13. Most of the increase came from sub-blocks 14E (the Friars), 16A (south Bruny), although it should be noted that some of this increase was reportedly due to divers filling Eastern Zone quota with Western Zone catch.

6.8 Recreational Fishery

The number of recreational abalone licences increased from 4151 in 1995-1996 to 7367 in 2000-2001, a rate of increase of about 10% per annum. However, there was a fall to 6227 licences in 2002. Rock lobster dive licenses also fell, but to a lesser extent (Fig. 17).

The recreational catch of abalone continues to represent a minor proportion of the commercial catch. However, it is unevenly distributed around the coast. From a recent survey of recreational catches for the 2000-2001 recreational season, about 140,000 abalone were taken. Over 50 percent of these were taken from the south-east between Marion Bay and Whale Head, with remainder of the east coast contributing about 25 percent, and the north west slightly less than half that amount. While these figures are indicative and not to be taken literally, it shows the catch is highest in the more stressed parts of the fishery. Recreational divers are also more likely to continue taking abalone from reefs where the abundance would be insufficient to maintain acceptable commercial catch-rates. We must now consider the possible effects of the recreational catch on stock levels, and make allowances for the recreational sector.

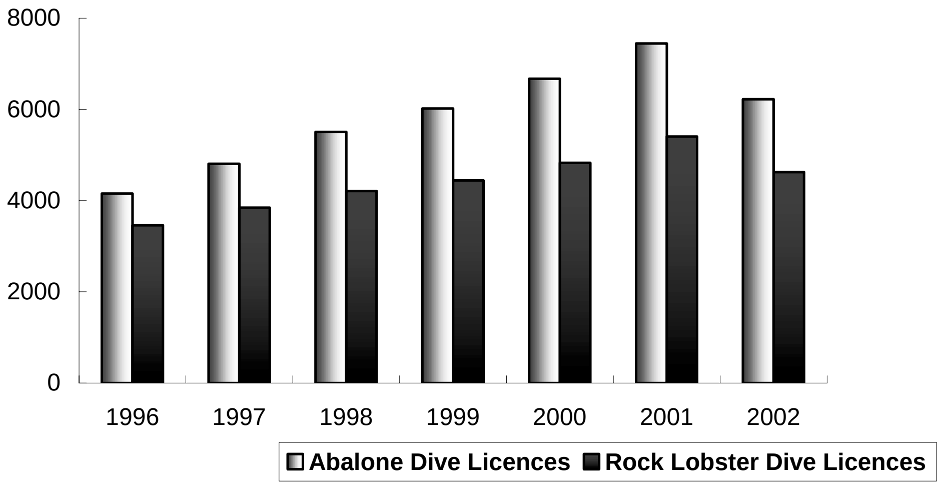


Fig. 17. The number of recreational dive licenses issued by DPIWE to catch abalone and rock lobster for the seasons 1995-96 to 2001-2002.

7. Discussion

7.1 Review of Performance Indicators

Stock assessments in the Tasmanian abalone fisheries rely primarily upon raw catch and effort data to infer changes in abalone abundance. The 2000 stock assessment (Tarbath, Hodgson, Karlov and Haddon, 2001b) noted the decline of abalone stocks in the Eastern Zone, particularly on the East Coast and in the South East. We noted that catches in those regions were at moderate levels in 2000 compared with historical levels of catch. Given that catch-rates were still relatively high measured against those from reference periods, we were unsure of the extent to which abundance had been reduced by the large catches of the preceding years.

With hindsight, we can see that there had been considerable depletion of stocks in these regions. The method used to analyse changes in catch rate for the 2000 and previous assessments provided ambiguous signals about the status of stocks, and its usage may have obscured important information. For this reason, we have reviewed the usage of the performance indicators used to monitor this fishery, and subsequently modified our approach to the way in which we use catch-rates and size-composition data.

7.1.1 The use of catch-rates as an index of abundance

To be of value as a performance indicator of a fishery, catch-rates must reflect the abundance if the targeted species in time and space. If diver efficiency or industry preferences for different size abalone change through time, the accuracy and utility of catch-rates are diminished. In most abalone fisheries, the use of catch-rates as a means of assessing changes in abundance has been discredited (Harrison, 1983; Breen, 1992; Prince and Shepherd, 1992). Catch-rates are widely perceived as being insensitive to abalone abundance because of the aggregating behaviour of abalone and the fishing behaviour of abalone divers, who are reported to be able to maintain high catch-rates by serially depleting populations where abalone are abundant. In addition, as a measure of abundance, catch-rates perform best when the average weight of animals remains constant through time. Changes in average weight of abalone in the catch will make catch-rates even less reliable as measures of abundance.

However, at the low stock levels currently prevailing in the Eastern Zone, divers are unable to move to areas of higher abundance when their catch-rates fall. With the possible exception of some deeper reefs, all areas are fished hard, and in some areas, reefs are fished almost daily. The confounding effect upon catch-rates caused by divers depleting successive reefs no longer applies. This high level of fishing pressure across the Eastern Zone also means that large aggregations of legal-size abalone are uncommon, and that usually abalone are collected as individuals. Divers spend most of their time searching, and time spent handling abalone is low. Furthermore, it appears that the average weight of abalone is stabilising as remnant large abalone become scarce and the fishery becomes increasingly dependent upon recruits.

Similar conditions have prevailed in the New South Wales abalone fishery for many years, where researchers now believe that catch-rate indices are reliable indicators of abundance (Worthington and Andrew, 1998).

In the Western and Northern Zones, stock levels appear to be much higher, and divers may move to better areas if they think that they can improve their catch-rates. Abalone are usually fished in large aggregations, comprising mostly individuals much larger than the legal minimum size (e.g. Appendix 6, Blocks 9 and 11). As a result, when divers locate a patch of abalone, high catch-rates prevail, being limited only by the diver’s ability to remove the abalone from the reef and land them in the boat. In these parts of Tasmania, divers search for aggregations, not individual abalone as they do in the Eastern Zone. Handling time, rather than searching time limits catch-rates.

7.1.1.1 The distribution of catch-rates and changes through time

A review of catch-rates as a performance indicator shows that generally, the frequency distribution of Western Zone catch-rates is changing (Fig. 18). Typically log-normally distributed (1992), in the peak years of the late 1990’s the skewness became less, because the median catch-rate increased while the variance changed little (1998). In 2001, the catch-rate distributions became more skewed as the mean catch-rate dropped but the standard deviation increased (Table 1).

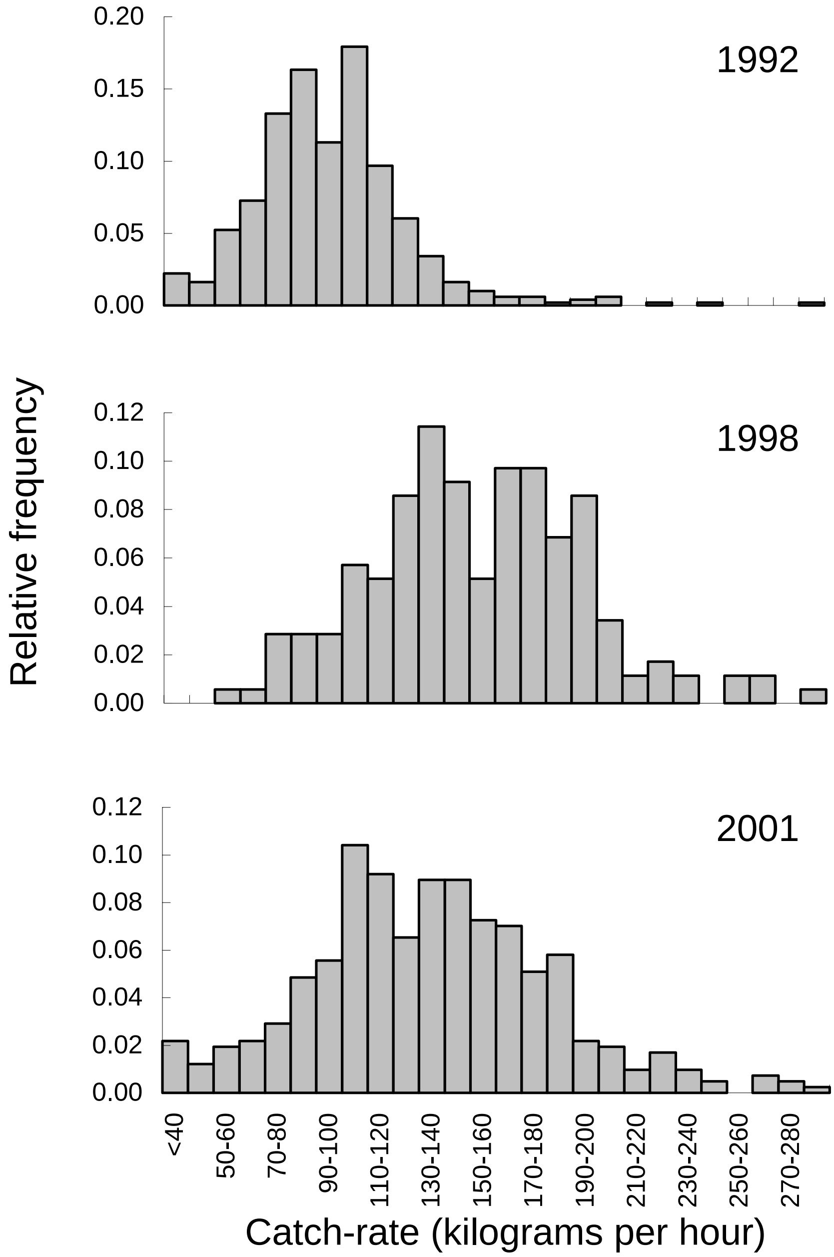


Fig. 18. Distribution of catch-rates from Block 6, 1992 to 2001, showing changes in distribution of catch-rate. Statistics for each distribution are shown in Table 1. In 1992, Block 6 was producing large quantities of abalone, mostly at relatively low catch-rates, but with occasional high catch-rates. By 1998, the fishery had recovered after catches had been at low levels for many years. Medium levels of catch-rate became common, and divers frequently experienced high catch-rates. In 2001, after several years of high levels of catch, stocks were declining. While high catch-rates were still relatively frequent, most divers experienced catch-rates substantially lower than in 1998.

Table 1. Distribution of catch-rates from Block 6, 1992 to 2001
Statistics of catch-rate distributions from Block 6 for the years 1992, 1998 and 2001 are shown.

	1992	**1998**	**2001**
Mean	93.538	156.258	139.456
Mode	82.693	138.118	116.502
Median	89.774	149.961	131.342
Ln(m)	4.497	5.010	4.878
stdev	0.287	0.287	0.346
ssq	1426.123	185.202	532.318

More symmetrical distributions of catch-rates might occur when mean catch-rates are high, abalone are abundant and no special skill or knowledge is required to find them, and most divers are operating within an approximately equal range of efficiency. This occurred in Block 6 in 1998.

There are several plausible reasons why catch-rates may be skewed. In particular, when abalone populations are depleted with generally low levels of abundance and high density patches of abalone are isolated and uncommon, most divers achieve only low catch rates. However a few experienced or lucky divers are able to locate isolated abundant patches and land their catches at far higher rates than the other divers. We assume the 1992 distribution is skewed due to depletion of abalone in Block 6 during the preceding decade when particularly large quantities were taken here. The mean catch-rate declined in 2001 relative to 1998 and catch-rates were more variable (Table 1). This statistical block is certainly at a lower stock level than in 1998, but appears healthier than in 1992.

This change in distribution of catch-rates effects our interpretation of catch-rate trends (Worthington and Andrew, 1998). Catch-rates that appear to be stable or falling slowly over time, give the illusion that immediate changes are not required. However, catch-rates may be propped up by some very large catches when divers hit isolated patches that have been unfished for many years. These isolated patches become progressively more scarce. When divers are unable to find dense patches, average catch-rates fall very quickly. This makes interpretation of catch-effort indices difficult and reduces the reliability of catch-rate indices as proxies for abundance in the Western Zone.

7.1.1.2 The effect of changes in individual average size on catch-rates

The effect that changes in average weight of abalone have upon catch-rates has generally gone uncommented in Australian abalone fisheries. This probably reflects high exploitation rates in recruit based fisheries where size-composition of the catch is relatively static and the size-range of the catch is small over the period in which assessments have taken place. In Tasmania, potential for growth, at least among the dominant species, blacklip abalone, seems to be much greater than in other states, and where reefs are fished infrequently, abalone grow to a much greater weight than when they first recruit. Studies of populations from more southern parts of the state show that abalone can grow to double their weight within six years of recruiting i.e. a 160-mm abalone weighs twice as much as a 132-mm abalone (D. Tarbath, unpublished data).

In the greenlip fishery, catch-rates are of variable value as an assessment tool. Some divers supply a market that prefers large abalone. These divers fish to market preferences, and set their own size-limit which may be 15 mm larger than the legal minimum size. Because these larger abalone are less common than abalone closer to the size-limit, their catch-rates may not reflect abundance of all legal-size abalone.

On King Island, both the high greenlip size-limit operating in 2001 combined with depredations of previous years meant that reasonable catch-rates were found in only a few areas supporting large abalone; these areas are fished consistently. Falling catch-rates here are likely to indicate that abundance of abalone at the 155-mm size-limit is low. In contrast, in the Furneaux Group and parts of the North East, divers were able to find aggregations that had evidently been unfished for many years, and high catch-rates were relatively common. Furthermore, because they had been unfished, stocks had rebuilt and the abalone were much larger, with high average weight contributing to the catch-rates. While increased catch-rates here may be associated with increased abundance, there is no certainty that these levels of catch are sustainable. If the unfished aggregations become more infrequent and divers are increasingly forced to fish recruits, we expect catch-rates to fall abruptly.

Previous assessments have included production data provided by Tasmanian Seafoods Pty Ltd showing the increase since 1995 of the percentage of cans produced containing one whole or one cut abalone from what is now the Western Zone (Officer and Tarbath, 2000; Tarbath *et al.*, 2001b). The minimum bled meat-weight of abalone in a can is 213 g. From known rates of weight-loss during processing (A. Hansen, pers. comm.) and length-weight relationships of abalone from the region, we estimate that such abalone would have a minimum length of 160 mm. The percentage of cans containing these large abalone has increased from about 15% in 1995 to 33% in 2000, and is an indication that the average weight of abalone increased in this part of the fishery. Use of this data in assessments has been discontinued because divers are increasingly sorting out small abalone from their catch for sale to live market buyers prior to delivery to Tasmanian Seafoods.

The increase in average annual catch rates from Western Zone blocks over the last ten years has been spectacular. For example, in 1999, catch-rates in Block 9 averaged 215 kg/hr, up from just 88 kg/hr in 1992. The increase in catch-rates was attributed to increased abundance, caused by diminished levels of fishing mortality, and follows the introduction of quota, a reduced TAC and an increased size-limit during the 1980's. Effort dropped in the west, because divers found it easier to fish on more accessible coasts. Although divers have become more efficient during the course of the fishery and a diver can now catch much more abalone per unit of effort than 30 years ago, over the last ten years methods of catching and handling abalone have altered little, and effort creep is considered to be an unlikely contributor to the increase. The best explanation now is that alongside the increase in abundance there was an exponential increase in individual average weight of abalone.

The average weight of abalone in the Western Zone is much higher than in the East, though this is becoming more variable as divers target areas where abalone are smaller to capitalize on the high prices offered by the live market. If Western Zone abalone are being caught at a smaller size because of high rates of fishing mortality i.e. the larger abalone become scarce, then abundance of abalone in this part of the fishery could fall quickly with no appreciable affect on catch-rates, and little awareness by divers of the changes occurring around them. Average catch-rates alone are unreliable indicators of abundance here.

Recently, catch and catch-rates in Block 13 have fallen, from 483 tonnes at 87 kg/hr in 1998 to 367 tonnes at 65 kg/hr in 2001. In this block, not only have the numbers of abalone declined, but their individual average weight has fallen. Samples from catches show a decline in average weight from 589 grams (S.E. 62) in 1998 to 480 grams (S.E. 16) in 2001 (D. Tarbath, unpublished data). The impact of high levels of fishing mortality on a population is exacerbated by reduced individual weights, because more individuals need to be taken to meet catch quotas. If both the individual size of abalone and the annual catch decline, this is a strong indication of depletion.

Finally, for many years we have been struck by the fluctuation in catch-rates between summer and winter in the east and south-east. In the warmer months, catch-rates are typically 20 or 30 kg/hr less than during late autumn and winter. An examination of catch-sampling charts displayed by month and year, particularly sub-blocks 13E and 13D, reveals an increase in size (i.e. shell length) between the beginning of each year and midyear, followed by a fall in size towards the end of the year. Current research indicates that peak growth occurs approximately for three months either side of the New Year between spring and early autumn. In this period, most pre-recruits grow through the size-limit. The new recruits continue growing, and in winter are considerably larger, coinciding with highest catch-rates. Most of these recruits are caught during winter, and in spring and summer divers switch to catching fresh recruits, and catch-rates fall.

These examples highlight the importance of considering changes in size-composition of the catch when reviewing catch-rates, and that catch-rate indices will only reflect abundance when size-composition of the catch is stable.

7.1.1.3 Reduction of the area of productive abalone reef

Raw catch-rates are also a poor indicator of stock-health when areas of reef are no longer productive. The best examples are the blocks in the northern part of the east coast (Blocks 28 to 31). For many years, Block 30 (St Helens Point to Eddystone Point) was a major contributor to the fishery, averaging 150 tonnes per annum over the period 1977 to 1987. Most of the Block 30 catch now comes from isolated patches, which fished infrequently, provide small catches at adequate catch-rates, but the recent ten year average is 14 tonnes. The reason why this block no longer produces at former levels is that much of the earlier abalone habitat no longer holds abalone (D. Tarbath, unpublished data).

In this region, there are currently reefs that are in the process of becoming unproductive, or have recently become unproductive. Examples occur in Block 28 and Block 29 at Long Point, where the distribution of productive quantities of abalone has shrunk. Formerly productive areas extended from the shallows to the reef between 10 and 15 metres deep. Now the deeper reef is unproductive, and divers are limited to working along the margins of the shore (N. Wallace, pers. comm.). Other areas of lost production on the East Coast have been reported to researchers by divers of long standing. The only clue provided by catch data is that catch-rates and catches simultaneously fall over a period of several years, but this is often obscured, particularly if the annual catch is small, and divers find isolated patches of recently unexploited reef which yield large but short-term catches. Catch-rates alone fail to indicate abundance decline due loss of productive reef.

Considering these caveats, reviewing trends in catch-rate in conjunction with catch size-composition data is currently the best performance indicator available for this fishery. The practise becomes more robust when catch-rates are standardised, and diver efficiency is constant throughout the review period.

7.1.1.4 Comparison of current catch-rates with those from the reference periods

Past assessments have compared catch and catch-rates with those from reference periods. This method has been used since 1996. Its use and the development of trigger points that fired with defined levels of change were adopted in the 1997 Management Plan (Anonymous, 1997). After problems became evident with this method, its use was modified in subsequent assessments (Officer, 1999b). However, the method still suffers from a number of problems.

Our knowledge of size-composition of the catch from the reference periods (1979-1982 and 1992-1995) is poor. We have size-composition data from these periods, but because catches from more remote areas within a block where abalone are large were mixed with catches from easily-accessible areas with greater quantities of small abalone, we are unable to say whether the size-composition of the catch has changed between the two reference periods and 2001. Changes in catch rate between the early reference period and recent years are certainly confounded by changes in diver efficiency, and between the later reference period and recent years probably by changes in size-composition. Generally, these comparisons are insensitive, and are poor indicators of performance. In both 1999 and 2000, they failed to give any warning of stock decline in the east and south-east until this year, which was too late.

A comparison of catch between the current year and the two reference periods offers more useful information than a comparison between catch-rates and reference periods. However, changes in levels of catch are often open to interpretation, when the between-block distribution and level of catch is affected by a range of issues such as market preference, management changes, or broad socio-economic changes that change the spatial distribution of divers within the state. However, they do permit easy comparison of change between current levels of catch and past catches, and if the reference periods are appropriate, enable us to easily detect changes of greater magnitude. Note that the first reference period is not appropriate for the North East, North West, the Furneaux Group or King Island, all of which had peak catches in years other than the period 1979 to 1982.

7.1.2 Levels of egg production

The original Management Plan and subsequent updates include levels of egg production as a performance indicator (Anonymous, 1997; Anonymous, 1998; Anonymous, 1999; Anonymous, 2000). Annual stock assessments have never used this performance indicator, probably because of lack of suitable data, particularly reliable estimates of mortality, but also because no relationship has been demonstrated between stock abundance and levels of egg production.

This argument that stock size determines future levels of recruitment is complex and unproven, yet has intuitive appeal. It assumes that because large abalone produce more eggs, that large abalone are more capable of providing for a sustainable fishery. However, do greater levels of egg production necessarily mean more recruits?

The life history of abalone may be categorised into eight stages from gamete production to the mature phase (McShane, 1995), with progression to successive stages uncertain. Mortality in pre-recruit stages of highly fecund marine species such as abalone is extremely variable, the variability (of mortality) acting exponentially upon recruitment, which makes demonstrating and testing stock-recruitment relationships with fisheries involving these animals difficult if not impossible (Koslow, 1992). No-one has demonstrated a stock-recruitment relationship for abalone populations (McShane, 1995) and Shepherd *et al* (1992) demonstrated that larval settlement varied independently of stock size.

Notwithstanding the above, the failure of other abalone fisheries has been associated with high levels of fishing mortality (Shepherd *et al.*, 1991; Shepherd, Baker and Johnson, 1995), or even natural mortality (Sloan and Breen, 1988), with correlation between diminishing levels of egg production and collapsing abalone fisheries (Shepherd and Baker, 1998).

The only conclusion that can be drawn from this is that currently in Tasmania, maintaining levels of egg production is not an appropriate general management tool for assessing potential levels of catch. On a broad scale, levels of egg production are probably irrelevant as performance indicators, and their use should be restricted to discrete stocks in small regions where there is some understanding of the biological parameters of local populations. The work by Officer (1999a) in the greenlip fishery in four regions in northern Tasmania is an example of this use. The inclusion of egg production as a performance indicator in the current Management Plan is of little value for the majority of the fishery.

An alternative indicator could be derived from one of the objectives of the management plan: to ensure that abalone are allowed to grow to a size where they have had two breeding seasons through the use of appropriate size-limits. There is no scientific basis to this objective, but it is the experience of managers of the fishery that areas containing populations where the gap between the median size at maturity and the legal size-limit is equivalent to two or more years growth have less fluctuations in abundance following periods of intensive fishing. Although uncommon, the two year rule (or similar versions) are or were used in other fisheries throughout the world (Ino, 1966; Tegner, 1989; Gendron, 1992).

This two year rule is variously interpreted to be either a crude means of maintaining egg production, or ensuring that there are sufficient emergent abalone on the reef to maintain suitable coralline substrate for settling larvae (McShane, 1991). Some Tasmanian divers take the second alternative further, and are convinced of the need for some minimum quantity of emergent abalone to actively maintain and regulate the development of settling organisms on the substrate. They point to reefs that have gone out of production following high levels of fishing mortality, where the coralline base has been replaced by sponges and other sessile or encrusting organisms atypical of abalone habitat.

If this measure was adopted, the performance indicator would be derived from both growth rates and median size-at-maturity from a number of sites within a region. Where the performance indicator showed a deficiency, the response would be to increase the size-limit.

7.1.3 Size composition of abalone populations

The third performance indicator, size composition, is appropriate for the Tasmanian fishery. The size-structure of abalone populations in Tasmania can have a profound effect upon catch-rates. Knowledge about size-composition of populations is also useful when assessing catch limits for regions. If catch-limits are set when size-compositions indicate that most of the catch is based upon abalone that have recruited for two or more years, and those year-classes subsequently decline, then greater numbers of smaller abalone will be taken to meet that catch-limit.

In 2000, the spatial scale on which catches were reported was increased with the introduction of sub-blocks. Each block was divided into about four sub-blocks. One of the consequences of this is that abalone from within a sub-block are more likely to share similar biological parameters, such as rates of growth and fishing mortality and therefore be of similar size, than they were when the scale at which catches were reported was much larger. It makes comparison of size-composition data from within a sub-block collected over a number of years meaningful, whereas the same data collected on a broader spatial scale cannot be reasonably interpreted. For this reason, the size-composition series compiled by block that was a feature of previous assessments has been discontinued.

From 1998, divers participating in the photographic catch-sampling program wrote down the name of the location where they fished, which was subsequently converted to sub-block during compilation of size-composition data. There are two important consequences of this. Firstly, in some of the more heavily fished areas we have size-composition data extending back to 1998, which in the case of sub-block 13E gave us information of immense value about the decline in size of fished abalone populations and its relationship with changes in catch-rate.

Secondly, the conversion of these locations to sub-block highlighted a problem which we had long suspected, but for which we had little proof. In 2000, divers returned photographs of their catches with location and sub-block. We found that some of these locations were in a near-by sub-block, and in a few cases, a near-by block, which meant that some divers had an inadequate knowledge of block and sub-block boundaries. It is fundamental to all aspects of this assessment that divers accurately report the location of their catch. DPIWE has recently prepared better maps of boundaries for divers, which we anticipate will reduce misreporting.

While the current catch-sampling program appears to be operating successfully, it needs reviewing. The following issues need to be considered:

- What are the optimum number of diver-days to sample, and are our resources adequate? Currently we are operating on the assumption that more (diver-days) is better, based on work by Andrew and Chen (1997), who found that for a given number of diver days, there was an optimal level of sampling, and that information from many diver days with small samples was better than a few diver days with large samples. A similar study is required in Tasmania.

- What blocks do we need the greatest level of information from, and how do we satisfy that need? Targeting areas for collection of data is very difficult. Our catch-samplers phone the factories the afternoon prior to visiting them, to make sure that they will have abalone on the premises. At that stage, the factories do not know where the abalone were caught, and often, who caught them. The office staff usually leave before the factories receive the abalone and catch dockets. Given a choice between several factories simultaneously processing catch, the catch-sampler inevitably chooses the one with the most catches, and may miss information from critical areas, perhaps over-sampling other areas.

- How do we get information from the west coast? Again, targeting of catches from this area has proven difficult. Most of the catch landed in southern Tasmania, where most catch-sampling takes place, comes from motherships. The catches are taken over multiple days, and more importantly, over multiple sub-blocks. Perhaps the solution is to work in conjunction with divers and ask them to label crates of abalone by sub-block, or to put TAFI staff on motherships.

- How do we deal with on-board sorting of catch? This problem has emerged recently, and occurs when divers sort smaller abalone from their catch, for sale to live-market buyers who pay premium prices for small abalone. The remainder of the catch goes to canners or other buyers. Sampling from either part of the catch obscures real trends in catch-composition. This problem occurs mostly with west coast product, but we have been told that divers are grading catches from other areas when buyers offer a better price for a specific product. As the share of the live market increases, we expect this problem to become more common.

An associated problem occurs when divers fish to market preferences. On the south coast divers providing catch for one particular buyer (who provides quota) leave abalone over a certain size on the bottom. In the greenlip fishery, where the premium product is larger abalone, some divers leave all abalone under 150 mm. We should avoid sampling these diver's catches, or consider data from these catches separately.

7.2 Review of fishery performance by zone.

7.2.1 Eastern Zone

In 2001, the Eastern Zone comprised the regions between Whale Head in the south and the Musselroe River in the north, covering part of Block 13, Blocks 14 to 30 and part of Block 31.

In the face of strong concern by divers that abalone abundance was declining, managers reduced the Eastern Zone TAC from 1190 tonnes to 1120 tonnes in 2001. Catch-rate trends fluctuated, and in the absence of informative size-composition data from the area, gave no indication of falls in abundance of the magnitude suggested by divers. Comparison of catch and catch-rate with reference periods indicated that stock levels were healthy.

A mid-year review of East Coast (Blocks 22 to 29) stock levels by TAFI researchers showed that in all but remote areas, legal-size abalone were extensively depleted (Tarbath *et al.*, 2001a). The fishery was dependent mostly upon recruits, lowering its potential yield and increasing the level of risk. Generally, levels of pre-recruits appeared sufficient to sustain future fishing, but perhaps at lower catch-rates. In some areas however, particularly the southern part of the east coast of Maria Island, and the coast between Bicheno and Wineglass Bay, levels of juveniles and pre-recruits were particularly low, and probably unable to sustain present levels of fishing. Note that catch-samples from sub-blocks 24D and 24E show size composition consistent with poor levels of recruitment in the last quarter of 2001 (Appendix 6).

The review concluded that the median size at sexual maturity and growth rates of abalone here were greater than provided for by the size-limit under the two year rule, and as such, stocks could only receive sufficient protection if the size-limit was increased. An increase to 138 mm would provide sufficient protection for most of the East Coast fishery between Long Point and Tasman Island. The size-limit was subsequently increased to 136 mm for 2002, and provision made for another 2-mm increase in 2003.

In the last quarter of the year, following the East Coast size-limit assessment, catch-rates in most parts of the zone dropped substantially. Block 13 was closed, shifting effort into less productive parts of the fishery. Divers were reduced to fishing new recruits, and in much of the fishery, catch-rates averaged less than 40 kg/hr, which is lower than seen for many years. Managers responded by reducing the 2002 TAC by approximately 270 tonnes to 857.5 tonnes.

A few areas continued to perform at satisfactory levels. Block 31 provided good catches. However, size-composition information, although sketchy and under-sampled, shows that the size-composition from catches late last year had few large abalone, indicating that the stock build up that was responsible for its stellar performance over the last couple of years has been reduced, that this block has been fished at rates that are unsustainable, and catch and catch-rates will fall if this level of fishing effort is maintained.

Following the closure of Block 13, divers moved to Blocks 14 (lower Channel and South Bruny) and 16 (Eastern Bruny), where some good catches were taken at the Friars and southern and eastern Bruny shores. Catch-rates were better than most parts of the zone, and the size-structure of catch-samples show good quantities of large abalone suggesting a relatively unstressed stock. However, most of the catch came from deeper water, and this combined with the area's relative exposure to weather potentially limits the amount of catch that can be taken here.

In the absence of a fish population model, we are unable to conclude that the reduction in TAC matches the stock decline, and is adequate to protect stocks. We suggest that the increased size-limit in 2002 will initially suppress catch-rates, but by mid-year when most of the 132-mm recruits have reached the new size-limit, catch-rates will significantly improve. The size-limit increase will improve protection to stocks in terms of the two year rule, and provided that natural mortality does not negate the increase in weight, will also cause divers to catch bigger abalone and reduce the number of abalone needed to provide the same yield.

In the past, we have examined historical catches, and made estimates of what we thought was sustainable by choosing levels between the extreme catches of the early 1980's and the lows of the early to mid 1990's. If, as we believe, areas of reef are becoming unproductive on the East Coast, then this is a poor strategy. Even levels of fishing that are conservative compared with 1990's catches may be too high for the current area of productive abalone reef in this fishery.

The concept of abalone reef becoming unproductive is mostly supported by anecdotal evidence, and explains the dramatic drop in productivity of the fishery on the northern part of the East Coast. A recent application for funding to the Fisheries Research and Development Corporation to support an abalone habitat mapping project was unsuccessful. In spite of this, we need to keep track of this resource, and be aware of changes. We need to review the issue, and explore avenues for future funding for the project. The absence of quantitative scientific data should not be used as a reason to prevent precautionary management options being adopted.

7.2.2 Northern Zone

The Northern Zone operated between the Arthur River in the west, and the Musselroe River in the east, with a TAC of 280 tonnes. The size-limit between Woolnorth Point and the Musselroe River was set at 127 mm, elsewhere 132 mm applied. In the first year of operation, this fishery has performed well. The reduced size-limit in the region has given divers the opportunity to fish blacklip stocks which have built up to high levels following years of fishing inactivity.

The distribution of the catch across the Northern Zone however, provides cause for concern. In particular, over 70 percent of the catch was taken from Blocks 5 and 49, which is greater than the historical average from this area. Conversely, only 27 tonnes was taken from King Island, from which we estimated that 90 tonnes would be an appropriate level of catch. The catches from the Furneaux Group and the North East were at the level of historical average catches. Managers may need to consider localised closures as has been done in the greenlip fishery, to direct blacklip effort to King Island.

For at least part of 2001, live-market buyers paid a higher price for abalone landed at Bluff Hill Point (Block 5) rather than Woolnorth (Blocks 49, 48 and northern part of Block 5). In addition, the owners of the property at Woolnorth through which the road passes charge $100 access fees to divers and processors trucks. This means that effort is unequally directed to the southern part of Block 5.

Unlike greenlip stocks, King Island blacklip stocks are plentiful, having been fished at negligible levels for many years. The establishment of a receiving depot at Currie has made it easier for divers to operate on the island, but transport costs of fish are still higher than in mainland Tasmania, and act as a disincentive for divers to work there. If catches cannot be pushed to King Island successfully, it may be necessary to reduce the Northern Zone TAC appropriately.

7.2.3 Western Zone

In 2001, all the major western zone blocks recorded catch-rate falls. We believe that the catch-rate fall is an indication that abalone populations that have built up following years of relatively low catches are now declining. The slow decline of average catch-rates over the last couple of years is masked by the unequal distribution of catch-rates, where the average catch-rate is skewed upwards by a few very high catch-rates. Lower catch-rates are now more common.

We have insufficient data to show that the size-composition of catch samples from the Western Zone is stable. The size-composition data that we do have indicates that abalone are still large with modal size-classes typically between 150 and 170 mm. By the standards of abalone populations, abalone stocks on the West Coast are patchily distributed. Furthermore, shallow water stocks occupy an often turbulent environment, with attendant high rates of natural mortality (Shepherd and Breen, 1992). Historically, stocks here appear to be prone to fluctuations in abundance. Any fall in modal size of size-composition of catch samples coupled with catch-rate declines will indicate significant stock depletion.

The remote blocks (Blocks 10 and 11) supported good catches, and divers who fish the area regard stock levels as stable. We have been unable to collect size-composition data from Block 10, and have data from only a few samples from Block 11. These samples although inadequate, are consistent with a stable catch size-structure.

Catch-rates in the more accessible blocks (Block 9 and Block 12) have now fallen for three successive years. Catch-rates are frequently close to 100 kg/hr, with occasionally much greater catch-rates as divers sporadically encounter unfished patches, lifting the average and masking the magnitude of the decline. Size-structure of sub-block 12D catch shows reduction in modal size, but this may be due to divers targeting smaller abalone from Cox's Bight. Stocks appear to be depleted in Block 9 and 12.

Further north, effort has shifted away from the two blocks fished from Granville Harbour (Blocks 7 and 8) because some divers who fished there now operate in the North West, where they have ready access to the Northern Zone. Additionally, many processors pay more for Western Zone catch taken at the 132-mm size-limit that applies in part of Block 6. This has placed increased pressure on Block 6. Experienced divers who frequently work here report that their catch-rates fell last year. Divers are now fishing deeper reefs or more remote parts of the block. Catch-rates indicate that stocks are being steadily depleted in Block 6.

7.2.4 Greenlip Fishery

The greenlip fishery continues to operate at satisfactory levels. The TAC in 2001 was 140 tonnes, and has been below 150 tonnes for three successive years. The more accessible areas received the most attention, and meant that closures were necessary to protect existing stocks and divert effort to more remote areas.

In the Furneaux Group, most of the 42 tonne local TAC was taken from the southern blocks, and very little was taken elsewhere. The catch from Franklin Sound, at under 9 tonnes and well below the 20 tonne limit was low because divers chose to fish in Blocks 33 and 32, where greenlip catch-rates were satisfactory and they could take Northern Zone blacklip as well. The southern blocks are accessible by runabout from mainland Tasmania, and it will be interesting to see if they can provide the same level of catch in 2002.

In the North East, managers imposed a 30 tonne catch limit to maintain viability of local stocks. It was reached in early October, and this part of the fishery closed. Most of the catch came from Block 39, and a lot of this from reefs that recover slowly. This region may not support the same level of catch in 2002.

In the North West, greenlip stocks fished satisfactorily, notwithstanding concerns by local divers during the previous year, who believed that the influx of divers from other parts of the state would impact adversely upon the region. Black Reef and adjacent reefs provided some surprisingly large catches, and some good catches were landed at Woolnorth in conjunction with Northern blacklip catches. Catch levels for the region were set at 40 tonnes, but eventually 47 tonnes was taken. Smithton is a convenient town from which divers can operate. It has ready access to both Western and Northern Zone abalone as well as the greenlip fishery, and divers can work through a range of weather conditions. In 2002, the size-limit is to be raised from 140 to 145 mm, and the 40 tonne local TAC re-applied. It has been reported by several local divers that there are currently unusually large quantities of juvenile greenlip in parts of the region.

King Island was allocated the remainder of the greenlip TAC, and just under 19 tonnes was landed. Catches and catch rates were lower than the other regions, and many divers believed that the 155-mm size-limit prevented economical fishing in otherwise productive areas. The size-limit in 2002 has been lowered by 5 mm, and this may help catch-rates and spread the catch away from the few areas supporting high growth rates, as well as meeting the management objective relating to breeding.

7.3 Implications For Management

There are two important features of this assessment. The first concerns the status of stocks in the Eastern Zone. There has been a substantial decline in abalone stocks on the East Coast and in the South East. The second feature is that Western Zone stocks show signs of depletion, and require protection in the short term.

In the Eastern Zone, catch-rates continue to fall throughout the fishery. The fishery is now mostly dependent upon abalone that have grown through the size-limit within the previous year, although in some areas, these are absent from the catch, consistent with low levels of larval settlement in the mid 1990’s. Larger abalone that have grown two or three years since reaching legal size are either absent from catches, or present only in low numbers. All of this indicates that fishing mortality is too high. If these trends continue in 2002, further quota cuts and possible size increases will be required.

Areas of reef that formerly produced substantial quantities of abalone are no longer productive (e.g. Blocks 28, 29 and 30). These reefs have failed to recover while divers have persistently removed any stock build up, and will not recover at current levels of effort. They may recover if closed to the fishery for a number of years.

We are unable to tell whether the reduction in TAC is appropriate for the current level of stocks in the Eastern Zone and whether stock levels will now stabilise.

In the Western Zone, continued catch-rate declines particularly in the blocks accessible to trailer-borne craft indicate that abundance has fallen. Catch-rates are not particularly reliable indicators of abundance here. Abundance is probably falling at a rate faster than indicated by catch-rates. We have insufficient catch-sampling data to judge whether size-composition is stable. Catch-rates in Blocks 6, 9 and 12 have fallen considerably over recent years, and these blocks require management intervention to divert effort to more remote areas.

The Northern Zone fishery is operating successfully, although effort is unequally distributed. Too much catch is taken from the North West and too little from King Island. Market forces are directing effort to the North West, so some intervention is necessary to protect this area and redistribute or reduce effort.

Apart from King Island, greenlip catch-rates appear to have stabilised or improved, and the problem at King Island may be associated more with the high size-limit there rather than depletion. The distribution of catch was managed successfully in 2001.

The impact of recreational divers, whilst still relatively minor, is mostly directed to parts of the East and South East where depletion by commercial divers is greatest. Managers need to consider what levels of recreational catch are appropriate, and by what means the recreational fishery should be monitored.

7.4 Recommendations For Future Assessments

- Use ten-year trends in standardised catch-rate as an index of abundance, and place less importance on comparison of catch-rates with reference periods.
- Review current years catch-rates at 1 August, with a similar period for past ten years. This assessment may confirm trends in depletion, and will provide more current information for allocation of TAC in 2003.
- Construct a population model of the Tasmanian abalone fishery. This model will use size-composition data and commercial catch data to predict changes in level of productivity in the fishery. This work has received FRDC funding and is currently in progress.
- Review catch-sampling program, with aim to maximising information for the level of resourcing.
- Establish a research program to map current abalone producing reefs. This will provide a snapshot of the fishery, against which future distribution of reefs may be compared.
- Investigate a means of improving the spatial resolution of catch data, with a view to establishing a historical database of catch by reef. This is the type of information required to examine change in productivity of reefs. Additional benefits include confirming that divers are accurately reporting correct sub-block, as well as an indication of the number of reefs swum over in a day to locate fishable quantities of abalone – another measure of effort.

—Review composition of the Abalone Fishery Assessment Working Group. Include a representative from the recreational fishery, as well as the area representatives from the Tasmanian Abalone Council divers' sub-council.

References

Andrew, N. L. and Chen, Y. (1997). Optimal sampling for estimating the size structure and mean size of abalone caught in a New South Wales fishery. *Fisheries Bulletin* **95**, 403-413.

Anonymous. (1997). Draft Abalone Management Plan and Policy Document. Department of Primary Industries and Fisheries, Hobart, Tasmania.

Anonymous. (1998). Review of the Tasmanian Abalone Fishery Management Plan: The greenlip abalone fishery around the Furneaux Group and the rest of Tasmania, and some minor clarifications. Hobart: Department of Primary Industries and Fisheries.

Anonymous. (1999). Review of the management plan of the Tasmanian abalone fishery. Department ofPrimary Industries, Water and Employment, Hobart.

Anonymous. (2000). The Tasmanian abalone fishery revised policy paper. Department of Primary Industries, Water and Environment, Tasmania, Hobart.

Babcock, R. C. and Keesing, J. K. (1999). Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. *Canadian Journal of Fisheries and Aquatic Sciences* **56**, 1668-1678.

Barrett, N. (1989). Population genetics of the blacklip abalone, *Haliotis rubra*. In *Zoology Department*. Hobart: University of Tasmania.

Breen, P. A. (1992). A review of models used for stock assessment in abalone fisheries. In *Abalone of the world: biology, fisheries and culture*, (eds S. A. Shepherd , M. J. Tegner and S. A. Guzmán del Próo), pp. 253-275. Oxford: Blackwell.

Brown, L. D. (1991). Genetic variation and population structure in the blacklip abalone, *Haliotis rubra*. *Australian Journal of Marine and Freshwater Research* **42**, 77-90.

Elliott, N. G., Bartlett, J., Evans, B., Haddon, M. and Officer, R. A. (2002). Application of Molecular Genetics to the Australian Abalone Fisheries: Forensic Protocols for Species Identification and Blacklip Stock Structure. no. 1999/164, Fisheries Research and Devlopment Corporation, Hobart.

Fleming, A. E. (1995a). Digestive efficiency of the Australian abalone *Haliotis rubra* in relation to growth and feed preference. *Aquaculture* **134**, 279-293.

Fleming, A. E. (1995b). Growth, intake, feed conversion efficiency and chemosensory preference of the Australian abalone *Haliotis rubra*. *Aquaculture* **132**, 297-311.

Foale, S. and Day, R. W. (1992). Recognizability of algae ingested by abalone. *Australian Journal of Marine and Freshwater Research* **43**, 1331-1338.

Gendron, L. (1992). Determination of the size at sexual maturity of the waved whelk *Buccinum undatum* Linnaeus, 1758, in the Gulf of St. Lawrence, as a basis for the establishment of a minimum catchable size. *Journal of Shellfish Research* **11**, 1-7.

Gorfine, H. K., Hart, A. M. and Callan, M. P. (1996). Evaluation of methods to assess abalone abundance. Fisheries Research and Development Corporation no. FRDC Grant 93/100, Victorian Fisheries Research Institute, Melbourne.

Harrison, A. J. (1983). The Tasmanian abalone fishery. *Tasmanian Fisheries Research* **26**, 1-42.

Hart, A. M. and Gorfine, H. K. (1997). Abundance estimation of blacklip abalone (*Haliotis rubra*) II. A comparative evaluation of catch-effort, change-in-ratio, mark-recapture and diver-survey methods. *Fisheries Research* **29**, 171-183.

Hart, A. M., Gorfine, H. K. and Callan, M. P. (1997). Abundance estimation of blacklip abalone (*Haliotis rubra*) I. An analysis of diver-survey methods for large-scale monitoring. *Fisheries Research* **29**, 159-183.

Ino, T. (1966). Abalone science and its propagation in Japan. *Fish. Res. Bd. Canada Tranl. Serv and Trans. No.* **1078**, 209.

James, E. (1981). Clinal variation in the maximum size of Tasmanian populations of the abalone, *Haliotis ruber* as a function of water temperature, pp. 20. Hobart, Australia: University of Tasmania.

Koslow, J. A. (1992). Fecundity and the stock-recruitment relationship. *Canadian Journal of Fisheries and Aquatic Sciences* **49**, 210-217.

Lyle, J. M. (2000). Assessment of the licensed recreational fishery of Tasmania (phase 2). FRDC Final Report no. FRDC Project No. 1996/161, Tasmanain Aquaculture and Fisheries Institute, Hobart.

Manahan, D. T. and Jaeckle, W. B. (1997). Implications of dissolved organic material in seawater for the energetics of abalone larvae *Haliotis rufescens*: a review. In *Abalone of the world: biology, fisheries and culture*, (eds S. A. Shepherd , M. J. Tegner and S. A. Guzmán del Próo), pp. 95-106. Oxford: Blackwell.

McShane, P. E. (1991). Density-dependent mortality of recruits of the abalone *Haliotis rubra* (Mollusca: Gastropoda). *Marine Biology* **110**, 385-389.

McShane, P. E. (1995). Recruitment variation in abalone: its importance to fisheries management. *Marine and Freshwater Research* **46**, 555-570.

McShane, P. E. (1996). Recruitment processes in abalone (*Haliotis* spp.). In *Proceedings of an International Workshop on Survival Strategies in Early Life Stages of Marine Resources*, pp. 315-324. Yokohama, Japan.

McShane, P. E. and Smith, M. G. (1989). Direct measurement of fishing mortality in abalone (*Haliotis rubra* Leach) off Southeastern Australia. *Fisheries Research* **8**, 93-102.

Morse, D. E., Hooker, N., Jensen, L. and Duncan, H. (1979). Induction of larval abalone settlement and metamorphosis by gamma-aminobutyric acid and its congener from crustose red algae II: Applications to cultivation, seed-production and bioassays and principal causes of mortality and interference. *Proc. World Maricult. Soc.* **10**, 81-91.

Nash, W. J. (1990). Abalone mature with age not size. *Fishing Today* **3**, 38-39.

Nash, W. J. (1992). An evaluation of egg-per-recruit analysis as a means of assessing size limits for blacklip abalone (*Haliotis rubra*) in Tasmania. In *Abalone of the world: biology, fisheries and culture*, (eds S. A. Shepherd , M. J. Tegner and S. A. Guzmán del Próo), pp. 318-340. Oxford: Blackwell.

Nash, W. J. (1994a). Fishery status report: Abalone. Internal Report no. 17, Tasmanian Sea Fisheries Division, Hobart.

Nash, W. J. (1994b). Growth and ageing of blacklip abalone (*Haliotis rubra*) in southern Tasmania (Abstract only). In *Second International Symposium on Abalone Biology, Fisheries and Aquaculture*. Hobart, Tasmania.

Nash, W. J. (1995). The development of new techniques for assessing and managing the Australian abalone fisheries. Final Report to the Fisheries Research and Development Corporation no. FRDC Grant 88/94, Department of Primary Industry and Fisheries, Tasmania, Hobart.

Nash, W. J. (1996). Stock Assessment Report: Abalone. Department of Primary Industry and Fisheries, Hobart, Tasmania.

Nash, W. J., Sellers, T. L., Talbot, S. R., Cawthorn, A. J. and Ford, W. B. (1994). The population biology of abalone (*Haliotis* species) in Tasmania. 1. Blacklip abalone (*H. rubra*) from the North Coast and the islands of Bass Strait. Technical Report no. 48, Department of Primary Industry and Fisheries, Tasmania, Hobart.

Officer, R. A. (1997). Update to the 1996 abalone stock assessment report. Internal Report no. 37, Department of Primary Industry and Fisheries, Marine Research Laboratories, Hobart.

Officer, R. A. (1999a). Size limits for greenlip abalone in Tasmania. Technical Report no. 5, Tasmanian Aquaculture and Fisheries Institute, Hobart.

Officer, R. A. (1999b). Tasmanian Abalone Fishery 1997/1998. Fishery Assessment Report Tasmanian Aquaculture and Fisheries Institute, Hobart.

Officer, R. A. and Tarbath, D. B. (2000). Fishery Assesment Report: Tasmanian Abalone Fishery 1999. Tasmanian Aquaculture and Fisheries Institute, Hobart.

Prince, J. D. (1987). World abalone fisheries offer a grim warning to Tasmanians. *FINTAS* **10**, 59-66.

Prince, J. D. (1989). The fisheries biology of Tasmanian stocks of *Haliotis rubra*. In *Department of Zoology*. Hobart: University of Tasmania.

Prince, J. D., Sellers, T. L., Ford, W. B. and Talbot, S. R. (1987). Experimental evidence for limited dispersal of *Haliotid* larvae (genus *Haliotis*: Mollusca: Gastropoda). *Journal of Experimental Marine Biology and Ecology* **106**, 243-263.

Prince, J. D., Sellers, T. L., Ford, W. B. and Talbot, S. R. (1988a). Confirmation of a relationship between the localized abundance of breeding stock and recruitment for *Haliotis rubra* Leach (Mollusca: Gastropoda). *Journal of Experimental Marine Biology and Ecology* **122**, 91-104.

Prince, J. D., Sellers, T. L., Ford, W. B. and Talbot, S. R. (1988b). A method for ageing the abalone *Haliotis rubra* (Mollusca: Gastropoda). *Australian Journal of Marine and Freshwater Research* **39**, 167-175.

Prince, J. D. and Shepherd, S. A. (1992). Australian abalone fisheries and their management. In *Abalone of the world: biology, fisheries and culture*, (eds S. A. Shepherd , M. J. Tegner and S. A. Guzmán del Próo). Oxford: Blackwell.

Rodda, K. R., Keesing, J. K. and Foureur, B. L. (1997). Variability in larval settlement of abalone on artificial collectors. *Molluscan Research* **18**, 253-264.

Sasaki, R. and Shepherd, S. A. (1995). Larval dispersal and recruitment of *Haliotis discus hannai* and *Tegula* spp. on Miyagi Coasts, Japan. *Marine and Freshwater Research* **46**, 519-29.

Seki, T. and Kan-no, H. (1981). Induced settlement of the Japanese abalone, *Haliotis discus hannai*, veliger by the mucous trails of the juvenile and adult abalones. *Bulletin of the Tohoku Regional Fisheries Research Laboratory* **43**, 29-36.

Shepherd, S. A. (1973). Studies on southern Australian abalone (genus *Haliotis*) I. Ecology of five sympatric species. *Australian Journal of Marine and Freshwater Research* **24**, 217-257.

Shepherd, S. A. (1986). Studies on southern Australian abalone (genus *Haliotis*) VII. Aggregative behaviour of *H. laevigata* in relation to spawning. *Marine Biology* **90**, 231-236.

Shepherd, S. A. and Baker, J. L. (1998). Biological reference points in an abalone (*Haliotis laevigata*) fishery. In *Canadian Special Publication in Fisheries and Aquatic Sciences*, vol. 125 (eds G. S. Jamieson and A. Campbell), pp. 235-245: Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management: Nanaimo, Canada.

Shepherd, S. A., Baker, J. L. and Johnson, D. W. (1995). Yield-per-recruit and egg-per-recruit analyses of the Omani abalone, *Haliotis mariae*. *Marine and Freshwater Research* **46**, 663-668.

Shepherd, S. A. and Breen, P. A. (1992). Mortality in abalone: Its estimation, variability and causes. In *Abalone of the world: biology, fisheries and culture*, (eds S. A. Shepherd , M. J. Tegner and S. A. Guzmán del Próo), pp. 276-304. Oxford: Blackwell.

Shepherd, S. A., Godoy, C. and Clarke, S. M. (1992). Studies on southern Australian abalone (genus *Haliotis*) XV. Fecundity of *H. laevigata*. *Journal of the Malacological Society of Australia* **13**, 115-121.

Shepherd, S. A., Guzmán del Próo, S. A., Turrubiates-Morales, J. R., Belmar, J., Baker, J. L. and Sluczanowski, P. R. (1991). Growth, size at sexual maturity, and egg-per-recruit analysis of the abalone *Haliotis fulgens* in Baja California. *Veliger* **34**, 324-330.

Shepherd, S. A., Lowe, D. and Partington, D. (1992). Studies on southern Australian abalone (genus *Haliotis*) XIII. Larval dispersal and recruitment. *Journal of Experimental Marine Biology and Ecology* **164**, 247-260.

Sloan, N. A. and Breen, P. A. (1988). Northern abalone, *Haliotis kamtschatkana* in British Columbia: Fisheries and synopsis of life history information. *Canadian Special Publication in Fisheries and Aquatic Sciences* **103**, 46 pp.

Tarbath, D. B. (1999). Estimates of growth and natural mortality of the Blacklip Abalone (*Haliotis rubra*) in Tasmania. Technical Report no. 3, Tasmanian Aquaculture and Fisheries Institute, Hobart.

Tarbath, D. B., Haddon, M. and Mundy, C. (2001a). East Coast Abalone Assessment: 2001. Internal Report Tasmanian Aquaculture and Fisheries Institute, Hobart.

Tarbath, D. B., Hodgson, K., Karlov, T. and Haddon, M. (2001b). Fishery assessment report: Tasmanian abalone fishery 2000. Marine Research Laboratories, Tasmanian Aquaculture and Fisheries Institute,

Tarbath, D. B. and Officer, R. A. (2001). Size-limits and Yield for Blacklip Abalone in Northern Tasmania. no. In Press, Tasmanian Aquaculture and Fisheries Institute, Hobart.

Tegner, M. J. (1989). The California abalone fishery: Production, ecological interactions, and prospects for the future.

Witherspoon, N. B. (1975). Sizes in the Tasmanian commercial catch of blacklip abalone (*Haliotis ruber*): Possible effects of changing habitat during growth. *Tasmanian Fisheries Research* **9**, 15-22.

Worthington, D. G. and Andrew, N. L. (1998). Improved indices of a catch rate in the fishery for blacklip abalone, *Haliotis rubra*, in New South Wales, Australia. *Fisheries Research* **36**, 87-97.

Worthington, D. G., Andrew, N. L. and Hamer, G. (1995). Covariation between growth and morphology suggests alternative size limits for the abalone, *Haliotis rubra*, in NSW, Australia. *Fishery Bulletin U.S.* **93**, 551-561.

Appendix 1: Annual Catches From The Western Zone 1975 - 2001.

Annual tonnages of blacklip abalone caught within the statistical blocks comprising the Western Zone in 2001. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights. The catch from part of Block 13 west of Whale Head is included in the Eastern Zone. In 2001, the Western Zone component of the Block 13 catch was approximately 43 tonnes, the recent two year average being 12% of the Block 13 catch.

Block	6	7	8	9	10	11	12	Total
1975	111	36	42	126	130	191	143	779
1976	64	56	77	255	179	240	154	1025
1977	53	24	23	123	98	153	189	663
1978	81	13	27	115	258	277	209	980
1979	115	19	23	172	166	269	325	1089
1980	197	81	63	316	195	338	351	1541
1981	264	89	87	444	260	417	246	1807
1982	147	34	34	249	100	303	235	1102
1983	231	102	58	199	175	431	242	1438
1984	309	78	40	248	284	682	258	1899
1985	327	99	23	246	140	479	155	1469
1986	213	97	11	134	127	289	194	1065
1987	185	84	44	251	82	339	195	1180
1988	244	53	27	160	126	276	162	1048
1989	193	49	46	120	110	212	145	875
1990	197	56	21	95	80	235	125	809
1991	169	54	30	102	106	219	140	820
1992	266	69	40	100	102	269	159	1005
1993	160	66	38	110	66	197	177	814
1994	82	37	38	78	60	200	160	655
1995	123	32	17	44	68	185	182	651
1996	113	68	13	59	81	145	148	627
1997	98	75	28	140	66	224	227	858
1998	129	51	27	78	44	165	202	696
1999	131	51	18	107	42	192	229	770
2000	183	61	23	205	148	333	286	1237
2001	212	32	15	185	152	311	290	1198
Average	170	58	35	165	128	280	205	1041

Appendix 2: Annual Catches From The Eastern Zone 1975 - 2001.

Annual tonnages of blacklip abalone caught within statistical blocks comprising the Eastern Zone in 2001. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights. The Eastern Zone includes catch from Block 13, part of which is in the Western Zone, and from Block 31, part of which is in the Northern Zone. In 2001, the Western Zone component of the Block 13 catch was approximately 43 tonnes and the Northern Zone component of the Block 31 catch was 11 tonnes.

Block	13	14	15	16	17	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
1975	247	111	10	48	12	0	16	27	49	74	15	16	5	44	69	16	45	39	843
1976	208	156	0	64	36	1	18	25	45	56	18	12	9	40	72	9	39	63	871
1977	245	232	2	190	13	1	23	35	37	53	11	10	9	55	90	22	122	60	1210
1978	322	218	6	120	24	1	32	65	60	88	22	13	11	93	87	25	137	113	1437
1979	374	251	8	148	25	2	51	52	43	30	10	23	7	80	52	12	107	71	1346
1980	272	255	7	145	30	1	33	30	42	46	158	34	7	108	91	27	148	109	1543
1981	254	299	18	127	48	4	45	69	35	77	137	19	15	68	154	22	146	58	1595
1982	337	218	15	147	24	3	36	62	63	49	97	21	9	89	100	32	171	75	1548
1983	255	300	10	189	28	3	43	63	55	92	99	31	14	100	105	66	298	113	1864
1984	318	297	18	166	35	5	47	70	73	61	109	10	11	106	112	53	149	126	1766
1985	256	262	4	89	83	11	69	80	43	44	120	20	17	86	71	5	91	225	1576
1986	221	262	22	82	93	4	65	67	70	56	88	13	20	50	58	14	126	203	1514
1987	225	229	7	47	80	1	43	44	32	34	66	12	8	77	45	11	68	86	1115
1988	219	258	6	76	57	4	62	44	43	34	79	10	6	65	52	16	96	132	1259
1989	156	172	2	56	43	2	61	42	22	16	34	7	8	41	31	11	41	49	794
1990	133	193	4	76	29	3	33	51	41	36	61	1	2	61	77	21	54	44	920
1991	127	207	2	60	37	3	53	50	47	31	67	2	9	64	66	12	30	42	909
1992	159	122	4	49	28	3	56	49	56	12	76	1	1	71	56	7	10	29	789
1993	271	121	4	107	47	1	67	79	49	24	75	1	1	87	39	8	15	24	1020
1994	300	148	10	118	65	2	122	85	62	17	57	0	3	104	24	8	11	34	1170
1995	313	256	2	106	35	4	108	78	41	21	43	0	1	81	19	6	11	50	1175
1996	392	195	0	80	18	3	74	55	44	29	69	3	6	90	39	11	28	31	1167
1997	470	137	0	64	25	2	79	49	47	32	106	1	13	190	32	32	23	50	1352
1998	483	109	1	116	23	2	85	64	63	44	160	2	25	182	77	31	10	19	1496
1999	474	66	1	106	34	6	97	61	47	53	139	0	9	94	60	24	10	43	1324
2000	436	98	2	71	29	4	62	60	69	44	104	1	8	101	16	21	10	102	1237
2001	367	157	3	108	20	2	56	50	40	24	111	1	14	68	9	27	13	98	1167
Average	290	197	6	102	38	3	57	56	49	44	79	10	9	85	63	20	74	77	1260

Appendix 3: Annual Catches From The Greenlip Fishery 1975 - 2001.

Annual tonnages of greenlip abalone caught within the statistical blocks comprising the Greenlip fishery in 2001. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights.

Year	31	39	40	32	33	34	35	36	37	38	47	48	49	5	1	2	3	4	Total
1975	7	3	4	3	17	14	49	69	14	11	0	7	2	8	0	3	0	1	212
1976	14	2	9	1	26	11	55	49	2	10	0	8	6	14	0	0	0	0	207
1977	6	8	4	6	23	21	50	24	1	22	0	40	2	17	0	0	0	0	224
1978	8	1	2	4	12	17	51	38	7	17	1	13	3	12	1	3	0	2	192
1979	11	6	2	10	21	8	46	15	4	4	0	11	0	8	0	0	0	0	146
1980	4	3	5	7	15	3	29	13	4	4	0	6	0	5	0	3	0	0	101
1981	6	4	2	12	17	17	34	10	9	0	3	12	1	9	0	12	0	4	152
1982	27	1	3	4	13	14	29	7	9	9	2	7	0	2	0	14	0	2	143
1983	23	2	0	4	21	8	34	9	4	8	14	40	11	9	0	9	0	5	201
1984	50	8	4	9	27	15	56	7	6	0	52	60	2	11	0	7	1	5	320
1985	53	5	4	9	20	15	42	4	7	7	12	36	3	3	0	1	0	1	222
1986	39	8	7	4	14	7	36	2	10	0	57	35	14	5	1	8	0	3	250
1987	32	12	1	8	20	10	30	8	10	7	37	33	3	8	13	125	5	69	431
1988	35	2	1	8	23	5	28	13	6	0	35	28	5	10	3	33	2	12	249
1989	22	5	2	4	16	2	22	10	3	0	20	27	4	6	1	70	3	10	227
1990	23	7	0	4	9	3	25	6	1	3	21	27	11	11	2	49	3	13	218
1991	20	6	0	4	7	2	31	6	3	0	13	32	6	12	2	29	3	16	192
1992	16	10	0	5	4	2	24	7	2	0	4	14	2	4	3	18	1	8	124
1993	9	2	0	2	5	2	22	8	3	0	2	26	3	2	1	17	0	9	113
1994	12	2	0	6	8	1	22	5	5	0	3	48	3	10	4	25	0	7	161
1995	25	6	2	5	9	3	21	3	3	9	5	23	5	8	14	10	0	13	164
1996	11	13	2	4	14	4	20	2	8	12	1	15	0	3	36	33	1	12	191
1997	17	22	1	8	13	1	12	4	11	15	1	28	3	6	35	33	0	6	216
1998	4	17	25	5	6	1	23	1	2	2	2	43	8	14	33	34	0	5	225
1999	6	2	4	2	17	1	15	1	2	4	0	18	1	10	21	25	1	10	141
2000	12	15	12	8	11	2	14	3	2	2	0	24	12	13	2	4	1	3	140
2001	7	20	4	14	14	2	9	3	1	0	0	35	9	3	8	8	1	2	140
Average	18	7	4	6	15	7	31	12	5	5	11	26	4	8	7	21	1	8	196

Appendix 4: Annual Catches From The Northern Zone 1975 - 2001.

Annual tonnages of blacklip abalone caught within statistical blocks comprising the Northern Zone in 2001. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights. The Northern Zone includes catch from Block 31, most of which is in the Eastern Zone, and from Block 5, part of which is in the Western Zone. In 2001, the Northern Zone component of the Block 31 catch was 11 tonnes, and there was no recorded catch from the Western Zone component of Block 5.

Block	39	40	32	33	34	35	36	37	38	47	48	49	5	1	2	3	4	Total
1975	3	1	2	9	1	7	7	0	2	1	12	9	39	32	1	27	14	167
1976	5	0	0	6	0	1	1	0	1	1	12	33	46	39	1	51	8	205
1977	5	2	6	11	0	0	2	0	2	0	8	17	50	17	1	87	8	216
1978	8	2	1	5	2	6	5	1	4	3	10	11	65	21	3	56	25	228
1979	6	1	2	9	0	0	1	1	2	0	27	7	85	24	3	10	10	188
1980	3	1	2	6	1	1	2	0	0	0	10	1	92	51	3	33	3	209
1981	7	1	0	7	1	1	0	2	0	2	33	9	120	19	8	33	10	253
1982	5	1	0	5	0	0	2	0	5	1	45	7	121	23	9	27	13	264
1983	7	4	0	4	0	0	5	1	4	9	44	19	227	22	2	32	51	431
1984	5	3	0	7	1	1	2	1	1	4	81	45	311	11	1	34	55	563
1985	5	2	4	6	1	2	0	0	0	4	48	50	319	43	0	26	12	522
1986	10	5	1	9	2	4	3	1	1	15	86	97	267	35	4	24	13	577
1987	6	1	0	7	0	3	1	2	1	18	58	68	197	44	61	24	53	544
1988	2	2	1	11	1	1	1	0	0	18	36	41	168	29	17	22	60	410
1989	1	0	0	4	0	1	0	0	0	14	16	24	88	14	7	10	5	184
1990	0	0	0	1	0	0	0	0	0	6	14	20	82	11	10	9	12	165
1991	1	0	0	2	0	0	0	0	0	8	12	10	97	6	7	13	27	183
1992	3	0	0	2	0	0	0	0	0	2	10	11	76	4	6	14	10	138
1993	0	0	0	3	0	0	1	0	0	1	6	7	66	10	4	8	9	115
1994	0	0	0	3	0	0	0	0	1	0	6	11	49	9	2	4	1	86
1995	0	0	1	1	0	0	0	1	0	0	6	2	62	12	5	2	7	99
1996	0	0	0	0	0	0	0	0	0	0	4	0	63	7	2	1	2	79
1997	1	0	0	0	0	0	0	0	0	0	5	2	56	9	1	10	6	90
1998	0	1	0	2	0	0	0	0	0	0	6	3	61	2	1	1	2	79
1999	4	1	0	2	0	0	0	0	1	0	13	4	45	3	1	4	6	83
2000	5	2	1	5	0	0	0	0	0	0	12	26	45	0	0	10	10	117
2001	11	3	5	10	1	0	0	0	3	0	17	72	117	2	1	12	12	267
Average	4	1	1	5	0	1	1	0	1	4	24	22	112	19	6	22	16	239

Appendix 5: The Influence Of Effort Creep On The Interpretation Of CPUE Data.

This appendix was first published in the 2000 assessment.

Background

Effort creep is an increase in the effectiveness of a single unit of effort. In the abalone fishery, the introduction of the use of droplines, better wetsuits, dive computers, as well as GPS and plotters, may have lead to divers being more efficient underwater. One day of effort using such technology may be far more effective than one day without. An increase in the effectiveness of effort implies an increase in the proportion of the available stock that can be taken with one unit of effort, i.e. the catchability, *q*.

The Tasmanian abalone fishery is assessed using catch per unit effort (CPUE), as an indicator of biomass. CPUE and the biomass of the available stock are related by the classic equation CPUE = *q*B, where *q* is the catchability coefficient, and B is the available biomass. If the effectiveness of effort changes through time, then *q* is not constant and the interpretation of CPUE as an indicator of biomass is no longer possible. Any change in biomass detected by CPUE, will be confounded with changes in catchability. It is therefore vital to know how *q* has changed through time due to such advancements in technology. Effort creep, indeed any factors that influence catchability through time, must be considered in all stock assessments that use CPUE data as an index of biomass.

Harrison (1983) first quantified effort creep in the Tasmanian abalone fishery, estimating that the effectiveness of a single unit of effort had doubled from 1965 to 1980. While there have been significant technological advancements since 1980, e.g. the introduction of the use of dive computers, their influence is yet to be quantified. Until further work is done to quantify effort creep in the Tasmanian abalone fishery, we cannot know the true relationship between CPUE and available biomass. The only strategy available is to consider a range of plausible levels of effort creep and determine their influence on the interpretation of raw CPUE as an indicator of available biomass. This will at least provide information on the potential range of the effort creep effect.

Materials and Methods

Effort creep scenarios were applied to the relative CPUE data for Blocks 13 and 14 (South East Tasmania) between 1975 and 2000. It is usually assumed that CPUE = *q*B and *q* is constant. Thereby CPUE alone can be used as an index of biomass. Where it is known that *q* varies with time, in this instance due to effort creep, the state of the available biomass, B, is given by CPUE/*q*. The annual mean CPUE is divided by the cumulative proportion of effort creep plus one. For example, where 5% effort creep per annum is considered, the mean CPUE in 1976 is divided by 1.05, in 1977 it is divided by 1.10, in 1978 it is divided by 1.15, and so on.

Using the estimates of Harrison (1983) and estimates obtained for other fisheries (e.g. Buckworth, 1987; Haddon and Hodgson, 2001) as guidelines, six plausible scenarios were constructed; continuous annual effort creep between 1975 and 2001 of:

- 2%,
- 5%,
- 10%;

effort creep of 5% per annum between 1975 and 1981, consistent with estimates by Harrison (1983), and between 1981 and 2001:

- no further effort creep,
- 2% per annum,
- 10% per annum.

Results

Assuming even a small level of effort creep, 2% p.a., the effect on the relative CPUE trend was significant for both blocks (Figs. 1 and 5, Tables 1 and 2). According to the raw data, the relative CPUE, as an index of the biomass of the stock, is estimated in 2000 at more than 1.5 times that of 1975; this is assuming no change in catchability through time. When 2% p.a. effort creep is included, the current stock size is almost no different from that in 1975 (Figs. 1 and 5). Even if it is assumed there has been no effort creep since 1981, and the effort creep prior to this was a constant 5% p.a., (an approximation of Harrison's 1983 estimate), the difference between the 1975 and 2001 biomass estimates are reduced considerably (Tables 1 and 2, Figs. 2 and 6). When the most extreme case of effort creep, 10% p.a., is applied, the current status of the fishery appears far direr than ever predicted from the raw data. The 2000 relative CPUE, and hence biomass, is only half of that in 1975, for both blocks (Tables 1 and 2, Figs. 1 and 5).

These results need to be considered in context of the specifications of the draft management plan for of the fishery (Anonymous, 1997). The average catch rates for two reference periods, 1979-1982 and 1992-1995, are used as reference levels with which to compare the current index (Anonymous, 1997; Officer and Tarbath, 2001). The inclusion of effort creep causes a decline in catch rates over time, compared to the raw CPUE trends, but the average values for the reference periods also change. For both blocks, the current 2000 relative CPUE, falls below the average for both of the reference periods when the effort creep is greater than or equal to 5% p.a. for all years (Figs. 3c-d, Fig. 4d, Figs. 7c-d, Fig. 8). It is also interesting to note that in all these cases the mean CPUE for the reference period 1992-95 is lower than that for 1979-82, as the application of such an effort creep scenario flattens the trajectory or indeed shows a declining trend. This is in contrast to the raw mean CPUE data or effort creep scenarios of less than 5% for some or all years (Table 3).

Table 1. Annual mean CPUE for each effort creep scenario for Block 13

The Raw Mean is the geometric mean. The six effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; (iii) 10% per annum; (iv) 5% per annum until 1981 only; (v) 5% per annum until 1981, and then 2% per annum until 2000; (vi) 5% per annum until 1981, and then 10% per annum until 2000. All values of CPUE are relative to 1975.

	RELATIVE CPUE						
YEAR	**Raw Mean**	**2% p.a.**	**5% p.a.**	**10% p.a.**	**5%, 0**	**5%, 2%**	**5%, 10%**
1975	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.941	0.923	0.896	0.855	0.896	0.896	0.896
1977	0.995	0.957	0.905	0.830	0.905	0.905	0.905
1978	0.991	0.934	0.861	0.762	0.861	0.861	0.861
1979	1.029	0.952	0.857	0.735	0.857	0.857	0.857
1980	0.952	0.865	0.761	0.634	0.761	0.761	0.761
1981	0.938	0.838	0.722	0.586	0.722	0.722	0.722
1982	0.978	0.858	0.725	0.575	0.753	0.741	0.699
1983	0.959	0.826	0.685	0.533	0.737	0.715	0.639
1984	1.012	0.857	0.698	0.533	0.778	0.744	0.632
1985	1.040	0.867	0.693	0.520	0.800	0.754	0.612
1986	0.980	0.803	0.632	0.467	0.754	0.700	0.545
1987	0.893	0.720	0.558	0.406	0.687	0.629	0.470
1988	0.884	0.701	0.536	0.384	0.680	0.614	0.442
1989	0.981	0.766	0.577	0.409	0.754	0.672	0.467
1990	1.044	0.803	0.597	0.418	0.803	0.706	0.475
1991	1.033	0.783	0.574	0.397	0.795	0.689	0.449
1992	1.283	0.957	0.694	0.475	0.987	0.844	0.535
1993	1.273	0.936	0.670	0.455	0.980	0.827	0.509
1994	1.495	1.084	0.767	0.516	1.150	0.959	0.575
1995	1.697	1.212	0.848	0.566	1.305	1.074	0.628
1996	1.807	1.273	0.882	0.583	1.390	1.130	0.645
1997	1.688	1.172	0.804	0.528	1.299	1.042	0.582
1998	1.715	1.174	0.797	0.520	1.319	1.045	0.572
1999	1.688	1.141	0.767	0.497	1.299	1.017	0.545
2000	1.527	1.018	0.679	0.436	1.175	0.909	0.477

Table 2. Annual mean CPUE for each effort creep scenario for Block 14

The Raw Mean is the geometric mean. The six effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; (iii) 10% per annum; (iv) 5% per annum until 1981 only; (v) 5% per annum until 1981; and then 2% per annum until 2000; (vi) 5% per annum until 1981; and then 10% per annum until 2000. All values of CPUE are relative to 1975.

	RELATIVE CPUE						
YEAR	**Raw Mean**	**2% p.a.**	**5% p.a.**	**10% p.a.**	**5%, 0**	**5%, 2%**	**5%, 10%**
1975	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.902	0.884	0.859	0.820	0.859	0.859	0.859
1977	1.194	1.148	1.085	0.995	1.085	1.085	1.085
1978	1.088	1.027	0.946	0.837	0.946	0.946	0.946
1979	1.097	1.016	0.914	0.784	0.914	0.914	0.914
1980	0.970	0.882	0.776	0.647	0.776	0.776	0.776
1981	0.982	0.876	0.755	0.613	0.755	0.755	0.755
1982	1.035	0.908	0.767	0.609	0.796	0.784	0.739
1983	1.066	0.919	0.761	0.592	0.820	0.795	0.711
1984	0.958	0.811	0.660	0.504	0.737	0.704	0.598
1985	1.017	0.848	0.678	0.509	0.783	0.737	0.598
1986	1.031	0.845	0.665	0.491	0.793	0.737	0.573
1987	0.939	0.757	0.587	0.427	0.722	0.661	0.494
1988	0.943	0.748	0.571	0.410	0.725	0.655	0.471
1989	1.009	0.788	0.593	0.420	0.776	0.691	0.480
1990	1.105	0.850	0.631	0.442	0.850	0.746	0.502
1991	1.158	0.877	0.643	0.445	0.891	0.772	0.504
1992	1.163	0.868	0.629	0.431	0.895	0.765	0.485
1993	1.212	0.891	0.638	0.433	0.932	0.787	0.485
1994	1.440	1.043	0.738	0.496	1.107	0.923	0.554
1995	1.666	1.190	0.833	0.555	1.281	1.054	0.617
1996	1.709	1.203	0.834	0.551	1.314	1.068	0.610
1997	1.613	1.120	0.768	0.504	1.241	0.996	0.556
1998	1.739	1.191	0.809	0.527	1.337	1.060	0.580
1999	1.588	1.073	0.722	0.467	1.222	0.957	0.512
2000	1.571	1.047	0.698	0.449	1.208	0.935	0.491

Table 3. Mean CPUE for the two assessment reference periods under each effort creep scenario

The Raw Mean is the geometric mean. The six effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; (iii) 10% per annum; (iv) 5% per annum until 1981 only; (v) 5% per annum until 1981, and then 2% per annum until 2000; (vi) 5% per annum until 1981, and then 10% per annum until 2000. All values of CPUE are relative to 1975.

		RELATIVE CPUE						
Block	**Reference period**	**Raw Mean**	**2%**	**5%**	**10%**	**5%, 0**	**5%, 2%**	**5%, 10%**
13	1979-82	0.974	0.878	0.766	0.633	0.773	0.770	0.760
13	1992-95	1.437	1.047	0.745	0.503	1.105	0.926	0.562
14	1979-82	1.021	0.921	0.803	0.663	0.810	0.807	0.796
14	1992-95	1.370	0.998	0.709	0.479	1.054	0.882	0.535

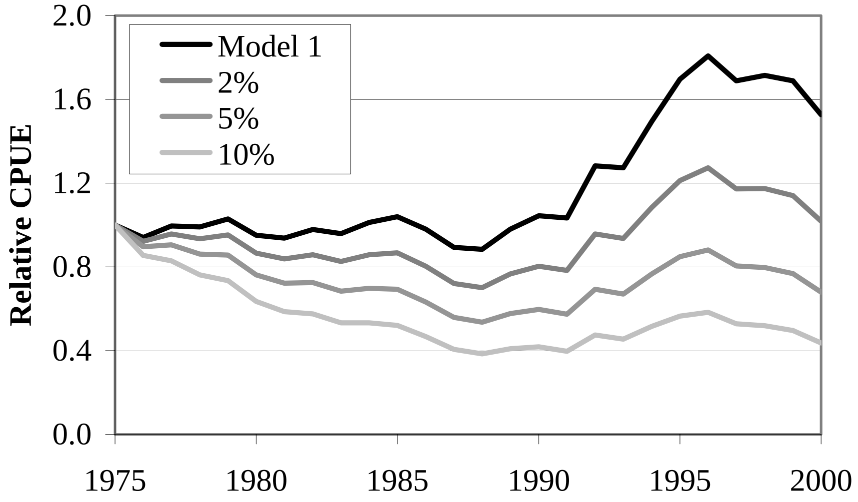


Fig.1. Relative CPUE indices for Block 13, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; and (iii) 10% per annum. All values of CPUE are relative to 1975.

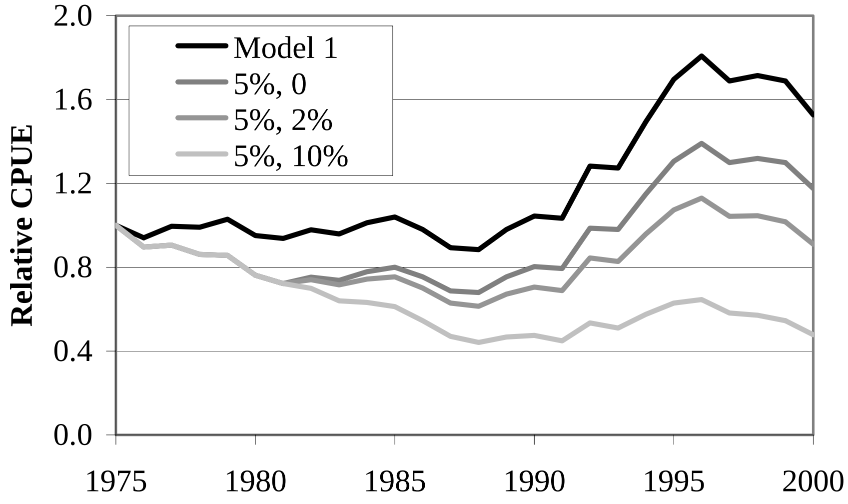


Fig. 2. Relative CPUE indices for Block 13, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 5% per annum until 1981 only; (ii) 5% per annum until 1981, and then 2% per annum until 2000; (iii) 5% per annum until 1981, and then 10% per annum until 2000. All values of CPUE are relative to 1975.

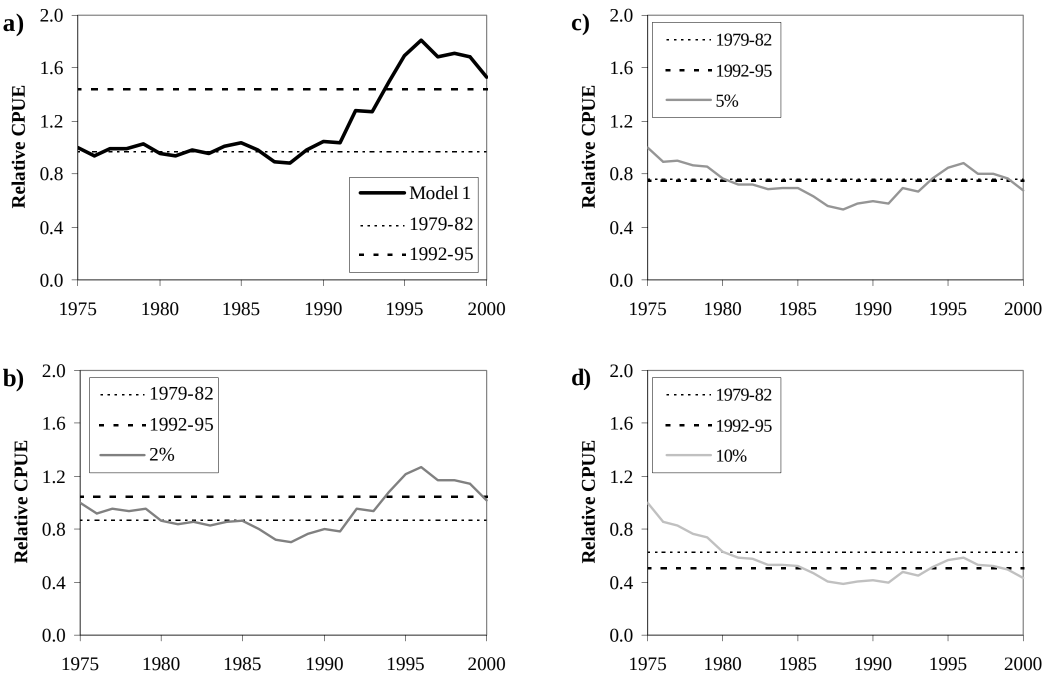


Fig. 3. Relative CPUE indices for Block 13, 1975-2000. Model 1, (a), is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (b) 2% p.a.; (c) 5% p.a.; and (d) 10% p.a. All values of CPUE are relative to 1975. The dotted lines are the mean CPUE for the two assessment reference periods.

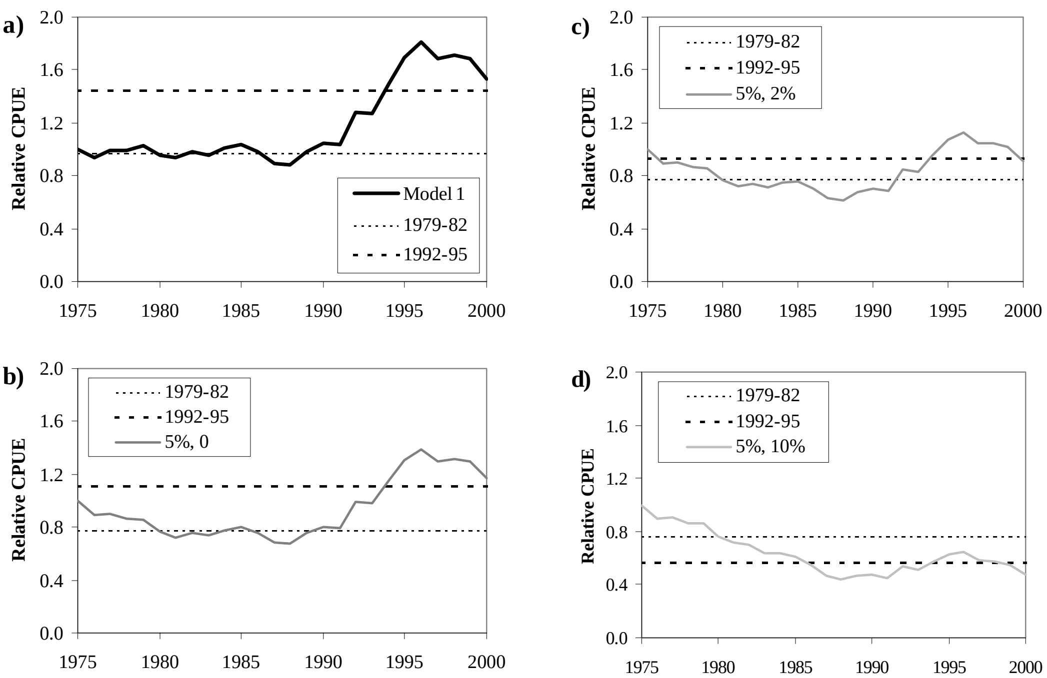


Fig. 4. Relative CPUE indices for Block 13, 1975-2000. Model 1, (a), is the raw geometric mean. The three effort creep scenarios considered are: (b) 5% p.a. until 1981 only; (c) 5% p.a. until 1981; and then 2% p.a. until 2000; (d) 5% p.a. until 1981, and then 10% p.a. until 2000. All values of CPUE are relative to 1975. The dotted lines are the mean CPUE for the two assessment reference periods.

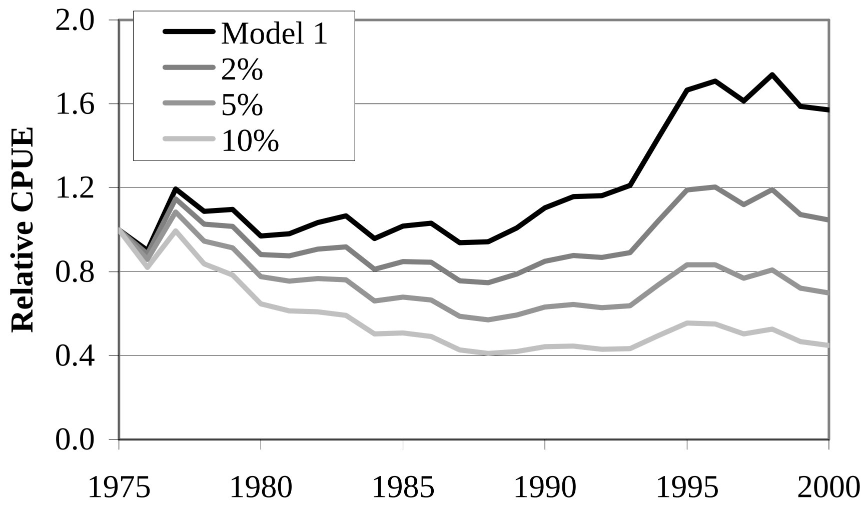


Fig. 5. Relative CPUE indices for Block 14, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; and (iii) 10% per annum. All values of CPUE are relative to 1975.

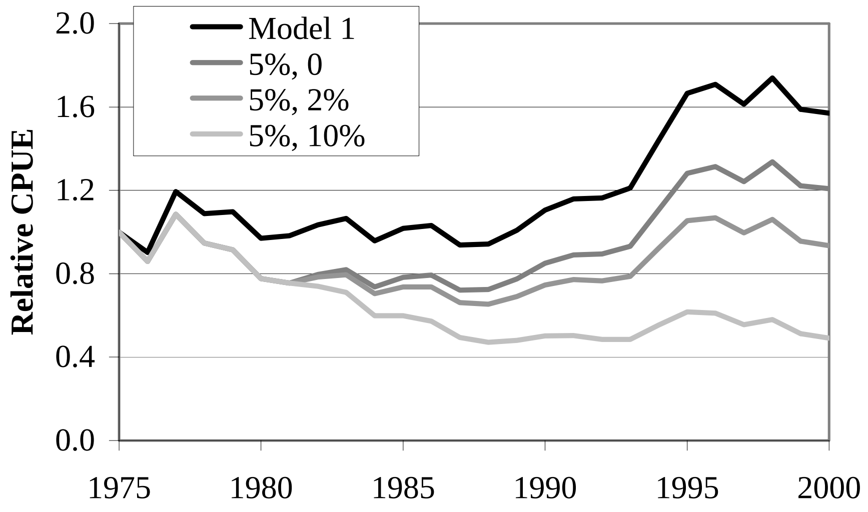


Fig. 6. Relative CPUE indices for Block 14, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 5% per annum until 1981 only; (ii) 5% per annum until 1981, and then 2% per annum until 2000; (iii) 5% per annum until 1981, and then 10% per annum until 2000. All values of CPUE are relative to 1975.

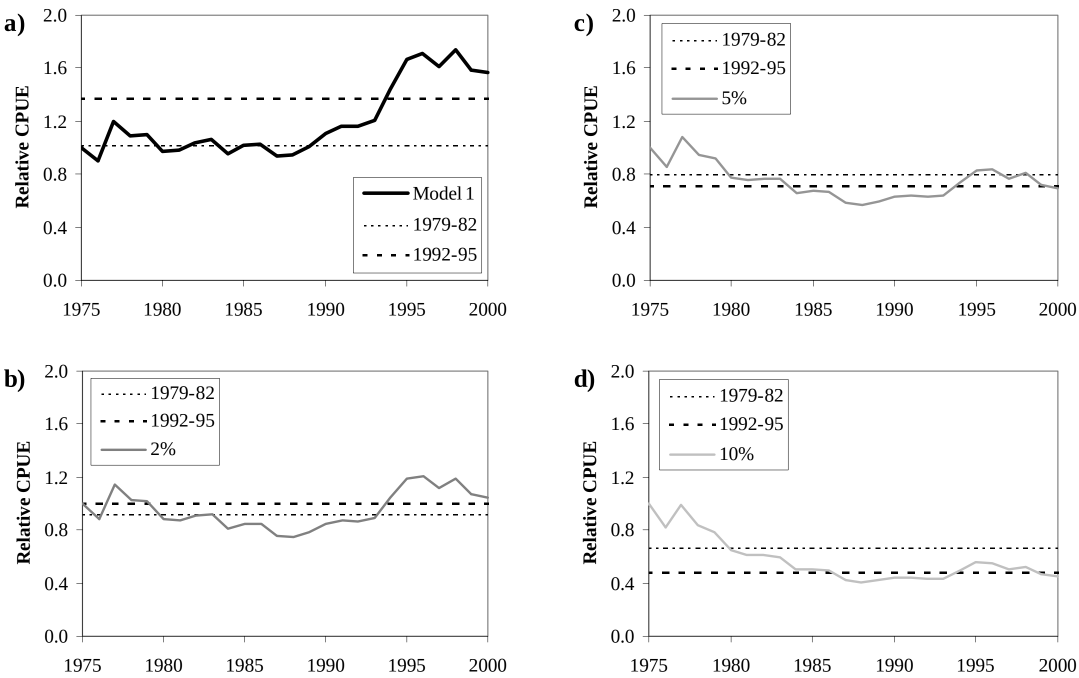


Fig.7. Relative CPUE indices for Block 14, 1975-2000. Model 1, (a), is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (b) 2% p.a.; (c) 5% p.a.; and (d) 10% p.a. All values of CPUE are relative to 1975. The dotted lines are the mean CPUE for the two assessment reference periods.

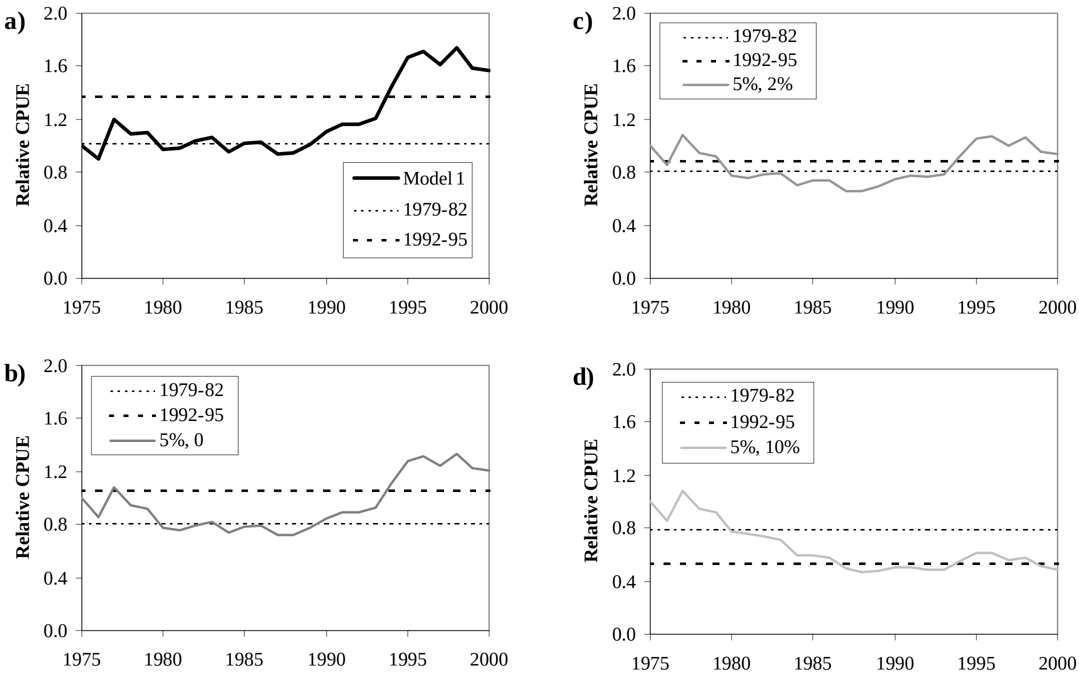


Fig. 8. Relative CPUE indices for Block 14, 1975-2000. Model 1, (a), is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (b) 5% p.a. until 1981 only; (c) 5% p.a. until 1981, and then 2% p.a. until 2000; (d) 5% p.a. until 1981, and then 10% p.a. until 2000. All values of CPUE are relative to 1975. The dotted lines are the mean CPUE for the two assessment reference periods.

Conclusions

Effort creep needs to be considered in future assessments of the Tasmanian abalone fishery. These results show that the inclusion of changing catchability due to effort creep can markedly change the trends in CPUE. Raw CPUE estimates of biomass will be positively biased if even a small amount of effort creep is ignored. While the raw CPUE trends for Blocks 13 and 14 predict a biomass above the average values of the two reference periods (as specified in the draft management plan; Anonymous, 1997), this is not necessarily the case when effort creep is considered. Where there has been 5% or more effort creep every year from 1975, the current biomass is estimated to be *below* both reference levels, and 50% less than that predicted by the raw CPUE relative to 1975.

While the scenarios presented use seemingly plausible levels of effort creep, it is unlikely that effort creep would have occurred in a continuous fashion through time. If a change in method or technology usage were adopted across the fishery relatively quickly, we would expect a sudden jump in the effectiveness of effort, but there would also be years where the catchability stays constant, until the next advancement. Future work will attempt to quantify effort creep for the Tasmanian abalone fishery, and will give a better indication of how and when effort creep has occurred and its impact on the interpretation of CPUE as an indicator of biomass.

References

Anonymous. (1997). Draft Abalone Management Plan and Policy Document. Hobart, Tasmania: Department of Primary Industries and Fisheries.

Buckworth, R. (1987) Changes in fishing effort and catching power in the DMZ tiger prawn fishery. *Northern Prawn Fishery Information Notes*, February 1987, CSIRO Division of Fisheries, Cleveland Australia.

Haddon, M and K. Hodgson (2000). Spatial and seasonal stock dynamics of Northern Tiger prawns using fine-scale commercial catch-effort data. *FRDC Final Report.*

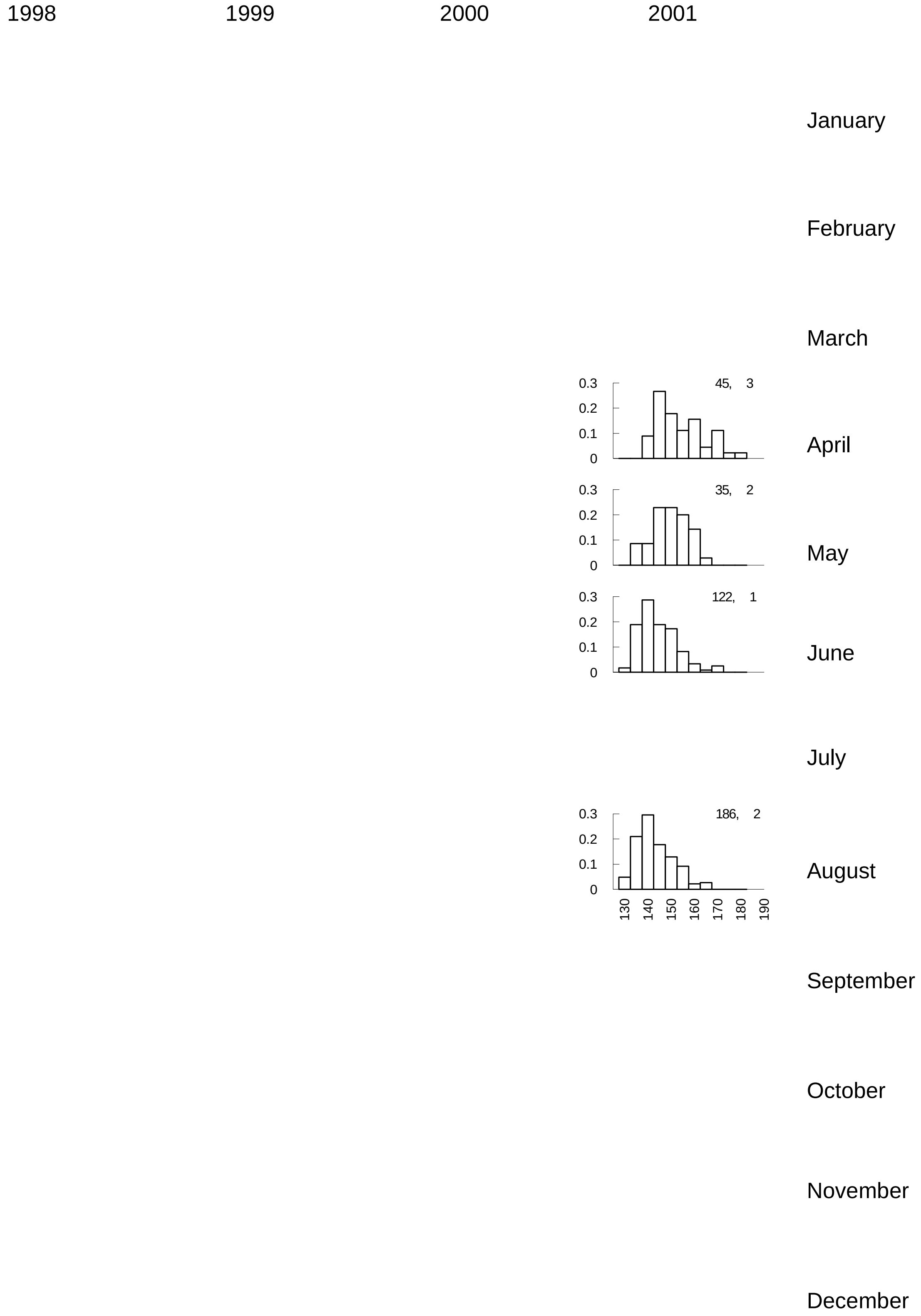
Harrison, A.J. (1983). The Tasmanian abalone fishery. *Tasmanian Fish. Res.*, 26, 1-42.

Officer, R and Tarbath, D. (2000). *Tasmanian Abalone fishery 1999.* Hobart: Tasmanian Aquaculture and Fisheries Institute.

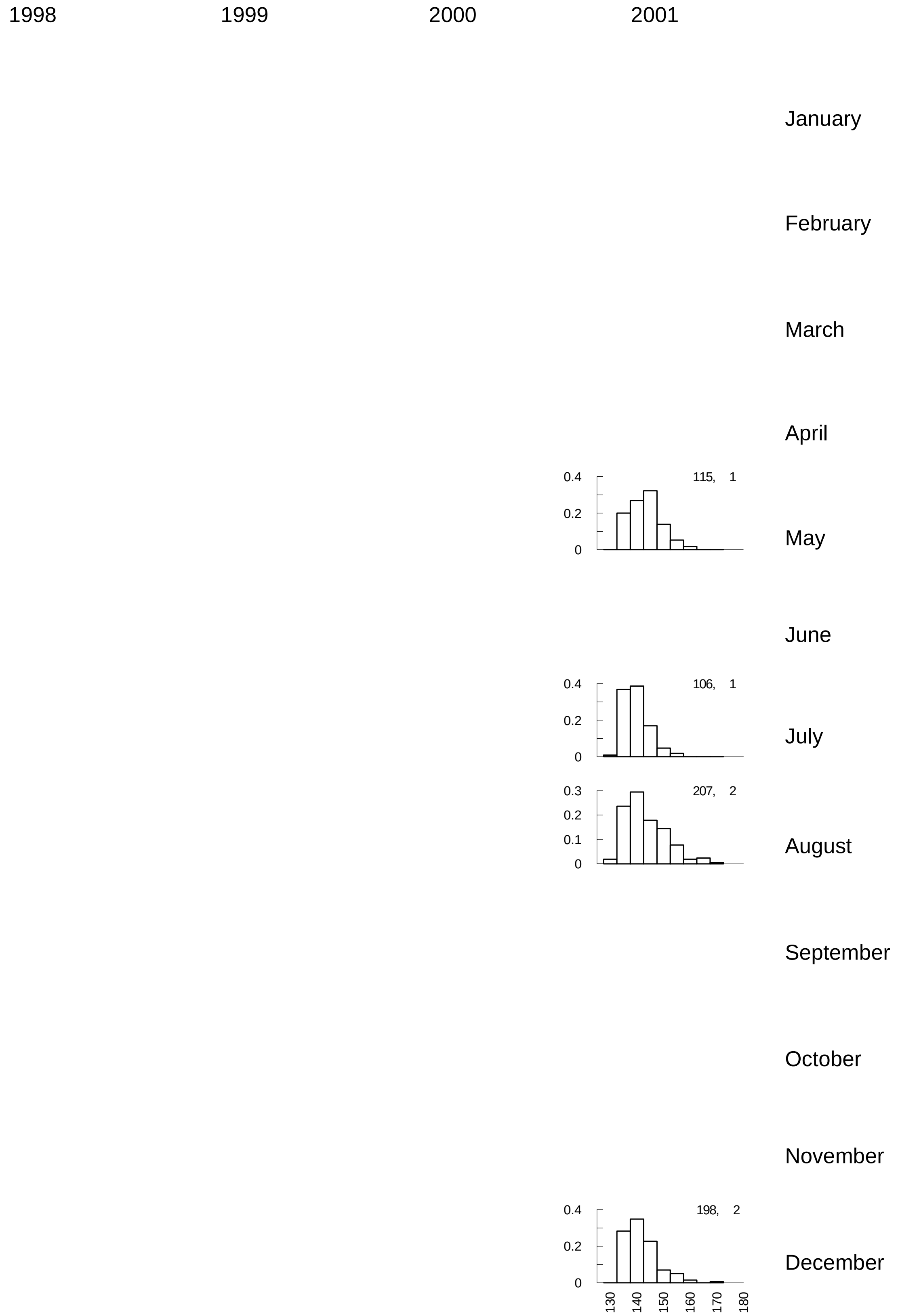
Appendix 6: Size-Composition Of Catch Samples By Sub-Block.

The relative frequency of each 5-mm size-class is grouped by sub-block, year and month. The top right hand corner of each chart shows the number of abalone measured, and the number of diver days sampled.

Sub-block 5A



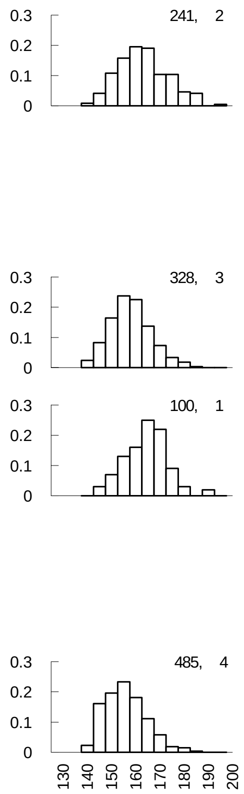
Sub-block 5C


1998
1999
2000
2001
January
February
March
April
0.4
0.2
0
115, 1
May
June
0.4
0.2
0
106, 1
July
0.3
0.2
0.1
0
207, 2
August
September
October
November
0.4
0.2
0
198, 2
December
130
140
150
160
170
180

Sub-block 9B

1998 1999 2000 2001

January



February

March

April

May

June

July

August

September

October

November

December

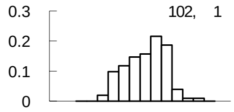
Sub-block 9C

1998 1999 2000 2001

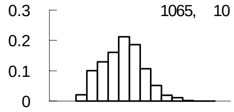
January

February

March

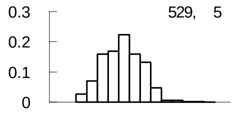


April



May

June

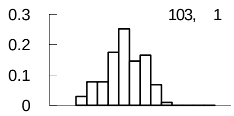


July

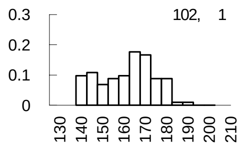
August

September

October



November

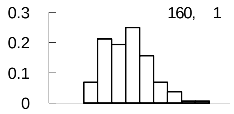


December

Sub-block 11A

1998 1999 2000 2001

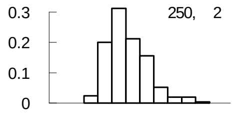
January



February

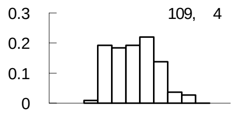
March

April



May

June



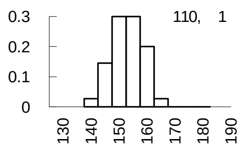
July

August

September

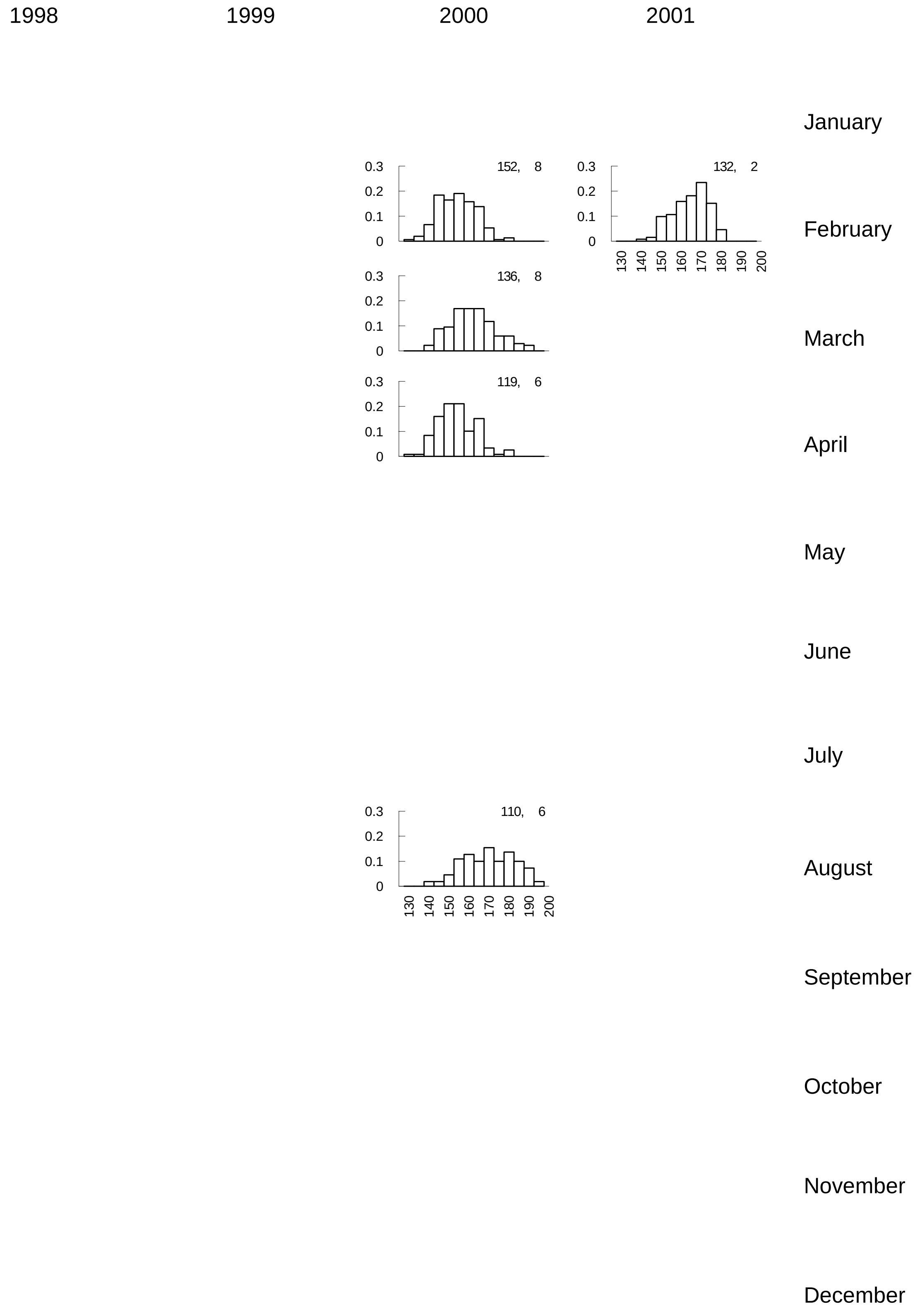
October

November

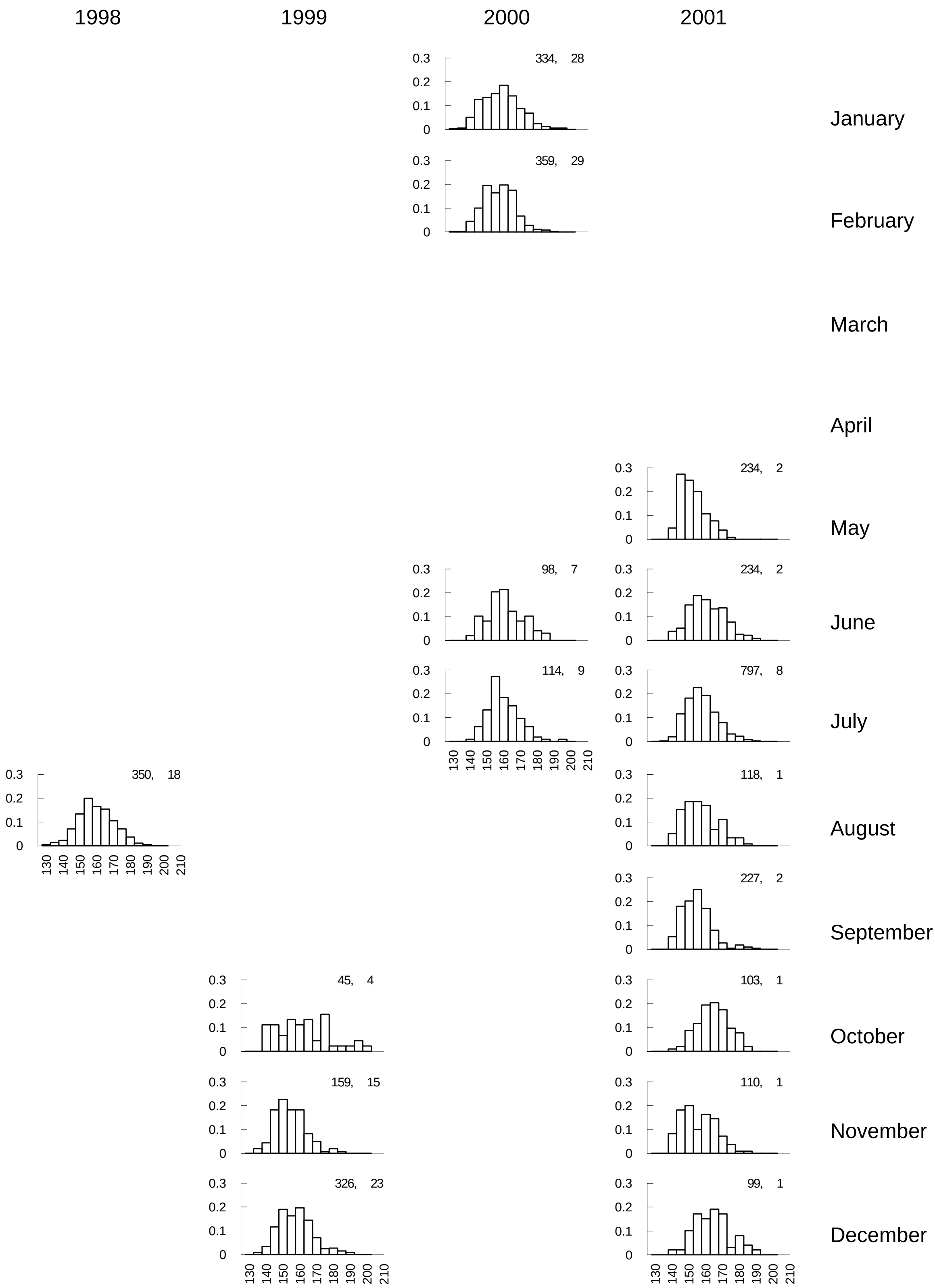


December

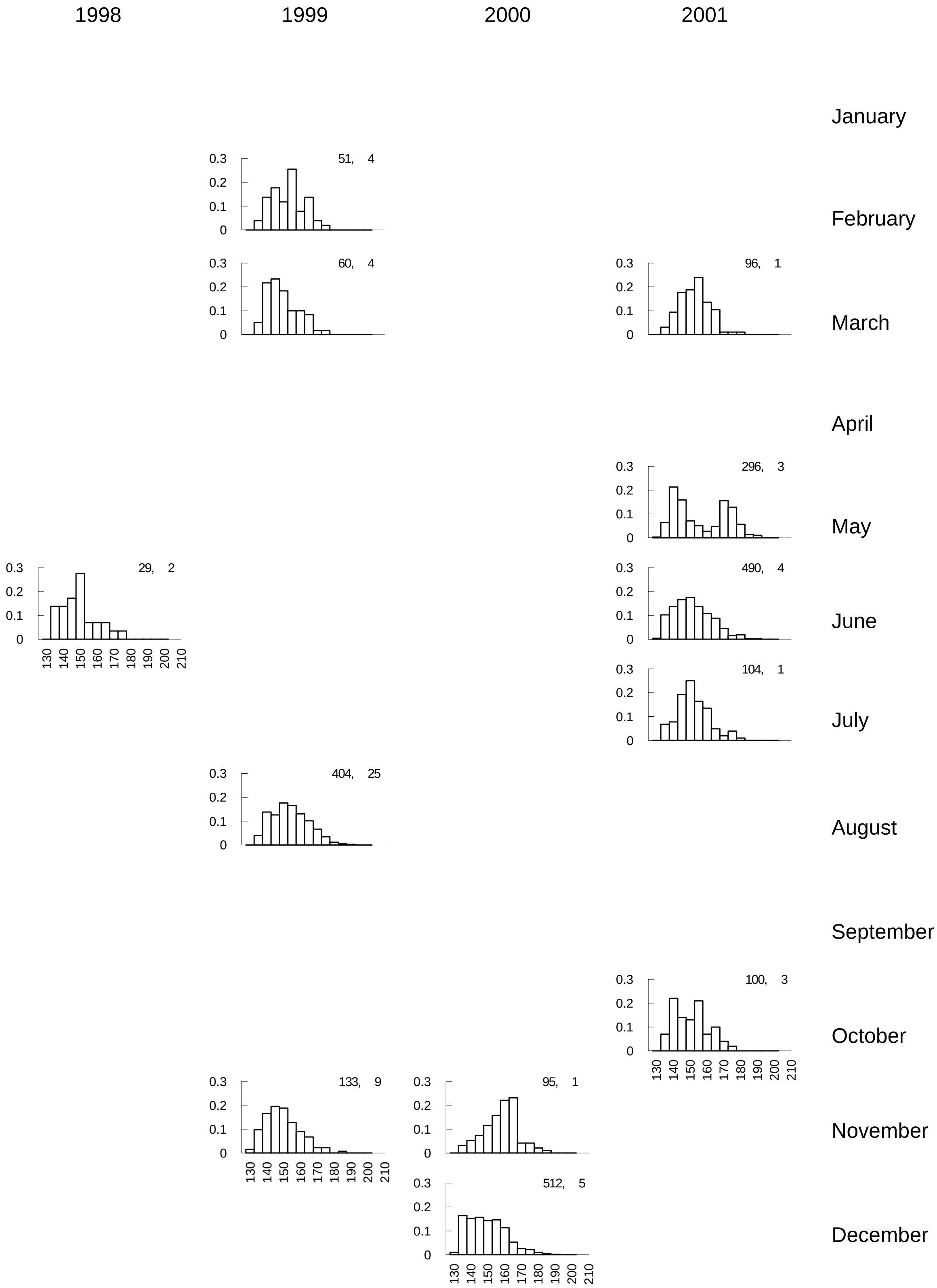
Sub-block 11E



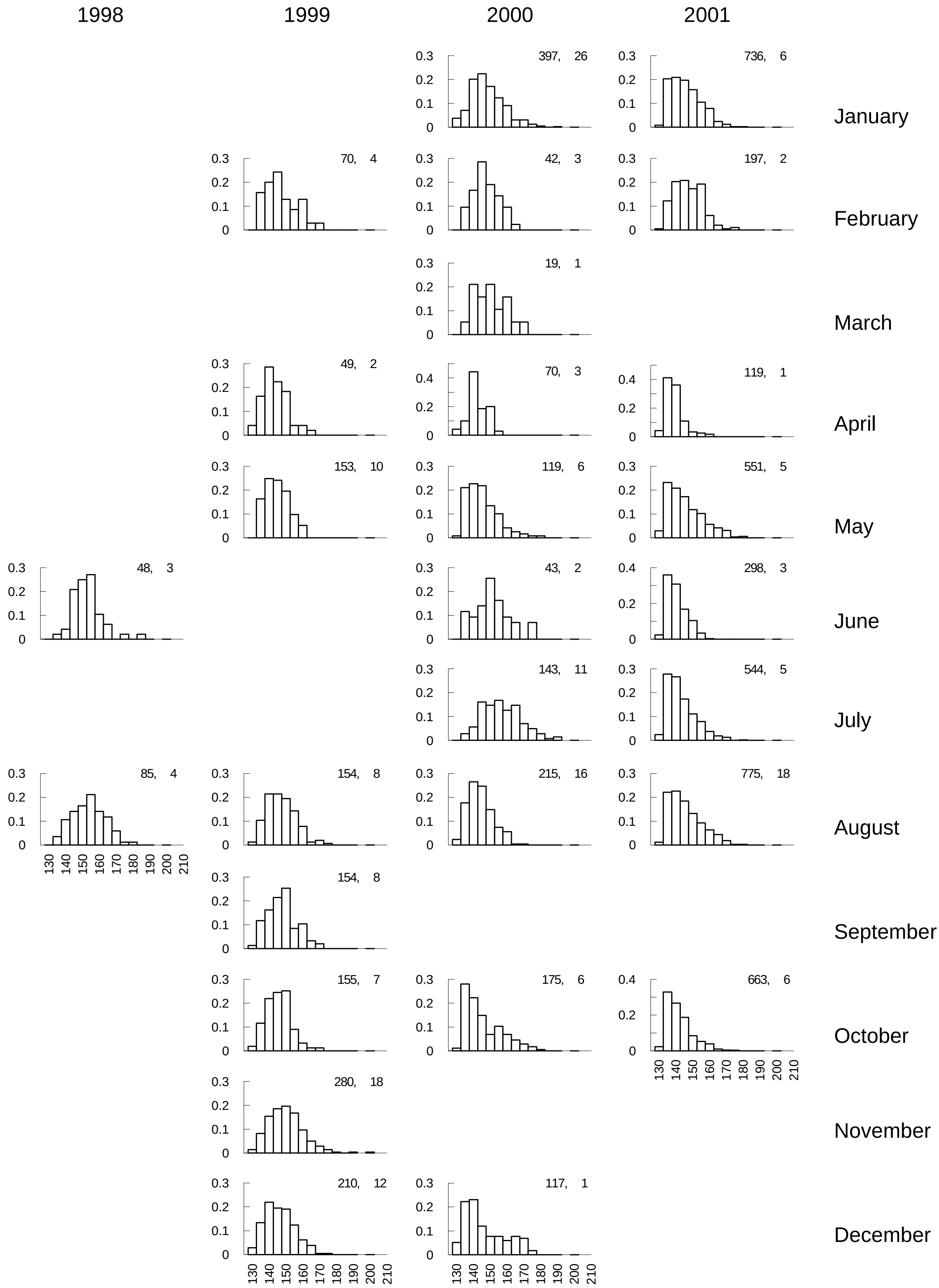
Sub-block 12D



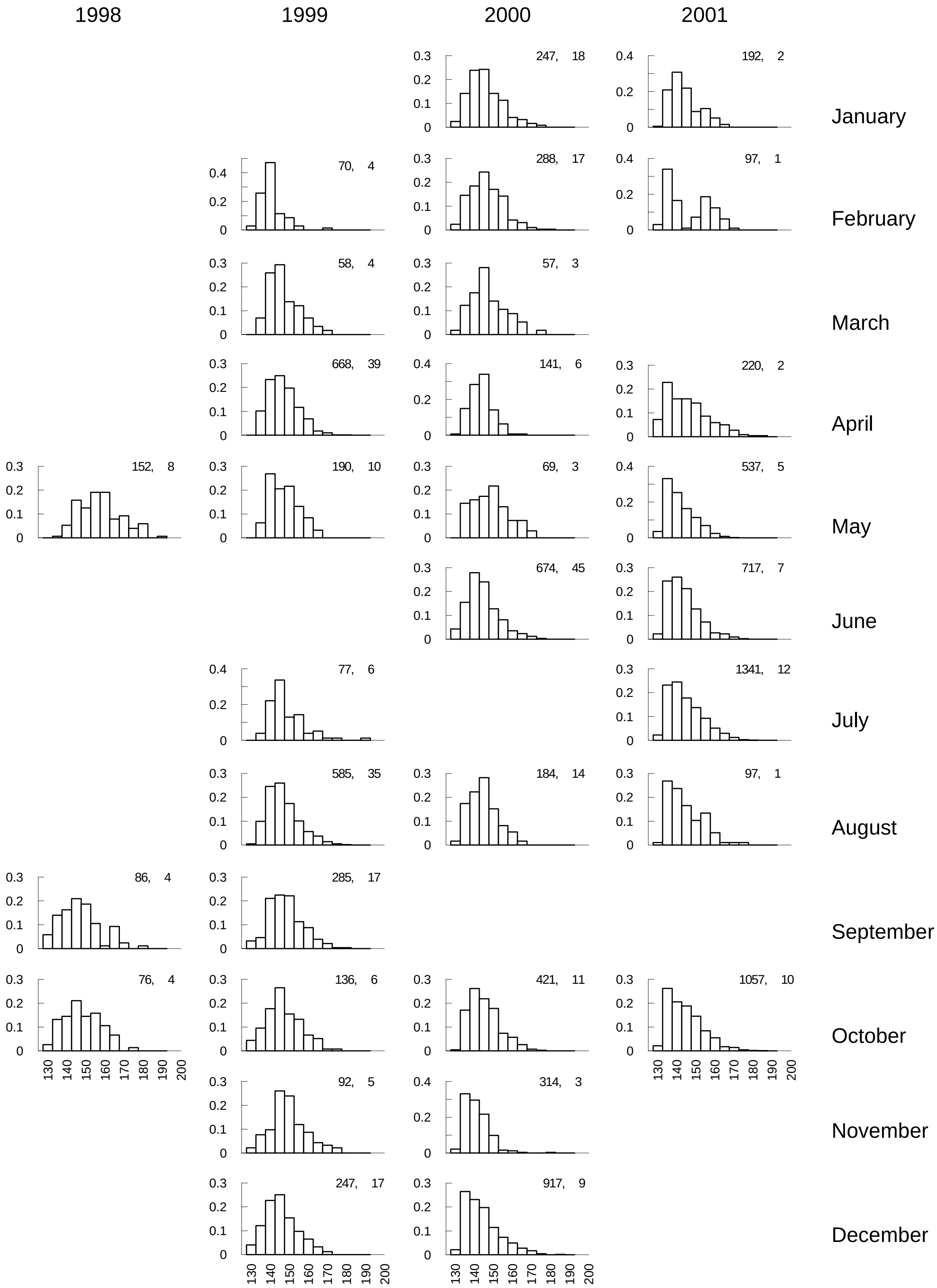
Sub-block 13C



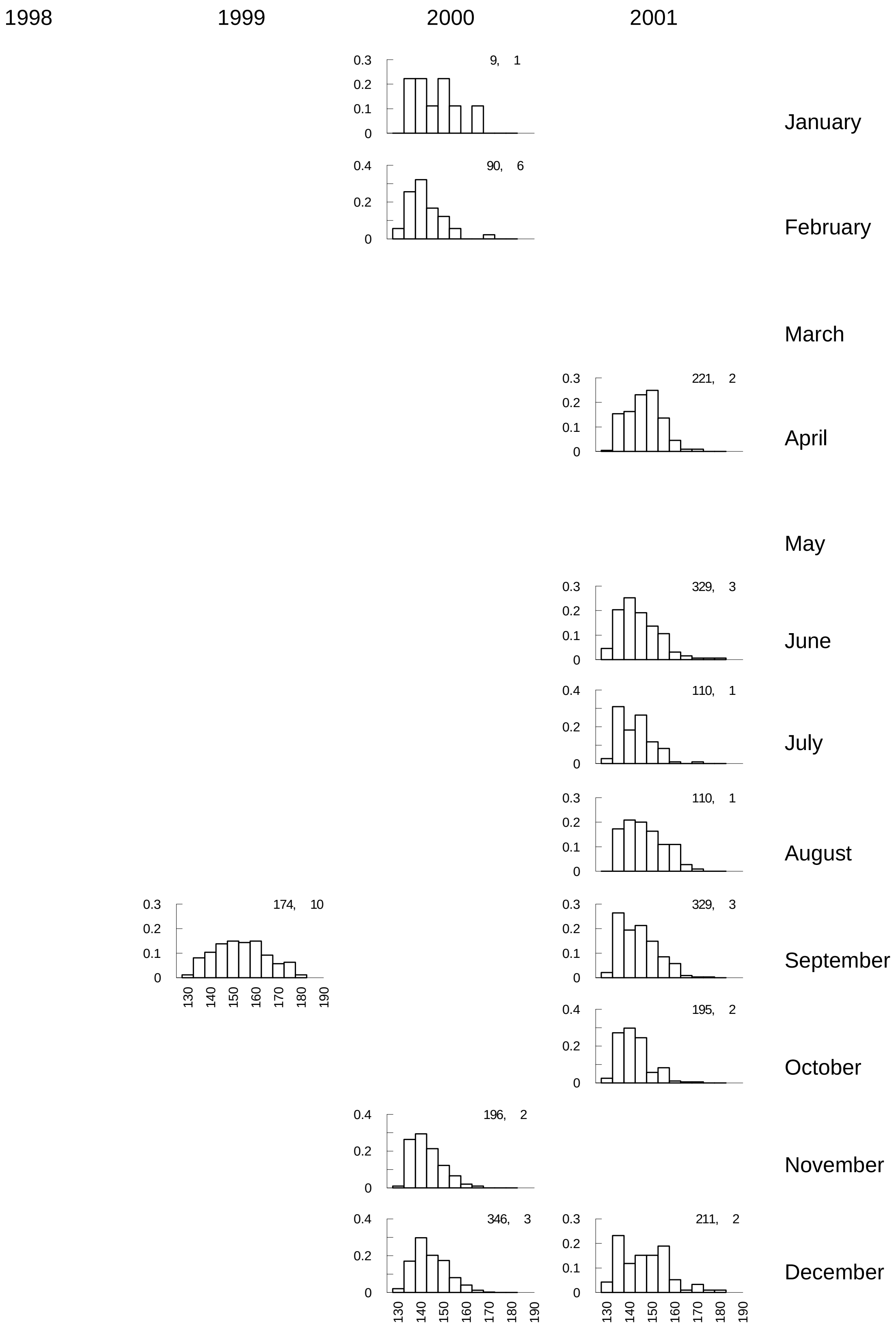
Sub-block 13D



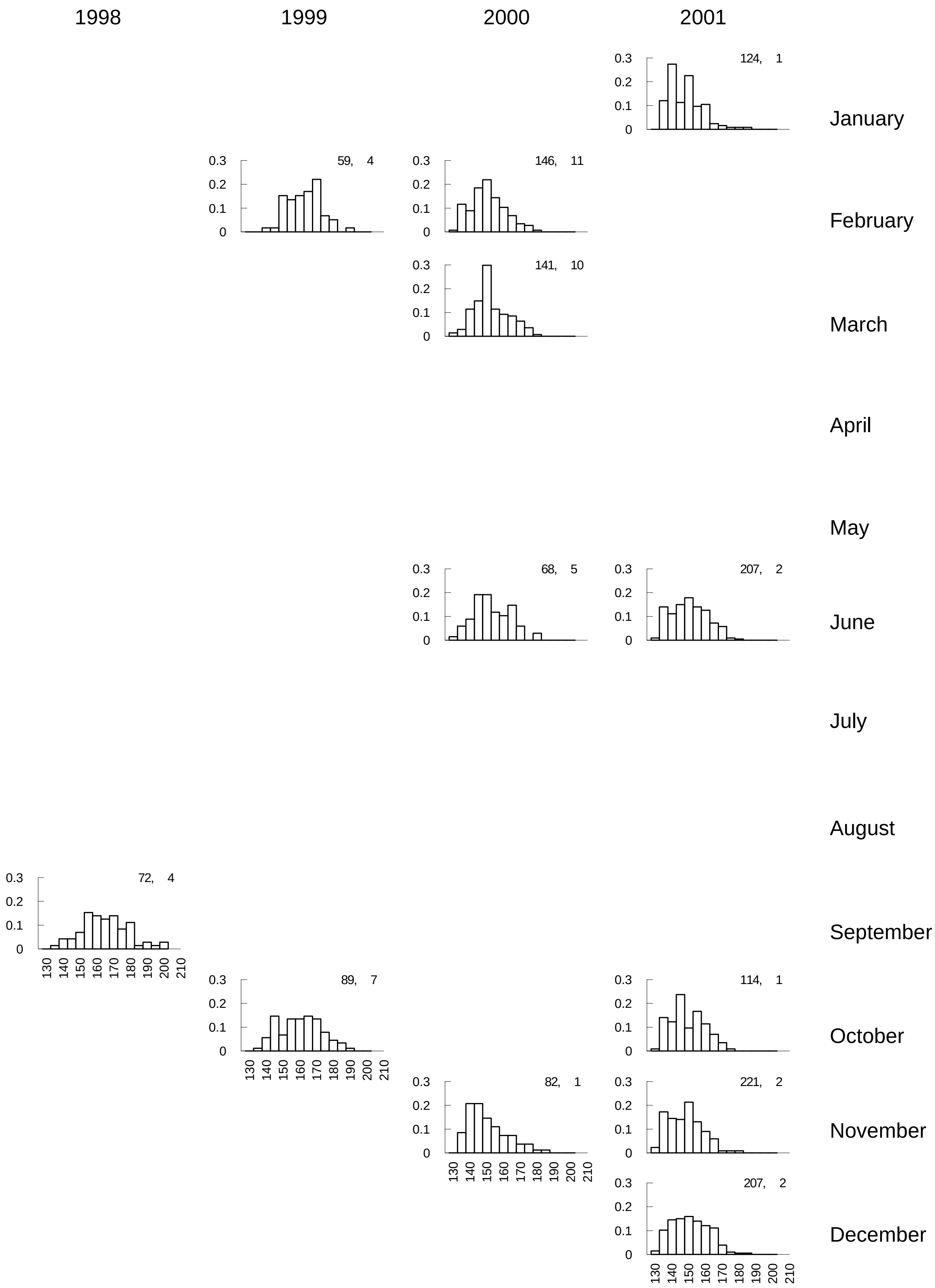
Sub-block 13E



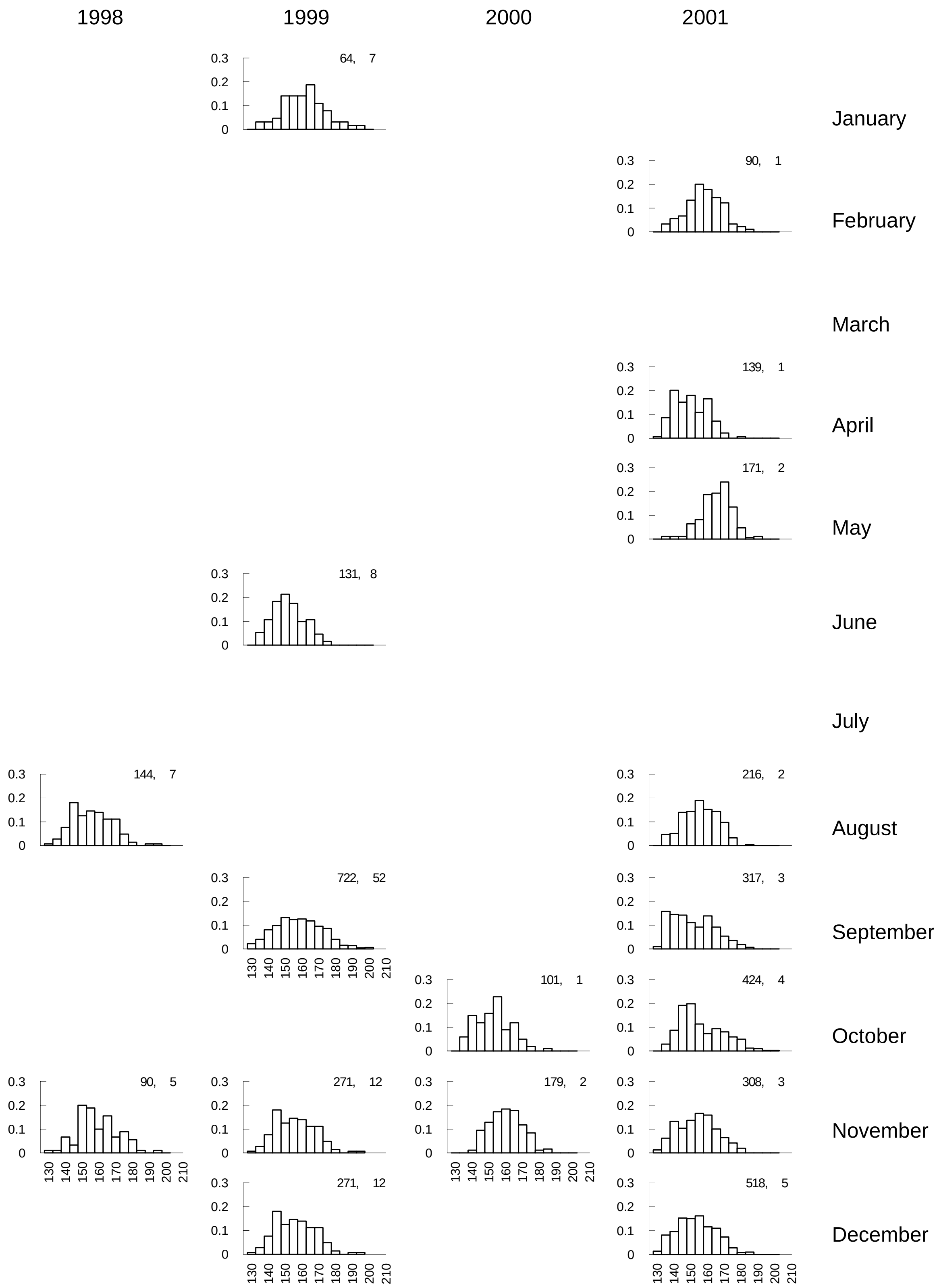
Sub-block 14A



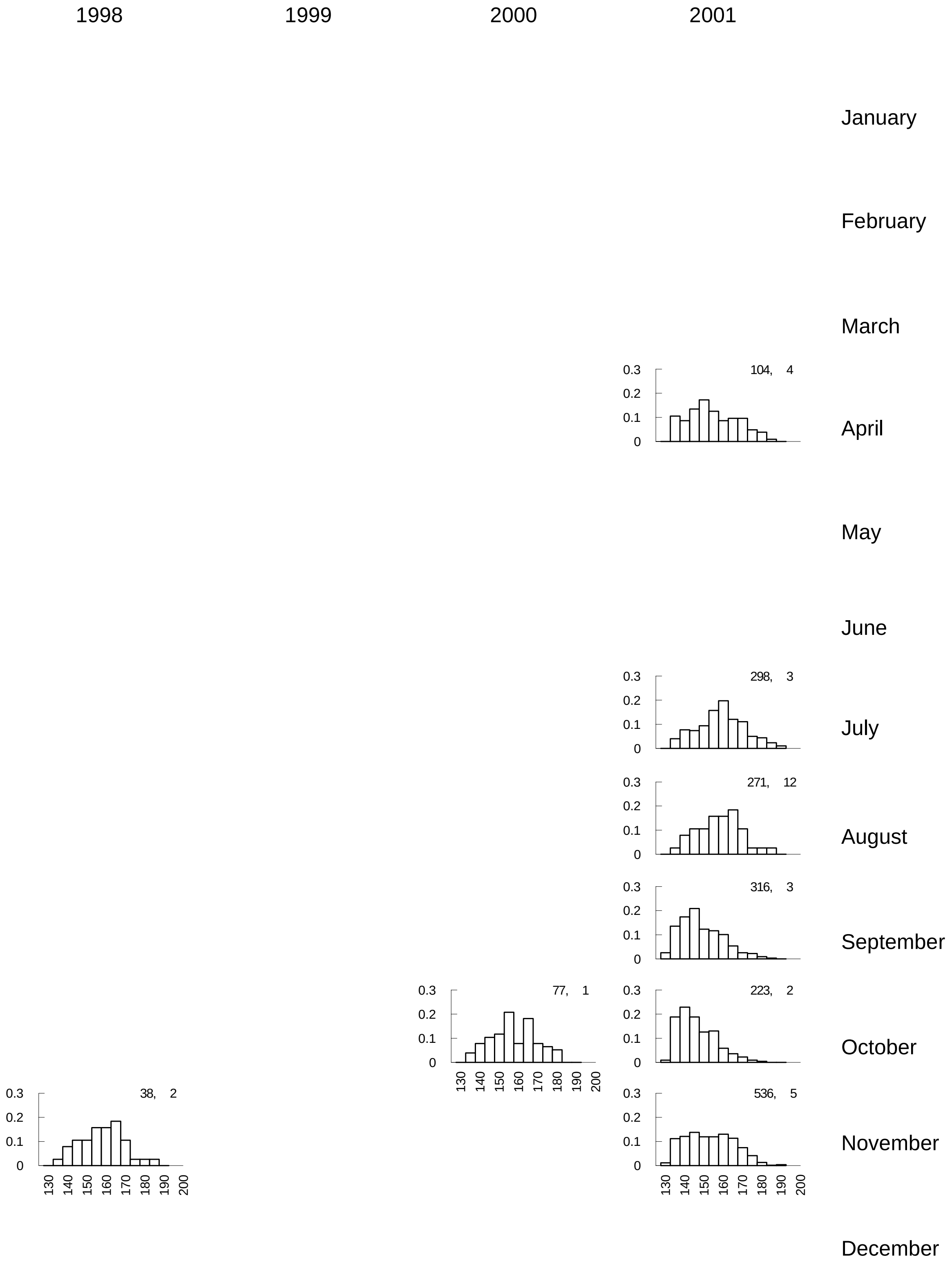
Sub-block 14D



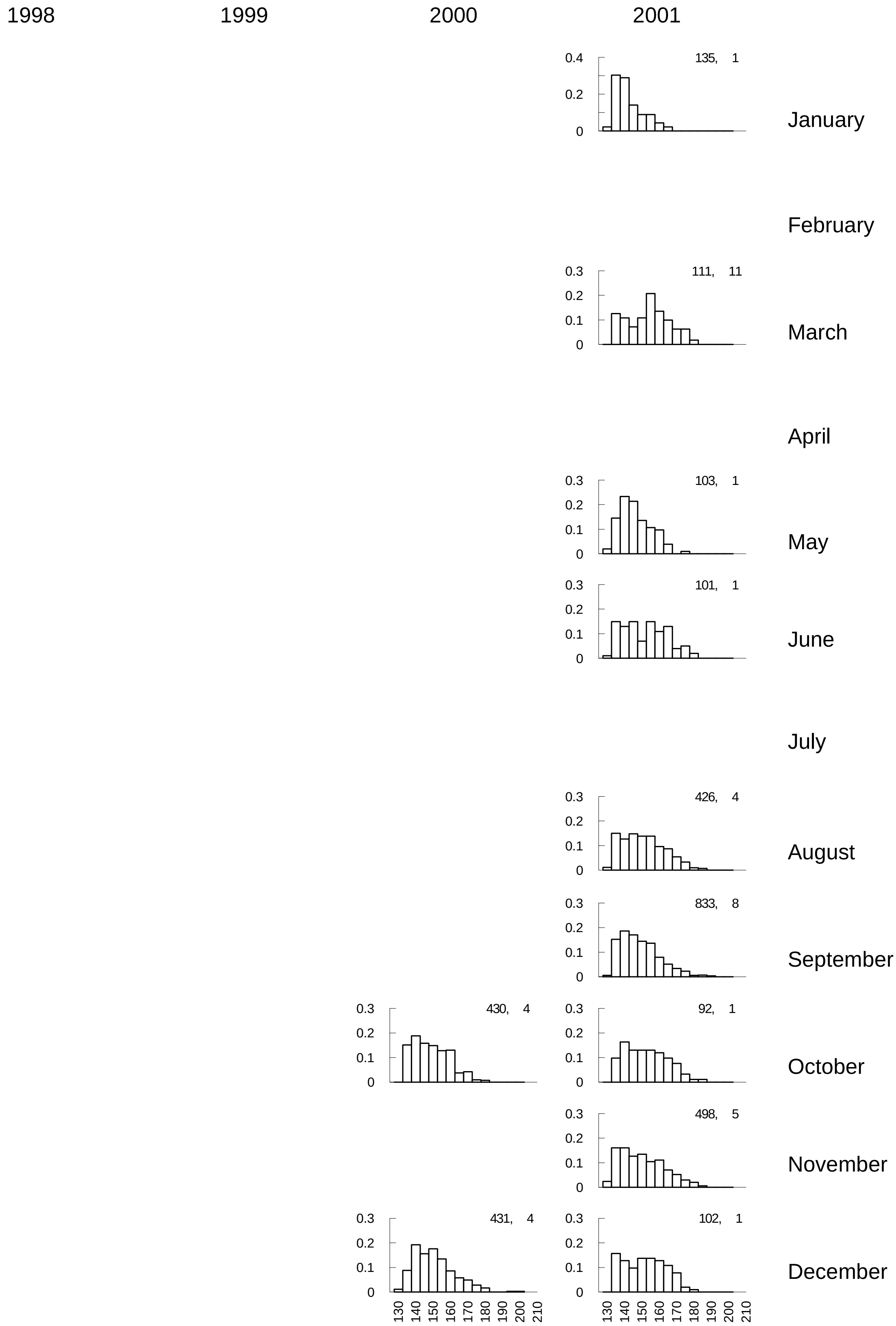
Sub-block 14E



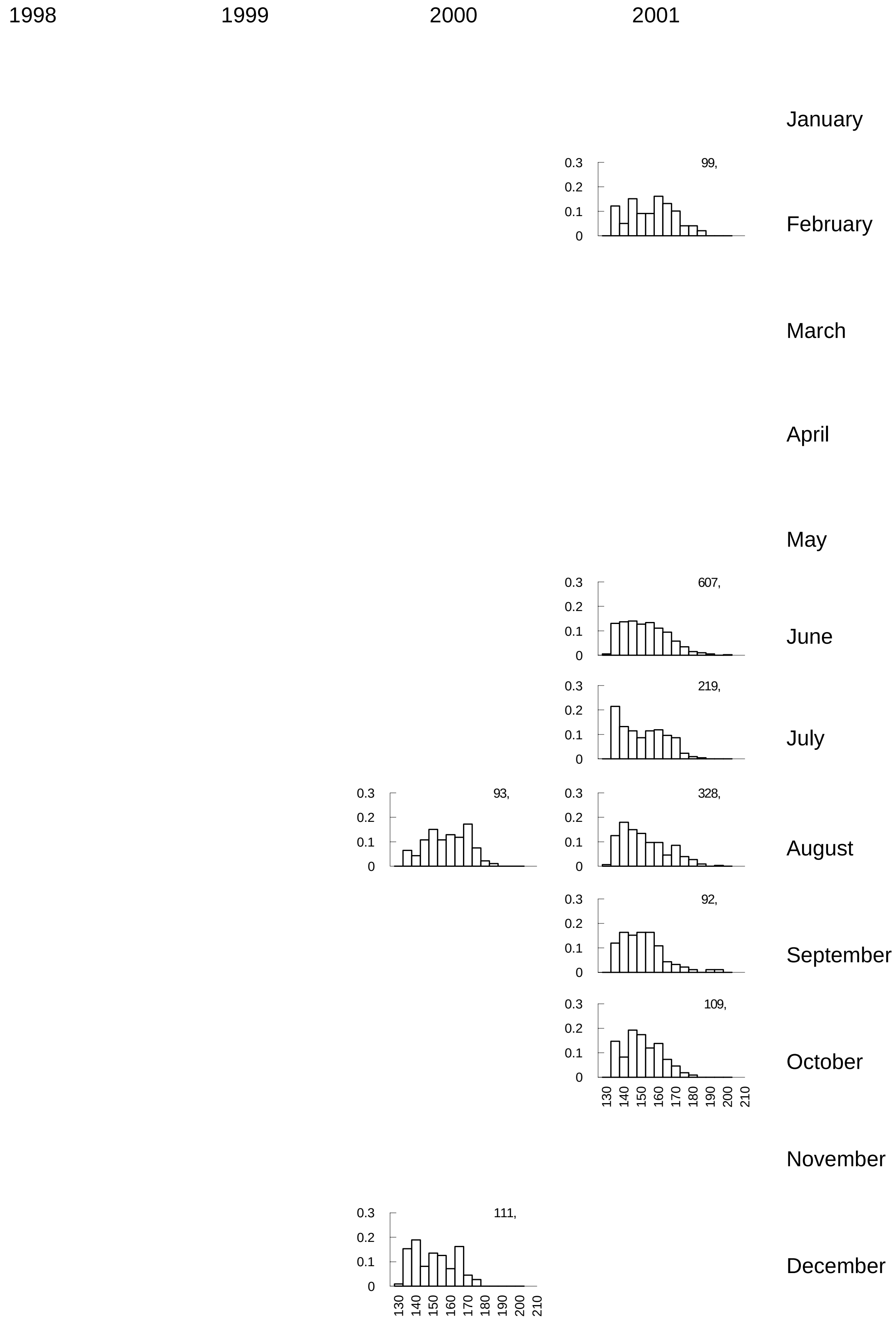
Sub-block 16A



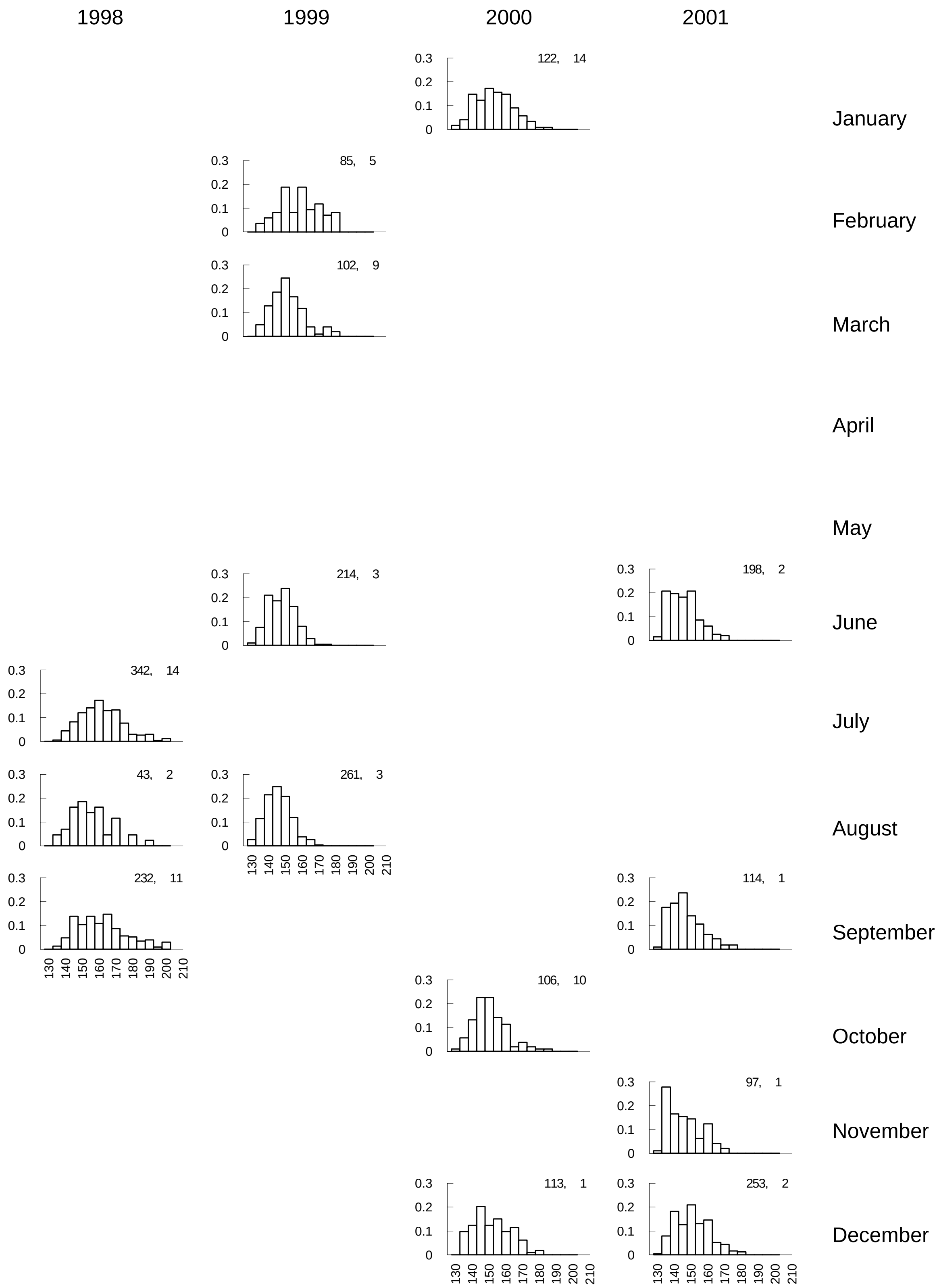
Sub-block 16B



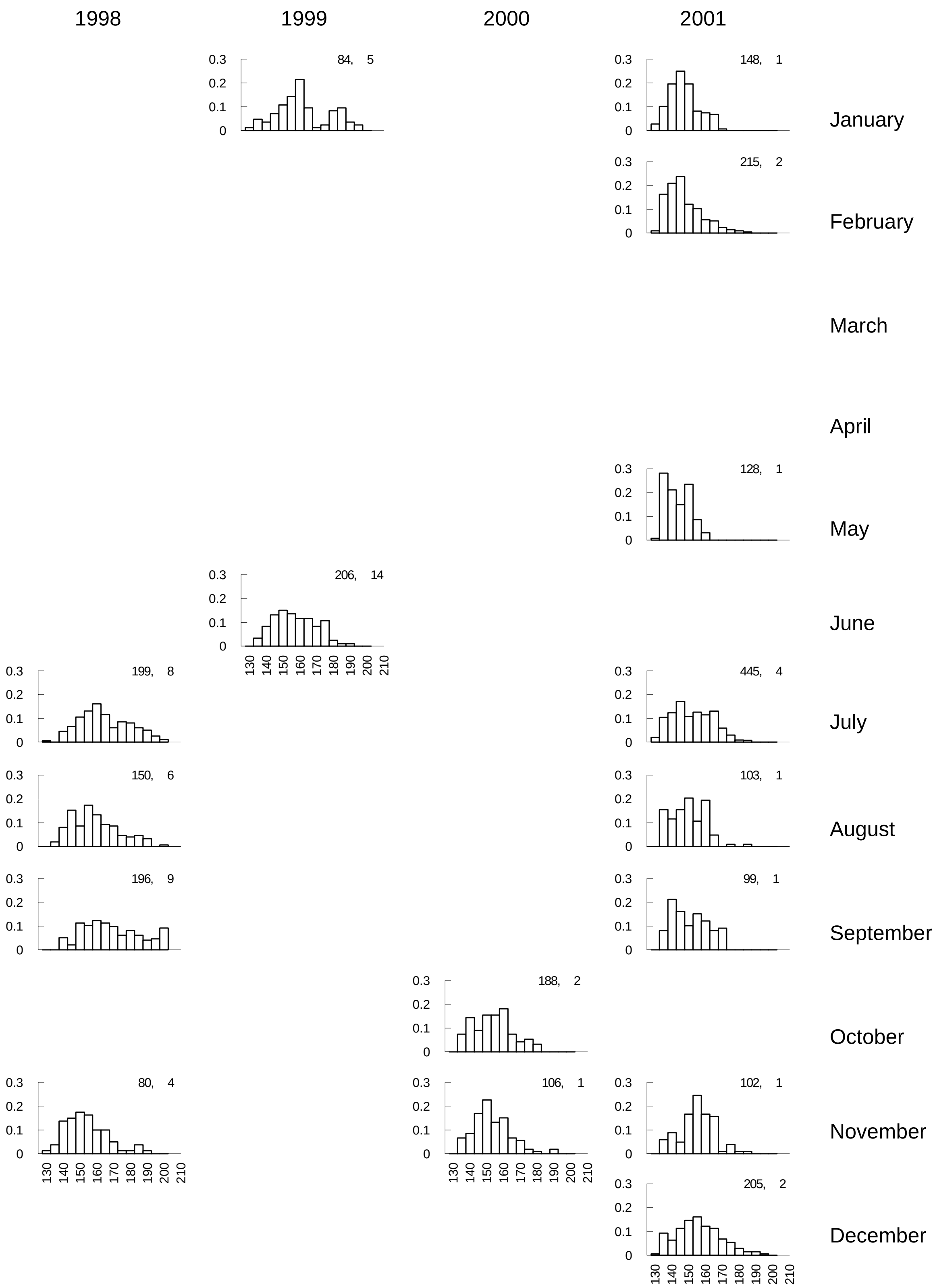
Sub-block 16C



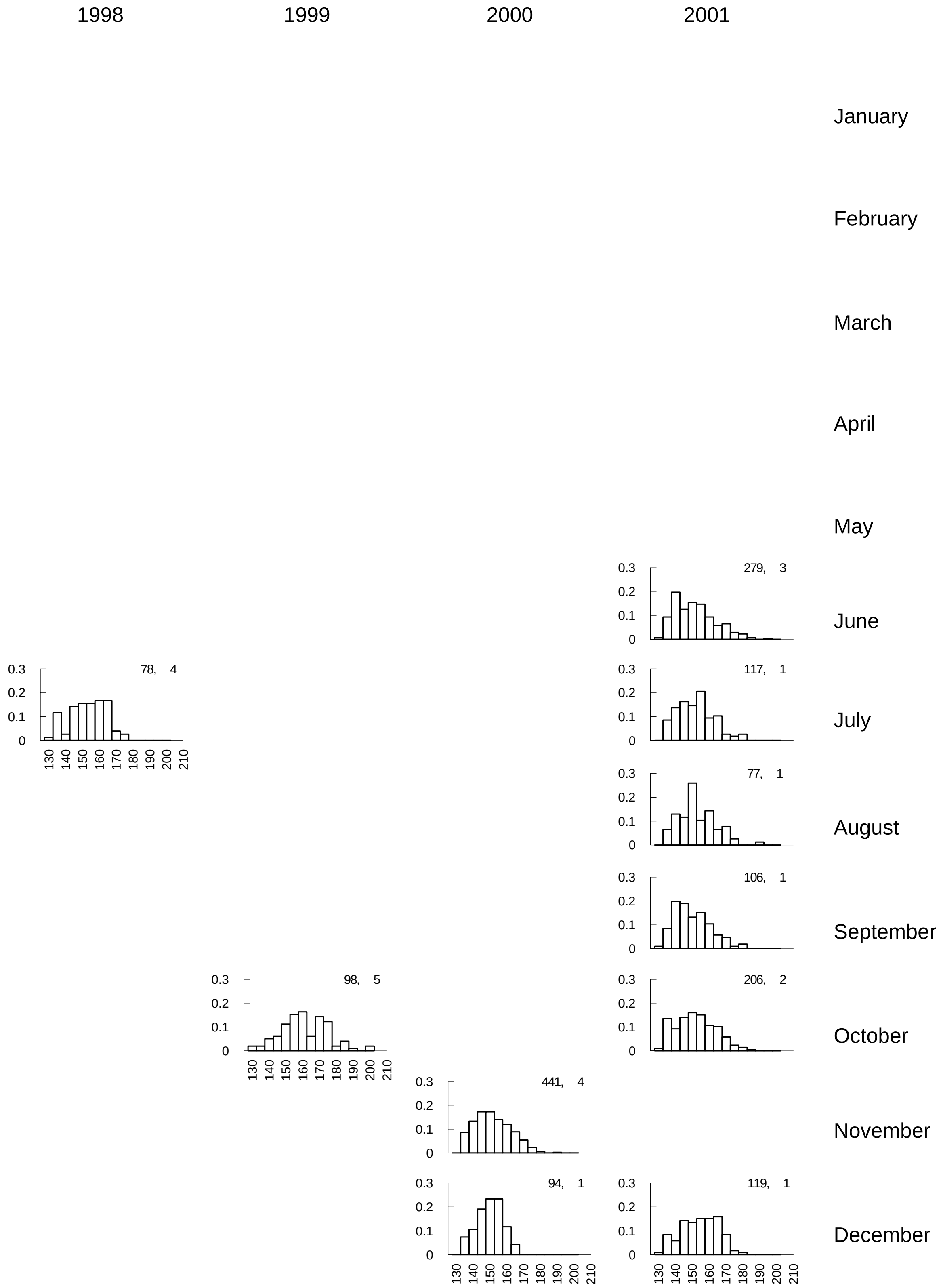
Sub-block 20B



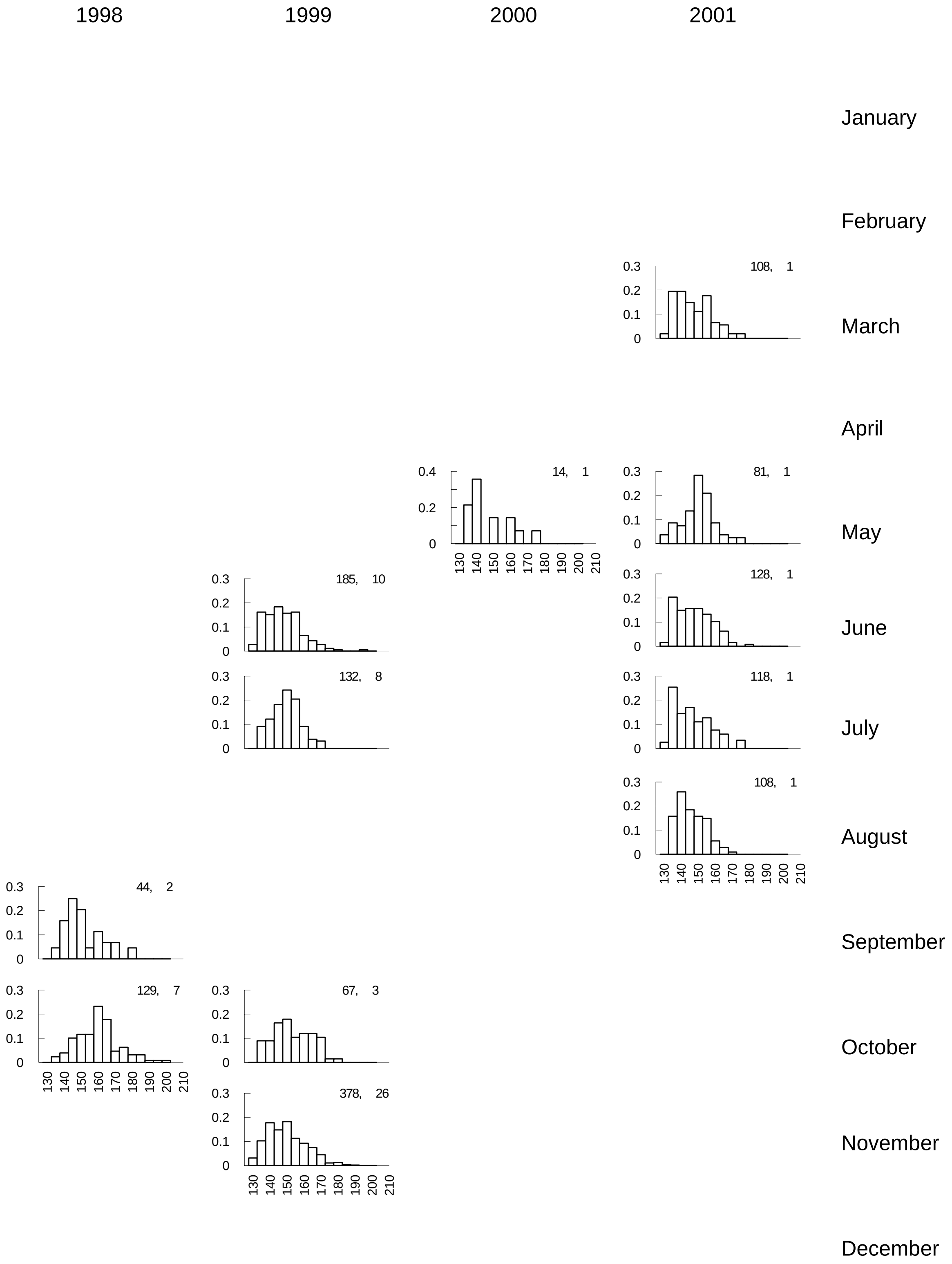
Sub-block 20C



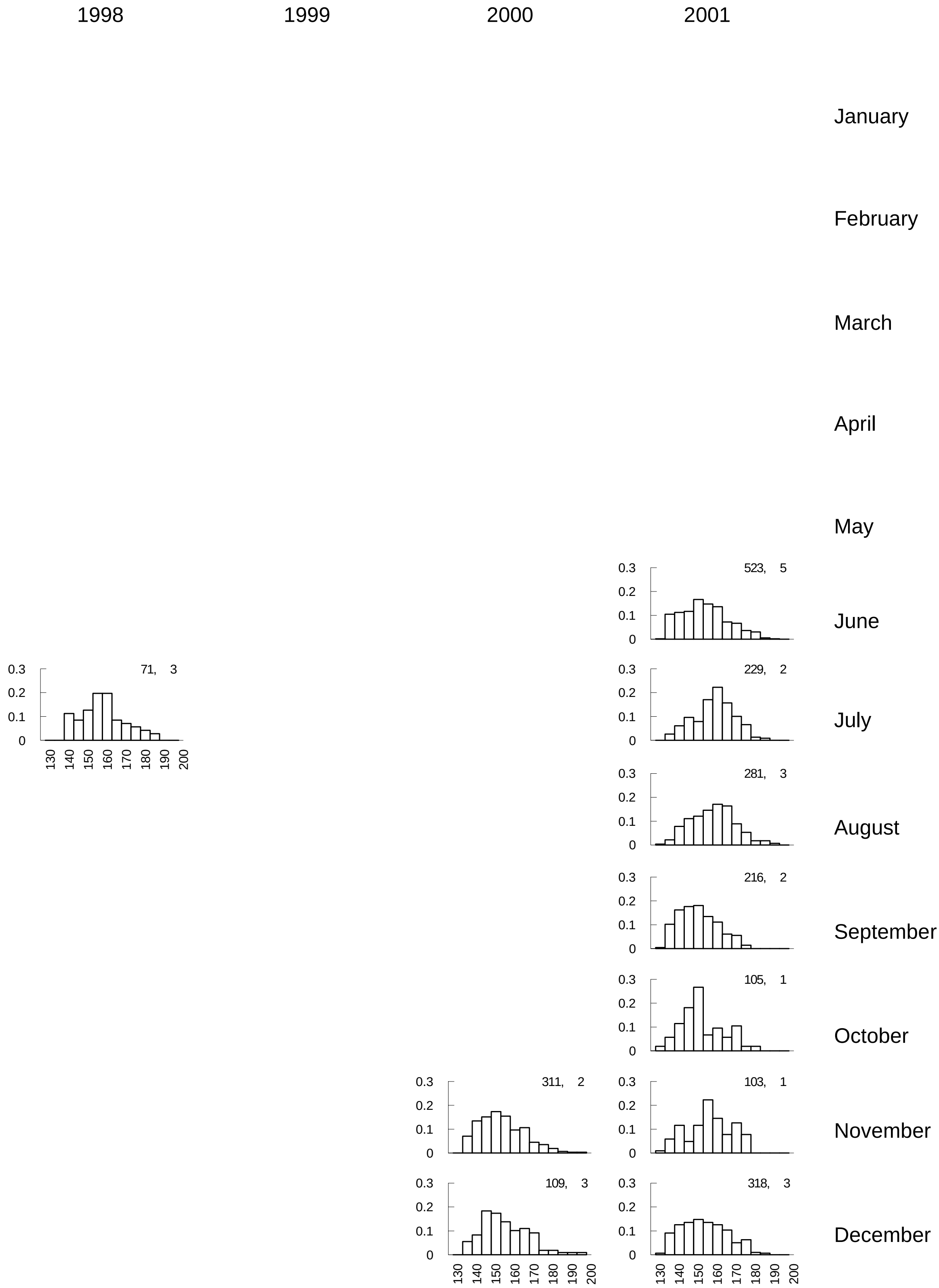
Sub-block 21A



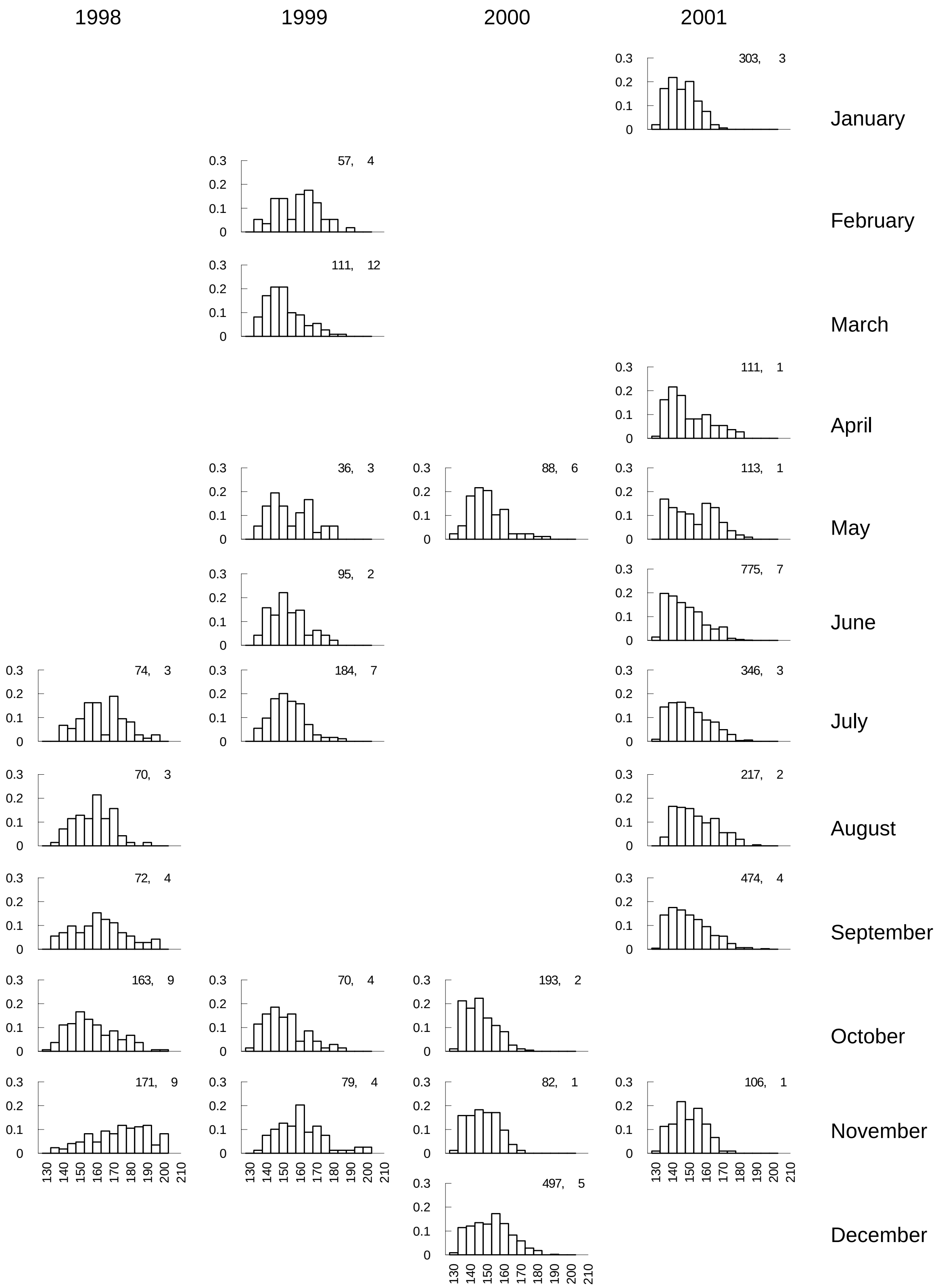
Sub-block 21B



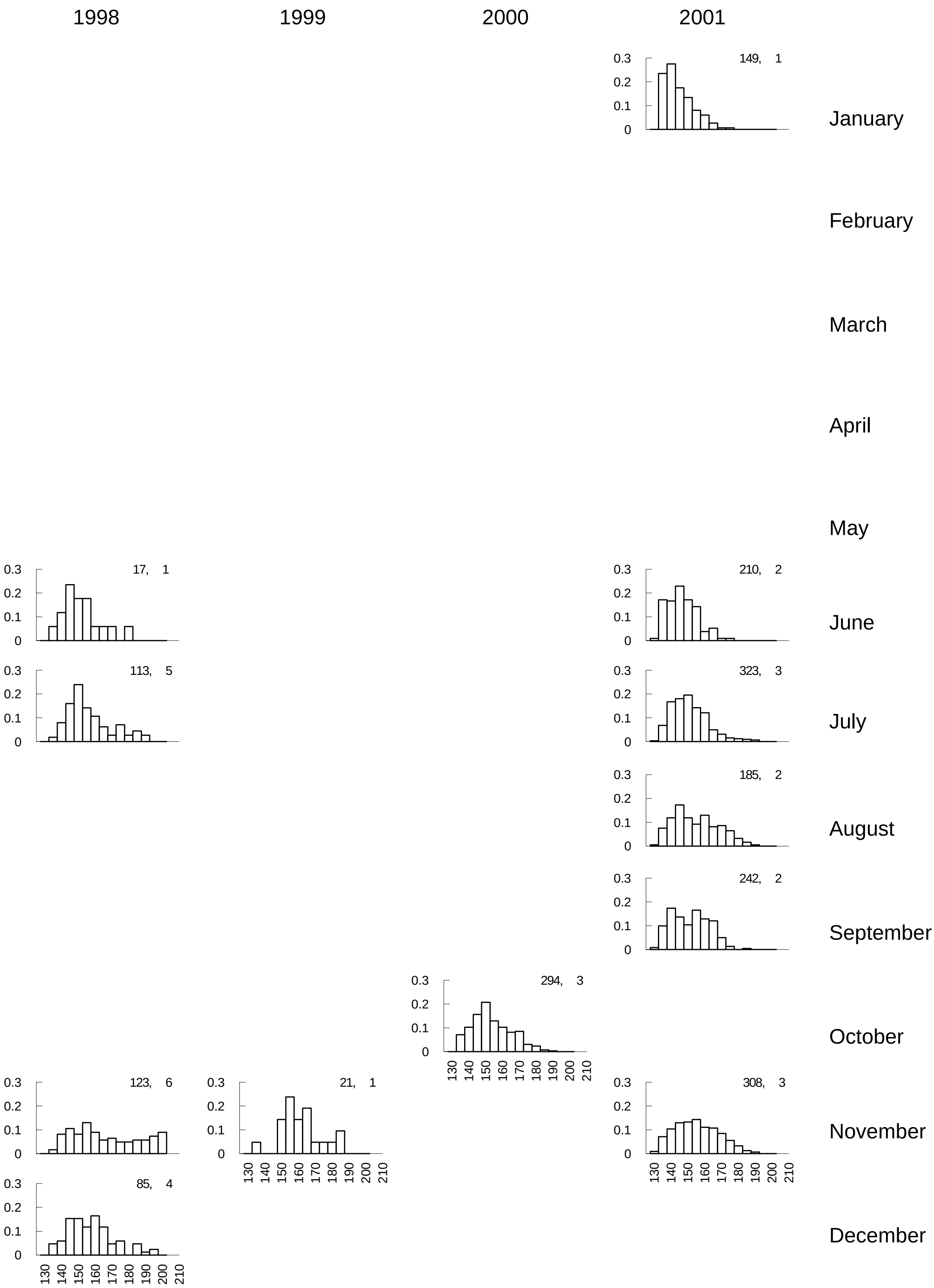
Sub-block 21C



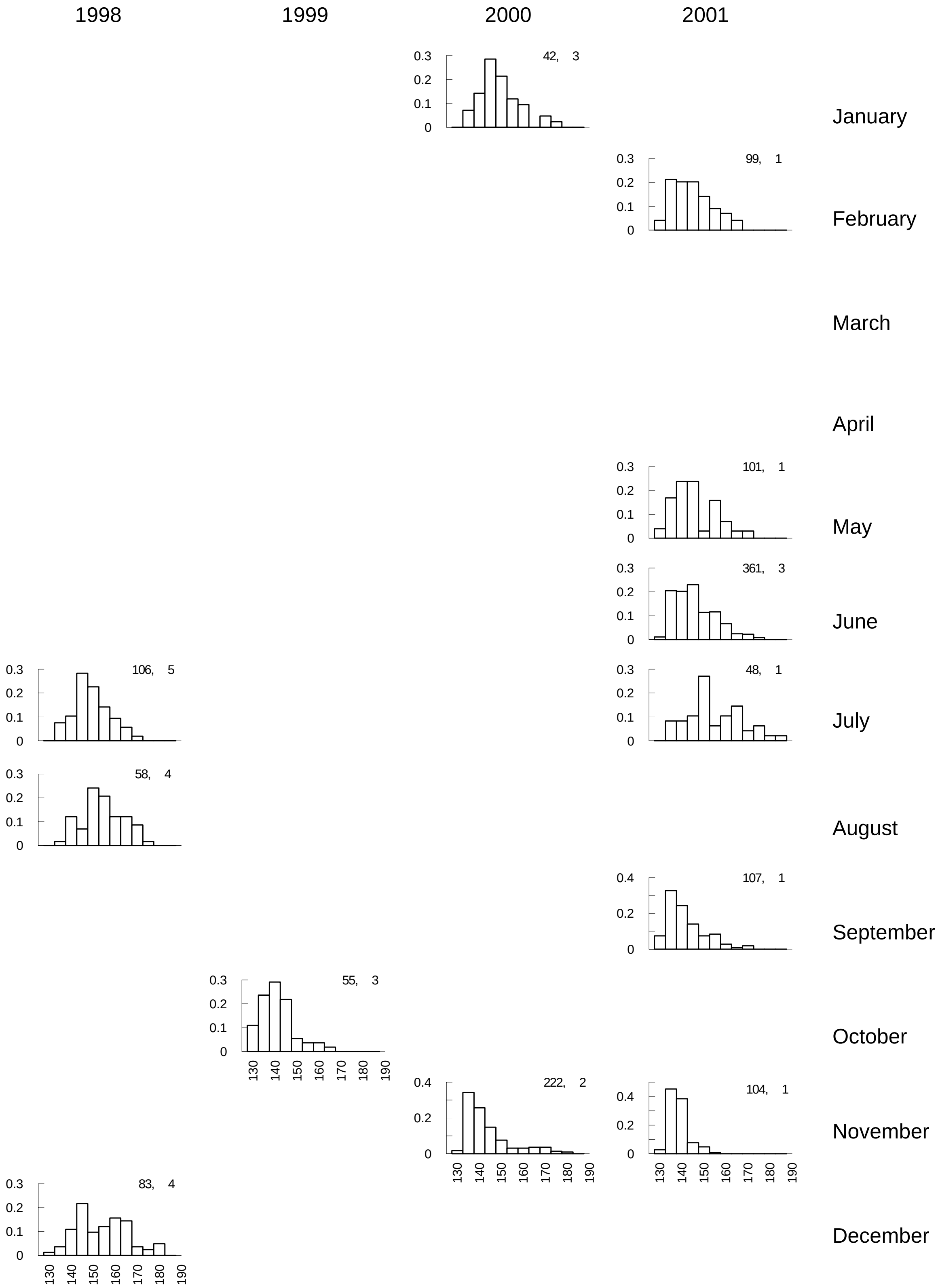
Sub-block 22B



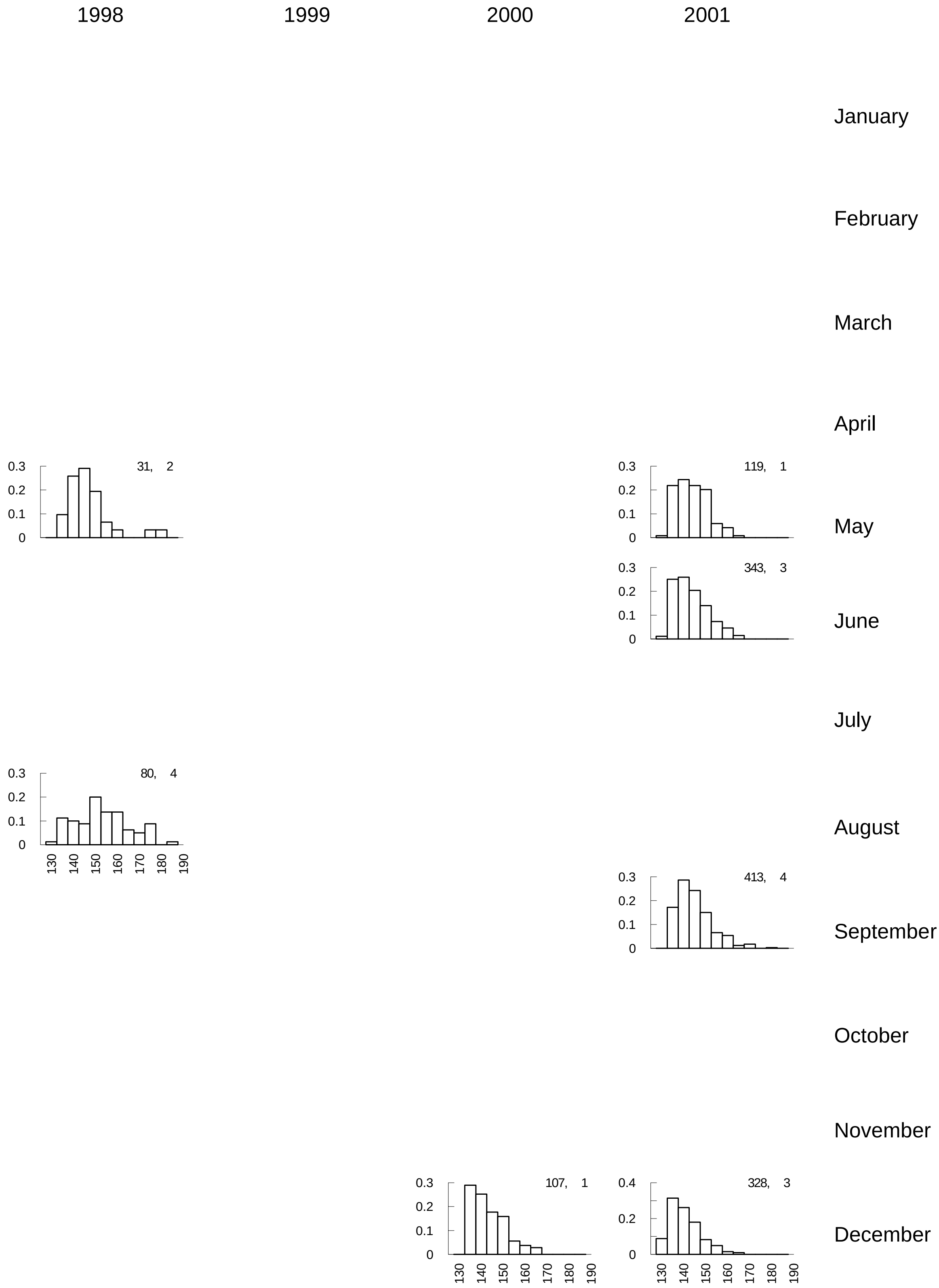
Sub-block 23A



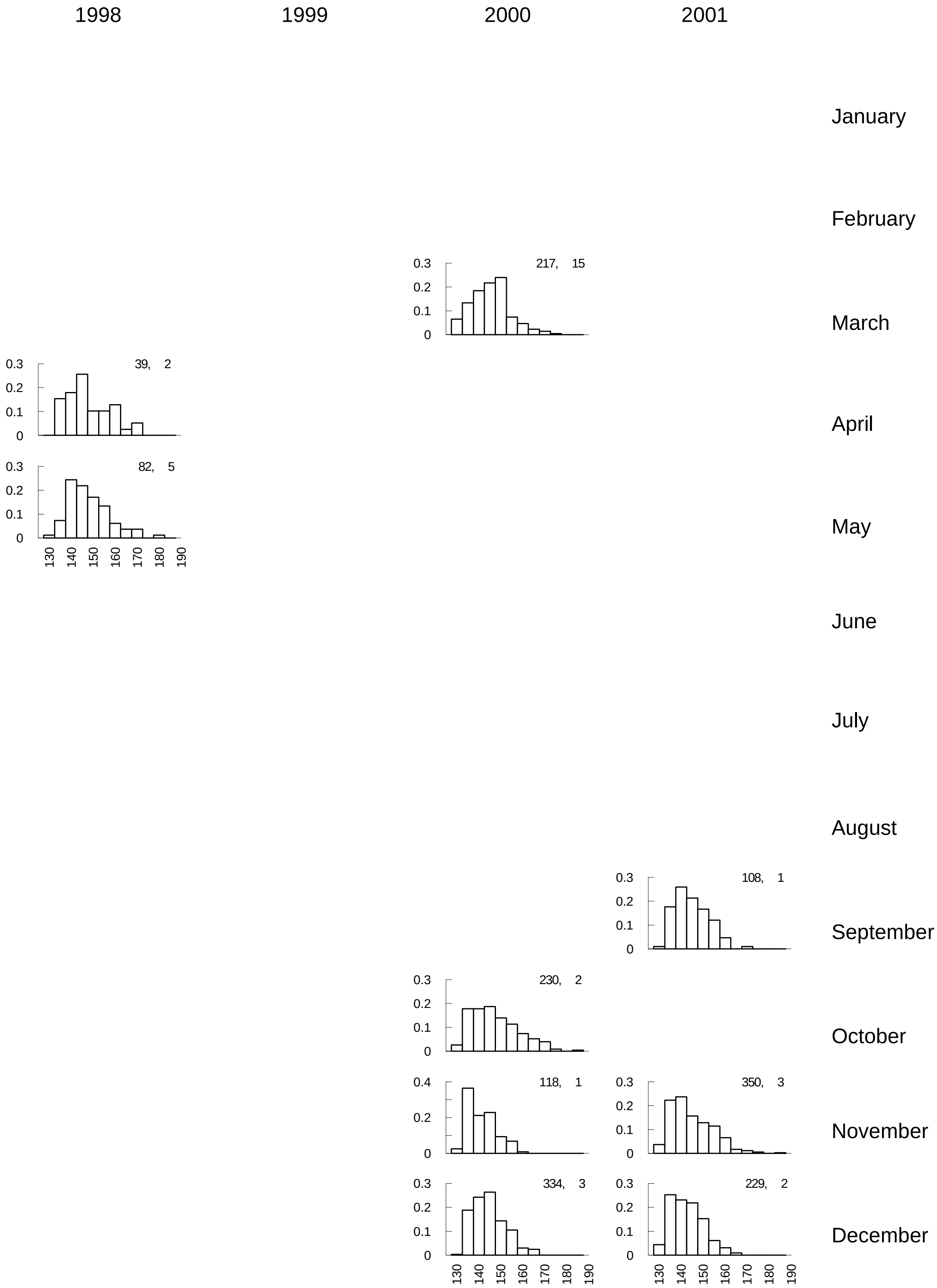
Sub-block 23B



Sub-block 24A

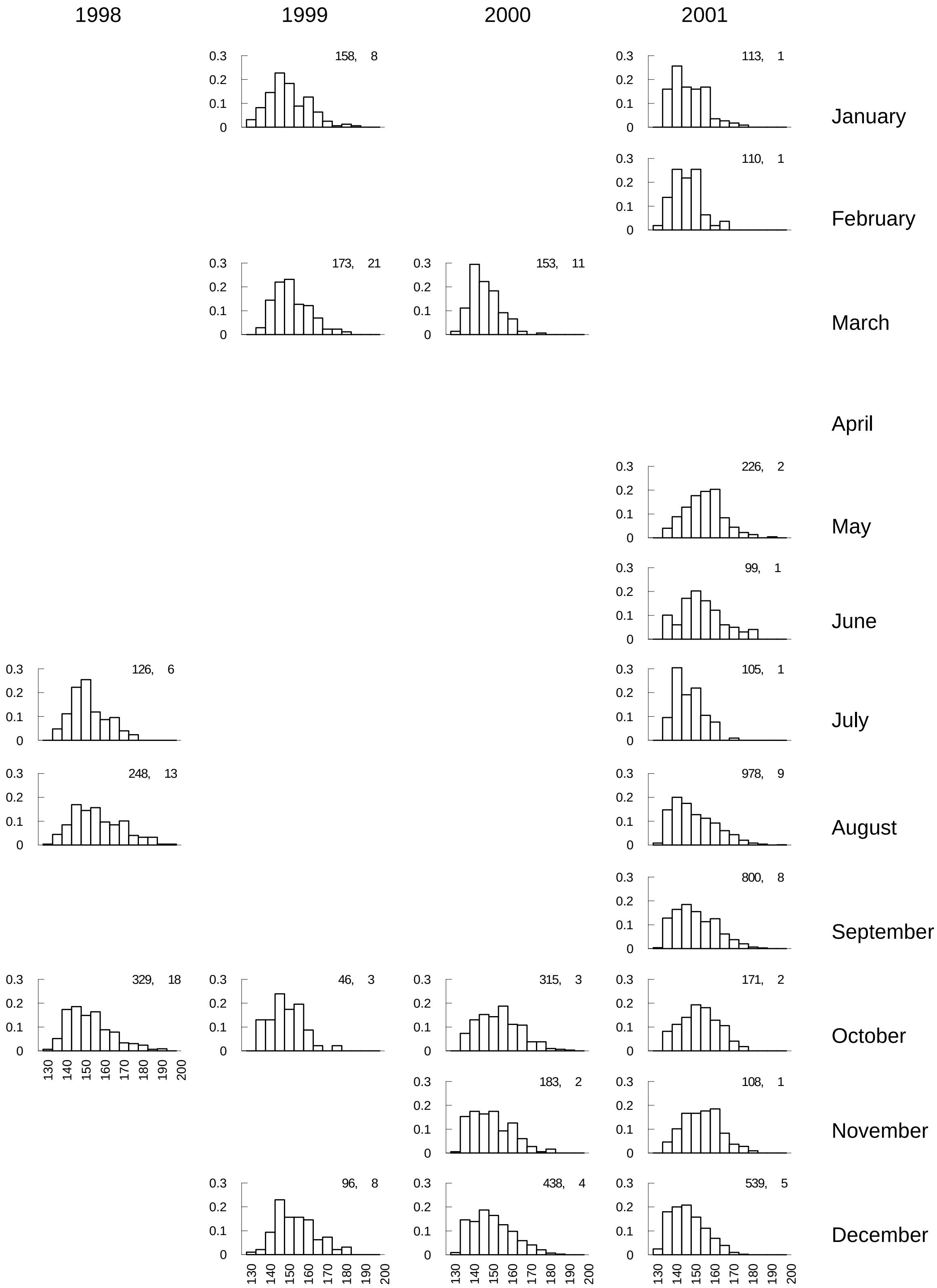


Sub-block 24B



Sub-block 24C

Sub-block 24D



Sub-block 24E

1998 1999 2000 2001

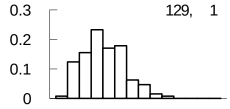
January

February

March

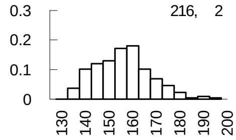
April

May

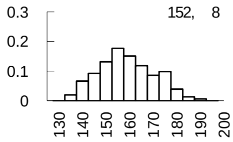


June

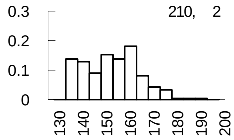
July



August



September

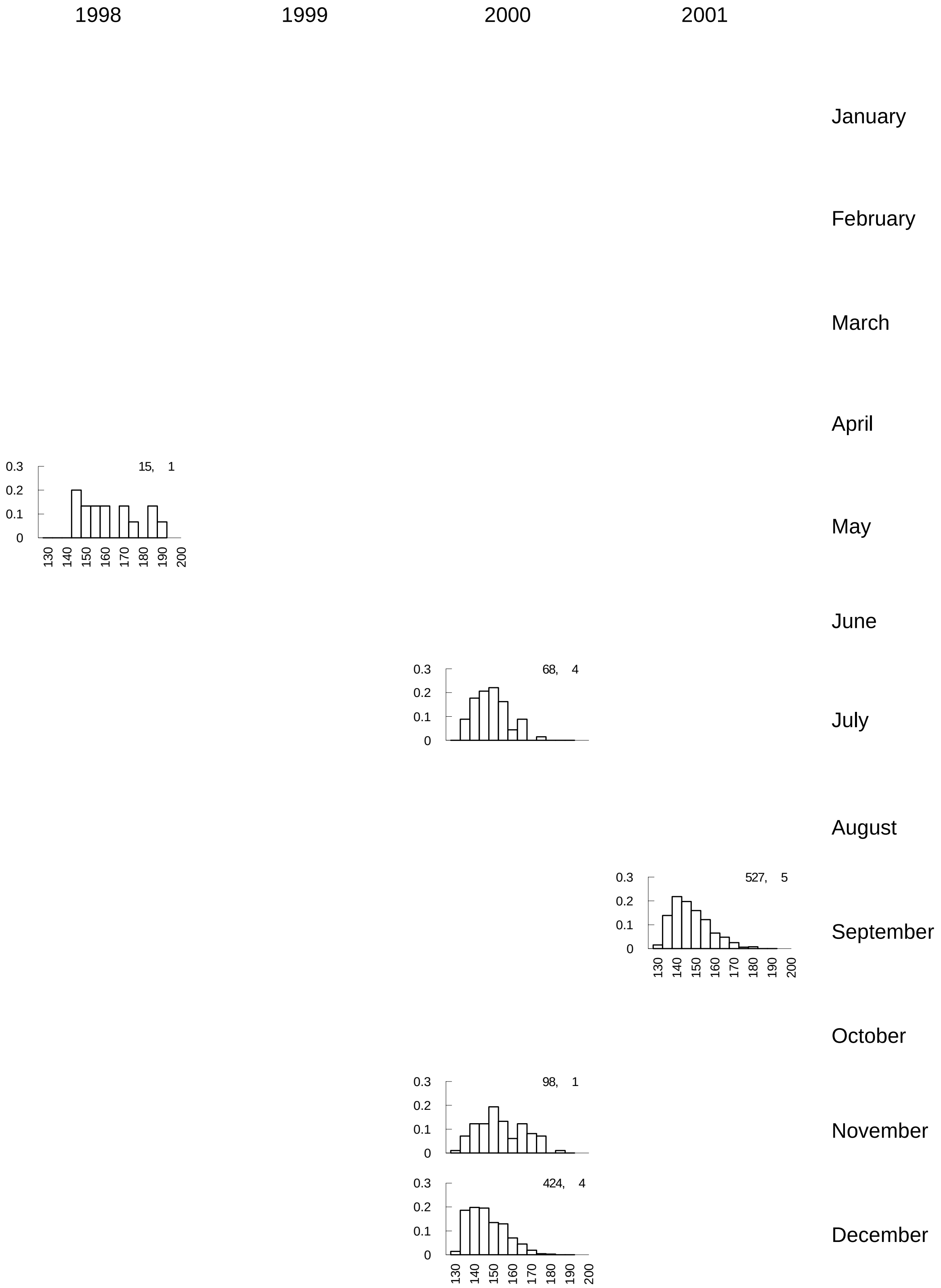


October

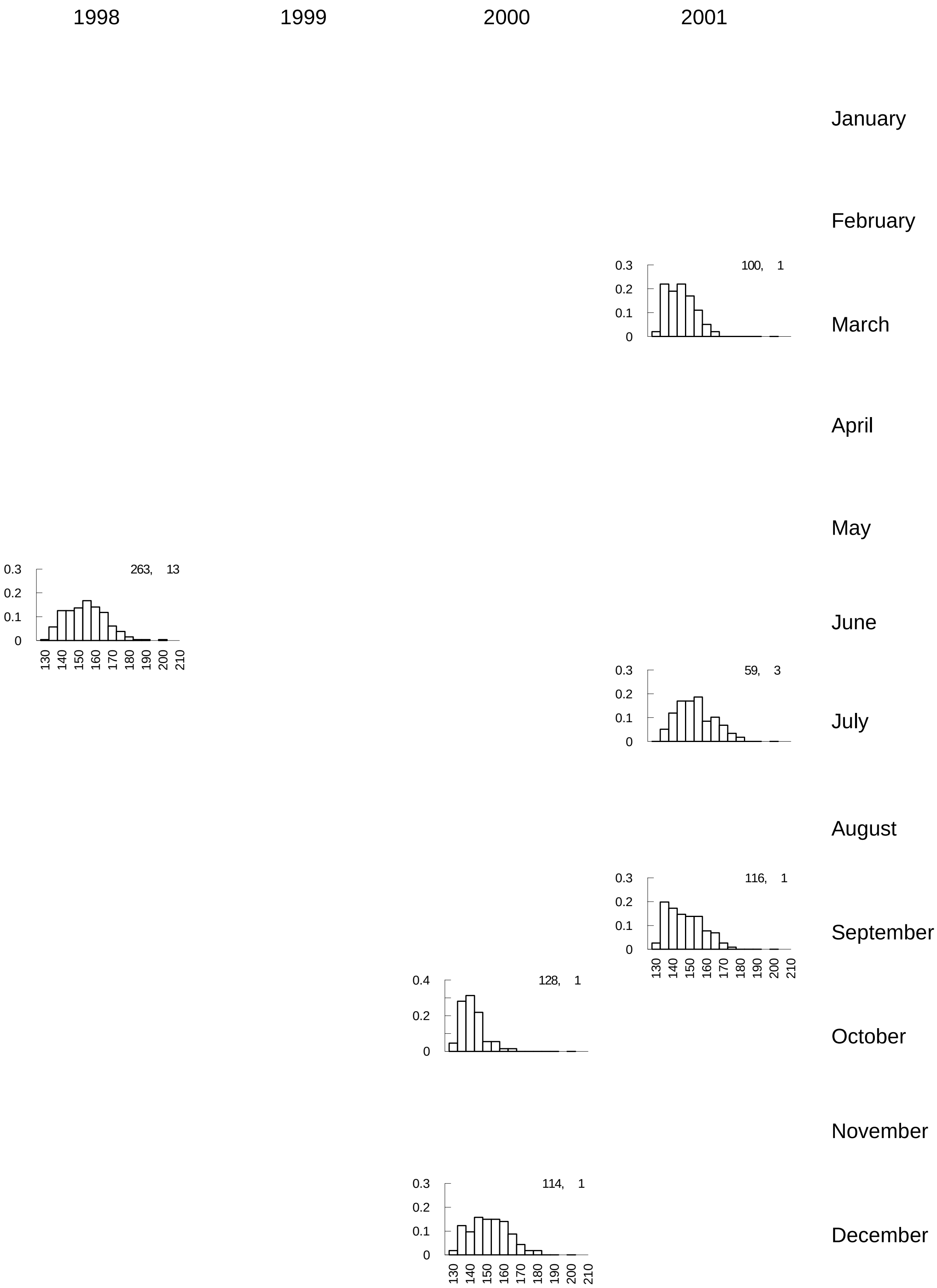
November

December

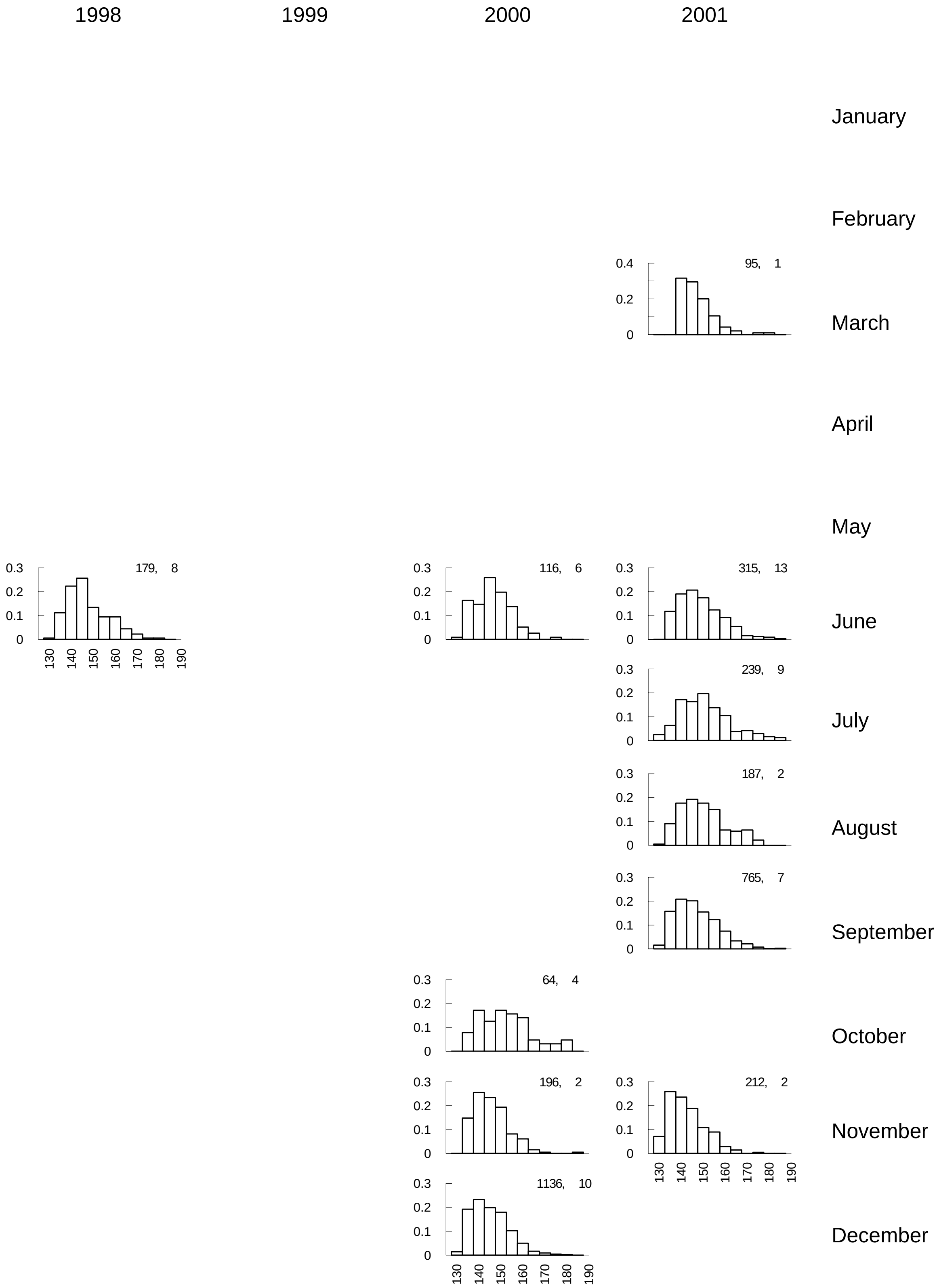
Sub-block 27A



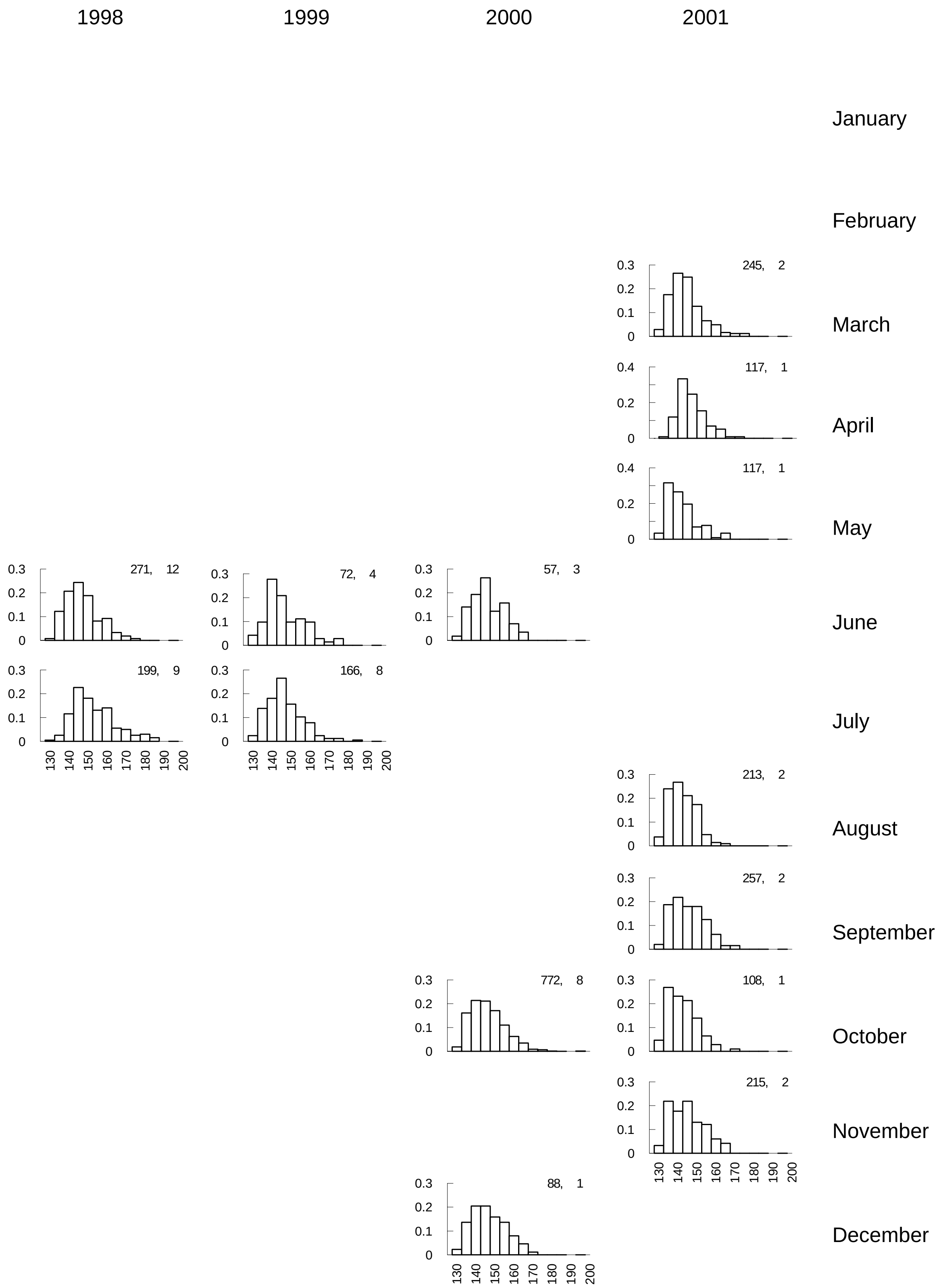
Sub-block 27B



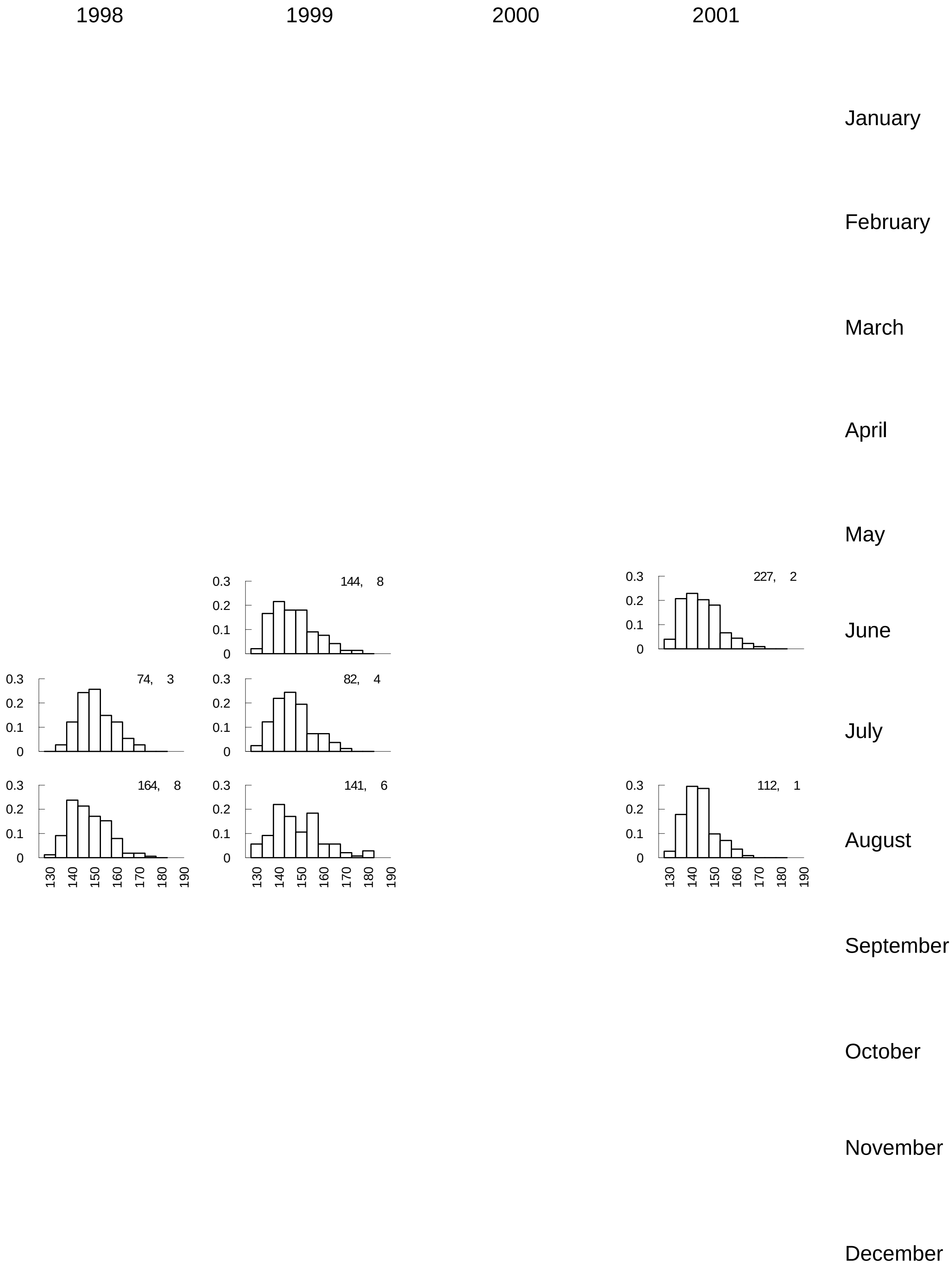
Sub-block 27C



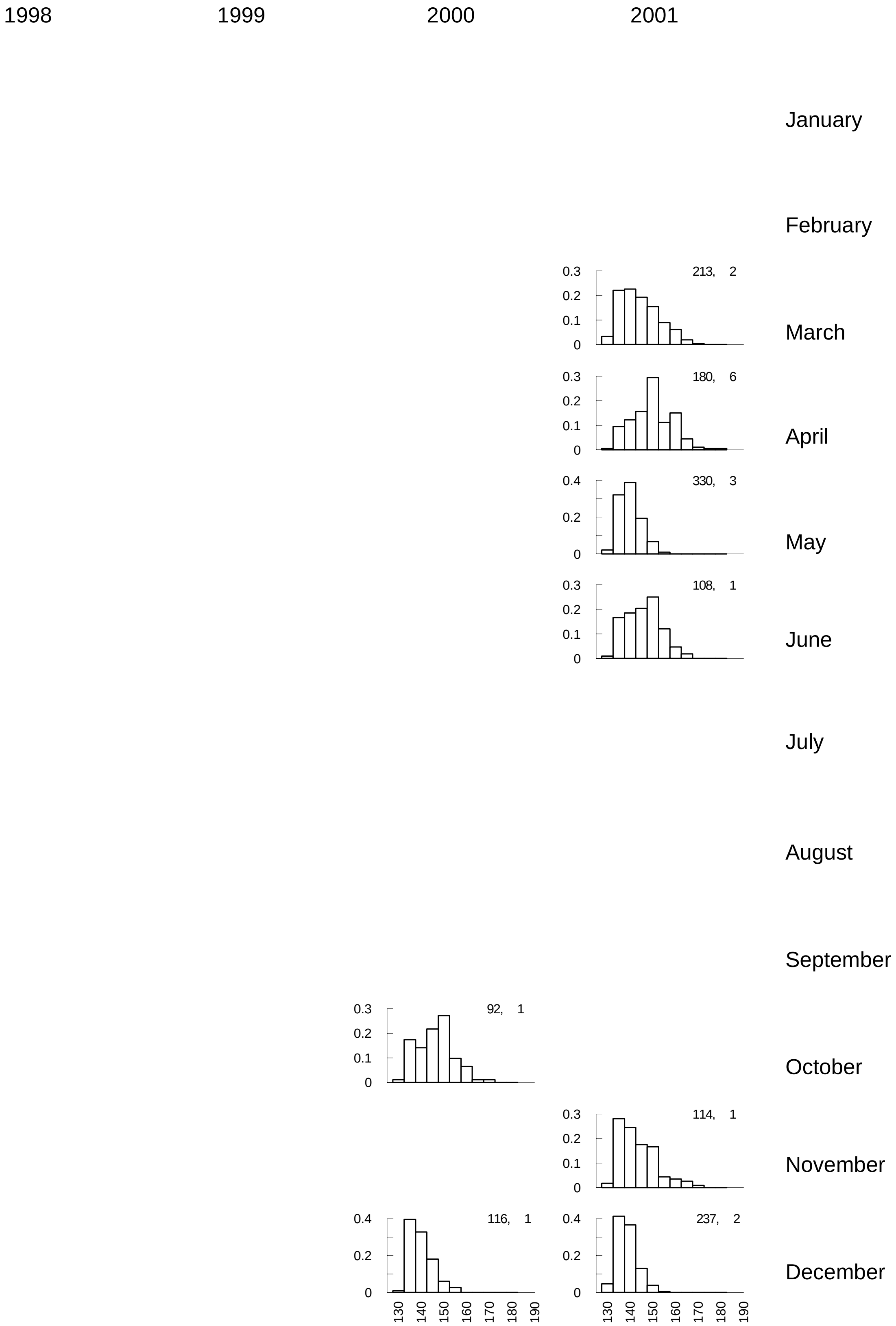
Sub-block 27D



Sub-block 29A



Sub-block 31A



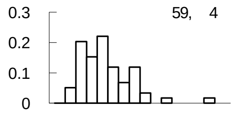
Sub-block 31B

1998 1999 2000 2001

January

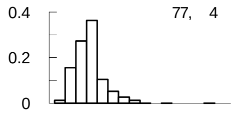
February

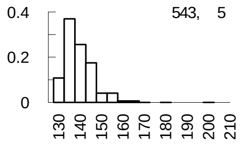
March



April

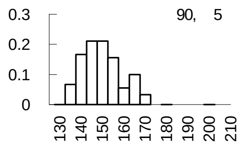
May





June

July



August

September

October

November

December

Sub-block 39A

1998 1999 2000 2001

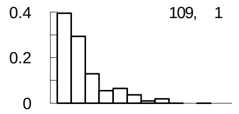
January

February

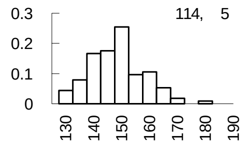
March

April

May



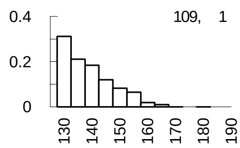
June



July

August

September



October

November

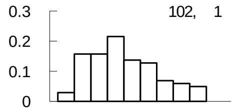
December

Sub-block 48B

1998 1999 2000 2001

January

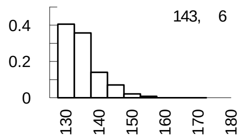
February



March

April

May



June

July

August

September

October

November

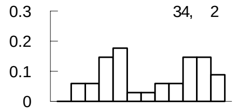
December

Sub-block 49A

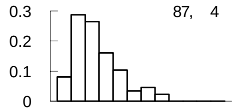
1998 1999 2000 2001

January

February

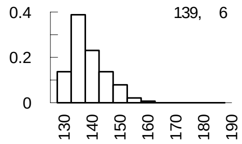


March



April

May

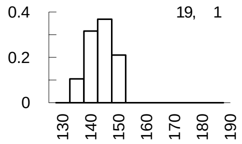


June

July

August

September



October

November

December

Sub-block 49B

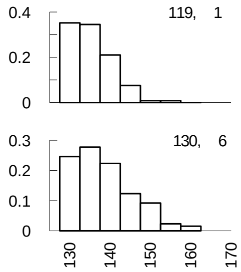
1998 1999 2000 2001

January

February

March

April



May

June

July

August

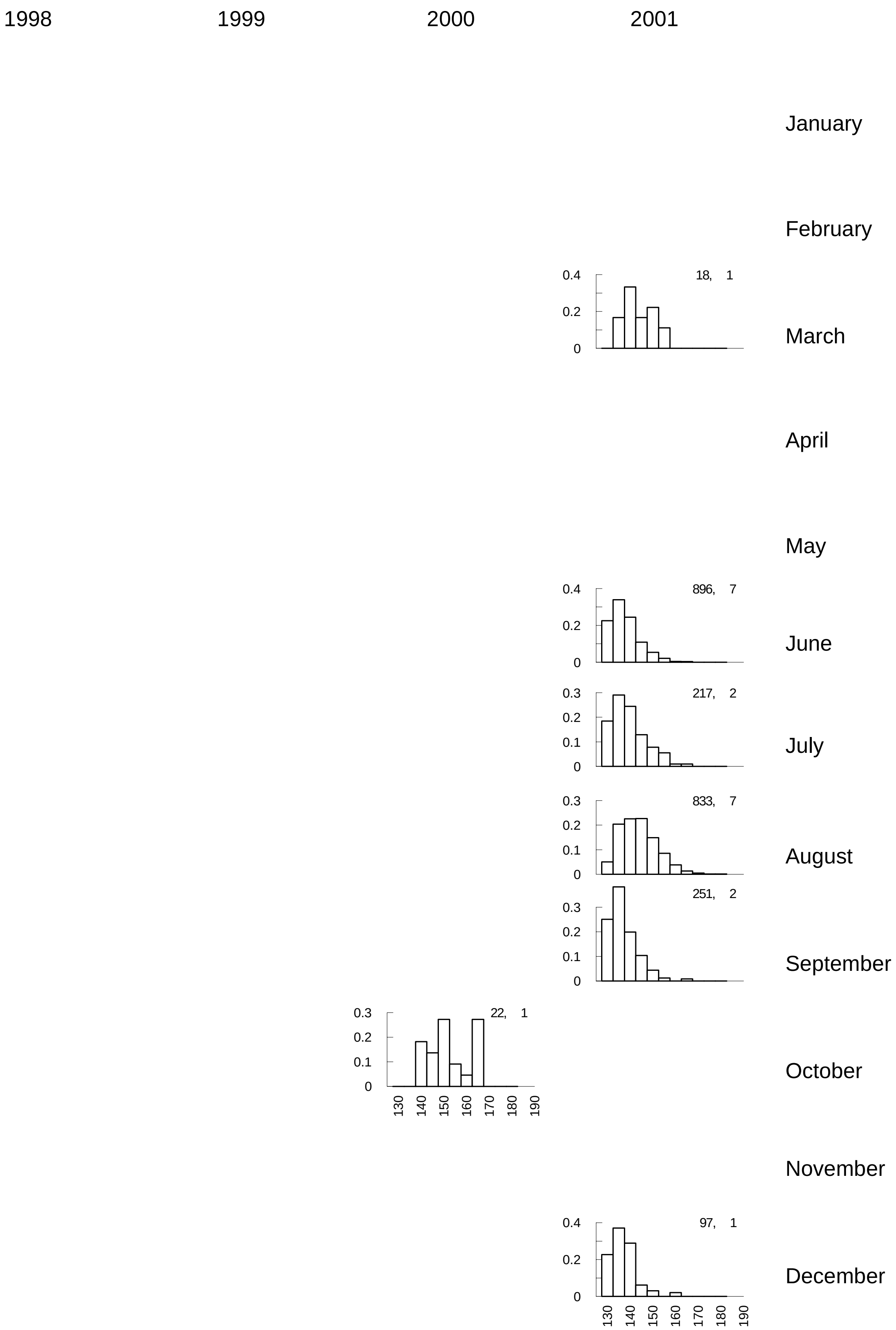
September

October

November

December

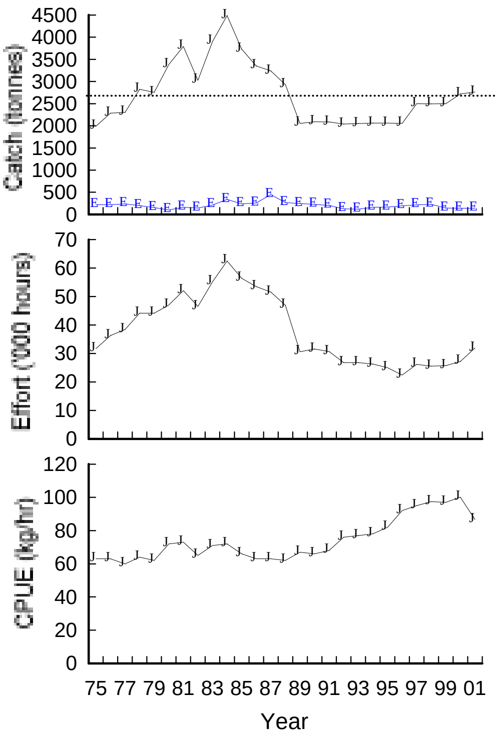
Sub-block 49C



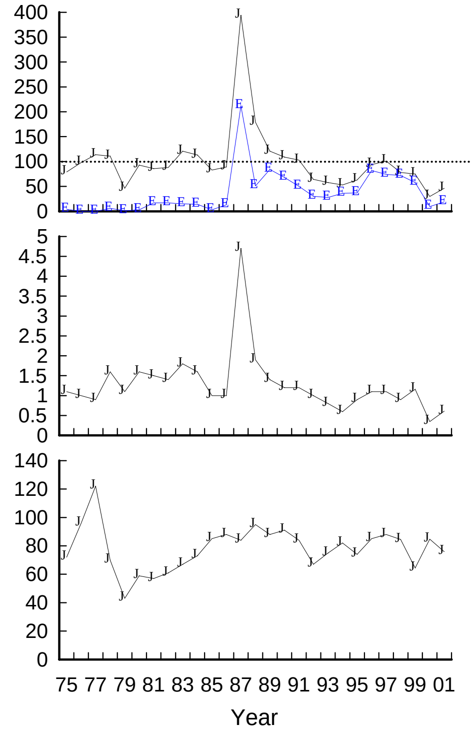
Appendix 7: Abalone Catch, Effort And Catch-Rate (CPUE) By Region And Year.

Where greenlip are caught, catch is plotted (○). Horizontal dotted line shows average total catch.

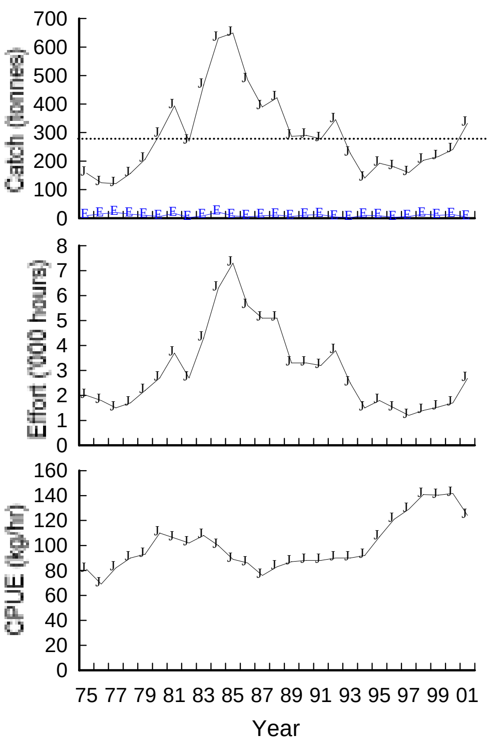
State-wide



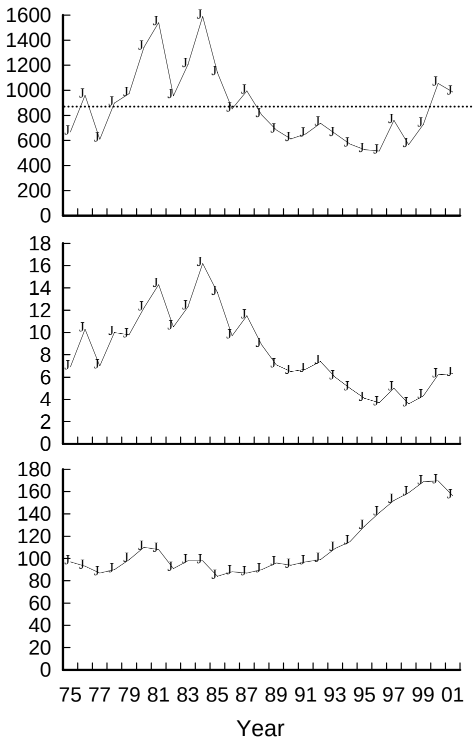
King Island (Blocks 1-4)



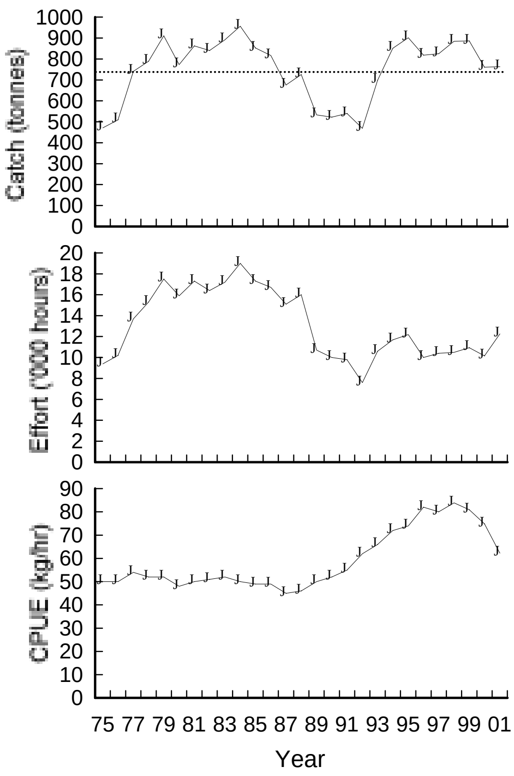
West Coast North (Blocks 5 & 6)



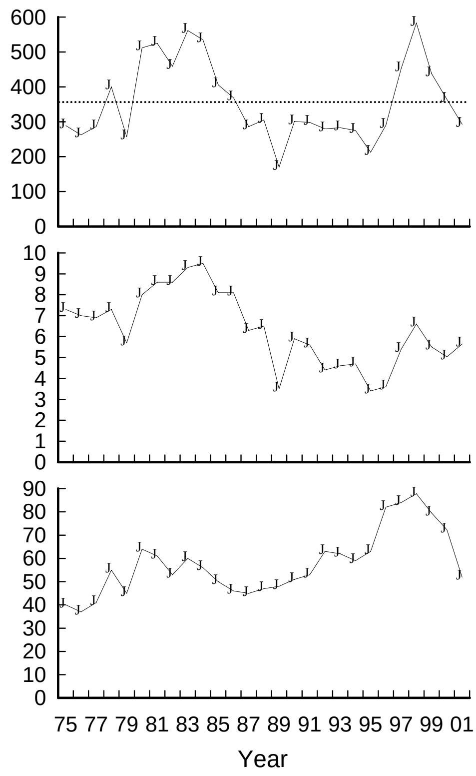
West and South-West (Blocks 7-12)



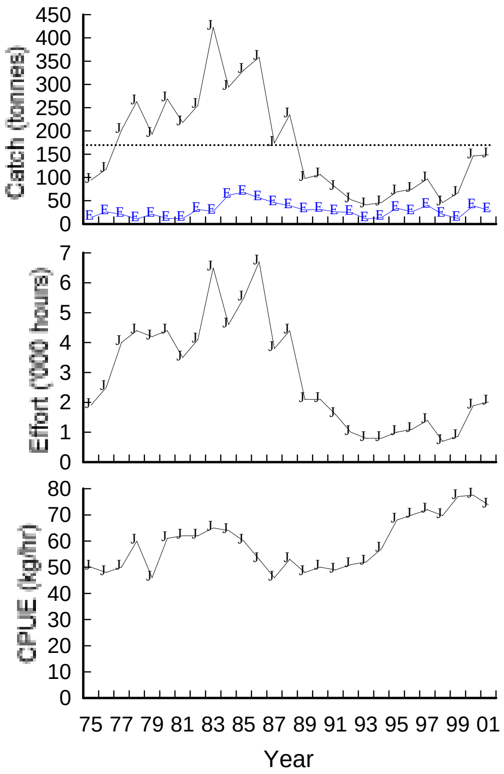
South East (Blocks 13-21)



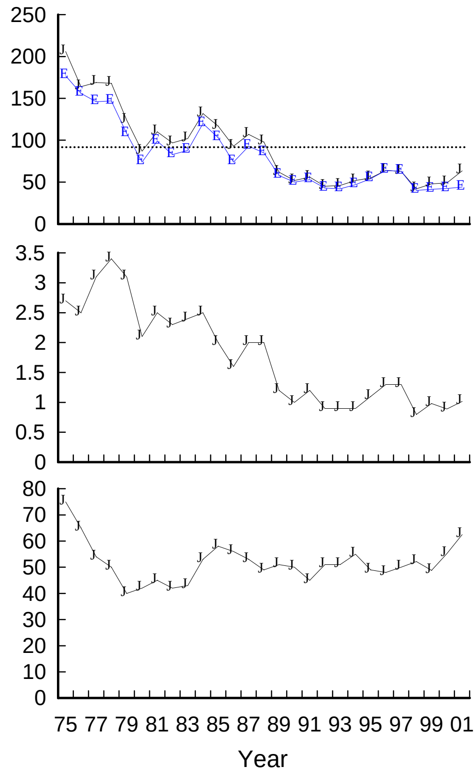
East Coast (Blocks 22-29)

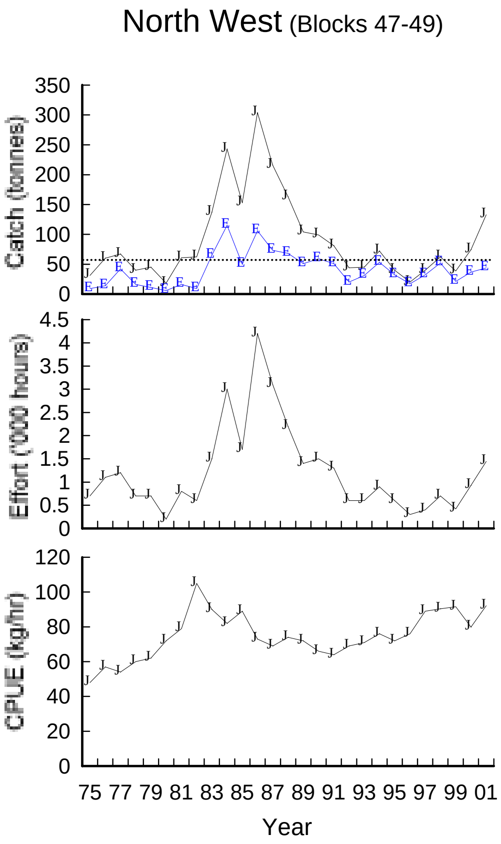


North East (Blocks 30, 31, 39 & 40)



Furneaux Group (Blocks 32-38)

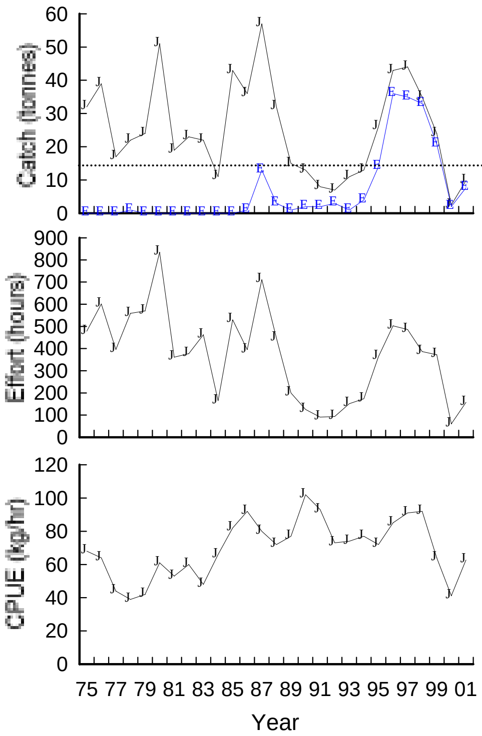



North West (Blocks 47-49)
Catch (tonnes)
350
300
250
200
150
100
50
0
Effort ('000 hours)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
CPUE (kg/hr)
120
100
80
60
40
20
0
75 77 79 81 83 85 87 89 91 93 95 97 99 01
Year

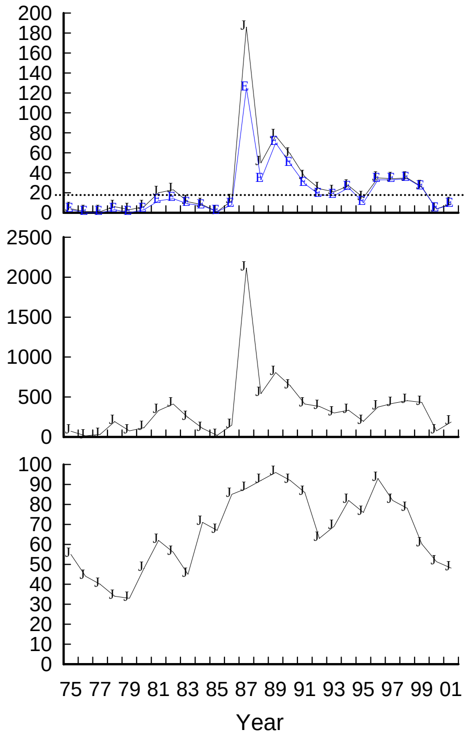
Appendix 8: Abalone Catch, Effort And Catch-Rate (CPUE) By Block And Year.

Where greenlip are caught, catch is plotted (○). Horizontal dotted line shows average total catch.

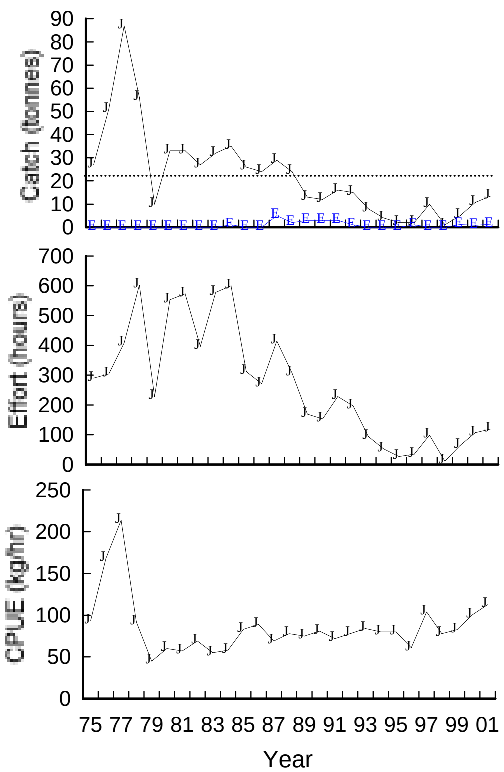
Block 1 (King Island)



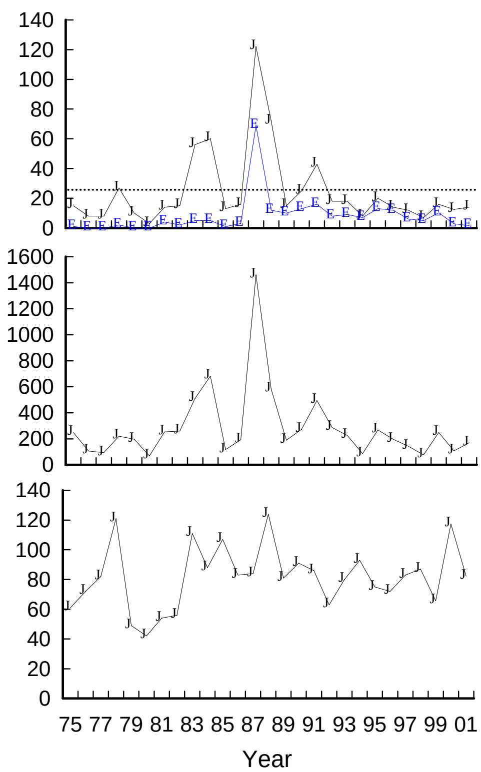
Block 2 (King Island)

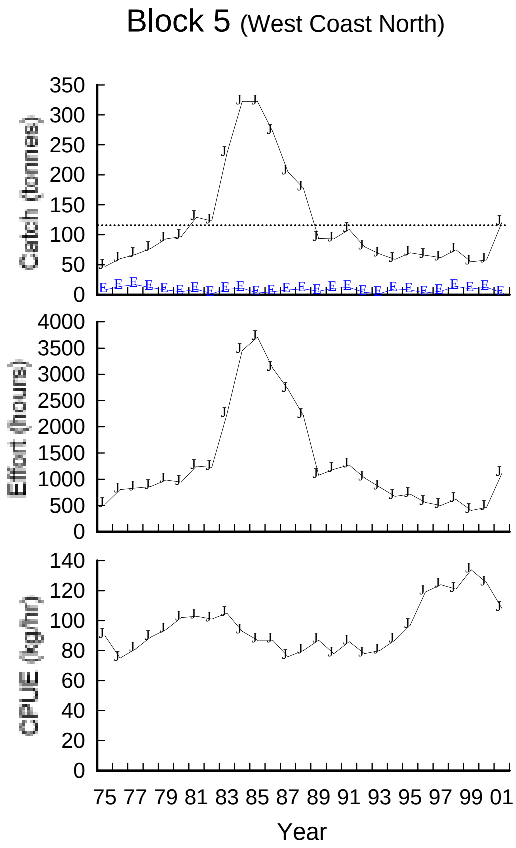


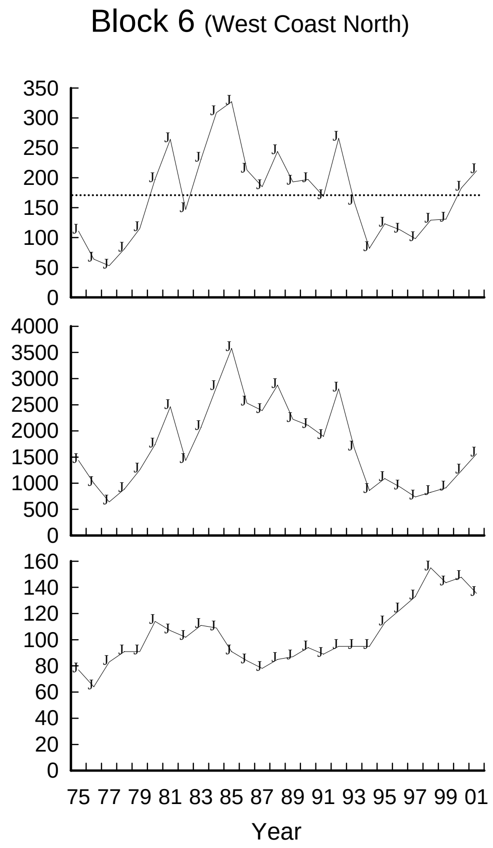
Block 3 (King Island)

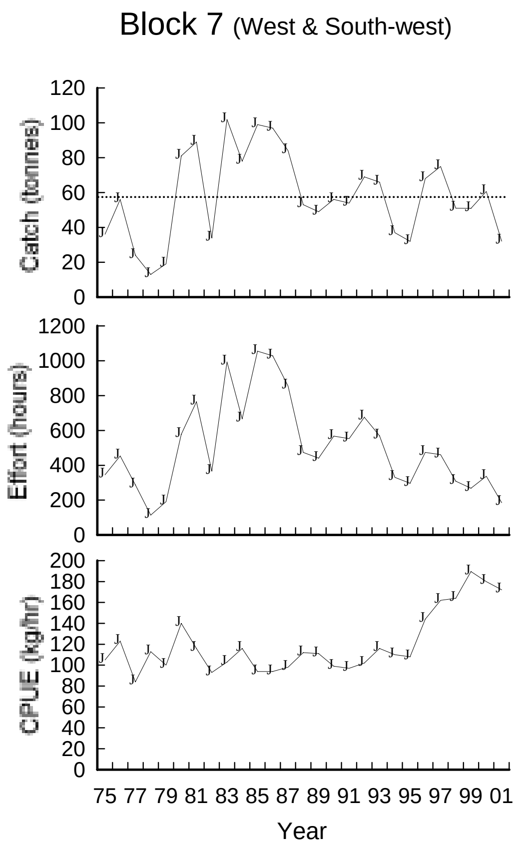


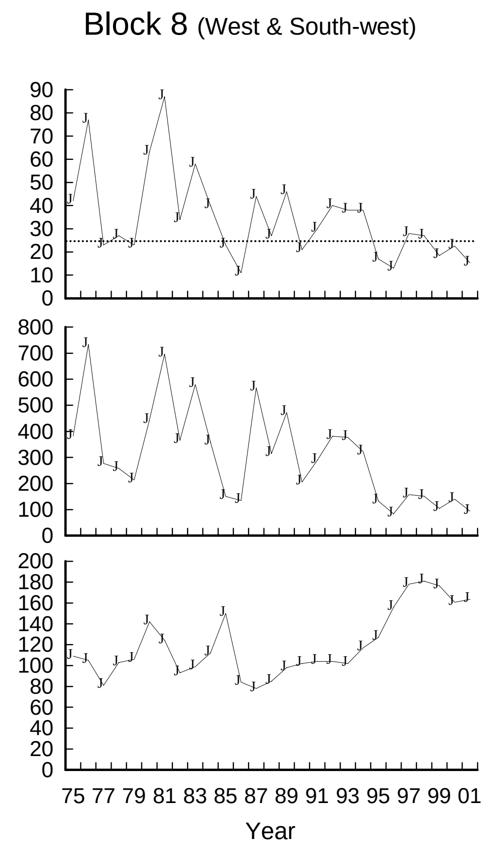
Block 4 (King Island)



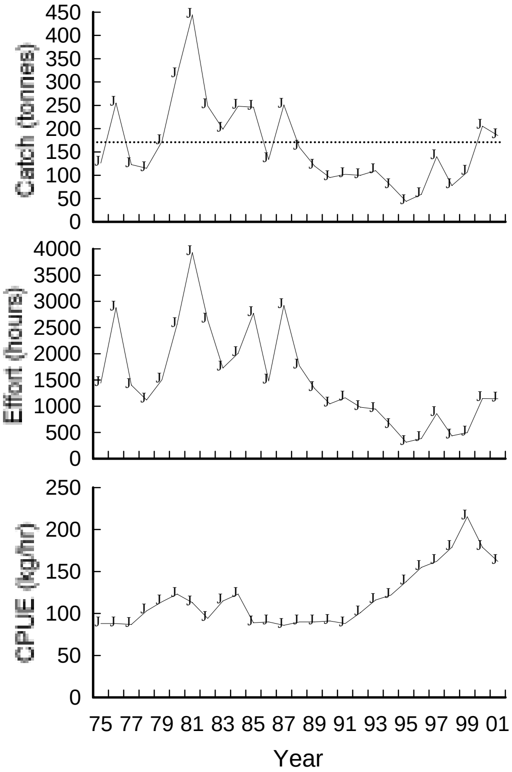

Block 5 (West Coast North)
Catch (tonnes)
Effort (hours)
CPUE (kg/hr)
Year


Block 6 (West Coast North)
Year

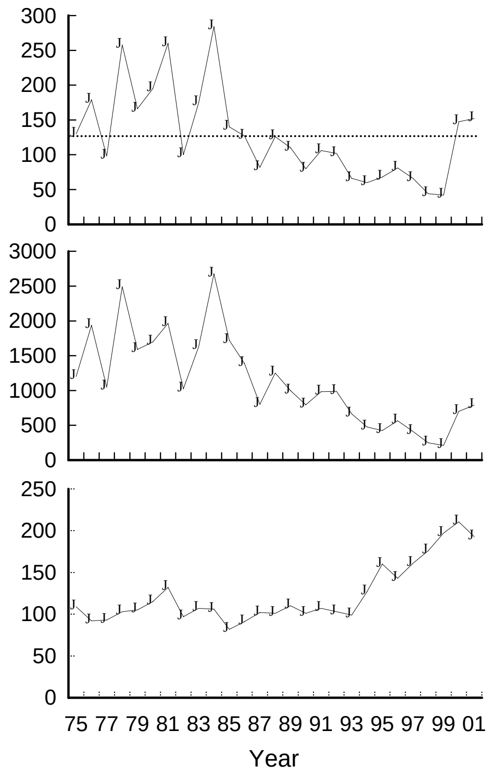

Block 7 (West & South-west)
Catch (tonnes)
Effort (hours)
CPUE (kg/hr)
Year


Block 8 (West & South-west)
Year

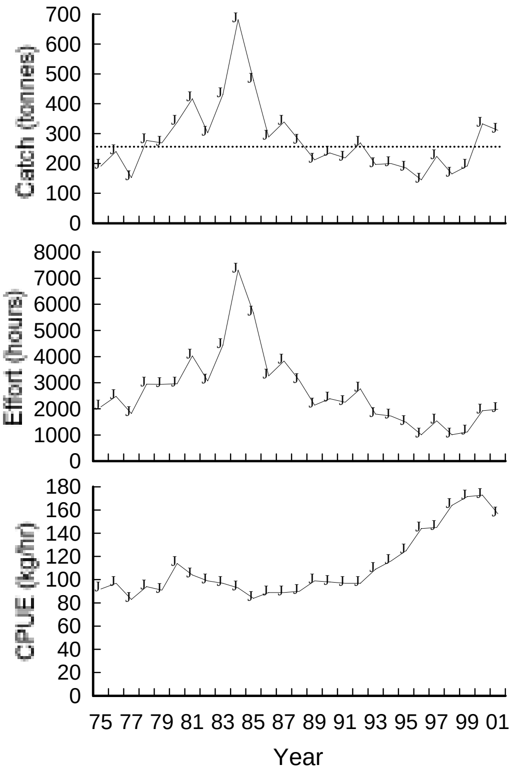
Block 9 (West & South-west)



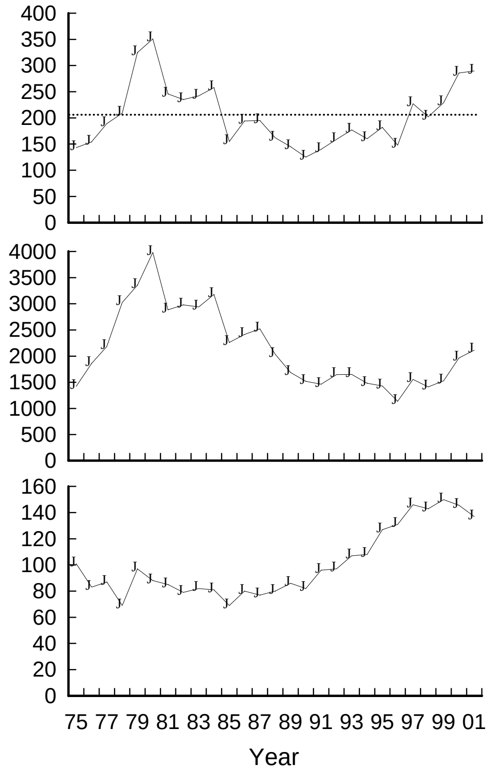
Block 10 (West & South-west)



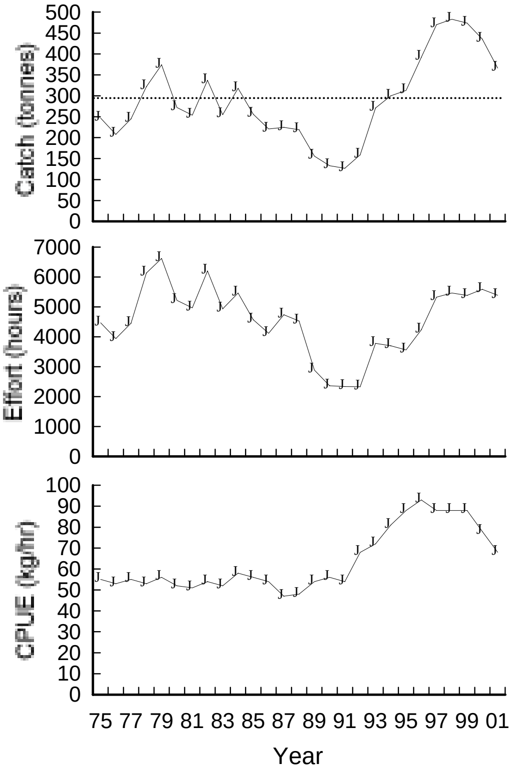
Block 11 (West & South-west)



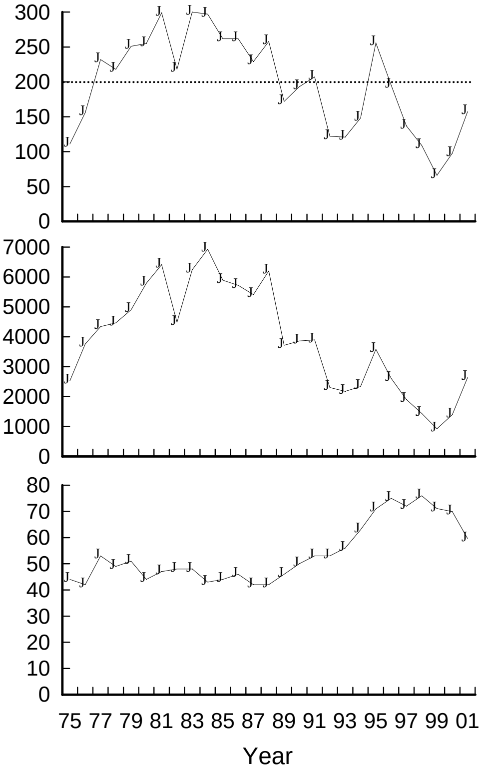
Block 12 (West & South-west)



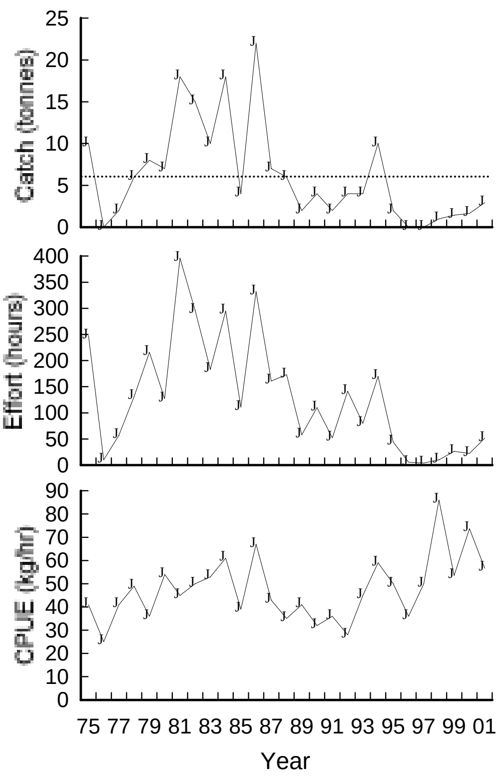
Block 13 (South East)



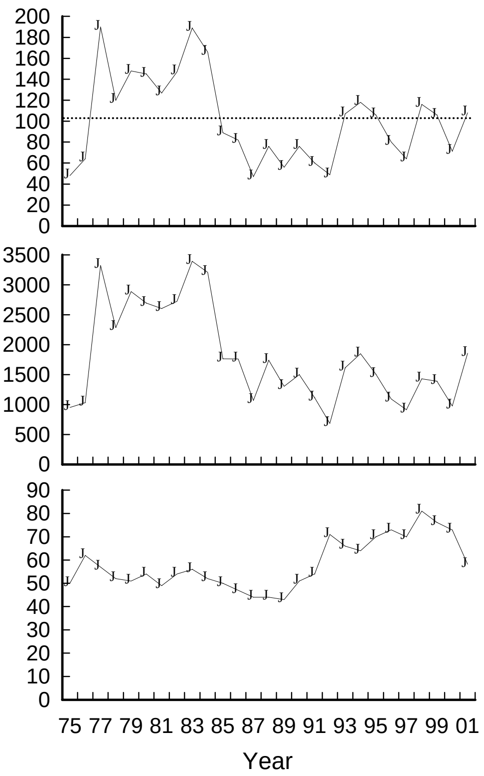
Block 14 (South East)



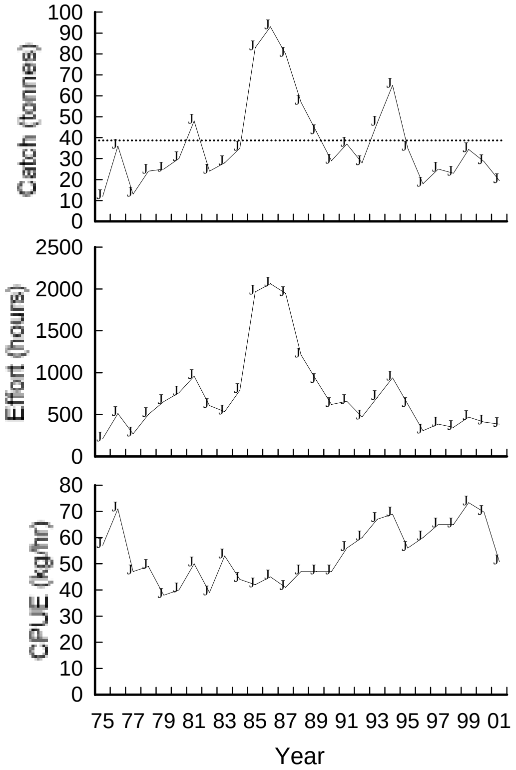
Block 15 (South East)



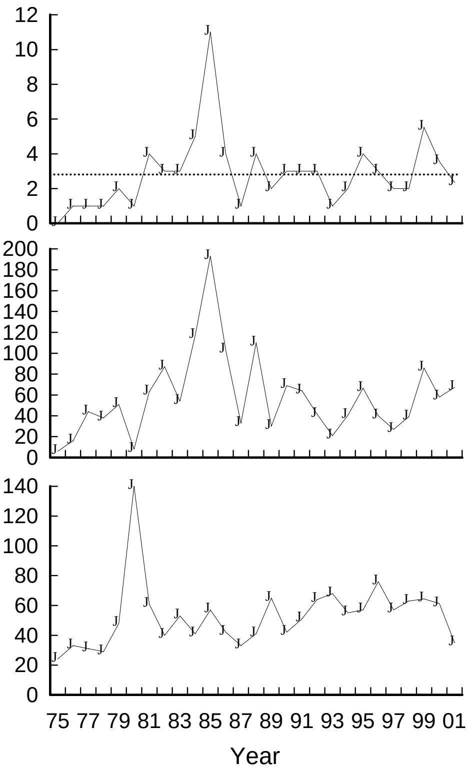
Block 16 (South East)



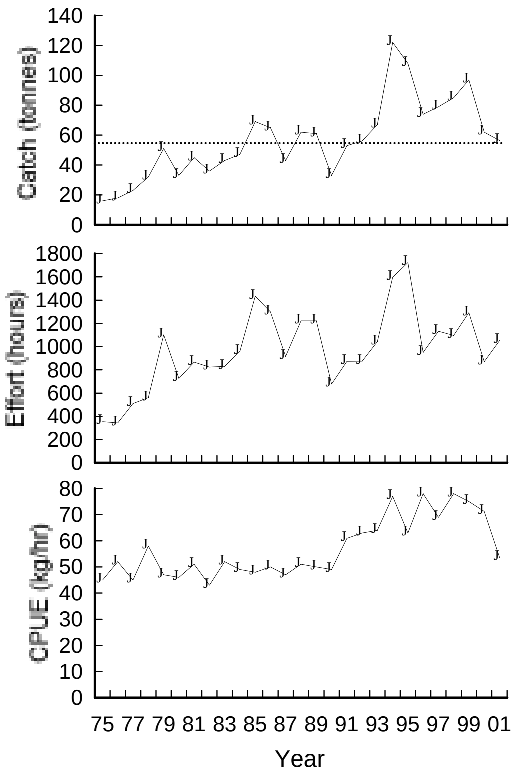
Block 17 (South East)



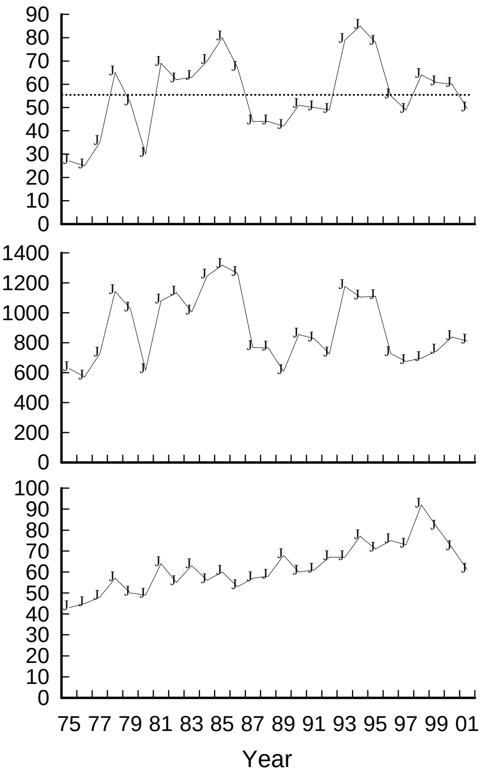
Block 19 (South East)



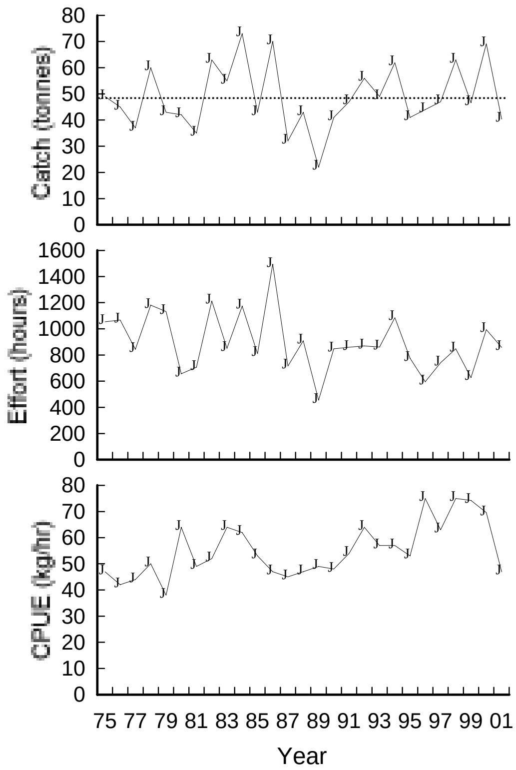
Block 20 (South East)



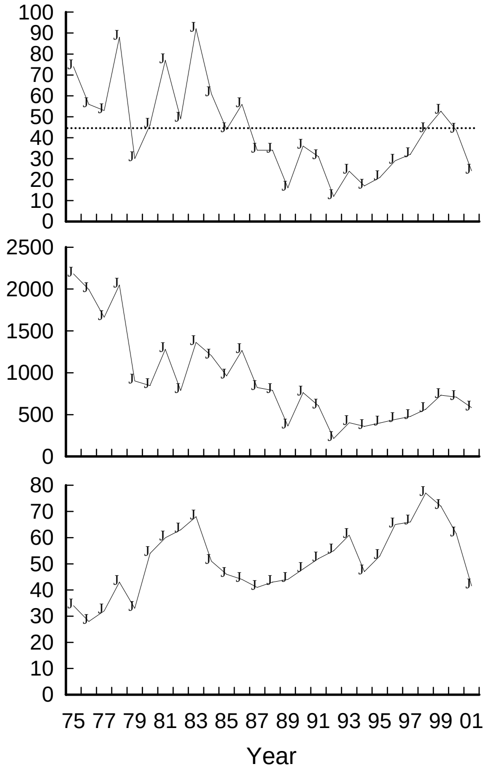
Block 21 (South East)



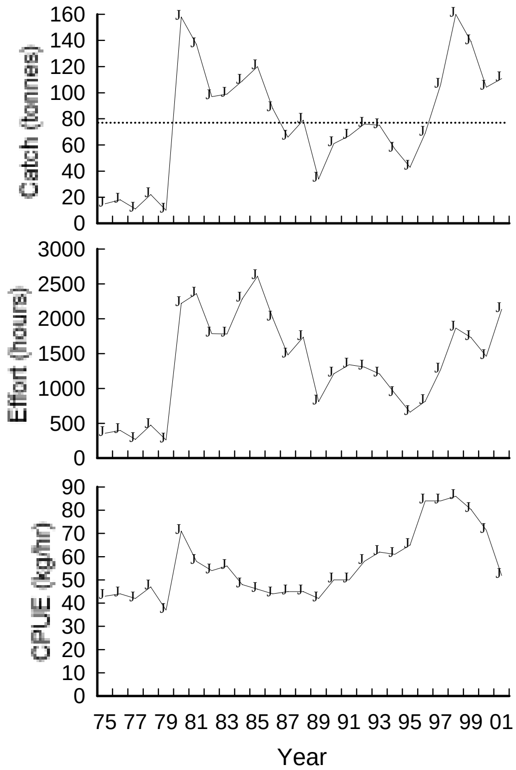
Block 22 (East Coast)



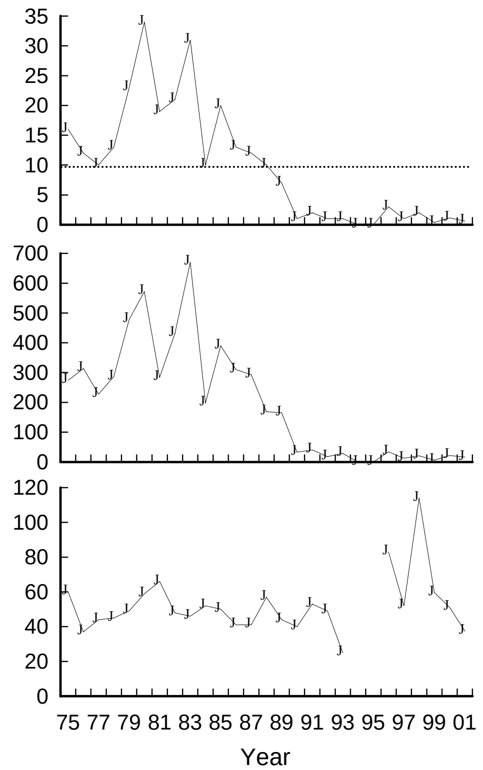
Block 23 (East Coast)

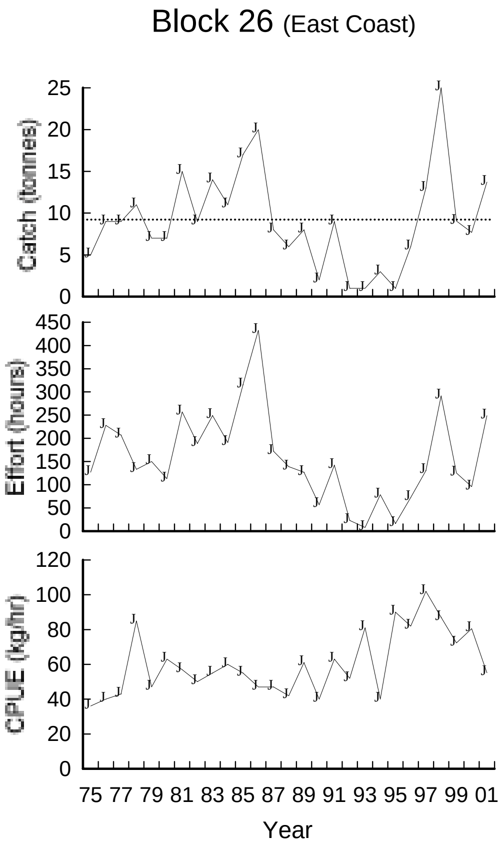


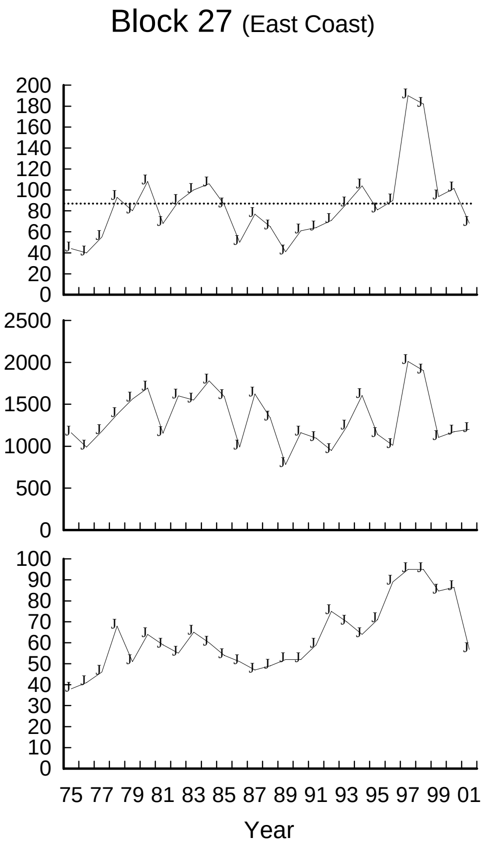
Block 24 (East Coast)

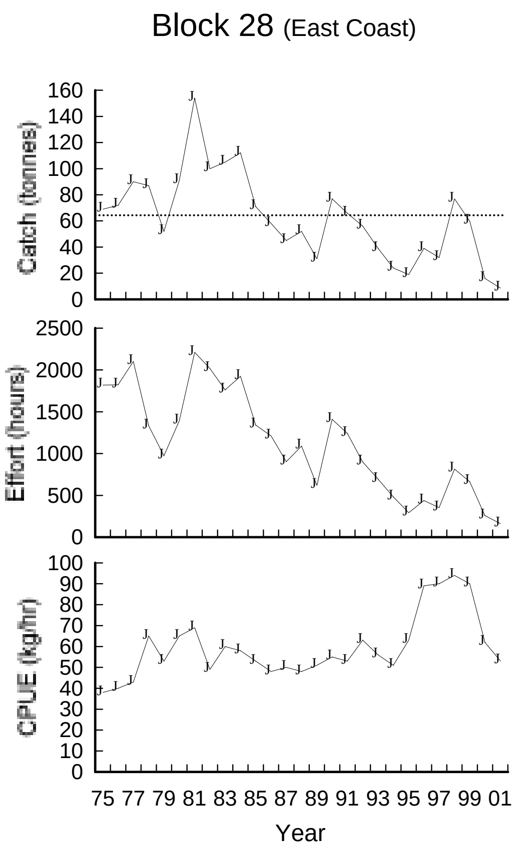


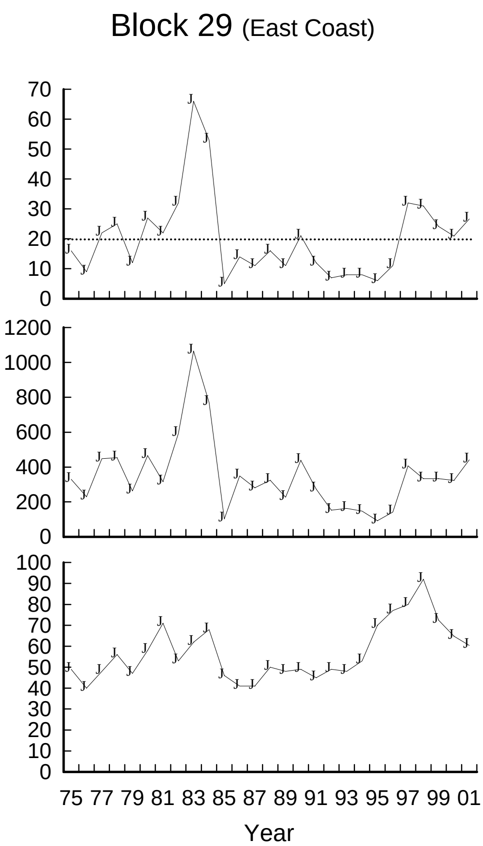
Block 25 (East Coast)



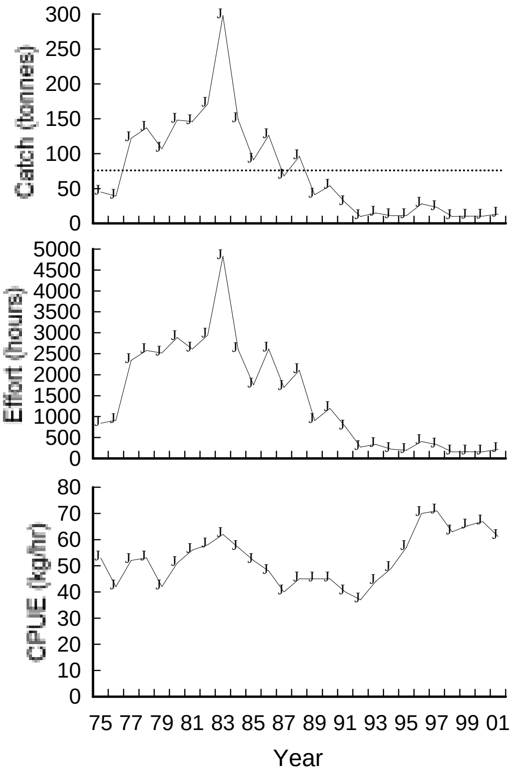

Block 26 (East Coast)
Catch (tonnes)
Effort (hours)
CPUE (kg/hr)
75 77 79 81 83 85 87 89 91 93 95 97 99 01
Year


Block 27 (East Coast)
75 77 79 81 83 85 87 89 91 93 95 97 99 01
Year

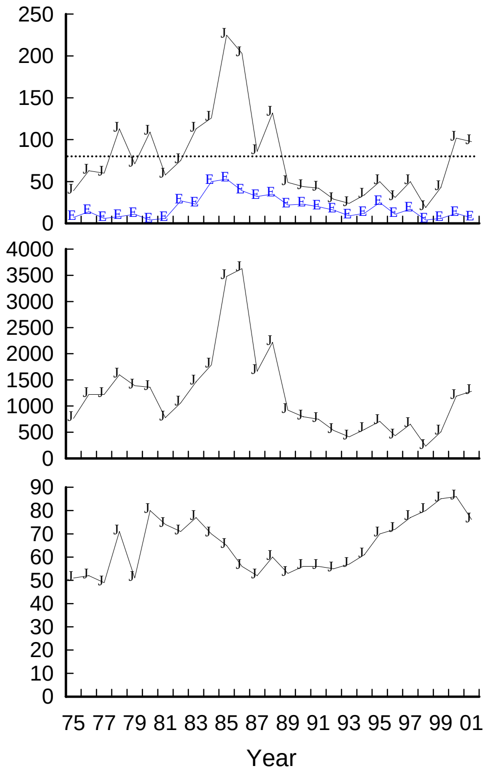

Block 28 (East Coast)
Catch (tonnes)
Effort (hours)
CPUE (kg/hr)
75 77 79 81 83 85 87 89 91 93 95 97 99 01
Year


Block 29 (East Coast)
75 77 79 81 83 85 87 89 91 93 95 97 99 01
Year

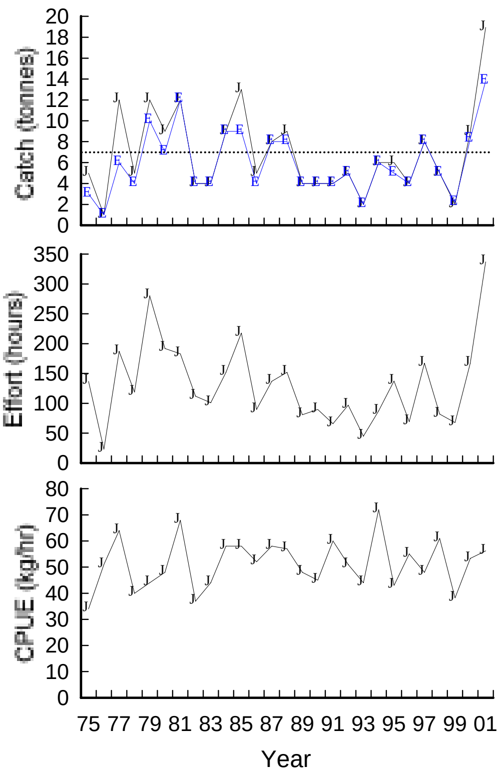
Block 30 (North East)



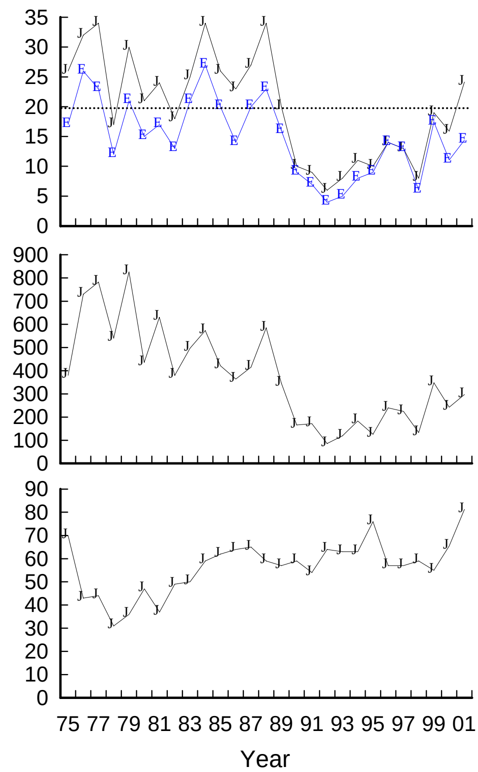
Block 31 (North East)



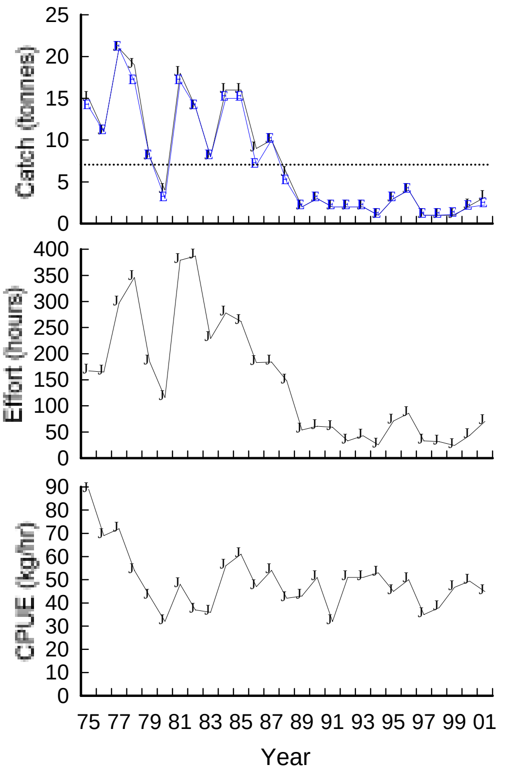
Block 32 (Furneaux Group)



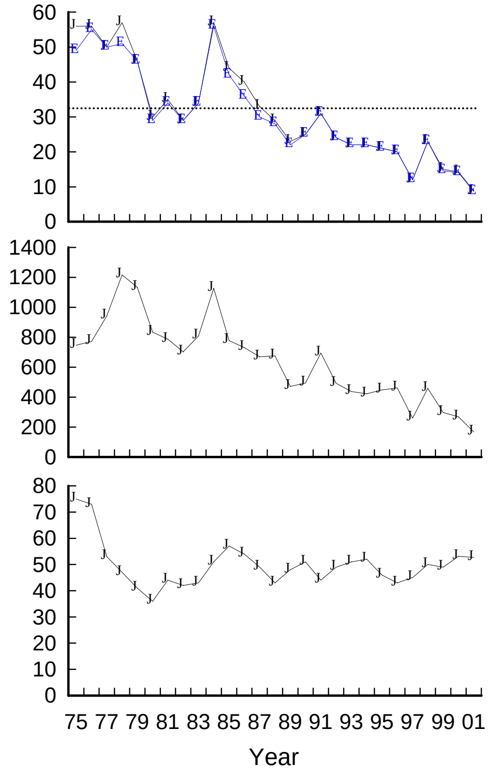
Block 33 (Furneaux Group)



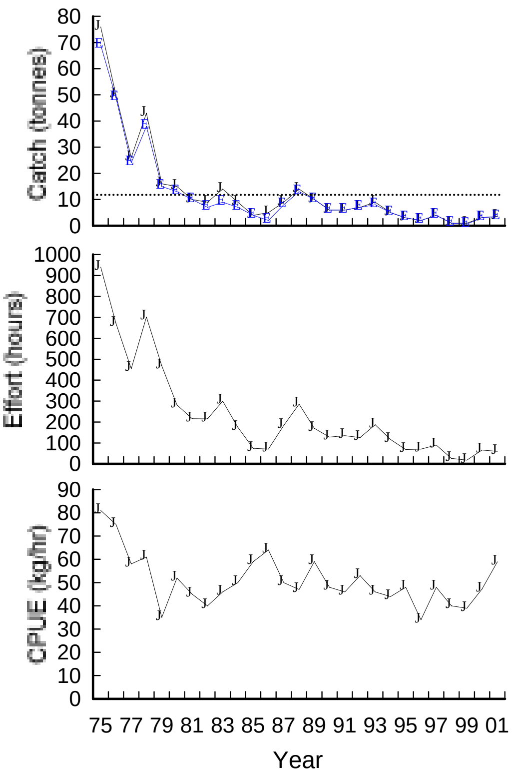
Block 34 (Furneaux Group)



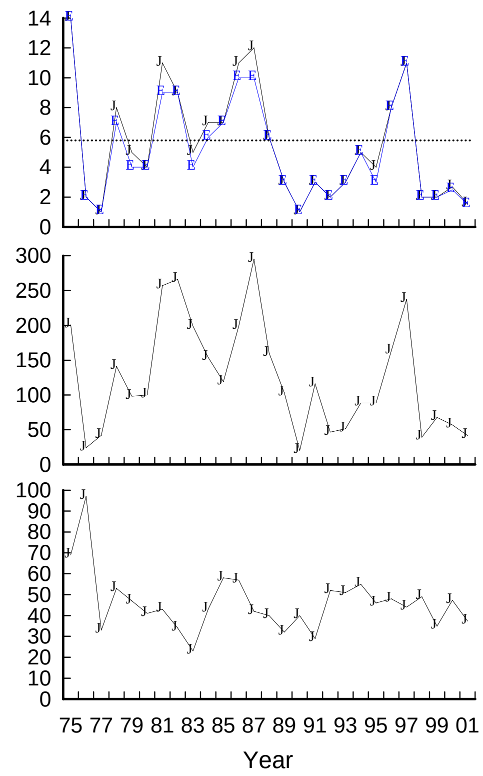
Block 35 (Furneaux Group)



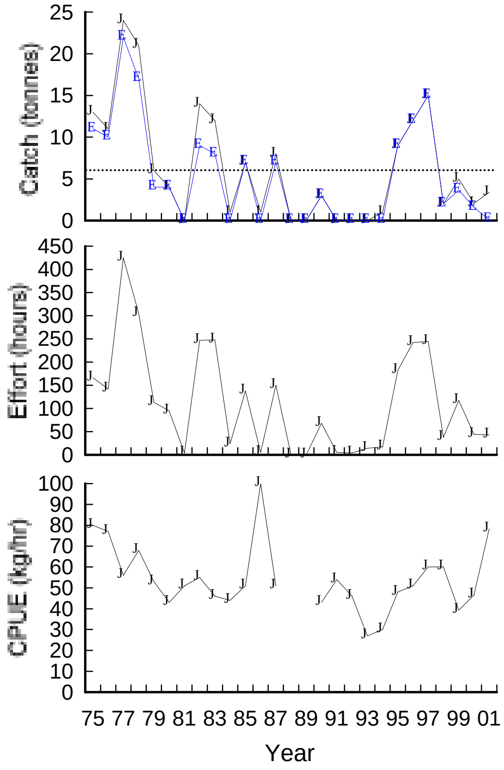
Block 36 (Furneaux Group)



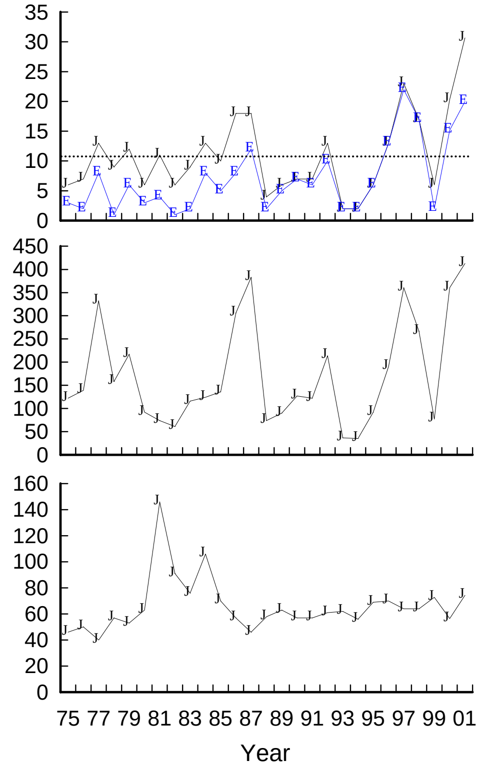
Block 37 (Furneaux Group)



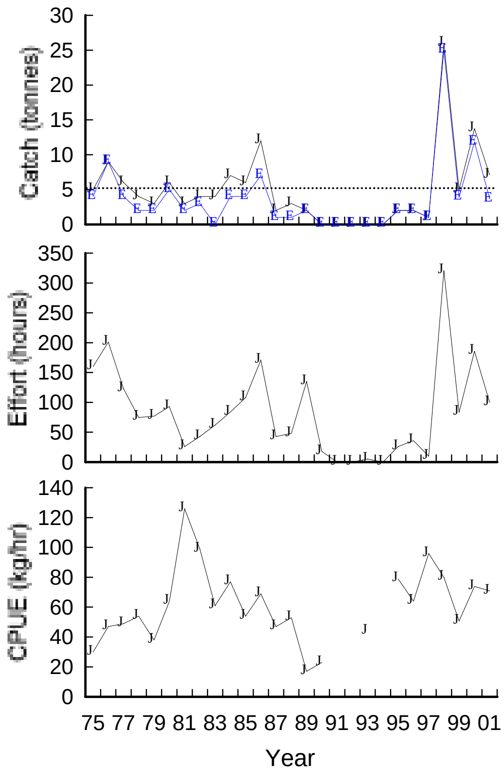
Block 38 (Furneaux Group)



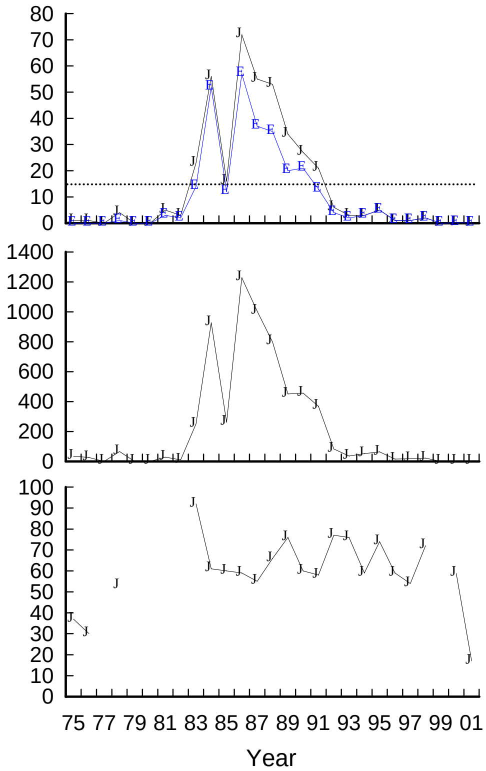
Block 39 (North East)

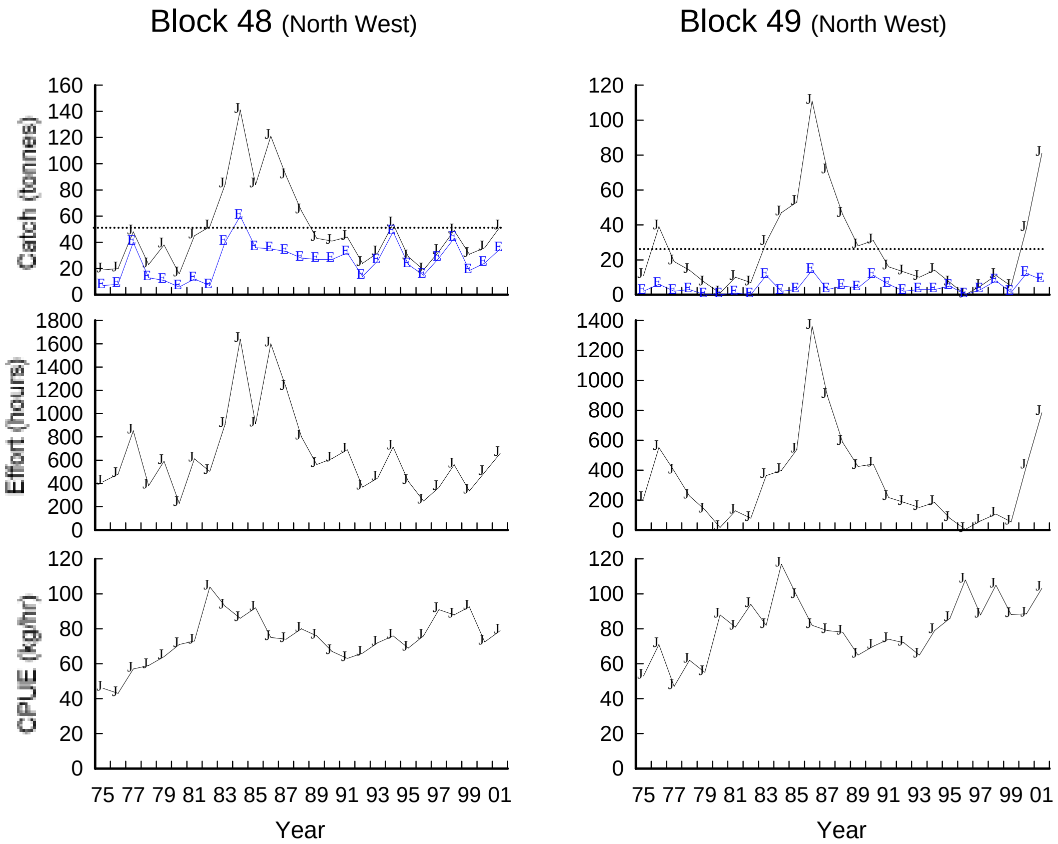


Block 40 (North East)



Block 47 (North West)




Block 48 (North West)
Block 49 (North West)
Catch (tonnes)
Effort (hours)
CPUE (kg/hr)
75 77 79 81 83 85 87 89 91 93 95 97 99 01
Year