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FISHERY ASSESSMENT REPORT

TASMANIAN ABALONE FISHERY

2000

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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 :

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Abalone Fishery Assessment: 2000

Summary

The Abalone Fishery Assessment: 2000 is 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 based upon data supplied by the State Department of Primary Industry, Water and Environment collected from catch dockets provided by licensed divers. The size-composition data were mostly collected by TAFI abalone research staff, either by sampling landed catches at fish-processing factories or by collecting samples of abalone populations from the water. Additional size-composition data were obtained from divers who photographed a sample of their catches. These photographs were analysed by TAFI for length composition. There is a full description of these methods in the Report.

In 2000, the Tasmanian abalone fishery was divided into separate fishing zones. 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. The blacklip fishery was divided into two geographical zones, the boundaries of which were Port Sorell in the north and Whale Head in the south. The coast to the east, including the regions described in this report as the South East, East Coast, North East and Furneaux Group formed the Eastern Zone. The coast to the west, including West and South-West, West Coast North, North West and King Island formed the Western Zone. The greenlip fishery was managed as a third fishing zone, distinct from the blacklip fishery.

Each zone was given a fixed total allowable catch (TAC). The Eastern Zone TAC was set at 1190 tonnes, the Western Zone TAC at 1400 tonnes and the greenlip fishery TAC set at 140 tonnes, enabling a state-wide catch of 2730 tonnes.

The assessment suggests that blacklip abalone stocks have declined in two regions of the Eastern Zone, the East Coast and the South East. These regions are of great importance to the industry and provide premium quality abalone to both live and canning markets and in recent years both have been subject to heavy fishing pressure and high levels of catch. Size distributions of abalone commercial catches and research samples from heavily fished areas in these two regions indicate that the 2000 catch was substantially dependent on recruits.

Particular attention is drawn to the coast between Southport and Whale Head (Block 13), one of the most productive and heavily fished areas in the South East. At two sites in this area typical of the surrounding fishery, it was found that abalone were relatively large, fast growing and recruited to the fishery within two years of becoming sexually mature. This showed that the minimum legal size in this area did not meet the stated objective of the management plan. This plan specifies an objective “that abalone shall be allowed to grow to a size where they have had two breeding seasons”. As a consequence recruitment from protected abalone is probably less in this area.

In 2000, there was also a fall in catches in these two regions, mostly due to implementation of zoning with fixed TACs and a managed reduction in the annual catch in the Eastern Zone compared with that of recent years. In the East Coast and South East regions catches fell to 74% and 88% of the average catch of the previous three years respectively. These catch levels matched the long-term (1975-2000) average.

Although catches in the South East and East Coast are now at moderate levels compared with historical catches, the extent to which abundance has been reduced by the intensive level of effort and correspondingly large catches during the late 1990’s is unclear. If abundance has been reduced to low levels, then current levels of catch may be too high and may be unsustainable. Abalone stocks are slow to respond to catch reductions and it may be many years before improvement in catch-rates are seen here. The *de-facto* index of abundance used in this report, raw catch-rates, is still relatively high and gives no clear indication that the Eastern Zone TAC needs to be further reduced.

Blacklip stocks in the Western Zone appear to be healthy. For many years, the catch in this part of the State has declined because it is harder to access abalone populations here than in the Eastern Zone. Previous assessments have highlighted an increase in stock levels (evidenced by successive rises in catch-rate), and the need to redistribute effort from the east to the west. In 2000 the TAC in the Western Zone was increased substantially over annual catches of previous years and is now greater than the catch from the Eastern Zone.

In the more accessible areas of the Western Zone (the coasts south of Strahan and Granville Harbour, and west of Whale Head), catch-rates fell. Stocks on the west coast were at particularly high levels (evidenced by very high-catch rates in recent years), and it is expected the large transfer in effort to this region might cause localised depletion around areas accessible to the small boats favoured by most divers. This catch-rate decline needs to be monitored to ensure that more serious levels of depletion do not occur.

In the remote areas of the Western Zone, catch-rates continue to increase, indicating that stock levels here were unaffected by the increased catch.

The blacklip fishery on King Island has continued to decline, not because of falling abalone stocks, but because it’s remote location and lack of fish-processing facilities meant that divers chose to fish elsewhere.

The greenlip fishery in the Furneaux Group has stabilised after management intervention in recent years. Catch-rates in 2000 were generally better than those of preceding years and indicate that stocks may be rebuilding. Greenlip effort has increased on the Tasmanian mainland, partly due to the restriction on catches in the Furneaux group and partly due to the effects of zoning causing divers to preferentially fish the more accessible areas of the North West and North East. As with the blacklip fishery, the greenlip fishery around King Island has good stock levels but catches have declined largely because it is remote from processors and operating costs for divers fishing this region are comparatively higher than more accessible areas.

This assessment is based largely upon interpretation of trends in catch-rates (kilograms per fishing hour), which are assumed to reflect changes in abundance. However, catch-rates may also reflect other factors such as market preferences and diver experience and consequently send confusing signals. Certainly, divers have become more efficient since the fishery began and are now able to collect abalone at a faster rate. Consequently the unit of effort (hours spent collecting abalone) used to derive catch-rates is much different in more recent years than at the start of the fishery. This means that although catch-rates may be higher now than earlier in the fishery, they may indicate lower abundance levels than those assumed. A full discussion of the effects of removal of extraneous factors affecting catch-rates (standardisation) and changes in diver efficiency (effort creep) is included in the Report.

In summary, the major findings of the assessment are:

- The implementation of zoning in 2000 has reduced catches on the East Coast and South East regions to historically average levels.
- There has been a decline in abundance of abalone in the Eastern Zone, particularly in the East Coast and South East regions.
- Size-limits in parts of the South East and East Coast may be too small to ensure adequate recruitment.
- It may take several years for the effects of catch-reductions to become apparent in improved catch-rates. Whether the catch reduction in the Eastern Zone is sufficient to halt the stock decline in these regions is unclear.
- The Western Zone blacklip fishery was healthy apart from localised declines about the more accessible areas.
- The greenlip fishery was improved in the Furneaux Group, but increased catch levels in the North East and North West need monitoring.
- The abalone fishery on King Island declined, not because of stock declines, but because it was cheaper and easier to fish elsewhere.
- The measure of abundance (raw catch-rates) is an unreliable indicator of abundance because of improvements in diver efficiency, and the inclusion of extraneous factors affecting the divers ability to collect abalone.

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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 (Harrison, 1983; Prince and Shepherd, 1992; Shepherd, 1973). 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 *et al*., 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 (S. Shepherd, pers. comm.).

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 *et al*., 1994). Spawning of greenlip abalone appears to be epidemic, occurring over a period of 2-3 days in late spring/early summer (Rodda *et al*., 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 two weeks or more.

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 *et al*., 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, 1995a), 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* has been an important part of the assessment of 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 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, 1999a).

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, 1999a).

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_∞, as 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 (Nash *et al*., 1994, unpublished data). 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, 1995a); movements of tagged blacklip abalone have been recorded over distances up to half a kilometre (Tarbath, 1999a).

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.

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 the perceptions of the condition of the fishery and 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). In 1999 the size-limit for this species was increased from 132 to 140 mm in the North West, and from 140 to 150 mm in all other greenlip-producing areas. This was reviewed, and in 2000 the size-limits were set at 145 mm in the North East and Furneaux Group and increased to 155 mm at King Island.

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, indicating 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 blacklip abalone fishery was divided into Eastern and Western zones, and the greenlip fishery made a distinct entity. 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 capped at 1190 tonnes. Catch from the greenlip abalone fishery was reduced to 140 tonnes and size-limits were changed (see above). The Tasmanian TAC for the entire abalone fishery for 2000 is the sum of these regional TACs i.e. 2730 tonnes. The zone allocation was reflected in each quota unit, with 400 kg, 340 kg and 40 kg being from the west, east and greenlip fisheries respectively.

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.

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 (2000) 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.

2.10 Greenlip Abalone

The Review of the Management Plan also revises measures to manage the greenlip abalone fishery. These include

- Limiting the state-wide greenlip catch to 140 tonnes;

- Participation in the fishery is by quota management, 40 kg of which is attached to each quota unit of the Tasmanian abalone fishery.

- Increased size-limits to be adopted in each of the four greenlip regions; King Island: 155 mm, North West: 140 mm, North East and Furneaux Group: 145 mm.

- Block 35 in the Furneaux Group is to be open for a limited period each year starting 1 April, closing 1 October to protect spawning abalone. This block’s TAC is capped at 20 tonnes.

- The catch from the Furneaux Group is limited to 42 tonnes *per annum.*

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.

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; Tarbath, 1999b). 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 (Breen, 1992; McShane, 1995; Shepherd *et al*., 1991).

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. Sampling was undertaken at much higher levels in 2000, but more sampling needs to be done, particularly in areas fished for live markets, parts of the east and north-east coasts and the areas accessible to runabouts on the west coast.

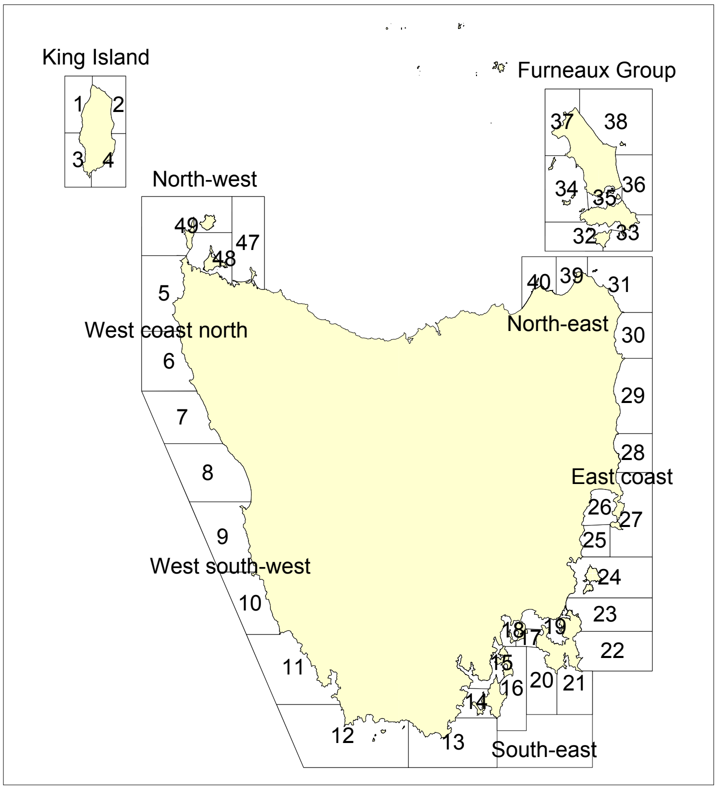

Fig. 1. Statistical blocks used in the Tasmanian abalone fishery. Statistical blocks are commonly grouped for analysis into eight regions: King Island (blocks 1 to 4), West coast north (blocks 5 and 6), West south-west (blocks 7 to12), South-east (blocks 13 to 21), East coast (blocks 22 to 29), North-east (blocks 30, 31, 39, 40), the Furneaux Group (blocks 32 to 38) and the North-west (blocks 47 to 49).

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. In all cases the modal length class was above the legal minimum length.

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 (Breen, 1992; Prince, 1987; Prince, 1989).

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). 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,
- 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).

A steady increase in catch-rate was noted in most areas (with some exceptions), accompanied by a change in the distribution of catch and fishing effort. Whilst catch-rates were regarded as a poor index of abundance, the catch-rate increases generally observed were taken to signify that, in general, there was little evidence of overfishing.

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.

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 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. However, 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 *et al*., 1996; Hart and Gorfine, 1997; Hart *et al*., 1997). The study concluded that including methods to evaluate the spatial distribution of abalone would enhance results.

4.3 Commercial Catch Sampling Data

The collection of commercial abalone catch-at-length data through the market-measuring program lapsed in 1995 and recommenced in 1998. 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 therefore provide no evidence that the Tasmanian abalone stocks are presently in a state of either growth overfishing or recruitment overfishing.

A commercial catch- sampling program was reinstated in 1998. These measurements are likely to prove an invaluable source of information when computer-modelling Tasmanian abalone stocks. Whilst such an analysis is not yet possible, continuation of the commercial catch-sampling program will improve both the immediate and ultimate utility of the data.

5. Assessment Methods

5.1 Commercial Catch-Effort Statistics

Like its predecessors, the 2000 assessment is based principally on an analysis of trends in the catch and catch-rate of the commercial fishery. These data are provided by licensed abalone divers on dockets submitted with all abalone landed. Catch and effort are reported by statistical block (Fig. 1) on these dockets. Catch and effort are estimated by block when the catch occurs over multiple blocks or days. Commercial catch and effort data are not standardised and therefore include variations due to factors such as season, weather, and diver experience. No attempt has been made to allow for improvement in diver efficiency between 1975 and the current year. Catch-rates for the main statistical blocks and regions have been 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.

5.2 Commercial Catch Sampling Data

The collection of size-composition data from the commercial fishery recommenced in 1998, using industry volunteers (divers, deckhands) to photograph part of their catches. A portion of catch is photographed against a calibrated background, the photographs are subsequently scanned and the abalone are measured from the scanned image using a computer. Data collected by this project up to 1/1/01 are included in this assessment.

Enthusiasm among industry for this work has waned, and photographic methods have mostly been superseded. Starting September 2000, commercial catch sampling is now done by MRL staff, who measure samples of diver's catches at fish processing factories.

These recent data are compared with those obtained by the previous market measuring program from 1984 to 1995, and, where possible, with size-composition data collected in 1997 by research divers. Research data includes measurements of fish below the legal minimum length. These data can therefore better indicate the true modal length of the population sampled and the proportion of the population not yet recruited to the fishery.

Size-composition data was also provided by Tasmania's largest abalone processor: Tasmanian Seafoods Pty Ltd. These data describe the proportion of factory production made up of large abalone. These data were provided from July 1995 to December 2000. Production figures were also provided for days in 1997-00 where the catch was obtained exclusively from the west coast.

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.

6. Fishery Assessment: 2000

This stock assessment compares the 2000 catch and catch-rates against the average catch and catch-rates of two reference periods: 1979 to 1982 and 1992 to 1995.

The 1979-82 average catches and catch-rates are from a period when annual landings were increasing prior to a record peak in the mid 1980's, and stock levels were assumed to be stable. The 1992-95 average catches and catch-rates are from a period that followed progressive quota reductions and size limit increases. Annual landings during this period were at a 20-year low, and stock levels were assumed to be stable or increasing.

This assessment reviews catch and catch-rate by comparing current catch information with that from the two reference periods. 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.

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

6.1 Blacklip Fishery Assessment: 2000

6.1.1 Evaluation of catch and catch-rate with reference to historical catches.

Blacklip abalone - Catch reference points: Regions

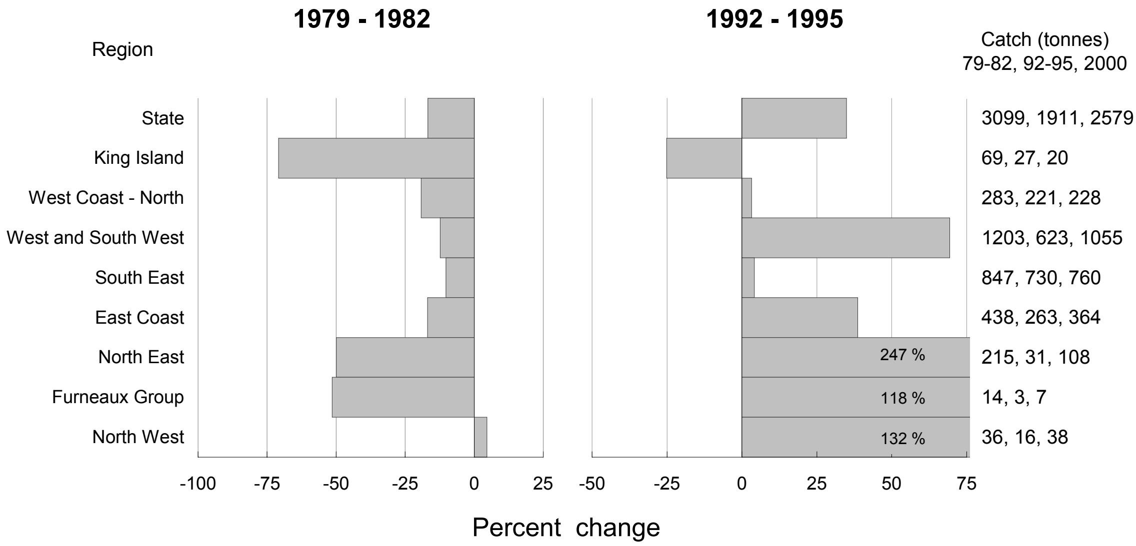

Fig. 2. The 2000 catch (tonnes) by region and state, expressed as percent change from the average catch-rates of the periods 1979-82 and 1992-95. The left-hand charts show the change in catch compared with the average catch of 1979-82, and the right-hand chart compares the catch with that of 1992-95 average. The average catches for 1979-82, 1992-95 and 2000 are shown on the right-hand side of the chart.

- State-wide, blacklip abalone catches have increased 35% on the 1992-1995 average, directly attributable to increases in TAC.

- Against the trend for the rest of the state, blacklip catches have continued to fall on King Island.

- Catches from the two west coast regions have increased, significantly in the West and South West. The 2000 catch from this region is more than 300 tonnes greater than the 1999 catch, although still below that of the 1979-1982 reference period.

- The South East (mostly Storm Bay) catch (760 tonnes) has dropped by 126 tonnes from the previous year, and is now only slightly larger (less than 5%) than the average catch from the 1992-1995 reference period.

- The East Coast (Tasman Island to St Helens Point) catch continues to decline, falling by over 70 tonnes from 1999, but is still much higher (39%) than that from 1992-1995.

- Catches in the North East are over three times greater than that from 1992-1995, but half that from 1979-1982.

- In the Furneaux Group, catches have increased, but are still very small (7 tonnes).

- Catches from the North West (blocks 47, 48, 49) have increased, and although twice that of 1992-1995, are of similar size to those of the 1979-1982 period.

Blacklip abalone - CPUE reference points: Regions

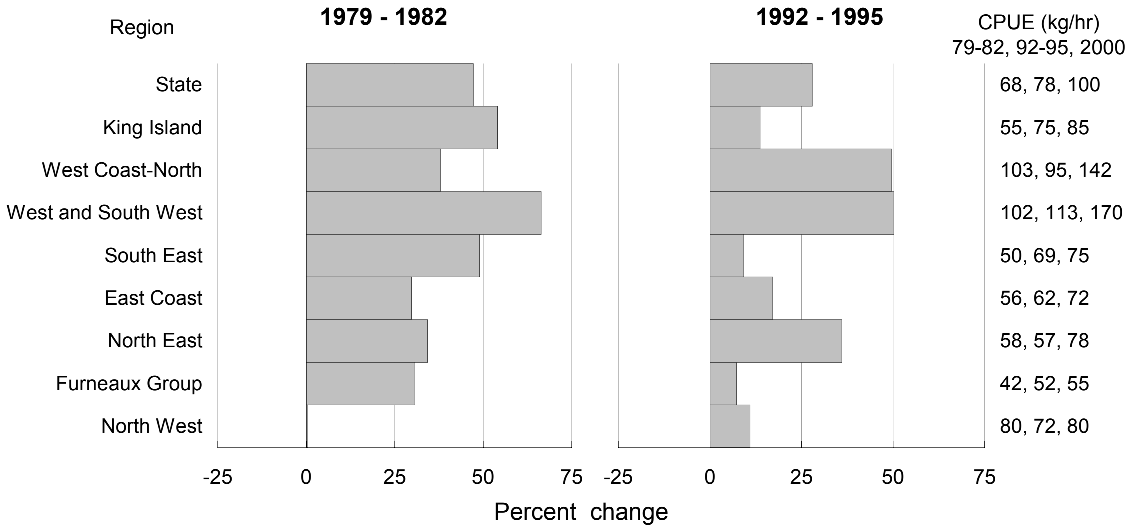

Fig. 3. The 2000 catch-rates (in kilograms per hour) by region and state, expressed as percent change from the average catch-rates of the periods 1979-82 and 1992-95. The left-hand charts show the change in catch-rate compared with the average catch-rate of 1979-82, and the right-hand chart compares the catch-rate with that of 1992-95 average. The average catch-rates for 1979-82, 1992-95 and 2000 are shown on the right-hand side of the chart. 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.

The following points are noted with respect to the regional blacklip catch-rate reference points (Fig. 3):

- The chart was produced using data that contained greenlip effort. In some regions (particularly the Furneaux Group, and King Island), the major part of the annual blacklip catch is caught incidentally to greenlip fishing operations. Where greenlip catches predominate, the information shown above may not reflect the reality of blacklip abalone fishing in those areas.

- The state catch-rate continues to rise, and is now over 100 kg/hr.

- All regions have catch-rates greater than those of the reference periods.

Blacklip abalone - Catch reference points: Blocks

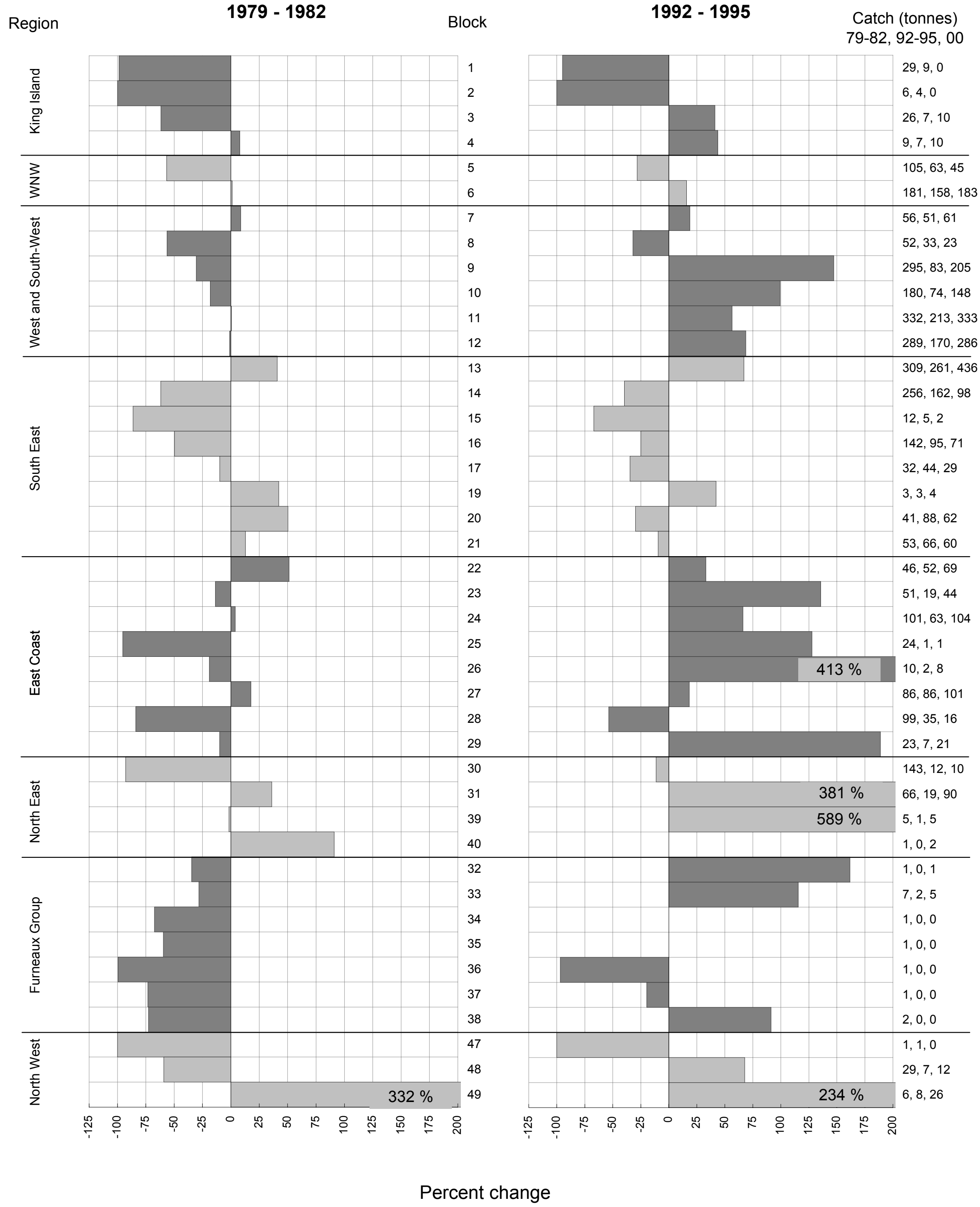

Fig. 4. The 2000 blacklip abalone catch by block, showing the deviation of the 2000 catch from two reference periods in the history of the fishery. The left-hand chart shows the change in catch compared with the average catch of 1979-82, and the right-hand chart compares the catch with that of 1992-95 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 2000 catch are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

Significant changes in the 2000 catch with respect to the two reference periods has occurred in the following blocks (Fig. 4):

- As previously mentioned, in 2000, King Island did not significantly contribute to the blacklip abalone fishery.
- While there have been large increases in the West and South-West catches, (particularly from Block 9 - Cape Sorell to Point Hibbs), catches from north of Strahan (Blocks 5 to 8) have not similarly increased. Catches in two blocks that were previously important in the West Coast-North and West and South-West (Blocks 5, 8) have declined.
- Although the Block 13 (Prion Bay to Southport, including Actaeons) catch is greater than that of both reference periods, the remaining significant blocks in the South-East show declines in catch.
- Over half the East Coast catch comes from Block 24 (Maria Island, Mercury Passage) and Block 27 (Freycinet Peninsula). Block 28 continues to perform poorly relative to earlier catch levels.
- Catches in Block 31 (particularly between Eddystone Point and Cape Naturaliste) have increased dramatically, but immediately south in Block 30 (St Helens Point to Eddystone Point) catches are about 7% of those from the 1979-1982 average.
- In the North West, blacklip catches have increased in both Blocks 48 and 49 (Smithton to Woolnorth Point).

Blacklip abalone - CPUE reference points: Blocks

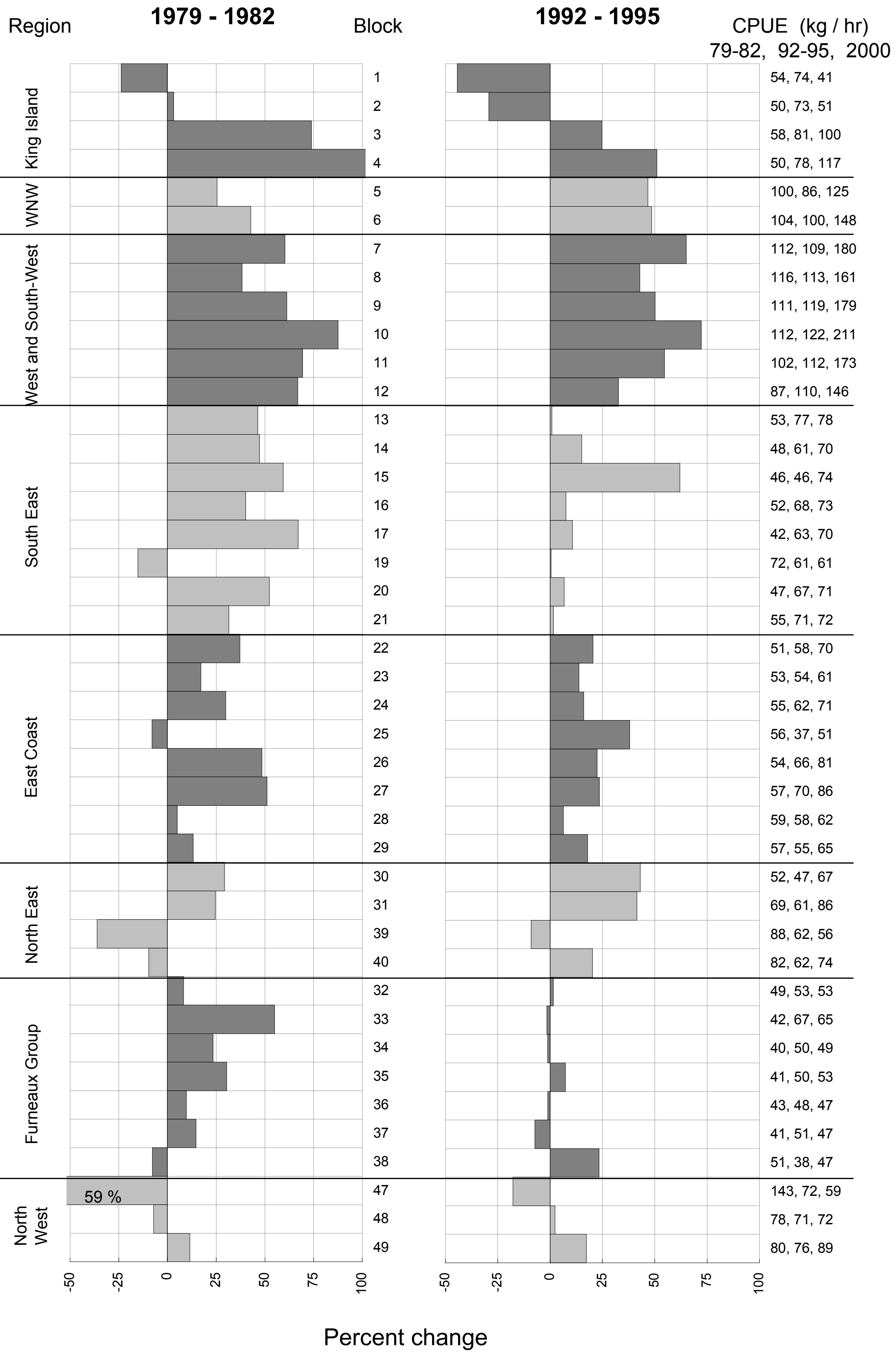

Fig. 5. 2000 catch per unit effort (CPUE) by block, expressed as percent change from the average catch-rates of the reference periods 1979-82 and 1992-95. Catch-rates from King Island, the Furneaux Group and North West Tasmania are calculated using effort data which includes a significant component of effort from greenlip abalone catches.

- Catch-rates show considerable fluctuation between blocks on King Island, and probably reflect changes to the way that data are collected rather than changes in abalone abundance.

- In most blocks that are significant contributors to the blacklip fishery, there was an increase in CPUE compared with the reference periods.

- West Coast blocks continue to show very high catch rates, mostly greater than 150 kg/hr.

- In the important fishing blocks in the South East and East Coast, catch-rate increases are slightly higher than those from the recent reference period.

6.1.2 Blacklip abalone: commercial catch distribution

The statistical blocks for the abalone fishery are shown in Fig. 1. To portray 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.

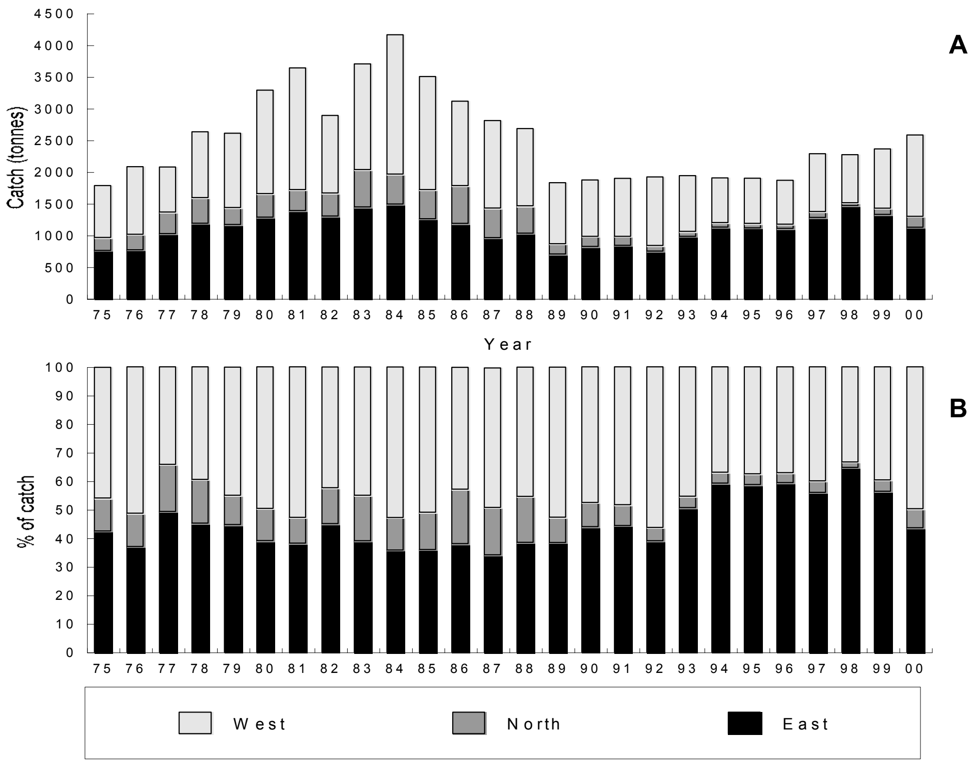

Fig. 6. The catch of blacklip abalone from the three main regions of Tasmania, by year from 1975 to 2000. East: southeast and east coast (blocks 13-29). North: King Island, North West, North East and Furneaux Group (blocks 1-4, 30-40, 47-49). West: West Coast North, West and South-West (blocks 5-12). Catches are expressed in absolute values (tonnes) (A), and as proportions of the total blacklip catch (B).

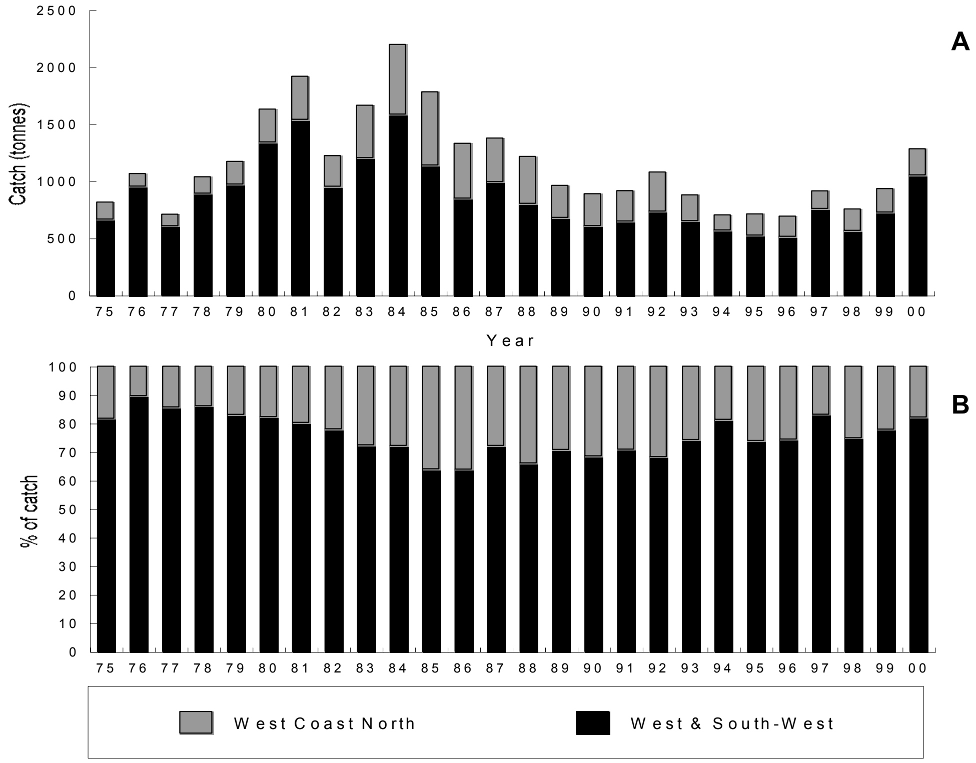

Fig. 7. The catch of blacklip abalone from the west of Tasmania, by year from 1975 to 2000. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total blacklip catch from that region.

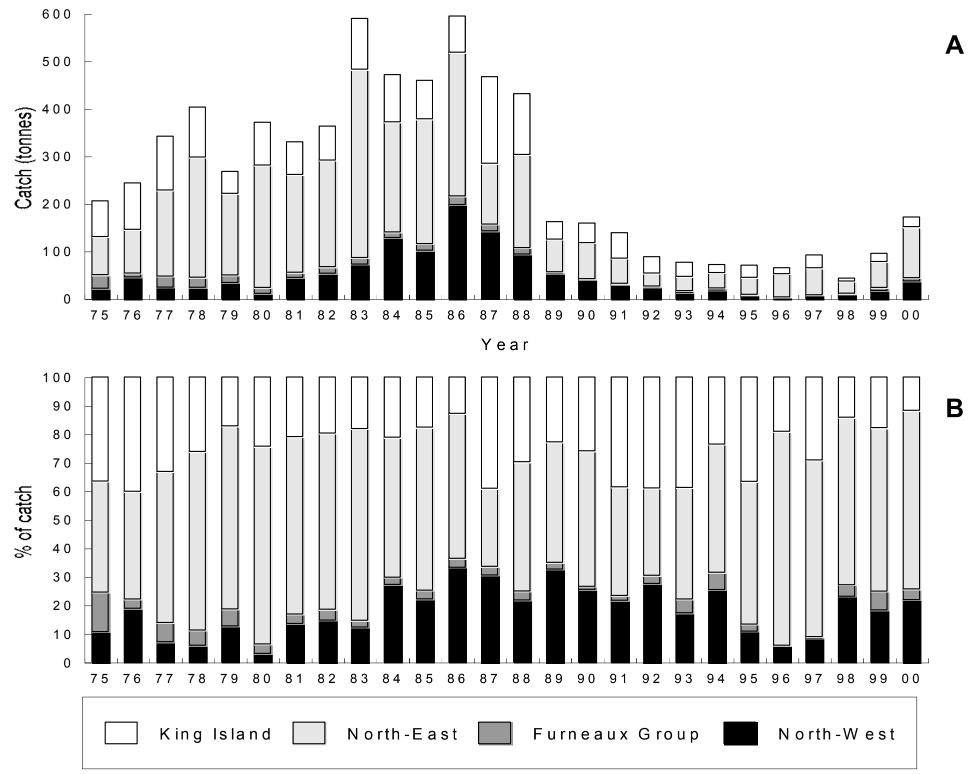

Fig. 8. The catch of blacklip abalone from the north of Tasmania, by year from 1975 to 2000. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total blacklip catch from that region.

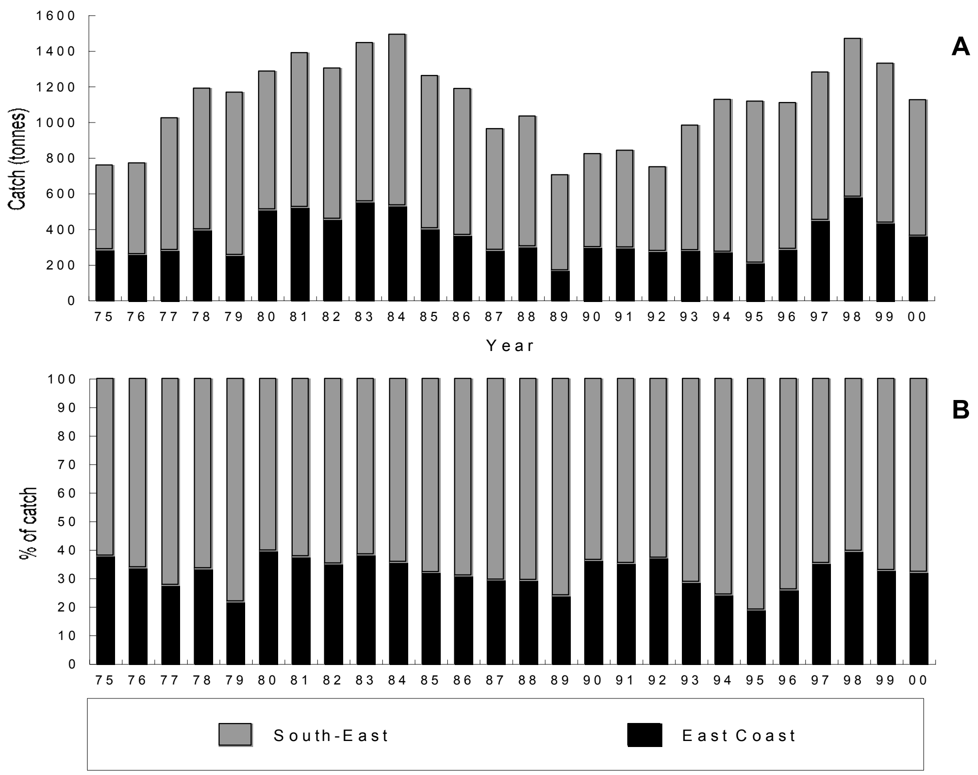

Fig. 9. The catch of blacklip abalone from the east and southeast of Tasmania, by year from 1975 to 2000. The catch from each region is expressed in (A) absolute values (tonnes), and (B) as a proportion of the total blacklip catch from that region.

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

- The bulk of the blacklip catch has traditionally been taken from the west of the state (blocks 5 to 12) (Fig. 6).

- From 1993 to 1999, fishing patterns changed and 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). In 2000, the West Coast again produced the greatest proportion 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: 2000

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 2000 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.

In recent years, strong market demand has put greenlip stocks under pressure. A number of processors, mostly in the north of the State and offshore islands, supply a premium product (i.e. large abalone) to a live fish market in Sydney, for which they receive a higher price than the blacklip beach price. Because the greenlip stocks are limited, there is competition between divers and processors for the resource, and the stocks were possibly fished at levels higher than could be sustained.

In 1998, the following management changes were introduced:

- Annual greenlip TAC of 148 tonnes state-wide,
- Annual Furneaux Group TAC of 42 tonnes, which was subdivided into monthly TACs of 3.5 tonnes,
- Allowing fishing on only two days a week. Originally these days were fixed, but after complaints by divers that they were being forced to work on days when weather conditions made diving hazardous, the divers were allowed to nominate any two days in the week.
- A 200 kg per day bag limit was introduced, as was a 200 kg per day landing limit. This effectively meant that catch could not be held on board a mother ship overnight.

These measures were of limited success. They achieved a reduction in catch. However there were monthly catch overruns (because of the difficulty of closely monitoring and accounting for catch). Consequently the Furneaux Group was closed in August when the regional TAC was met. Greenlip were caught in other parts of the State, although the state-wide TAC was also overrun.

A detailed assessment of the greenlip abalone fishery was published in 1999 (Officer, 1999a), and from this, a number of structural changes were made to the way in which the fishery was managed. The catch and landing limits were dropped, and other changes introduced:

- The greenlip fishery was divided into east (Furneaux Group and North East) and west (King Island and North West) with quarterly TACs of 17 tonnes and 20 tonnes respectively.

- The greenlip TAC was set at 140 tonnes.
- New size-limits were adopted to better protect stocks and increase yield. In all areas the size-limit was increased by 10 mm except in the North West, where it was increased by 8 mm.

Once again, competition for the resource led to overrun of TACs and the entire greenlip fishery was shut down early in the final quarter of 1999.

These management changes, especially the introduction of area specific TACs, 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 are more likely to reflect the implementation of TACs, and not necessarily changes in abundance.

In 2000, following the introduction of zoning, the greenlip fishery was partitioned from the blacklip fishery. Access to the fishery changed from being open to all divers and quota holders (until the TAC was caught), to a more regulated system controlled by greenlip quota. Each of the 3500 quota units comprised portions of greenlip quota (40 kilograms per unit) as well as potions for each of the blacklip zones. In 2000 the greenlip quota was about 5% by weight of the quota unit.

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, now effectively controlled access to a considerable part of the greenlip fishery. This means that many divers who previously caught greenlip now catch less than they previously used to, and that other divers who had never caught greenlip now catch large quantities.

Considering these covenants, the 2000 catch and catch-rate information compared with the reference periods is presented without further comment.

Greenlip abalone – regional catch

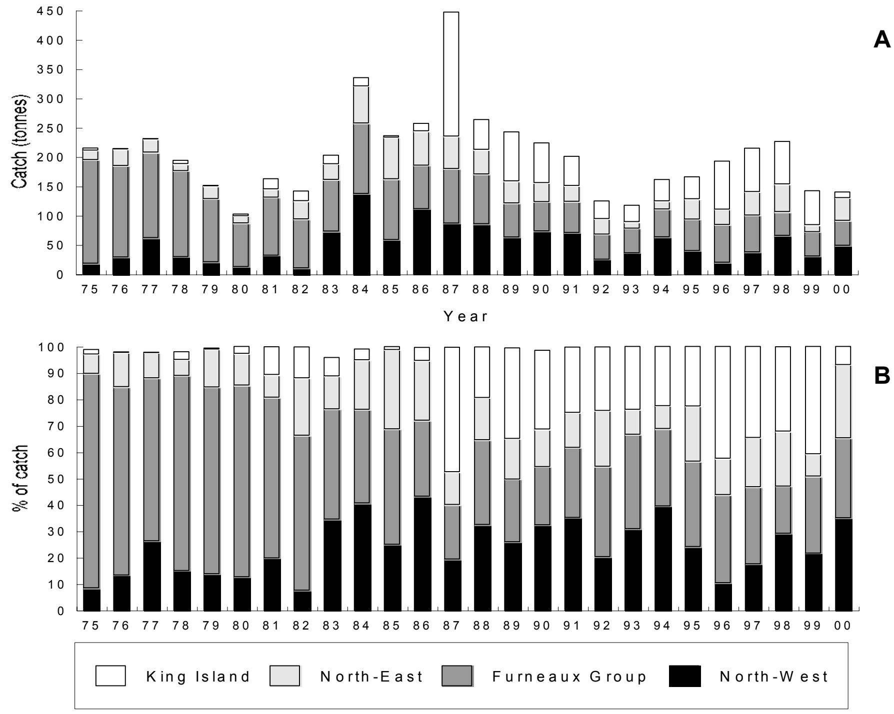

Fig. 10. The catch of greenlip abalone from the four main greenlip-producing regions of Tasmania, by year from 1975 to 2000. King Island includes blocks 1-4. North East includes blocks 30, 31, 39 and 40. The Furneaux Group includes blocks 32-38. North West includes blocks 5, 6, 47, 48 and 49. The catch 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

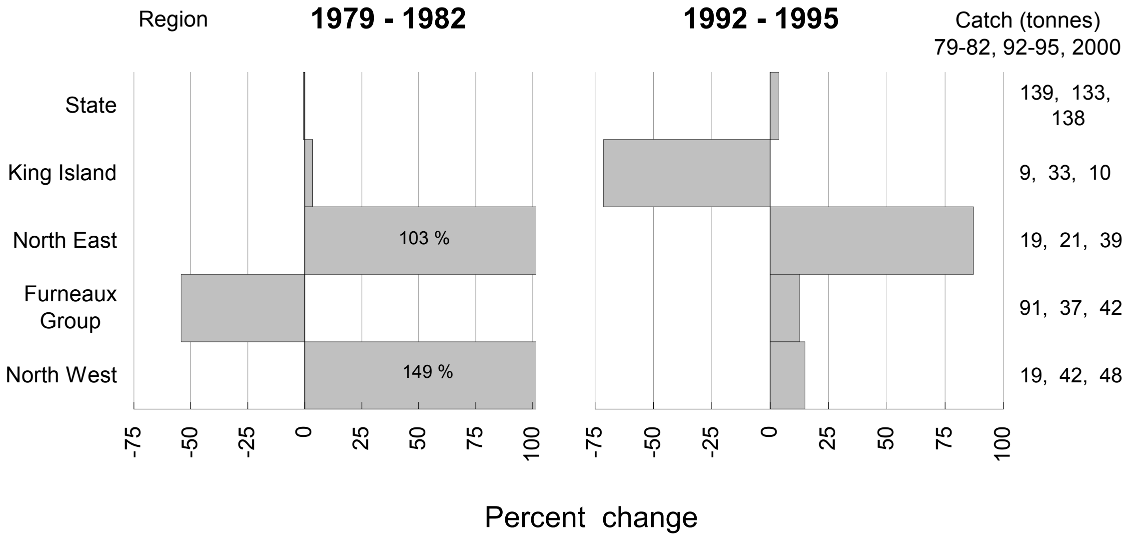

Fig. 11. The 2000 greenlip catches by region, showing the differences between catches in 2000 and the average of those from the 1979-82 and 1992-95 reference periods. The average catch (tonnes) for the periods 1979-82 and 1992-95 and the 2000 catch is shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

Greenlip abalone – CPUE reference points: Regions

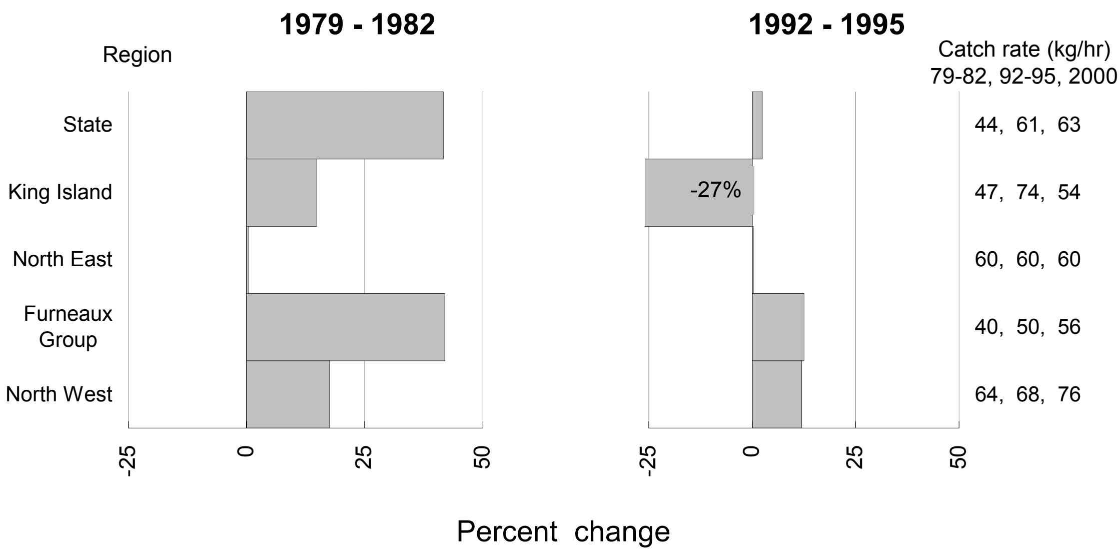

Fig. 12. The 2000 greenlip catch-rates by region, showing the differences between catch-rates in 2000 and the average of those from the 1979-82 and 1992-95 reference periods. The average catch-rate (kilograms per hour) for the periods 1979-82 and 1992-95 and the 2000 catch-rate are shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

Greenlip abalone – Catch reference points: Blocks

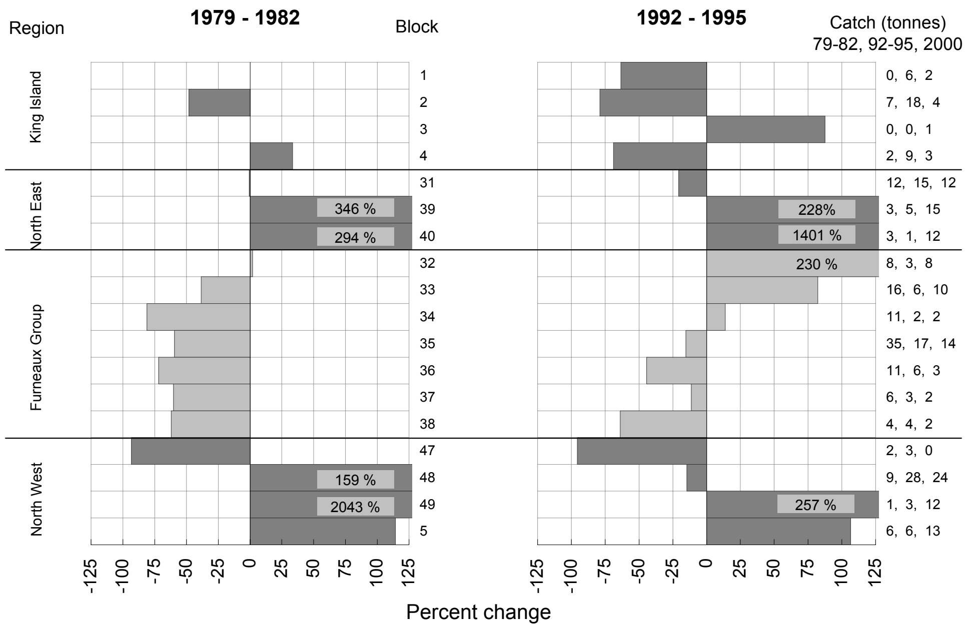

Fig. 13. The 2000 greenlip catches by block, showing the differences between catches in 2000 and the average of those from the 1979-82 and 1992-95 reference periods. The blocks (shown in the column between the two charts) are grouped by region (shown on the left-hand side of the page). The average catch (tonnes) for the periods 1979-82 and 1992-95 and the 2000 catch is shown on the right-hand side of the page. Where the chart is truncated, percentage change is indicated.

Greenlip abalone – CPUE reference points: Blocks

Fig. 14. The 2000 greenlip catch-rates by block, showing the differences between catch-rates in 2000 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 2000 catch-rate 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 these graphs:

- The greenlip catch and catch-rates have fallen at King Island (Fig. 10, Fig. 11, Fig. 12).
- The catch that was taken from King Island in 1999 (57 tonnes) was taken from the North East and North West in 2000.
- Catch-rates are stable or have increased at the Furneaux Group (Fig. 12, Fig. 14).
- There has been a steady decline in the annual greenlip catch from the Furneaux Group, from 175 tonnes in 1975 to about 40 tonnes in recent years (Fig. 10).

6.3 Blacklip And Greenlip Abalone: Trends In Catch And Catch-Rate

The statistical blocks have been grouped into eight regions (Fig. 1) to show broad regional trends in catch, effort and catch-rate (CPUE) (Appendix 1). The state-wide trend is also shown in Appendix 1. Catch, effort and catch-rate data for most of the individual statistical blocks for the period 1975 to 1996 are shown in Appendix 2. Statistical block 18 (the Derwent River estuary) and block 41 to 46 (central north coast) have been excluded for brevity; the catch in these blocks is very small or zero.

The following points are noted with reference to these catch-effort graphs:

- State-wide, high catch-rates are continued. The overall catch-rate (100.1 kg/hr) is higher than it has ever been (Appendix 1).
- On a regional basis, catch-rates remain high, although the increases of recent years are no longer apparent. Catch-rates have plateaued at King Island, West Coast North and West and South West, fallen in the South East, East Coast and North East and risen slightly in the Furneaux Group (Appendix 1).
- The record catch-rates in Block 9 (Cape Sorell to Point Hibbs) in 1999 (215 kg/hr) have fallen in 2000 to 179 kg/hr. Block 10 (Hibbs to Low Rocky) now has the highest average catch-rates (211 kg/hr) (Appendix 2).
- Catch-rates and catches are slowly but steadily falling in most of the eastern and south-eastern blocks. In Storm Bay, catch-rates are declining off the peaks of the late ‘90s. Similarly at Maria Island (Block 24) and the blocks between Bicheno and Eddystone Point (Blocks 28, 29 and 30) catches and catch-rates fell (Appendix 2).
- Few parts of the east coast showed improvement over previous years. On the east coast of the Tasman Peninsula (Block 22), catches increased by over 50%, while catch-rates, although falling slightly, remained high. The blacklip catch in the southern part of Block 31 (Musselroe to Eddystone) has risen sharply in the last few years, and catch-rates continue to increase (Appendix 2).

- Catches and catch-rates from the Freycinet Peninsula (Block 27) showed limited improvement over 1999, and remain at moderate to high levels.

- While past assessments have tracked the movement of trends in catch and catch-rate by block, even at a regional level there is considerable inter-annual variation that cannot reasonably be interpreted as change in abundance. Interpreting catch and catch-rate trends on a smaller spatial scale (i.e. at block level) without reference to other information can produce erroneous information.

- Prior to partitioning of the greenlip fishery in 2000, where both blacklip and greenlip abalone are harvested, fishing effort is often supplied for both species combined; it is therefore generally impossible to calculate catch-rate figures for these species separately. However, in blocks where only one of these species is the sole or predominant component of the catch, the catch-rate figures may better represent the trends for that species. In 2000, where both greenlip and blacklip contribute to the annual catch (Blocks 39 and 48), catch rates have generally fallen (Appendix 2).

- For the first time in many years the regional catch-rate on the West and South West coasts has fallen, corresponding with a sharp increase in effort after an increase in regional TAC. In the North West catch rates have also fallen following increased effort. In the Furneaux Group catches and catch rates have risen slightly, while on the northern part of the West Coast, catch rates are stable while the catch has risen (Appendix 1).

6.3.1 Commercial catch sampling data

The measurement of abalone caught commercially recommenced in 1998, after lapsing for several years. In 2000, 7080 abalone were measured from photos supplied by divers and deckhands, and a further 14,656 abalone were directly measured by TAFI staff at processing factories and boat ramps. While the level of sampling from many statistical blocks is low and insufficient to make meaningful comparisons with earlier years, good samples have been obtained from some of the more heavily fished blocks – Blocks 12, 13, 14, 16, 20, 24 and 27 (Fig. 15 to Fig. 21). Block 28 (Fig. 22) is represented, but the level of sampling is too low to be meaningful.

In none of the major blocks does the size-composition of the commercial catch show knife-edge fishing indicative of growth overfishing. In all blocks where size-composition data from research samples is available the large proportion of the population below the legal minimum length suggests that recruitment to the populations sampled will be maintained in the immediate future.

From the start of 2000, divers have been recording their catches on a smaller spatial scale. In 1999, the blocks were divided into smaller portions, and it is now possible analyse catches by sub-block. Changes to the catch sampling program at MRL have enabled targeting of catches from particular blocks to ensure adequate sample sizes.

During the year, catches from sub-block 13E (Actaeon Islands and associated reefs east of and not including Black Reef) were sampled at regular intervals (Fig. 23). Generally, small samples sizes limit the benefit of targeting catches from a particular area, but in this case the sheer volume of catch taken at the Actaeons enabled the development of a time-series of size-composition histograms. Fig. 23 shows changes in size-composition of the catch at the Actaeons over the course of the year. Of particular concern is the removal of most of the larger abalone (size-classes 146 and greater) during the later part of the year, indicating that fishing pressure is very high at the Actaeons.

Most samples contained a small number of abalone (generally about 5%) that measured less than the legal size-limit. While divers are usually careful to gauge the size of each abalone, sometimes they include other shell fish or algae growing on the shell, or the shell becomes chipped in transit.

The results of a review of the catch-sampling program are included in Appendix 8. It discusses the problems encountered with both the photographic and the factory - measuring methods and future directions of the program.

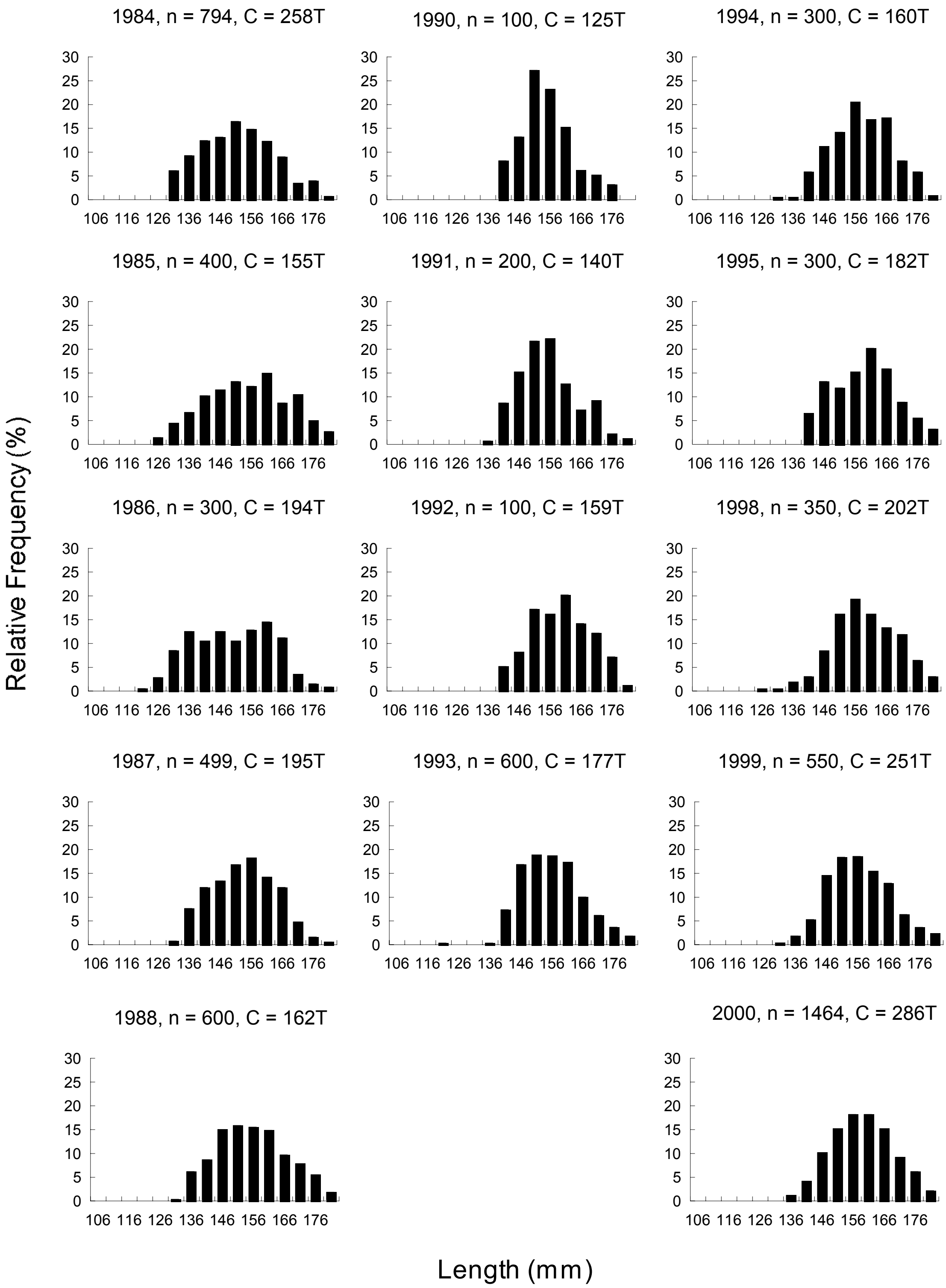

Fig. 15. Size-composition of the commercial catch from statistical block 12. Samples were measured at processing factories from 1984-95 and 2000, and supplied by divers in 1998-99. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

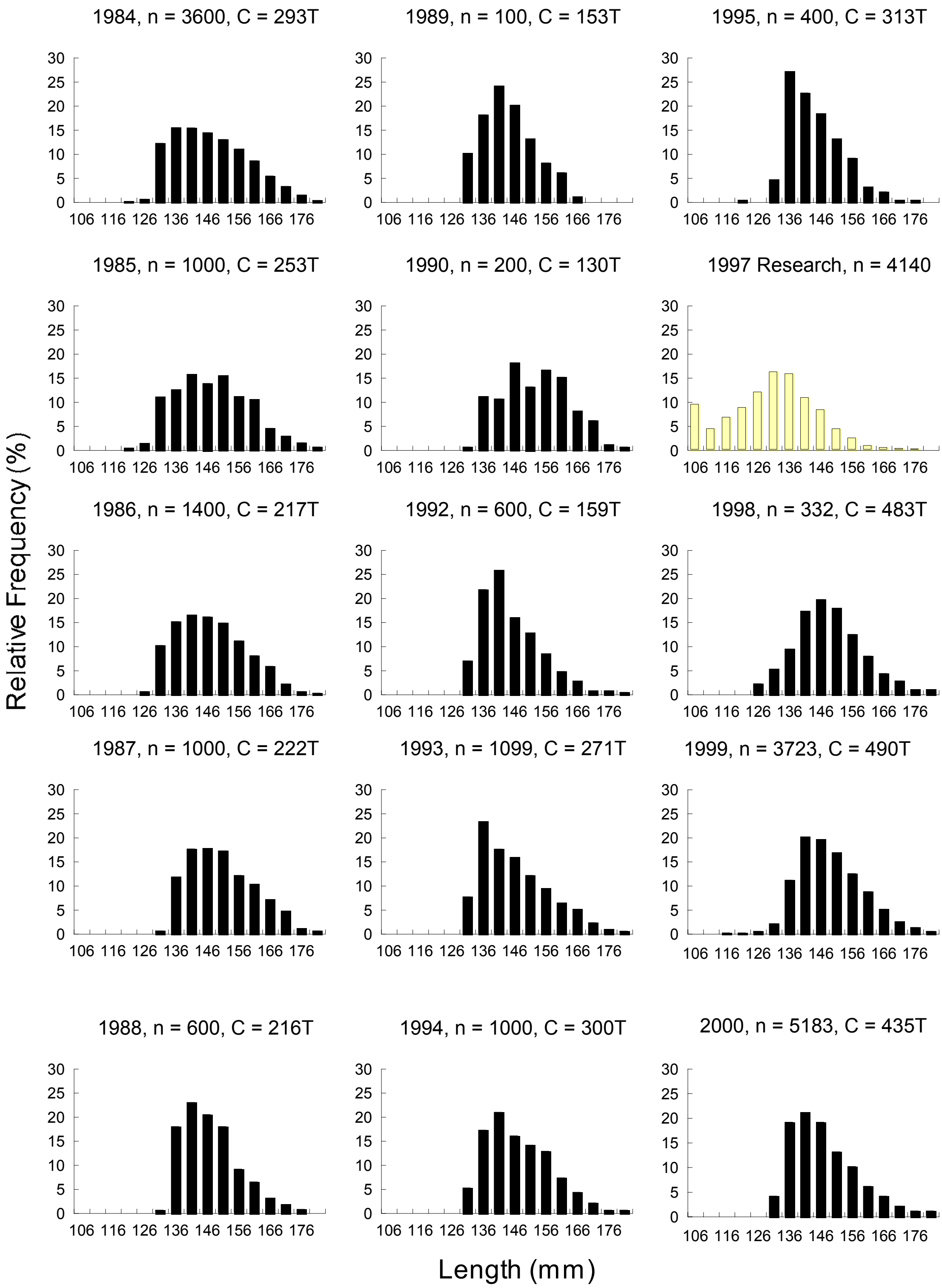

Fig. 16. Size-composition of the commercial catch from statistical block 13. Samples were measured at processing factories from 1984-95 and 2000, and supplied by divers in 1998-99. The size composition of samples taken by research divers in 1997 is also shown for comparison. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

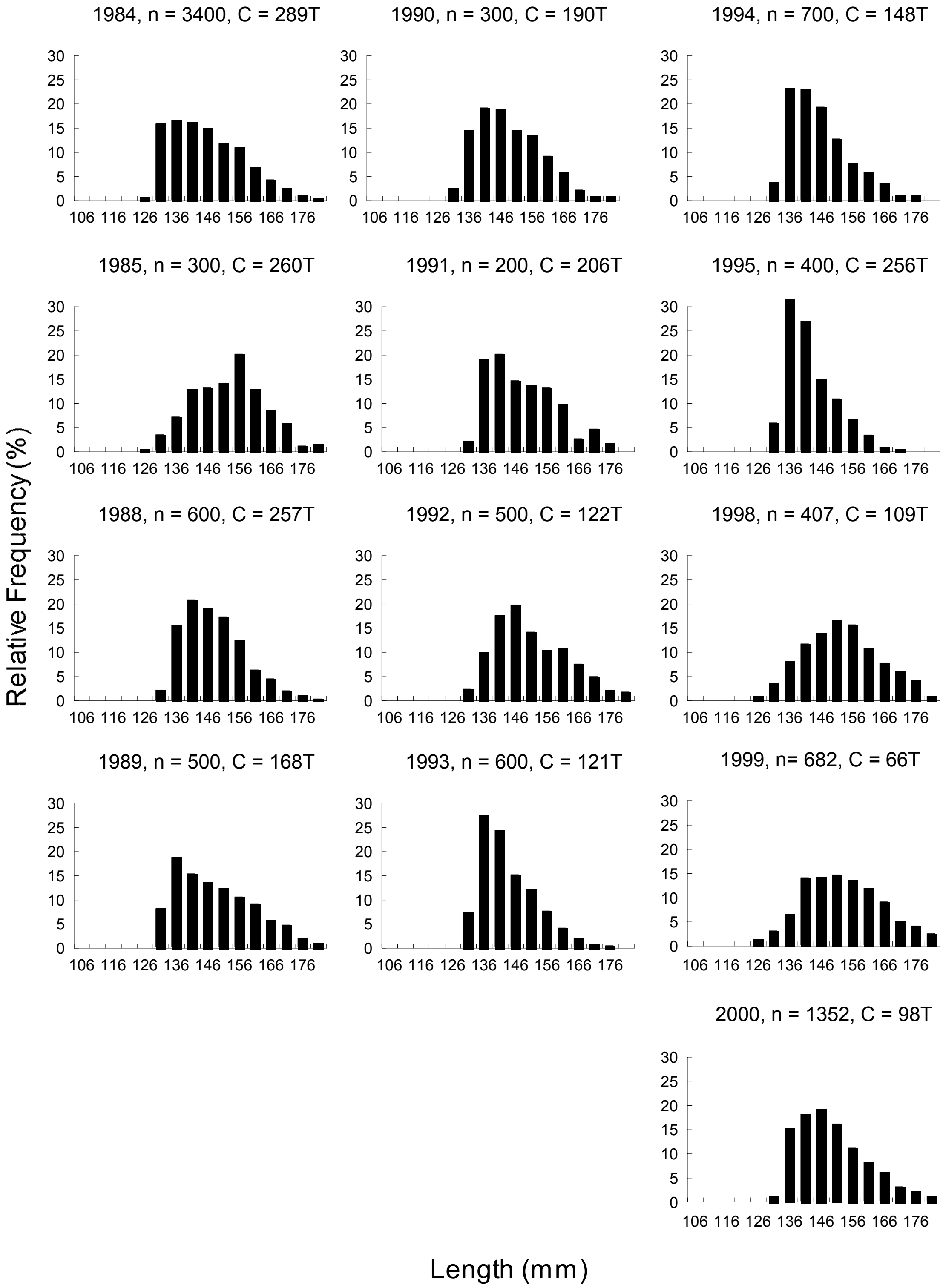

Fig. 17. Size-composition of the commercial catch from statistical block 14. Samples were measured at processing factories from 1984-1995 and 2000, and supplied by divers in 1998-99. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

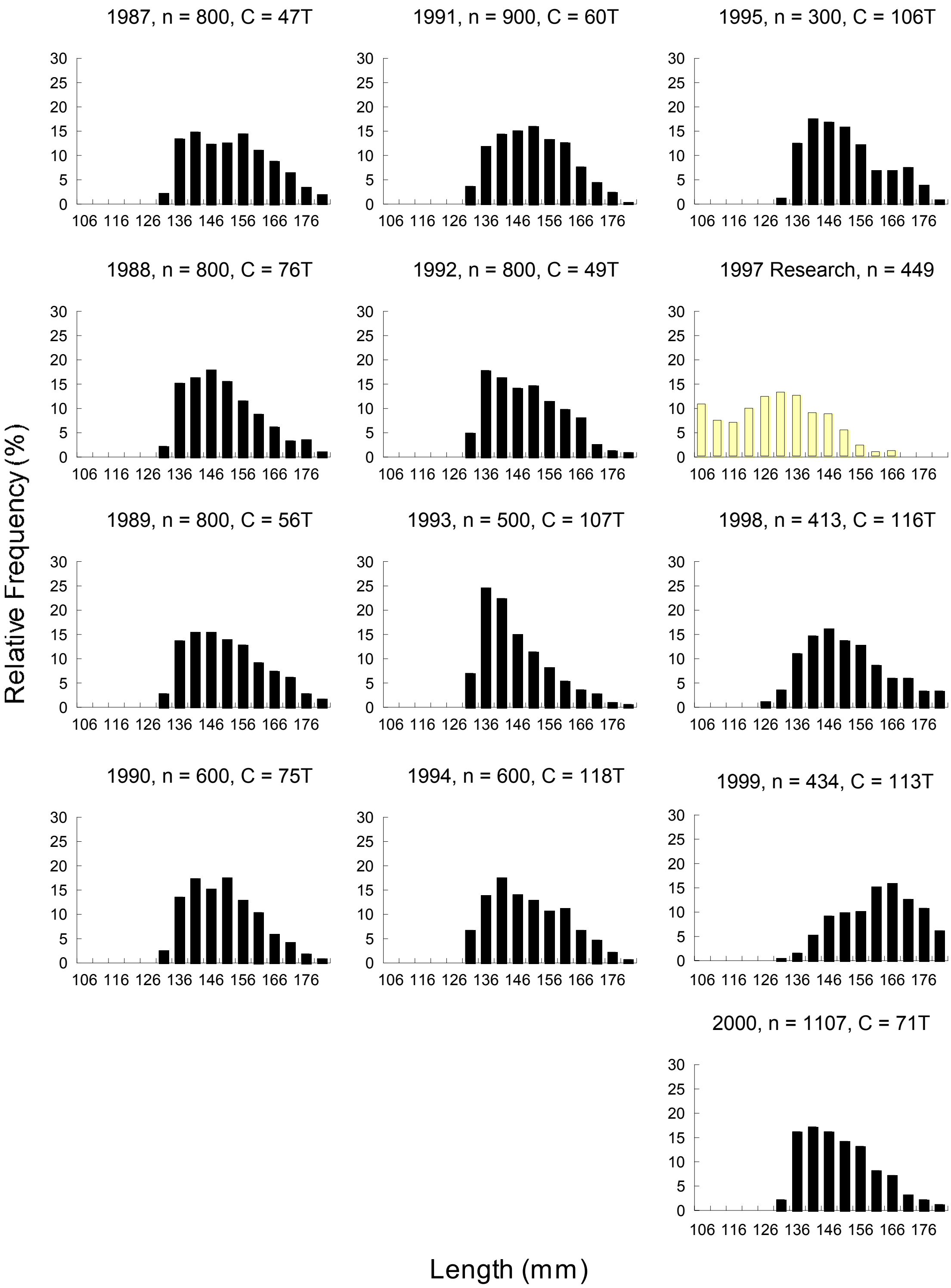

Fig. 18. Size-composition of the commercial catch from statistical block 16. Samples were measured at processing factories from 1984-1995 and 2000, and supplied by divers in 1998-99. The size composition of samples taken by research divers in 1997 is also shown for comparison. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

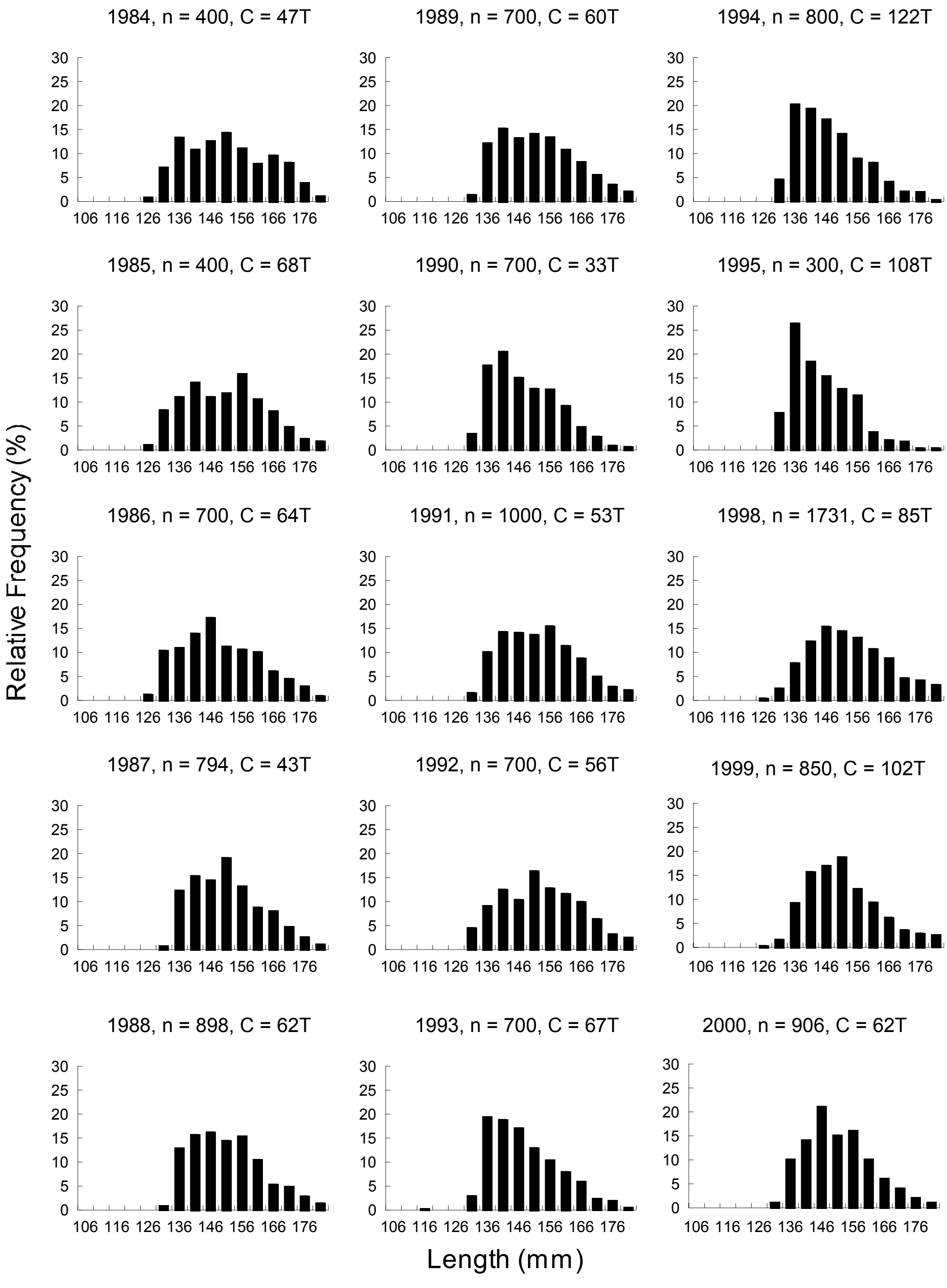

Fig. 19. Size-composition of the commercial catch from statistical block 20. Samples were measured at processing factories from 1984-1995 and 2000, and supplied by divers in 1998-99. The size composition of samples taken by research divers in 1997 is also shown for comparison. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

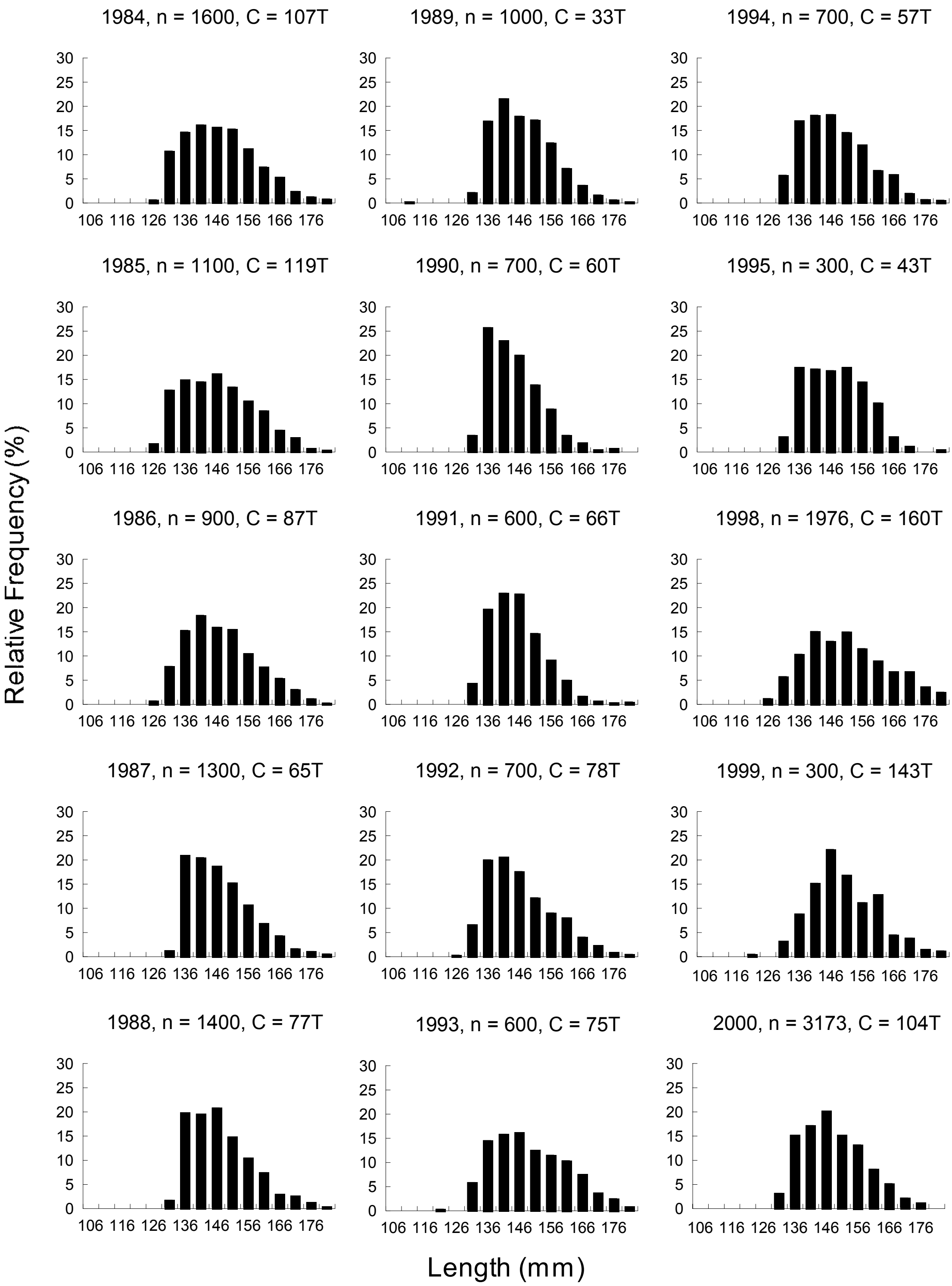

Fig. 20. Size-composition of the commercial catch from statistical block 24. Samples were measured at processing factories from 1984-1995 and 2000, and supplied by divers in 1998-99. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

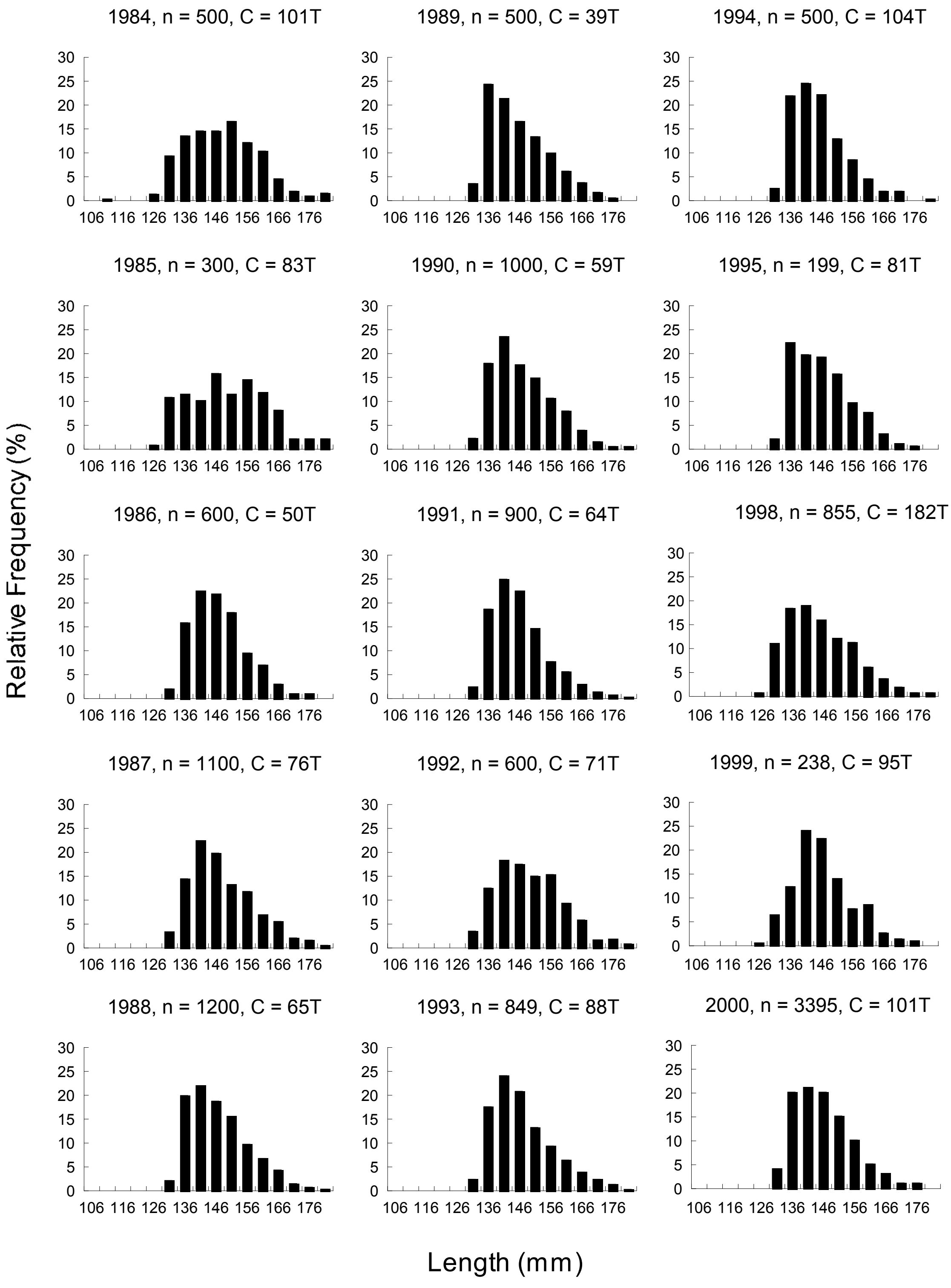

Fig. 21. Size-composition of the commercial catch from statistical block 27. Samples were measured at processing factories from 1984-1995 and 2000, and supplied by divers in 1998-99. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year.

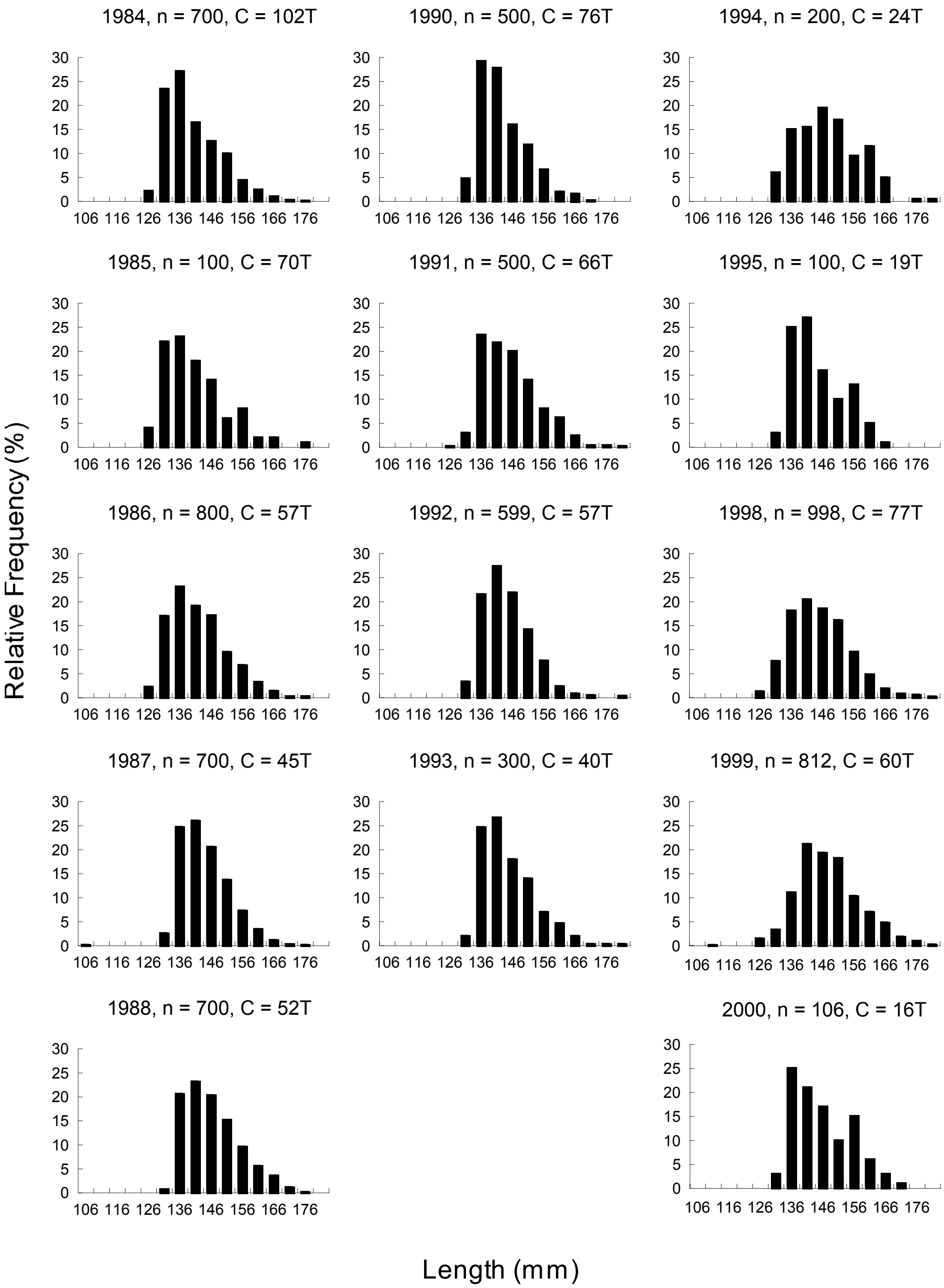

Fig. 22. Size-composition of the commercial catch from statistical block 28. Samples were measured at processing factories from 1984-1995 and 2000, and supplied by divers in 1998-99. The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each year. The 2000 sample was derived from only one diver's catch.

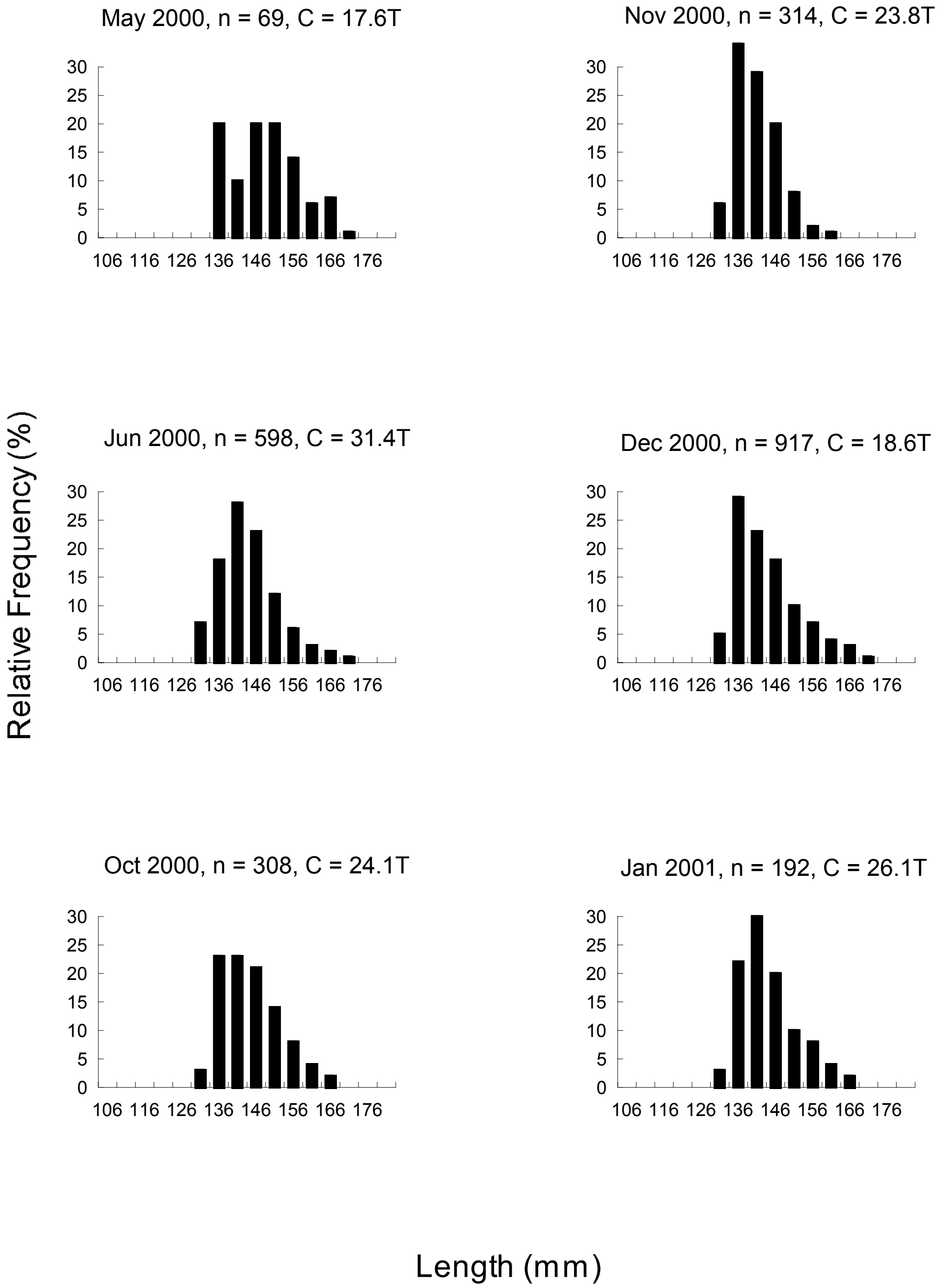

Fig. 23. Size-composition of the commercial catch from statistical block 13E (Actaeons and associated southern reefs and breaks, east of and not including Black Reef). Samples were measured at processing factories (principally Tasmanian Seafoods Pty Ltd (Margate) and Southern Ocean Seafoods (NSW) Pty Ltd (Dunalley). The number of abalone sampled (n) and the annual catch in tonnes (C) is given for each month.

Samples collected from Block 12 (and other west coast blocks not shown because of inadequate time series) suggest that about 50% of abalone measured at least 160 mm. An analysis of production data provided by Tasmanian Seafoods Pty. Ltd. strengthens this conclusion. These data analyse the proportion of production of cans containing one whole abalone or one abalone cut so as to fit it within a can. Such abalone would have a minimum length of 160 mm given the minimum bled meat weight within a can of 213 g, known rates of weight loss during processing (A. Hansen, pers. comm.) and bleeding (Nash, 1995b), and known length-weight relationships (Nash *et al.*, 1994).

Overall production from fish sourced in all areas showed an increase from 1995 to 2000 of product canned one piece whole and larger (Table 1). There was some reduction in this percentage from 1997 to 1998, and an increase to 1999, corresponding with a shift in relative size of the catch from the east and west coasts during that period (Table 1). In 2000, there was a much greater increase, not because the abalone are now larger, but because the smaller abalone were sold on the live market and were not canned.

Table 1. Factory output of large abalone

Details from the total production July 1995 to December 2000, of all grades of abalone product canned by Tasmanian Seafoods Pty Ltd (Margate), showing the percentage of cans produced containing one abalone, or one cut abalone.

Year	Month	One piece whole as % of production
1995	July-December	15%
1995	**Total**	**15%**
1996	January-June	19%
1996	July-December	14%
1996	**Total**	**16%**
1997	January-June	26%
1997	July-December	17%
1997	**Total**	**21%**
1998	January-June	17%
1998	July-December	16%
1998	**Total**	**16%**
1999	January-June	24%
1999	July-December	21%
1999	**Total**	**23%**
2000	January-June	35%
2000	July-December	31%
2000	**Total**	**33%**

Very little of the west coast catch is sold to the live market, most of it being canned. When catches from the west coast are analysed exclusively the proportion of very large abalone on the west coast becomes apparent. These data show that 50% of the west coast abalone production was canned one piece whole in 2000, the same as the previous year, indicating the average weight of abalone is being maintained in the west (Table 2).

Table 2. Factory output of abalone from West Coast

Production of cans by Tasmanian Seafoods Pty Ltd (Margate), containing one (or one cut) abalone, as a percentage of all grades of abalone product processed on days when west coast abalone were processed exclusively.

Year	Period	One piece whole as % of production
1997	January-July	53%
1997	July-December	48%
1997	**Total**	**51%**
1998	January-July	48%
1998	July-December	43%
1998	**Total**	**42%**
1999	January-June	54%
1999	July-December	48%
1999	**Total**	**50%**
2000	January-June	53%
2000	July-December	49%
2000	**Total**	**50%**

6.4 Block 13 Population Monitoring

Block 13 is one of the most important abalone producing areas of the State. It covers coastline between the New River at Prion Bay on the South Coast eastwards and northwards to the start of the Big Lagoon Beach south of the mouth of Southport Lagoon, and includes the Actaeons and associated reefs to the east.

Following the introduction of sub-blocks to the diver's logbook in 2000, it became possible to see from where in Block 13 the catch was taken. In 2000, the islands and reefs of the Actaeons contributed over half the catch, with almost another quarter coming from Recherche Bay and reefs and coast to the east (Fig. 24).

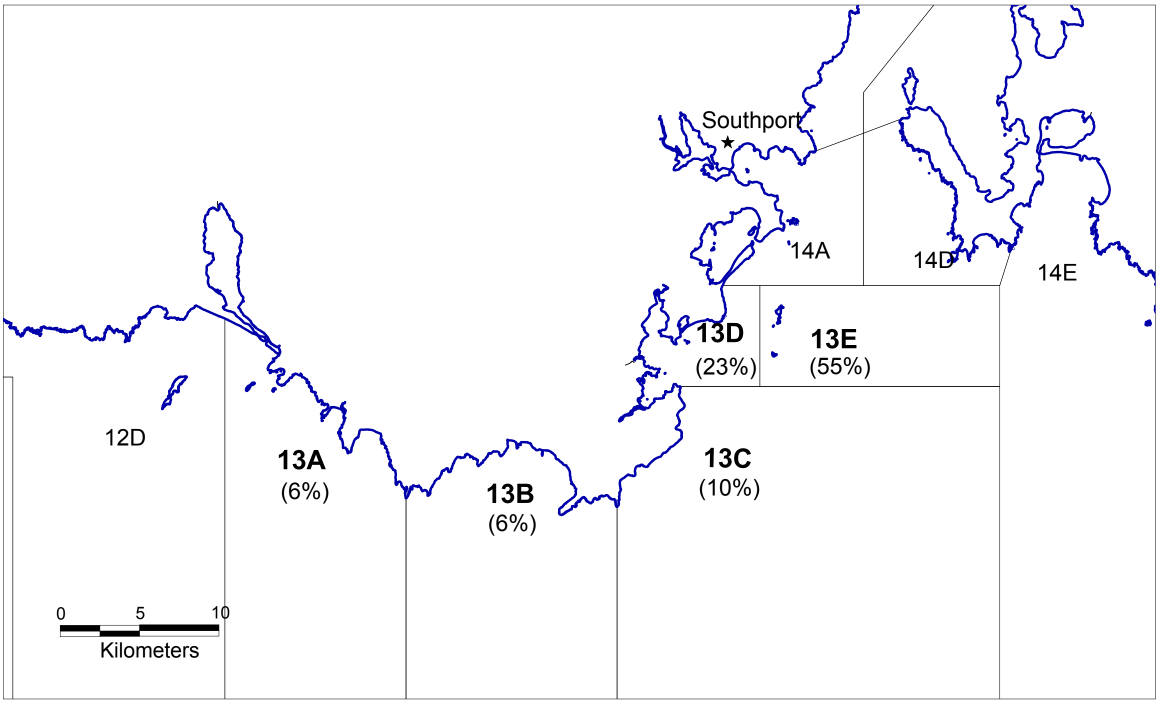

Fig. 24. South-east Tasmania, showing the sub-blocks of Block 13 and their percentage contribution (in brackets) to the 2000 catch of 435.5 tonnes.

Like most of the fishery, catches and catch-rates in Block 13 improved remarkably during the early 1990's, reaching a peak in the mid to late 90's, from which they have since fallen (Fig. 25). A surge in abundance followed the catch reductions of the late 1980's, causing the high catch-rates of the 1990's.

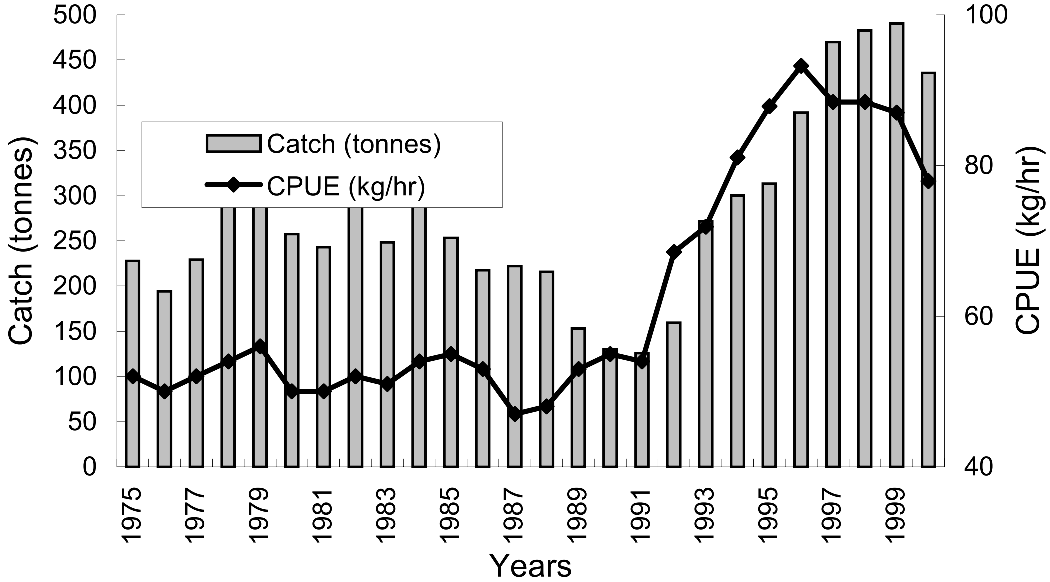

Fig. 25. Catch and catch per unit effort, Block 13, 1975 – 2000.

Effort, in terms of hours in the water has increased, and despite the fall in catch in 2000, is greater than 5,500 hours (Appendix 2). Viewed in terms of number of trips to the block by divers by month, traditionally most Block 13 fishing is done in winter when weed growth is less and abalone are more abundant, and effort is directed elsewhere during summer. However, in 2000 the number of trips between November and January 2001, was greater than during the 2000 winter (Fig. 26).

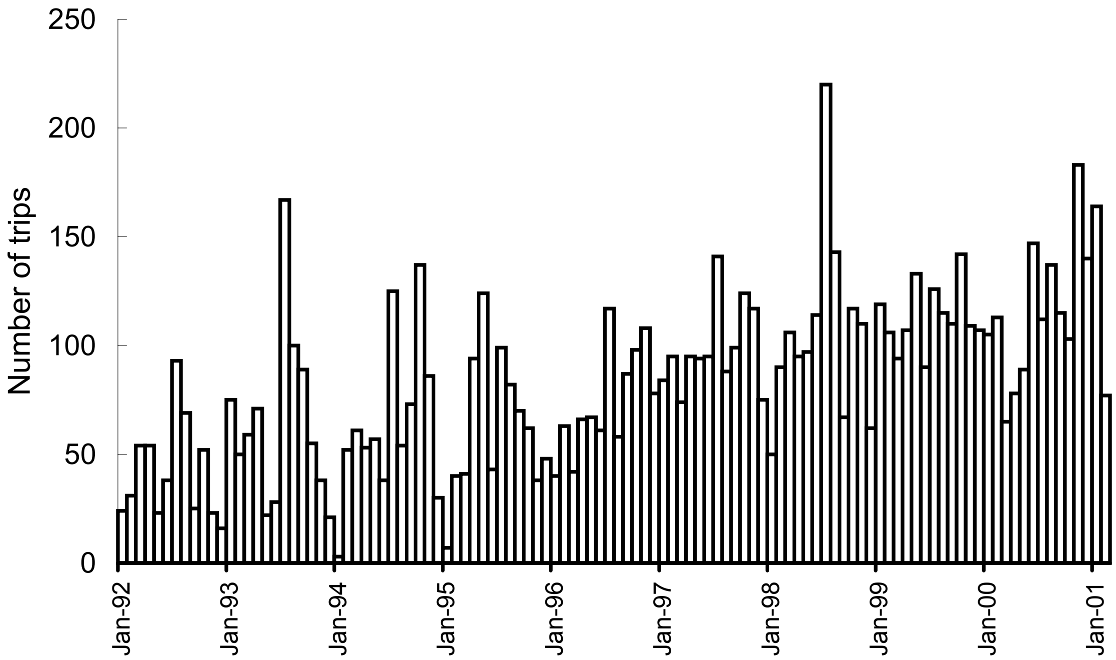

Fig. 26. Escalation of effort in Block 13 between 1992 and 2001, showing the total number of trips made by divers to that block each month. The annual total of trips has risen from 500 in 1992 to nearly 1400 in 2000. While the greatest number of trips occurred in July 1998 (220), there was a sharp increase in effort between November 2000 and January 2001 when 183, 140 and 164 trips were made in those three months.

From September1999, studies of abalone populations have been undertaken at several sites in Block 13. This work has focussed on producing information about abalone growth, size at sexual maturity and size-composition.

Samples of about 200 abalone have been collected randomly from two sites at the Actaeons at approximately monthly intervals since that time. The same sampling strategy was used whenever a sample was collected. These abalone were measured, and the resultant size-composition data charted (Fig. 27).

The size-composition of abalone from the Western Reef (Sterile Island) shows that the proportion of legal-size abalone fluctuates seasonally. Over the sampling period, the proportion of legal-size abalone is less in spring and summer than in autumn and winter.

By following each chart sequentially, it can be seen that the modal size class moved through the size-limit in February 2000, but while tending to increase in size, failed to do so in 2001. We interpret this as recruitment of a cohort to the fishery in early autumn in both years, but particularly heavy fishing between November 2000 and January 2001 (Fig. 26) reduced the proportion of abalone that would otherwise have been caught at a larger size during the following autumn and winter.

Note also the paucity of large abalone (i.e. greater than 146 mm) and the large proportion of abalone less than the size-limit, indicating that in spite of growth over-fishing, the recruitment base is still strong.

This is consistent with anecdotal evidence, catch-rate declines (Appendix 2) and size-composition data from catch-sampling (Fig. 23). It indicates that this reef is being heavily fished, and that the annual catch is dependent almost entirely upon recruitment to the fishery from the previous year.

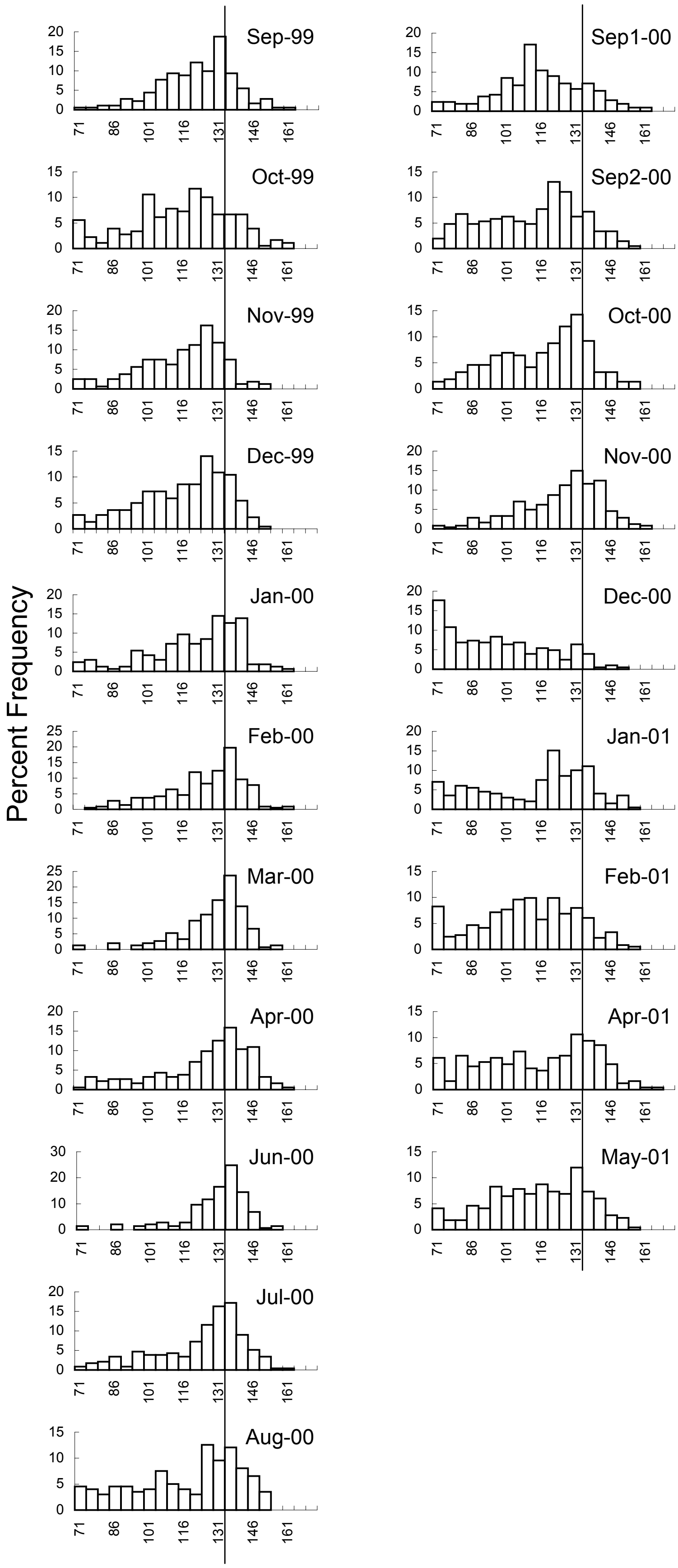

Fig. 27. Size-composition by percentage frequency of 5-mm size-classes, of samples of randomly collected abalone, taken from Western Reef, Sterile Island (Little Actaeon) at approximately monthly intervals. The two vertical lines indicate the position of the size-limit

6.5 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. During the same period, rock lobster dive licenses also increased, but at a lesser rate (Fig. 28), perhaps indicating a shift in recreational effort from rock lobster (which in the south east is heavily exploited) to abalone.

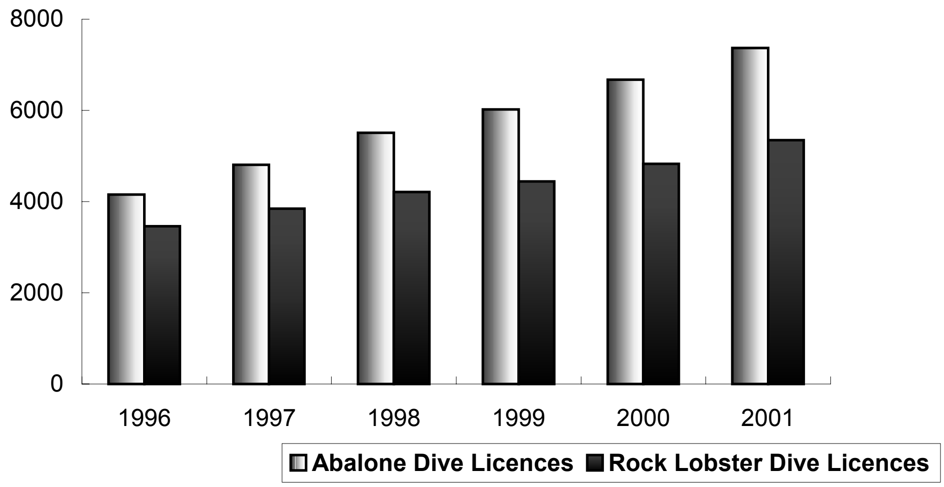

Fig. 28. The number of recreational dive licenses issued by DPIWE to catch abalone and rock lobster for the seasons 1995-96 to 2000-2001.

Surveys of recreational fishing undertaken by the Department of Primary Industry and Fisheries suggest the recreational abalone harvest in 1997 was approximately 37.5 tonnes (about 1.5 percent of the commercial harvest) (Lyle, 2000). The distribution and magnitude of the recreational abalone catch in 1997 is shown in Fig. 29. These data suggest that the recreational fishery focuses on blacklip abalone and that 70% of the recreational catch comes from the South East and East Coast. The highest estimated recreational catch was in the North West (5 % of the commercial catch). This percentage appears high not because the recreational catch itself was large, but because of the decline in the commercial catch from this region (Fig. 29). More contemporary data will become available following completion of the National Recreational Fishing survey in 2001.

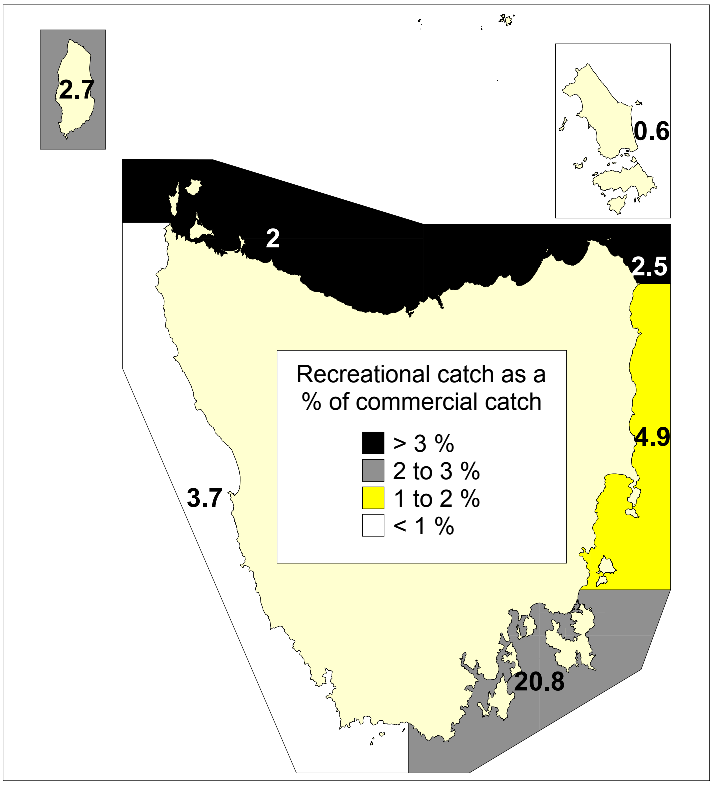

Fig. 29. The 1997 recreational catch in tonnes and as a percentage of the commercial catch for the seven regions used in surveys of recreational fishing in Tasmania (Lyle, 2000). Numbers indicate the catch in tonnes, shading indicates the value of these tonnages as a percentage of the commercial catch from each region. Regional boundaries are adjusted from those normally used in abalone assessment to better reflect the boundaries used in recreational fishing surveys.

Surveys of recreational fishing in Tasmanian suggest that the recreational catch of greenlip abalone is relatively small (Fig. 29) (Lyle, 2000). These data suggest that the recreational fishery on King Island and the Furneaux Group yielded 2.6 and 0.5 tonnes respectively in 1997.

7. Discussion

7.1 Comparison Of Catch And Catch-Rates With Those From Reference Periods

This stock assessment relies primarily upon raw catch and effort data to infer changes in abalone abundance. Notwithstanding the shortcomings of this approach (Harrison, 1983), (Breen, 1992), (Prince and Shepherd, 1992), it currently provides the best means available to assess the fishery in Tasmania. 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. The inaccuracy in the relationship between catch-rates and abalone abundance is the principal reason for the uncertainty in this assessment.

Abalone tend to aggregate in preferred habitat (Officer *et al*., 2000), and divers target these aggregations. Divers maintain high catch-rates by moving from aggregation to aggregation, and it is only when there are very small numbers of abalone remaining (too few to reform aggregations) that catch-rates show a marked decline.

Similarly, when effort on the stock declines, catch-rates may increase because the abalone have more time between fishing events to aggregate. In such cases catch-rates may increase not necessarily due to an increase in abundance, but because the abalone are more easily caught in aggregations.

Earlier assessments attempted to use fixed trigger-points to signify noteworthy events (particularly fishery declines) but were found wanting due to the confusing nature of raw catch-effort data that also reflects factors other than changes in abundance. In future, following extensive standardisation of data to remove extraneous effects, there may be a return to fixed trigger-points, but in the interim the fishery is reviewed with “soft” trigger points i.e. allowances are made for the effects of unstandardised data.

The process of standardising catch-effort data has begun with two blocks in the South East (Blocks 13 and 14), and is discussed in Appendix 6. A number of factors thought to affect catch-rate were identified (including month, diver, port and processor) and catch-rates were modified to remove their effects. While catch-rate trends remain, the magnitudes of such trends differ from raw data.

Increases in catch-rate over time almost certainly reflect increases in fishing power. Since the start of the fishery, divers have improved harvesting techniques, yet the method by which effort is determined has remained static. The interpretation of trends in catch-rate is confounded by this improvement in the efficiency of divers (fishing power). It is likely that fishing power increased during the late 1980s, when drop-lines became widely adopted. Most divers now use lines from the bottom to the boat to board their catches, instead of swimming to the surface with each net as it fills. This undoubtedly saves time, and enables divers to spend a greater proportion of time underwater catching abalone, thus increasing their fishing power. There are other factors that may improve catch-rates: better equipment (e.g. wetsuits, air-supplies), new technology (e.g. dive-computers, GPS) as well as more efficient harvesting techniques (e.g. the progression from untended, anchored boats to moving boats stationed above the diver).

If, as some abalone divers have stated, divers’ fishing power continues to improve, then the catch-rate trends may be optimistic with respect to changes in abundance. Thus, for example, a 20 percent increase in catch-rate would overestimate the increase in fishable biomass if there has been an increase in fishing power over the same period of time. Investigations into improvement in diver efficiency (effort creep) are being undertaken at MRL. Preliminary analyses and their implications are discussed fully in Appendix 7.

7.2 Eastern Blacklip Fishery

In 2000, the Eastern Zone comprised the regions between Whale Head in the south and Port Sorell in the north, loosely covering the South East, East Coast, North East and Furneaux Group regions of this report. Note that 12% of the Block 13 catch was caught in the Western Zone in 2000 (part of the block is west of Whale Head) (Fig. 24), and that the blacklip catch north of Block 31 and in the Furneaux Group was negligible.

Management actions have caused significant catch reductions in both the East Coast and South East region (Appendix 1). Catches in the two regions fell to 74% and 88% respectively of the average catch of the previous three years, and in 2000 were at levels matching the long-term (1975-2000) average. The reason for these reductions is because the annual catch in the Eastern Zone was limited to 1190 tonnes. Furthermore, some of the catch that might have been caught in the South East and East Coast was caught in Block 31, which is still the Eastern Zone, but is reported separately as the North East region.

7.2.1 South East

In the South East, catches are only marginally greater than during the second reference period when catches were at lowest levels (Fig. 3). Closer examination of the data (Fig. 4) shows that most of the South East catch now comes from Block 13 which is being fished at high levels (almost 40% and 70% greater than the first and second reference periods respectively). Catches from the other South East blocks – Blocks 14 and 16 (Lower Channel and Bruny Island) and Blocks 17, 20 and 21 (Forestier and Tasman Peninsula shore from Blackjack to Tasman Island) have declined below those of the two reference periods. Catch rates are generally equal to or better than those of the reference periods.

At Sterile Island in the Actaeons (Block 13), recent field research shows that the catch is comprised mostly of recruits (Fig. 27). That the fishery here is dependent upon just one year class exposes the fishery to much risk and uncertainty, should the pre-recruit cohort fail. It seems likely that other heavily fished areas in the South East and East Coast are now also increasingly dependent on recruits for most of the catch.

Abalone that are recently recruited to the fishery are favoured by buyers and processors for the live-fish market because they are smaller than the older fish that dominate the catches in less intensively fished areas. They attract premium prices, encouraging effort into the heavily fished areas like the Actaeons and parts of the East Coast.

Analysis of size-at-maturity data shows that abalone at the Actaeons are maturing at sizes less than two years growth from the size-limit. This is contrary to the general rule adopted for the Tasmanian abalone fishery. It reduces the protection available to stocks, and increases the risk of recruitment failure, which would impact severely on the fishery.

7.2.2 East Coast

On the East Coast, the regional catch is intermediate between the catches of the first and second reference periods (Fig. 2) and at the long-term average when compared with all previous catches (Appendix 1). Along the east coast of the Tasman and Forestier Peninsulas (Blocks 22, 23) while effort and catch are both relatively high, catch-rates are declining slowly (Appendix 2). Further north in Mercury Passage and Maria Island (Block 24) catches and catch-rates have declined for the third successive year, albeit from very high levels. Along the shores of the Freycinet Peninsula and Schouten Island catches and catch-rates have lifted slightly from last year, although they are far from the record levels of 1997-98.

From the Freycinet Peninsula north to Eddystone Point, catches and catch rates are falling. Block 28 (Friendly Beaches to Seymour Point) catches have declined against average catches from both reference periods (Fig. 4), and are now at a historical low (Appendix 2). Since 1985, catches in this block have cycled from high catches to low catches over approximately five year periods: 2000 seems to be at the tail end of a cycle. Block 29 (Seymour Point to St Helens) has undergone a similar decline, but measured against the reference years, has performed better. However the 1992-1995 reference period was a period of historically low catches, and comparisons may be meaningless.

200 abalone were randomly collected by MRL staff from the northern end of Seymour Point in August 2000 (Fig. 30). While abalone of legal size were relatively scarce, there was no shortage of abalone between 100 mm and the size-limit, indicating that fishing is outstripping the ability of stocks in the area to replenish, but that given some respite, stock levels should rebuild quickly. It indicates that the fishery here is dependent upon the previous year's pre-recruits, similar to the Actaeons. Other samples collected at sites in Block 27 show varying degrees of dependence upon the previous years crop. This is evidence of heavy fishing pressure (high fishing mortality on legal-sized abalone), but not of recruitment failure.

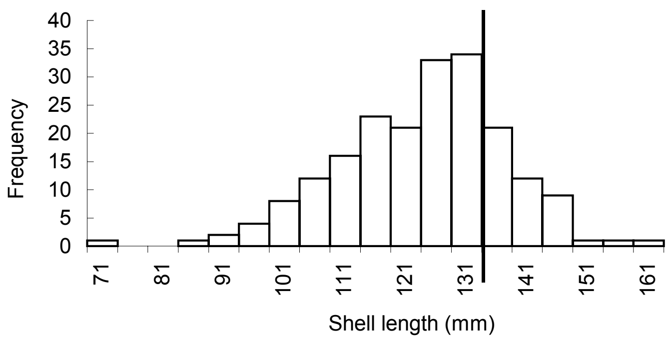

Fig. 30. Size-composition of 200 blacklip abalone taken from the northern end of Seymour Point (Block 29) in August 2000. The position of the legal minimum length (132 mm) is shown as a vertical line. The reduced numbers at smaller size reflects the difficulty in obtaining representative samples of cryptic animals, not necessarily reduced abundance.

7.2.3 North East

In the North East, Block 30 (St Helens to Eddystone Point) catches are at low levels, as they have been since the early 1990's. In contrast to the rest of the fishery, there was no increase in catches between 1990 and 1998, and it can be assumed that sustained high levels of effort in the early 1980's impacted upon stocks to the extent that localised recruitment failure occurred. Divers say that they can fish a reef here and obtain good catches, but only once or twice per year. Subsequent fishing is at very low catch-rates, usually below the diver's economic threshold. Transect surveys of abalone stocks by DPIF in 1995 at Skeleton Bay, Binalong Bay, Sloop Rock and the Gardens found that significant patches of abalone were infrequent, and that abalone were usually found clustering only along the shore margins. This explains why good catch-rates can be maintained, but only while fishing effort is at very low levels. Once a diver has fished a patch, the stocks are unable to replenish quickly enough to allow repeat fishing. It is evidence that a once productive block has been depleted to such an extent that it is failing to repopulate. This is recruitment failure.

The blacklip fishery north of Eddystone Point (Block 31) is in sharp contrast to that further south. The fishery showed some promise in 1999 with rising catches and catch-rates, and in 2000 the catch-rate was maintained while catch was more than doubled. It has out-performed the two reference periods, in terms of both catch and catch-rate. If catches follow historical patterns, it is likely that catch-rates will fall here in future unless escalating catch levels are curbed.

The remaining Eastern Zone blocks of the North East (Blocks 39 and 40) and the Furneaux Group (Blocks 32 to 38) did not contribute significantly to the fishery in 2000. Furthermore, interpretation of earlier catch data is made difficult because of mixed catches of greenlip and blacklip abalone.

7.2.4 East Coast historical catches

The East Coast blocks north of Schouten Island have interesting historical catch patterns, which may contribute to our understanding of how the fishery performs here. For example, Block 27 has been remarkably consistent, fluctuating between 40 and 110 tonnes (a relatively small range) over most of its history. However, in 1997 and 1998, the catch rose to above 180 tonnes, effectively double the average catch (Appendix 2).

Exceptional catches also feature in other blocks. In the early 1980's, there was a greater concentration of divers living on the East Coast between Bicheno and St Helens than at any other time and localised effort was much higher. In Block 28, catches peaked in 1981 when 154 tonnes was caught. Blocks 29 and 30 both peaked in 1983, and Block 31 peaked in 1985. It is interesting to note that these peaks are more than double the average annual catch until the time of the peak, and that following the peak, the fishery progressively declined in all blocks.

Following the years of the peak catches, catch-rates declined across most of the East Coast blocks, as they have done recently. Divers believed that there were widespread declines in abalone abundance, particularly in the east and south. Certainly, it appears that in some areas, abalone numbers were reduced beyond growth overfishing to the extent that recruitment was affected, and in parts of Block 28 and Block 30, abalone populations no longer exist in commercial quantities where once they were fished.

However, the parallel between the fishery of the 1980's and that of recent times ends here, as there are some important differences:

- The tonnages caught in the early 1980's were much higher than those caught in recent years (Appendix 2).
- The increase in size-limit of 1987 offers better protection to East and South East stocks, and reduces the risk of recruitment failure.
- The northern blocks (Blocks 28, 29 and 30) feature beach coastlines with intermittent reef, while the Freycinet Peninsula is reef and cliff coastline, with isolated beaches. The northern blocks may therefore be more prone to serial depletion and recruitment (in the context of settlement) failure.
- Superficially, recent catch rates, even after falling for several years, are much higher than they were during even the best years of the 1980's. However, this difference may be illusory given the use of unstandardised data (Appendix 6) and the effects of effort creep (Appendix 7).

While catches in the South East and East Coast are now at moderate levels compared with historical catches, the extent to which abundance has been reduced by the intensive level of effort and correspondingly large catches during the late 1990's is unclear. If abundance has been reduced to low levels, then current levels of catch may be too great. However, the de-facto index of abundance used in this report, raw catch-rates, are still relatively high and give no clear indication that the Eastern Zone TAC needs to be reduced.

7.3 Greenlip Fishery

Assessment of greenlip abalone stocks by catch-rate analysis is complicated by recent changes to the way in which the fishery is regulated. The introduction of greenlip fishery management in which all quota units are assigned equal share (40 kilograms) has meant a radical redistribution of both market share and diver participation. Instead of the fishery being concentrated in the hands of a few dedicated participants who set up dedicated infrastructure to best exploit the fishery, now all quota holders are involved in the fishery. A few divers with minimal greenlip fishing experience have now replaced some of the experienced greenlip divers because:

- formerly dedicated greenlip suppliers have been forced to buy quota, downgrade their operations or expand their blacklip operations,

- significant tonnages of greenlip quota are concentrated in the hands of the holders of large quantities of quota units (fish processing factories, specialised abalone quota operations),

- the large quota-holders contract divers to catch abalone and many of these divers live in the south of the State, are new divers to the fishery and consequently had little previous experience in catching greenlip abalone.

Catch-rates might be expected to slump as a result of lack of local knowledge, but in all areas except King Island and Block 48 in the North West, catch-rates have remained static or risen slightly. Either the new divers made up for lack of knowledge by increased enthusiasm, or knowledge and experience are not critical factors in determining catch-rates.

Block 48 has good greenlip reefs that are relatively easy to access, and is adjacent to a large abalone processing factory: hence divers continue to fish there at catch-rates that they would move from in more remote areas. Local divers expressed concern for greenlip stocks here because they attracted so much effort, and they felt that overfishing was taking place.

King Island attracted few divers in 2000. The island is seen by most divers as being too remote for economically viable fishing. It is difficult to sell abalone on the island because there is no local fish processor. The cost of maintaining a runabout and tow-vehicle on the island is prohibitive, as is the cost of a mothership, particularly when quota can be caught elsewhere at a lower cost. Weather and sea conditions frequently make diving difficult. Finally, the size-limit has been increased in Island waters, and catch-rates will be lower until abalone grow through the size-limit. There is just one diver living on the island, who was licensed for only part of 2000.

In the Furneaux Group, there has been a general improvement in catch-rates to the extent that local divers would like to increase the cap on catches that applies there. Most of the catch was taken from the southern blocks (Block 32 and Block 33) and Franklin Sound (Block 35), all of which were fished extensively from mother-ships and by local divers. In the north, Blocks 37 and 38 were only lightly fished because the more accessible areas in the south had adequate stocks.

The greenlip catch in the North East rose in 2000. Like the North West, the North East is easily accessible, and close to processors and divers. Under current management strategies, divers will focus on the North East and North West in preference to King Island and the Furneaux Group, and some form of annual catch control will be necessary to limit localised stock declines.

7.4 Western Blacklip Fishery

The TAC in the Western Zone was set at 1400 tonnes, an increase in catch of between 300 and 400 tonnes beyond that prevailing over recent years. Most of this catch was taken from the West and South-West region (Blocks 7 to 13). Catch rates in this region were generally maintained at high levels, but in areas easily accessible to runabouts there have been localised declines in catch-rates (western portion of Block 13, Block 12, Block 9 (near Strahan), Blocks 7 and 8 (near Granville Harbour). It is likely that abundance is falling and that catches should not exceed current levels in these areas. Size-composition data from Block 12 factory samples appears to be stable (Fig. 15), but it is unlikely that small changes in the impact of fishing can be detected until there is an adequate time series of data at the sub-block level.

The more remote areas of the West and South-West (Blocks 10 and 11) continue to perform well with small increases in catch-rate.

In Blocks 5 (Woolnorth Point to the Arthur River Beach) and 6 (Arthur River Beach to Italian River, south of Sandy Cape), catch-rates are relatively stable. Following the TAC increase, there has been relatively little increase in effort here compared with blocks further south and in view of the high catch-rates, a greater annual catch could be expected.

In the North West, blacklip catches have increased in Block 49, mainly due to the influx of divers who would normally fish in the south but have been attracted to the area for the greenlip fishery.

As mentioned in the greenlip section above, the blacklip fishery on King Island continues to decline; not because of falling abundance but because abalone are cheaper and easier to catch elsewhere.

Size-composition data from Block 12 and Tasmanian Seafoods Pty Ltd’s records show no change in the size-structure of the catch. It is still dominated by abalone of greater than 151 mm shell-length, indicative of a relatively low rate of exploitation. Historical market measuring data has to be viewed with caution. The data is not weighted according to size of catch, and one or two samples of big abalone may mask any sign that larger abalone are being removed from the population. Similarly, live buyers may offer a premium price for smaller abalone, leaving Tasmanian Seafoods Pty Ltd with larger abalone. In 2000, the percentage of large abalone (one piece whole to a can) from the Eastern Zone being canned by that processor has risen because their abalone are sourced from catches which are not favourable to live buyers - the abalone are larger.

7.5 Recreational Catch

The recreational catch of abalone reported continues to represent a very minor proportion of the commercial catch. At such levels there is little danger of the recreational catch impacting upon the commercial fishery. However, this does not mean that the recreational catch should be disregarded. It was noted above that the number of recreational abalone fishing licenses is increasing at about 10% per annum, and whilst the recreational catch is small overall it is likely to be significant in areas that are close to population centres. Recreational divers are also more likely to continue taking abalone from reefs where the abundance would be insufficient to maintain acceptable commercial catch-rates. For these reasons the level of the recreational catch should continue to be monitored.

7.6 Implications For Management

The most important feature of this assessment is the status of stocks in the Eastern Zone. There has been a decline in abalone stocks on the East Coast and in the South East. In parts, the fishery is dependent upon abalone that have grown through the size-limit within the previous year. Larger abalone that have grown two or three years since reaching legal size are either absent from catches, or present only in low numbers.

In 2000, catches in the East Coast and South East regions fell to 74% and 88% respectively of the average catch of the previous three years, and were at levels matching the long-term (1975-2000) average. Appendix 3 tables the annual catch for each of the regions that comprised the Eastern Zone in 2000.

Because larger abalone produce greater numbers of eggs, their absence potentially impacts upon recruitment. Also potentially impacting upon recruitment is the large size at sexual maturity of some of the heavily fished stocks in the south: they receive less than two years protection after becoming sexually mature. In 2001, the MRL will undertake a survey of stocks in the East and South East to measure size-at-maturity in heavily fished areas and determine degree of protection offered stocks with a view to determining whether that the current size-limit is adequate.

Abundance (and catch-rates) will not necessarily increase if catch levels are further reduced in the Eastern Zone. There is a time-lag between reducing catch and the corresponding rise in catch-rates and it may take years for substantial improvement in catch-rates to take effect after catch-levels have been cut. The catch and catch-rates shown in Fig. 25 illustrate the lag: falling catches during the mid to late 1980's did not result in substantially improved catch-rates until 1992.

In the Western Zone, intensity of fishing effort is impacting upon catch-levels in the more accessible parts, and abundance will fall if catch is unrestricted. Abalone abundance in the remote areas seems unaffected by current levels of catch.

The fishery on King Island is declining for economic reasons: stock levels of both species are comparatively high in Island waters. When catch levels were determined for the Western Zone from historical catch data, a component of catch was allocated for King Island. If abalone are not caught from here, then increased pressure will be put upon the remaining area of the Zone.

In contrast to previous years, the greenlip fishery in the Furneaux Group appears to have stabilised. There are however concerns that levels of catch in the more accessible parts of the fishery on the Tasmanian mainland are rising and that abundance will fall.

7.7 Recommendations For Future Assessments

- Develop a population-sampling program to monitor relative changes in abundance and size-composition at fixed fished and unfished sites, and incorporate this information into the assessment. This requires the location of sites that are recognised by industry as being representative of the commercial fishery (not merely just sites where abalone are found). Size-composition and abundance counts would be made at these sites at regular intervals. Time series of these data will enable relative abundance estimates of abalone populations at each site, which will be extrapolated to cover the fishery. This work has recently been funded by FRDC and is in progress.

- 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.

- Standardise catch and effort data to remove extraneous factors affecting catch-rates, and compensate catch-rates for increases in fishing power. Initial standardisations have been performed on catch data from Blocks 13 and 14 (Appendix 6), and will be applied to data from other parts of the State during the coming years. Factors influencing diver efficiency will be examined, their effects quantified and catch-rates modified accordingly.

- Expand the MRL market-measuring program to gather representative samples of the catch from the north of the State. Abalone landed in the north are difficult to regularly sample from the MRL (in the south). Casual market-measuring staff at northern factories would alleviate the problem if funding could be found.

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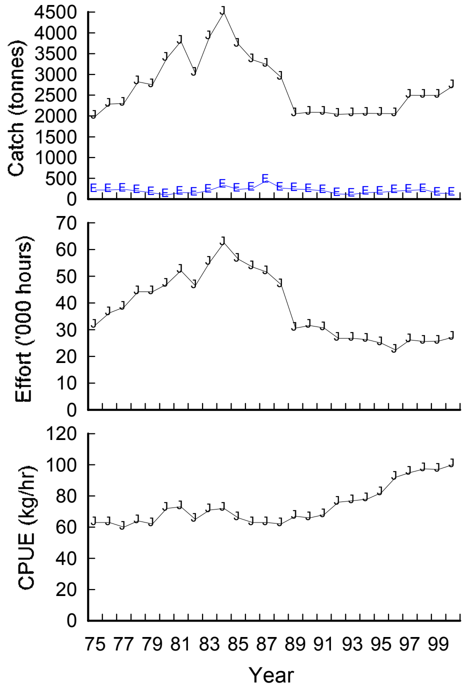
Appendices

Appendix 1: Abalone Catch, Effort And Catch-Rate (CPUE) By Region And Year.

Greenlip catch is plotted (○) where it is an important part of the total catch.

State-wide



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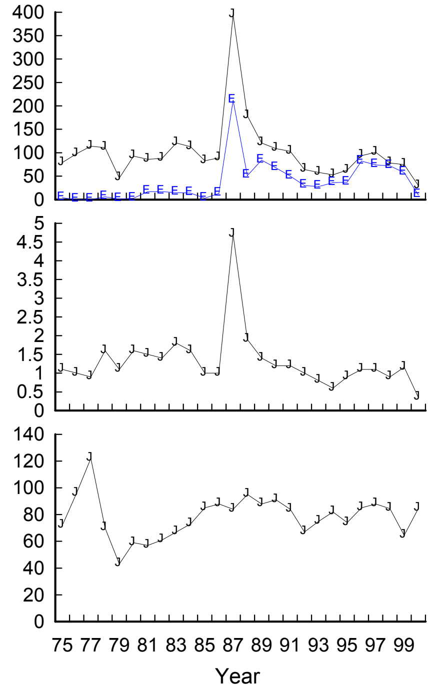
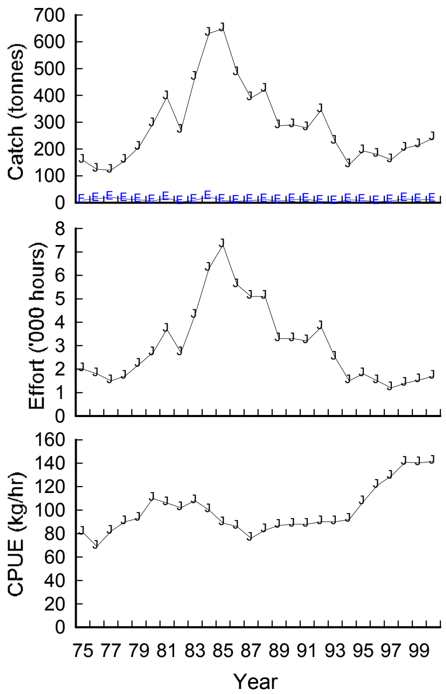
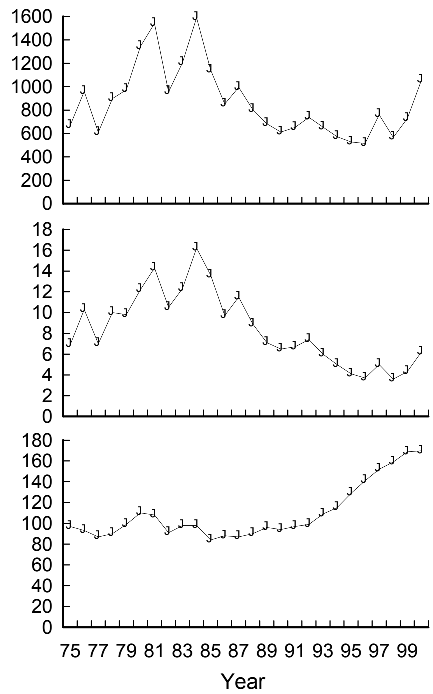


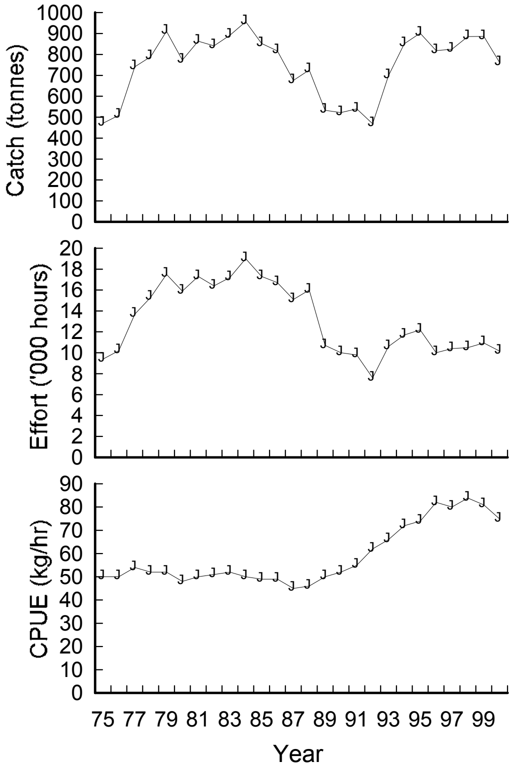
West Coast North (Blocks 5 & 6)



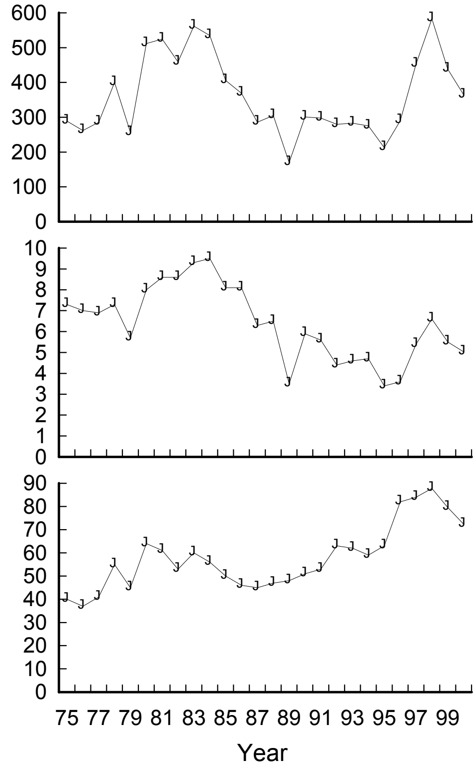
West and South-west (Blocks 7-12)



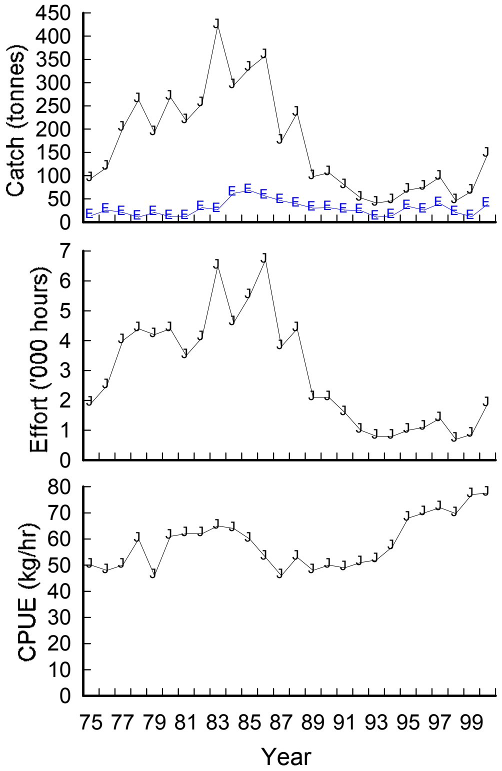
South East (Blocks 13-21)



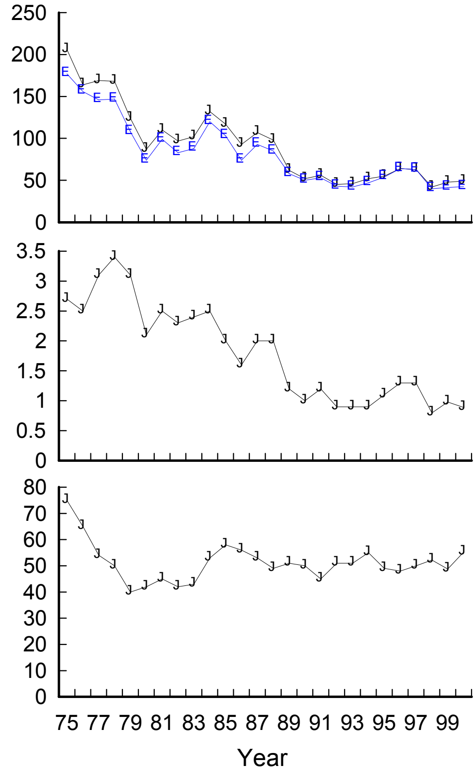
East Coast (Blocks 22-29)

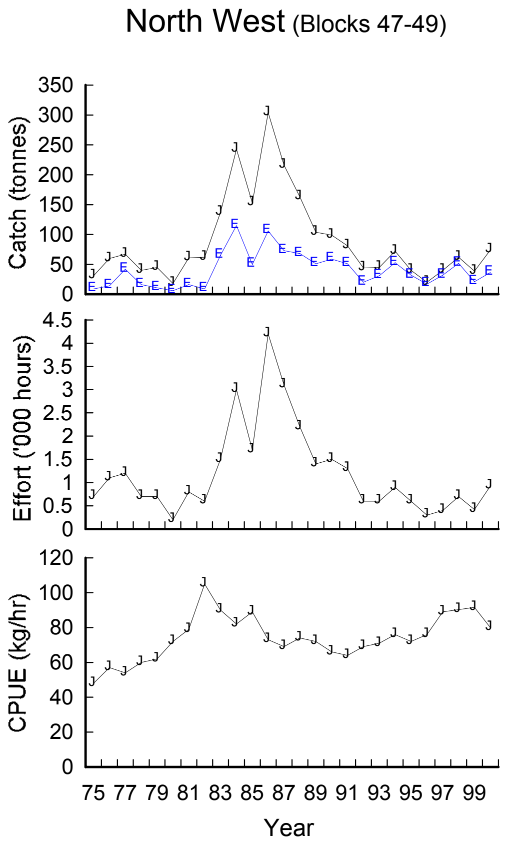


North East (Blocks 30, 31, 39 & 40)



Furneaux Group (Blocks 32-38)

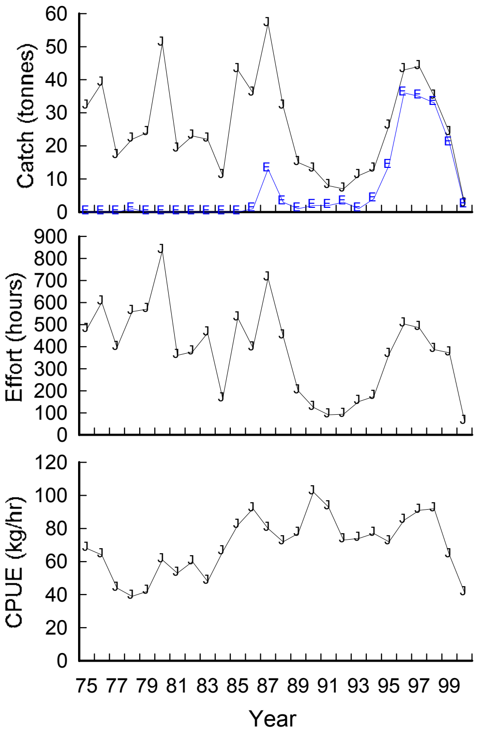



North West (Blocks 47-49)
Catch (tonnes)
Effort ('000 hours)
CPUE (kg/hr)
Year
75 77 79 81 83 85 87 89 91 93 95 97 99

Appendix 2: Abalone Catch, Effort And Catch-Rate (CPUE) By Block And Year.

Greenlip catch is plotted (○) where it is an important part of the total catch.

Block 1 (King Island)



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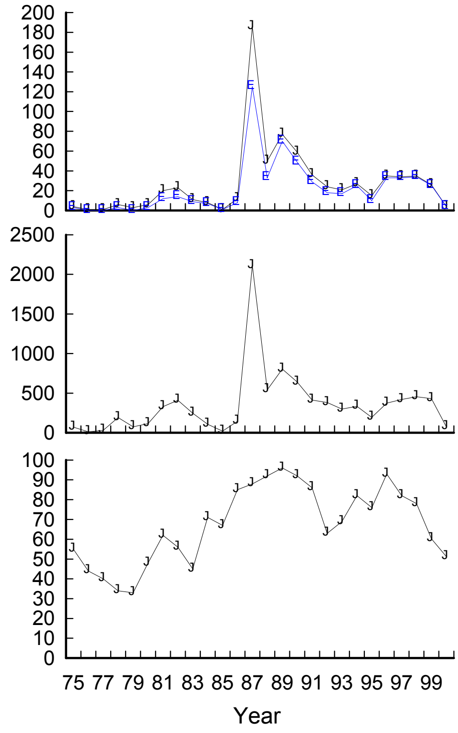

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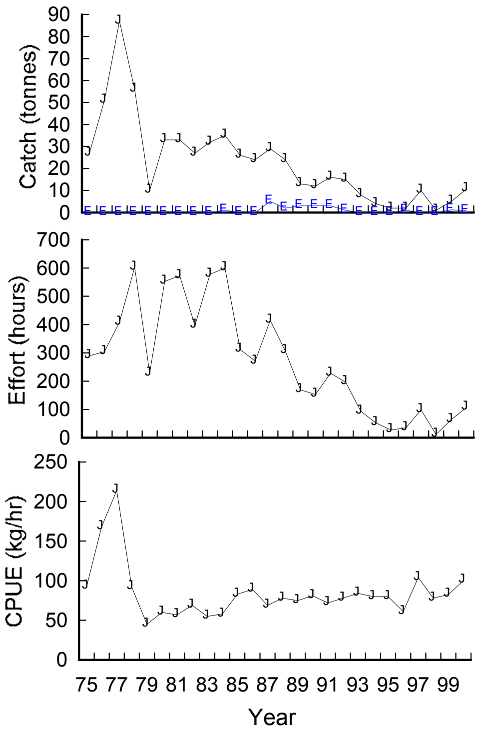

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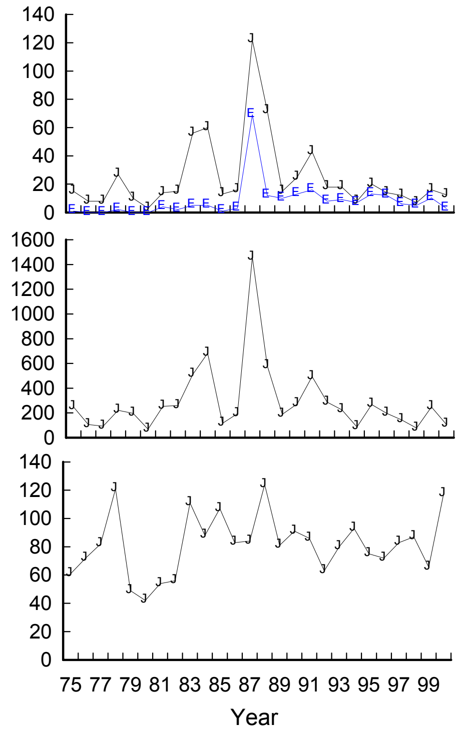

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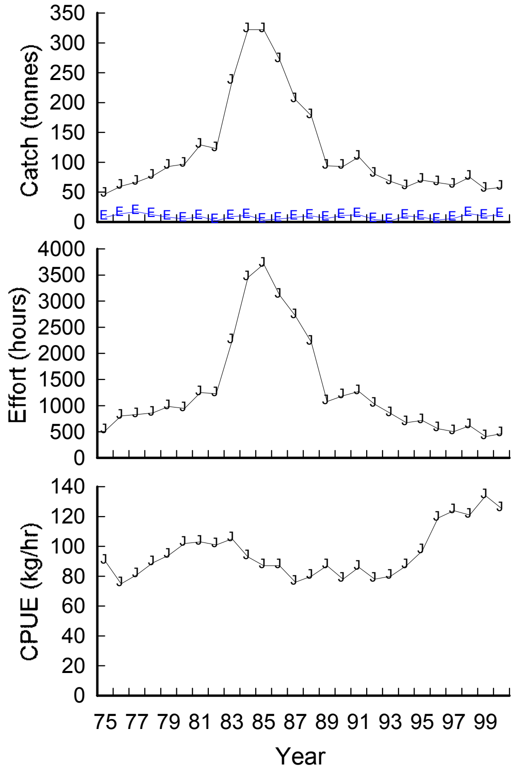

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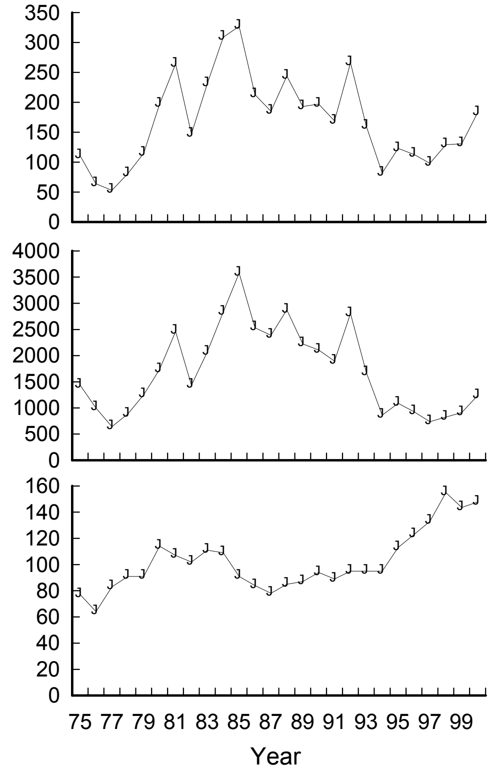
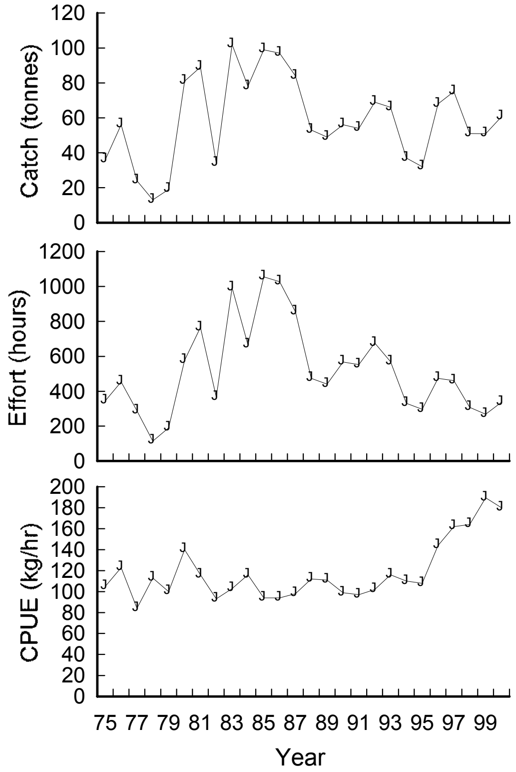


Block 7 (West & South-west)



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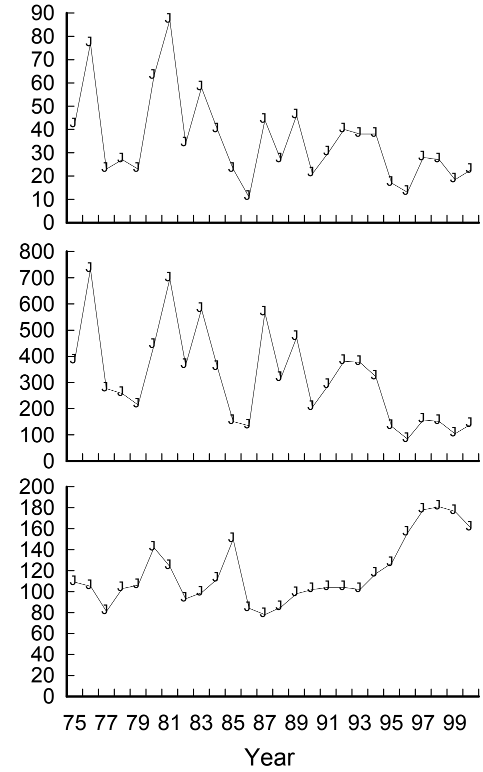

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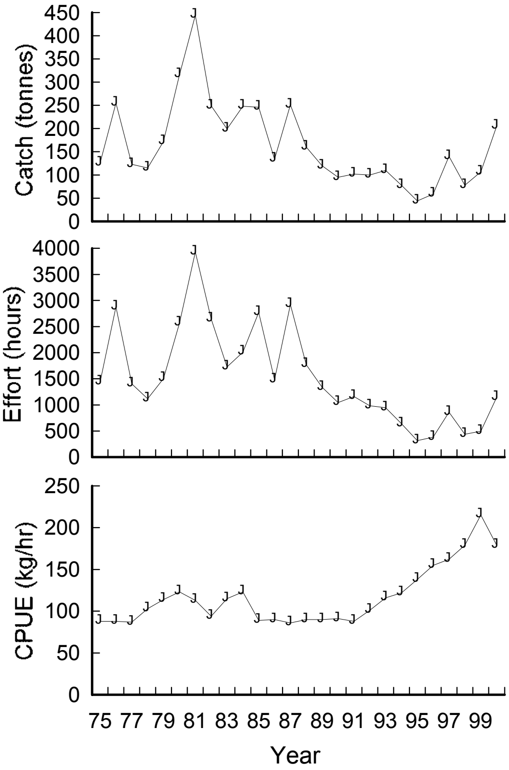

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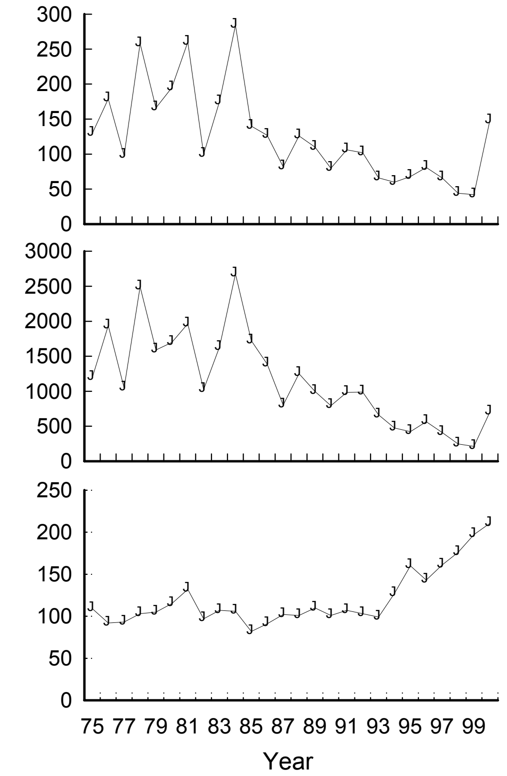

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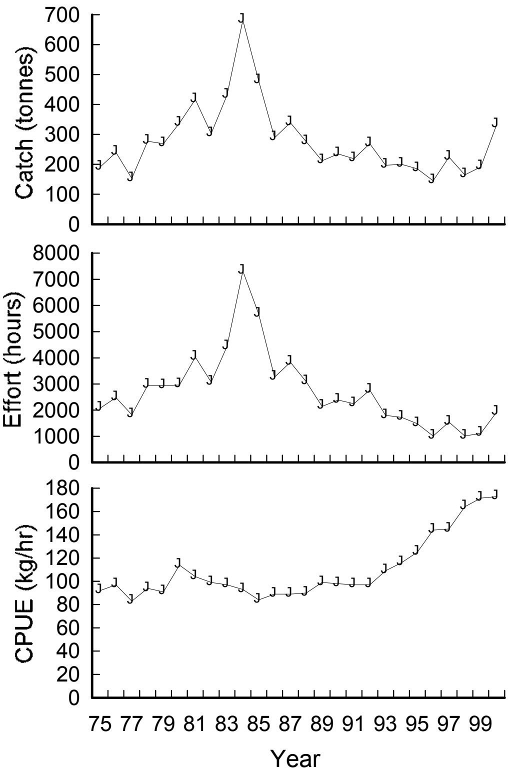

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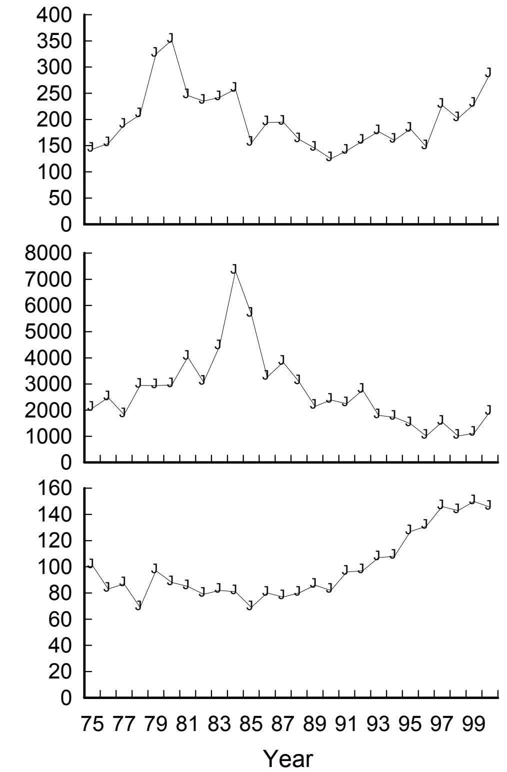

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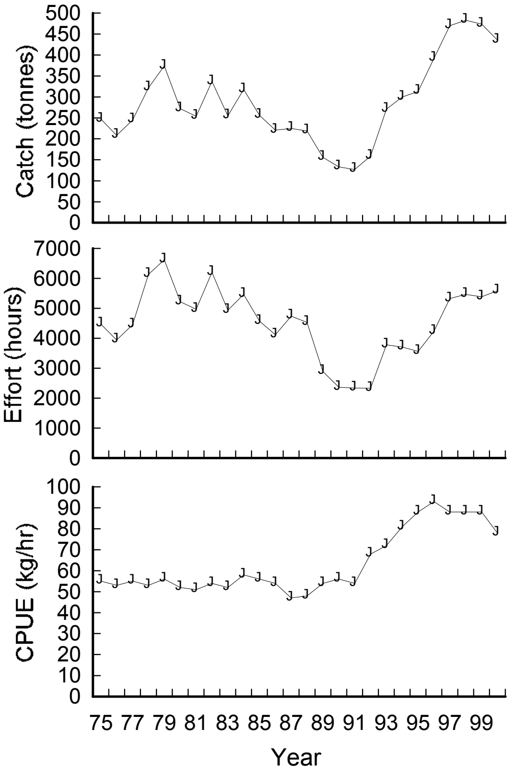

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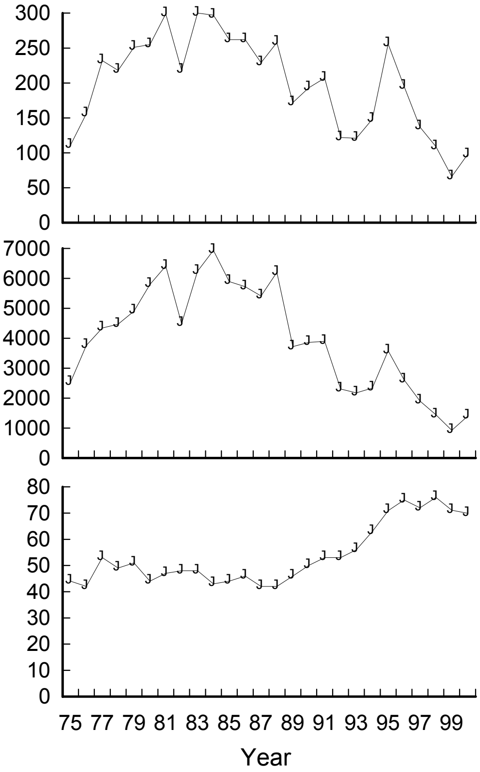

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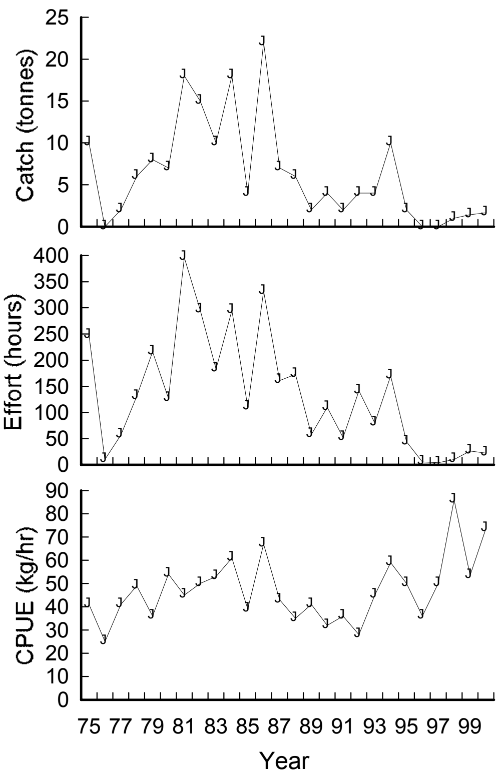

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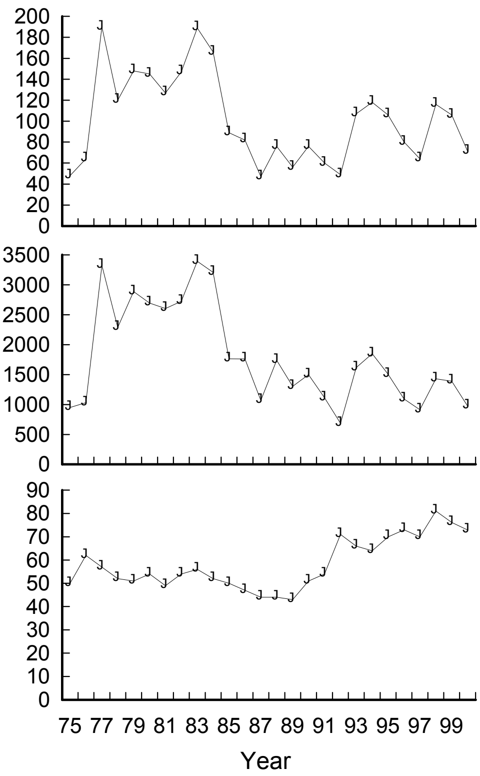

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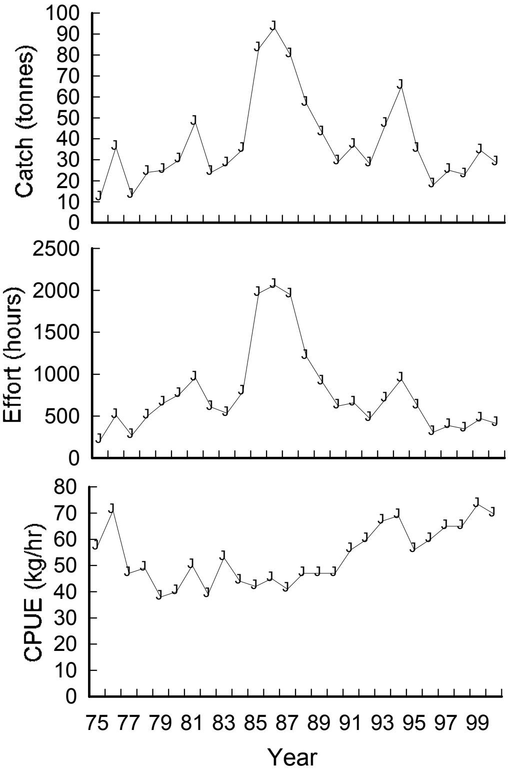
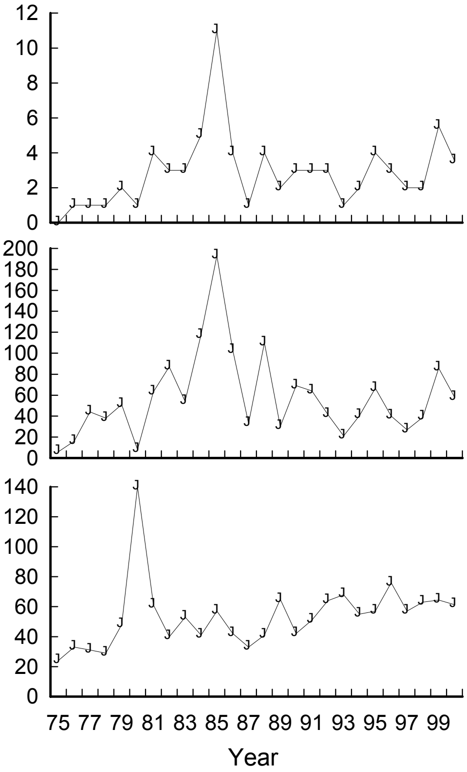


Block 19 (South East)



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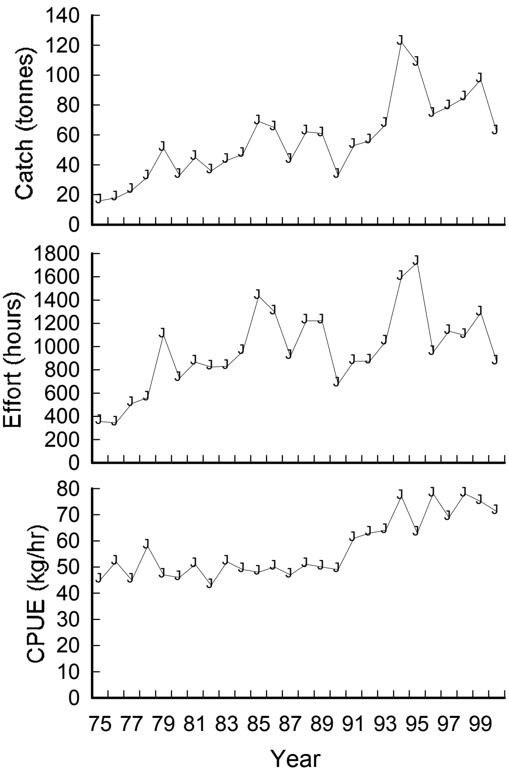
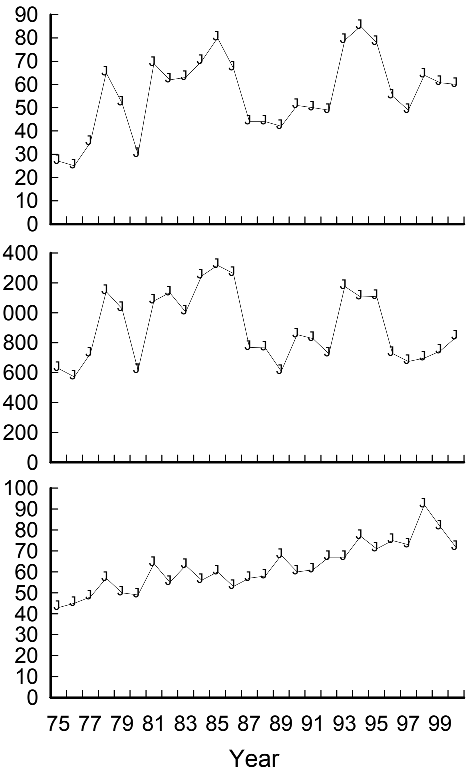
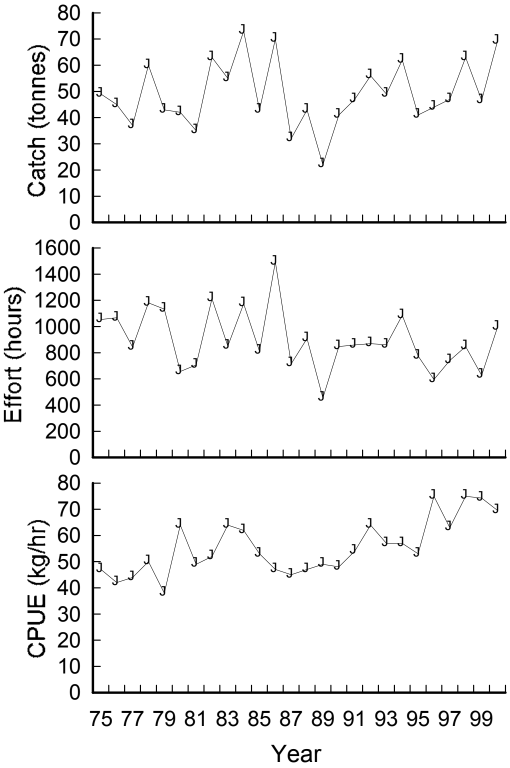


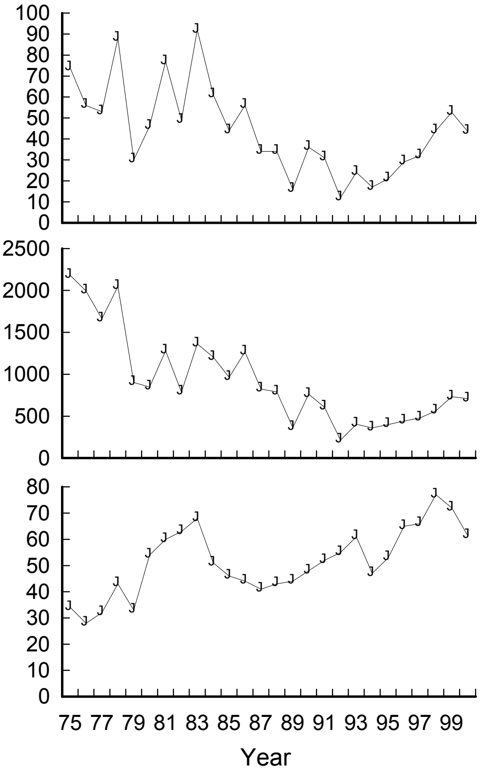
Block 21 (South East)



Block 22 (East Coast)



Block 23 (East Coast)



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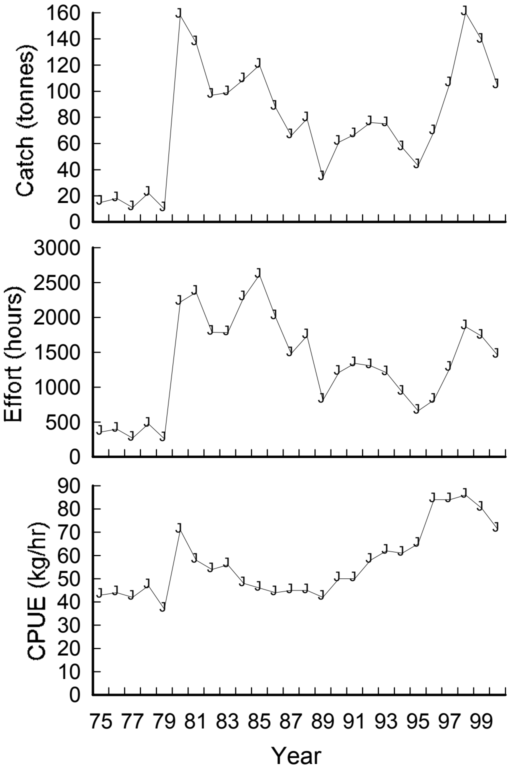

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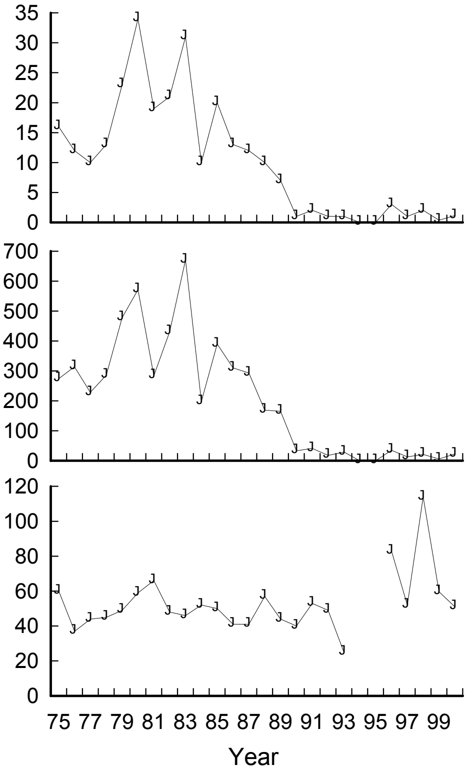

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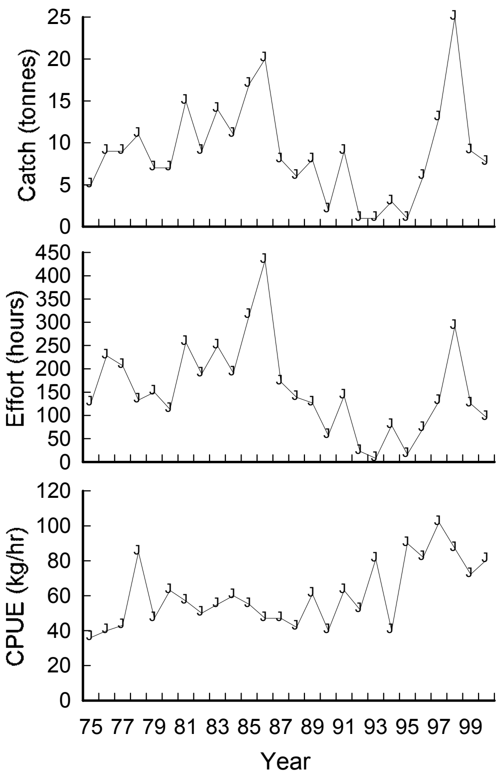

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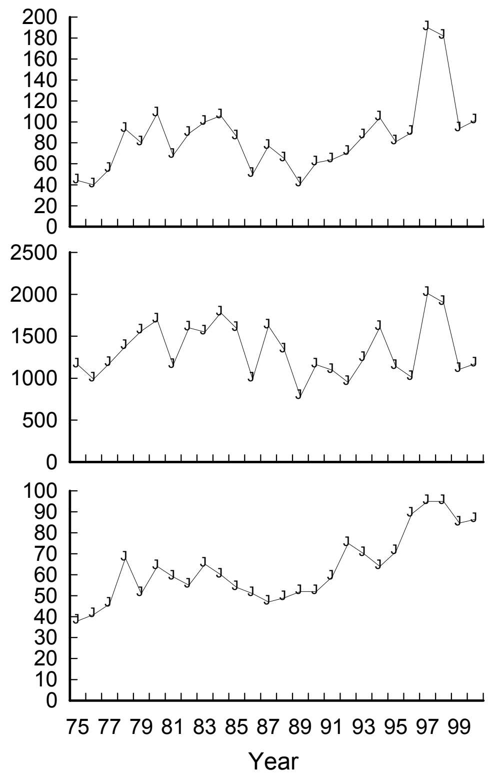
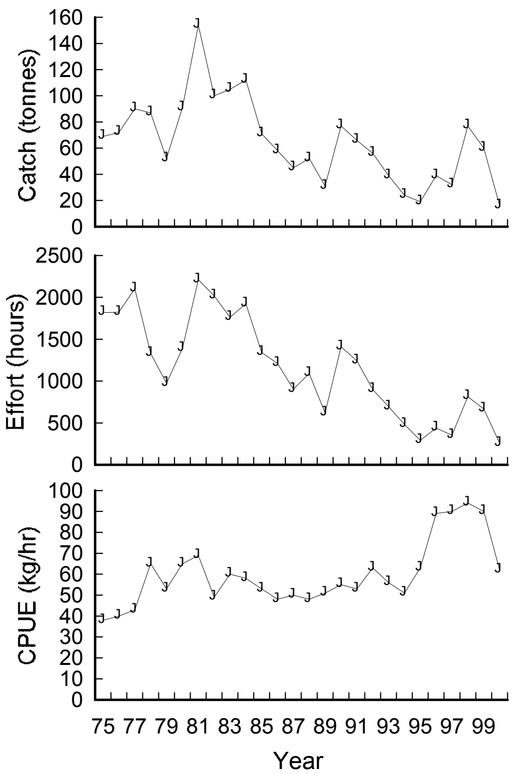
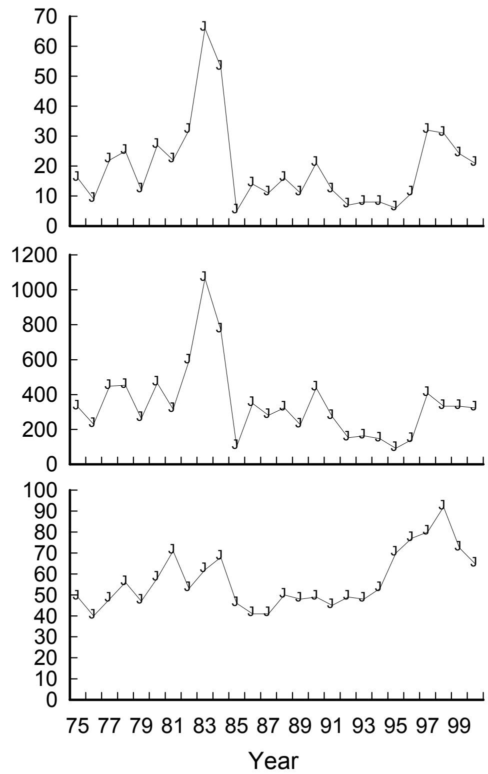


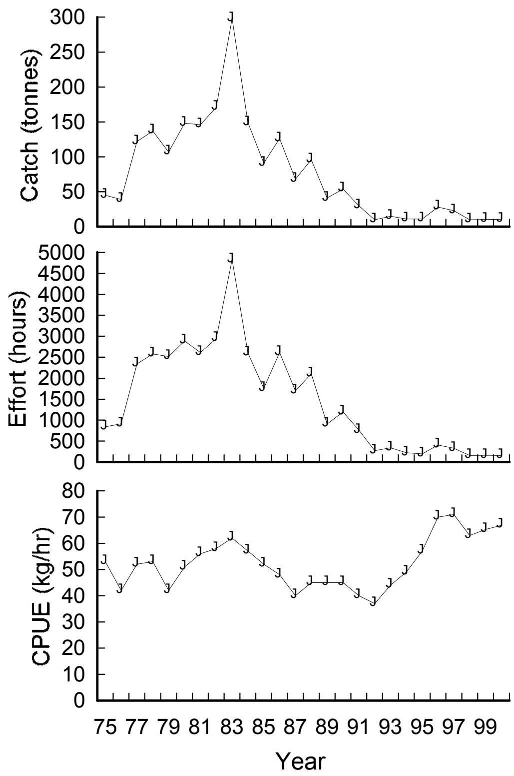
Block 28 (East Coast)



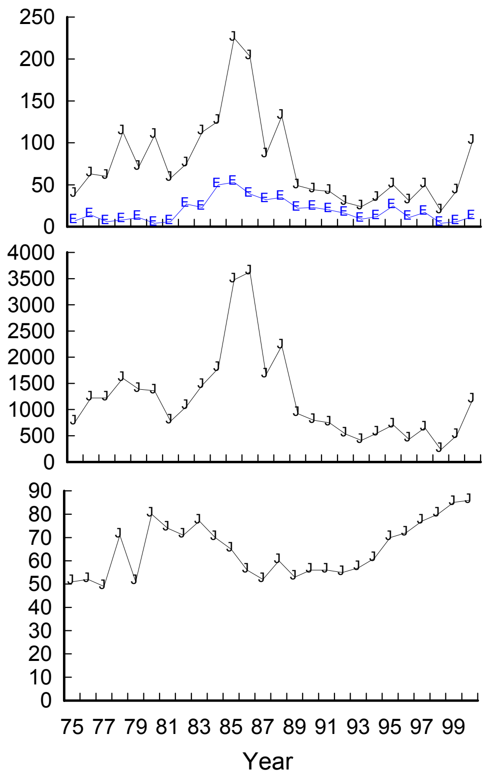
Block 29 (East Coast)



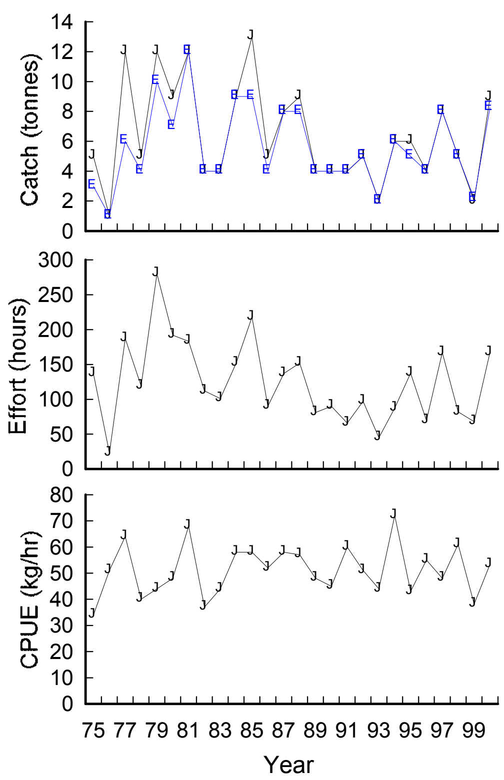
Block 30 (North East)



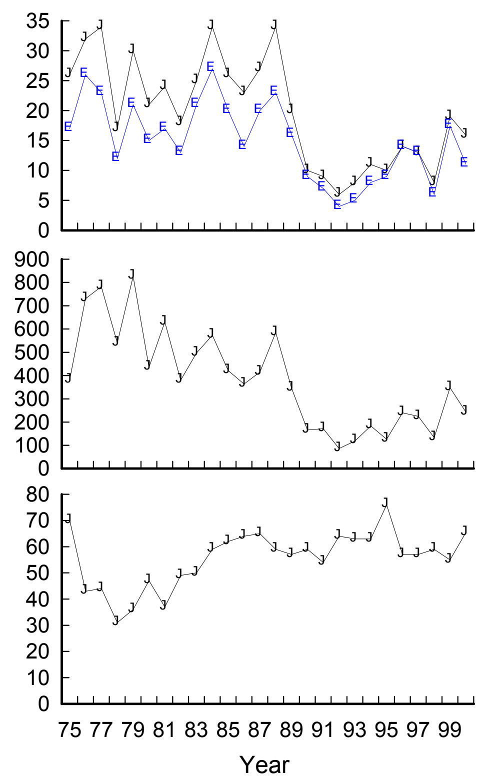
Block 31 (North East)



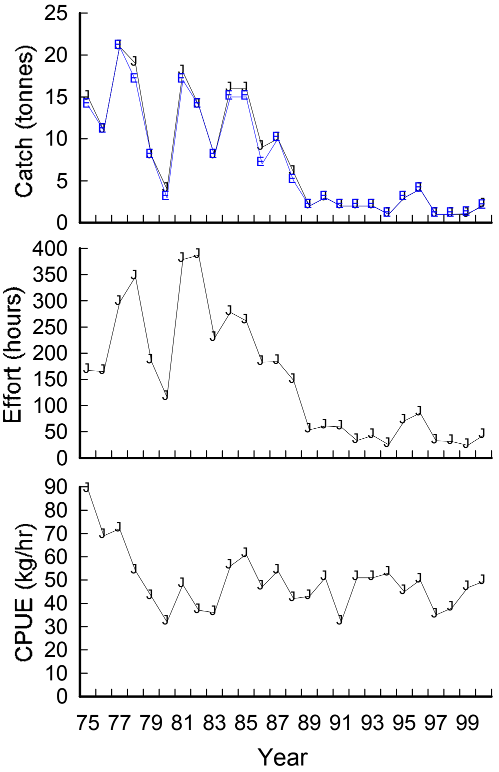
Block 32 (Furneaux Group)



Block 33 (Furneaux Group)



Block 34 (Furneaux Group)



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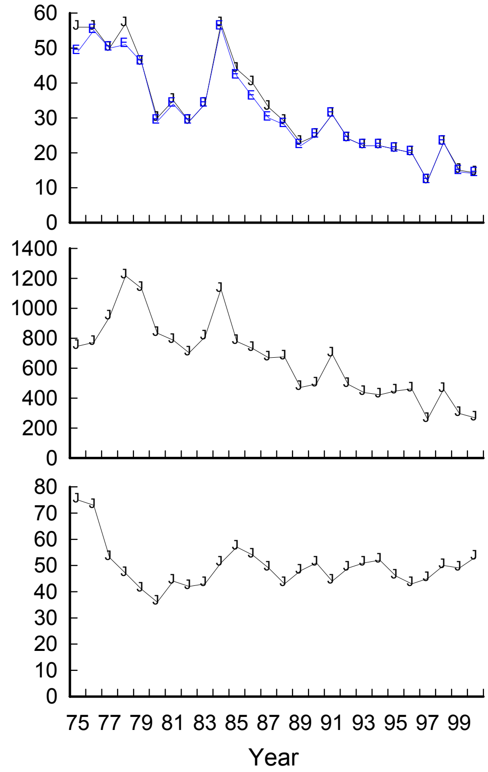
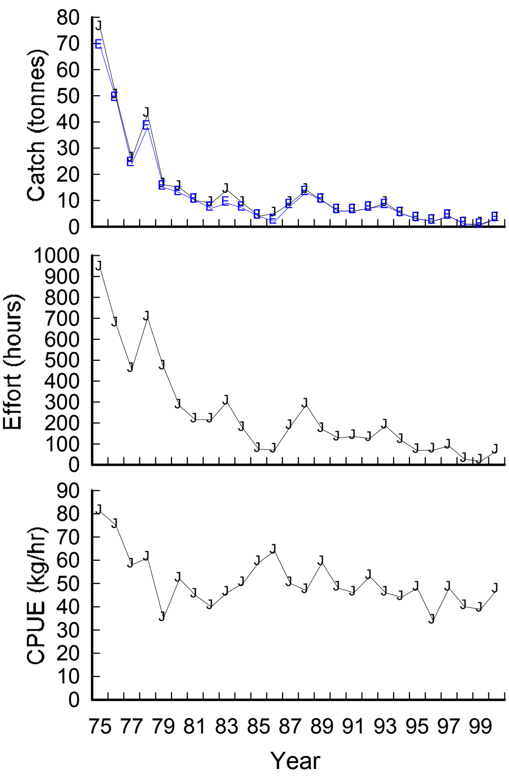


Block 36 (Furneaux Group)



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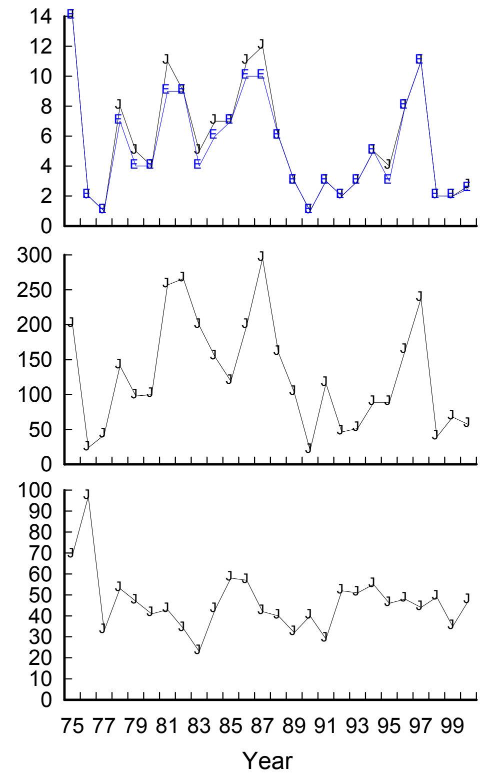
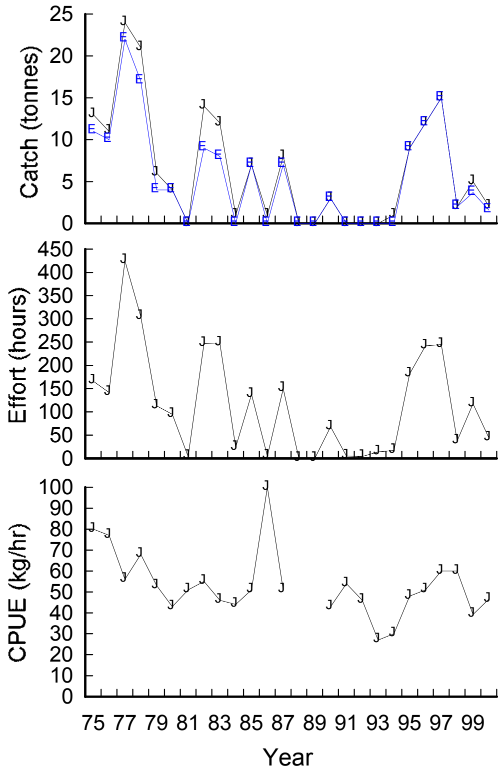
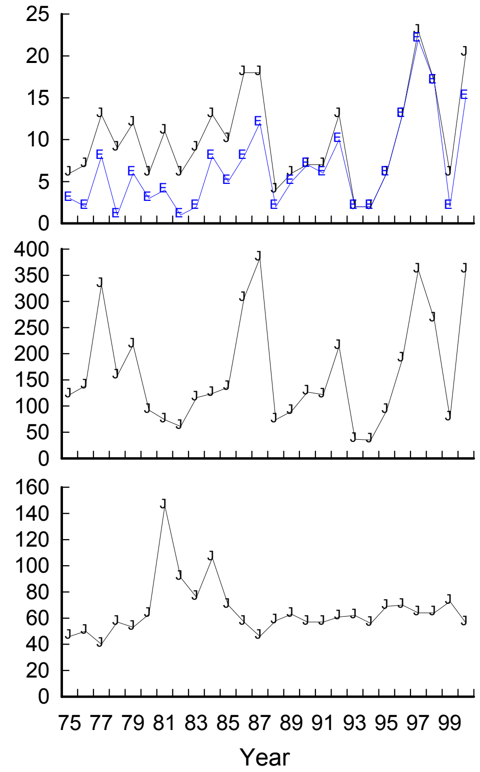


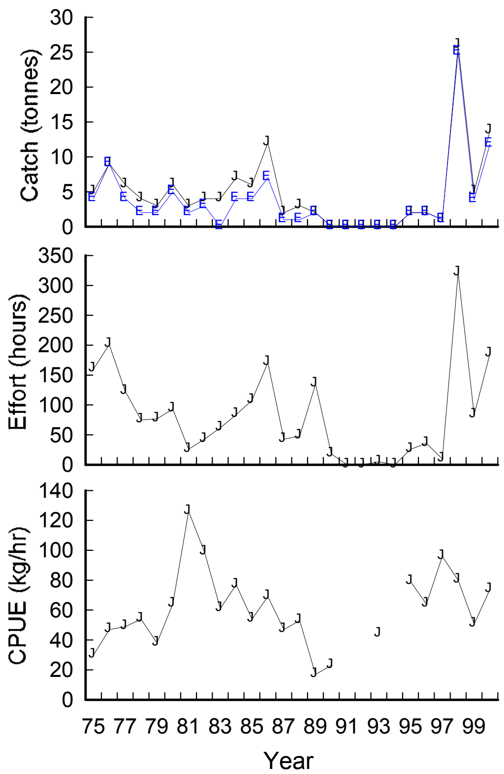
Block 38 (Furneaux Group)



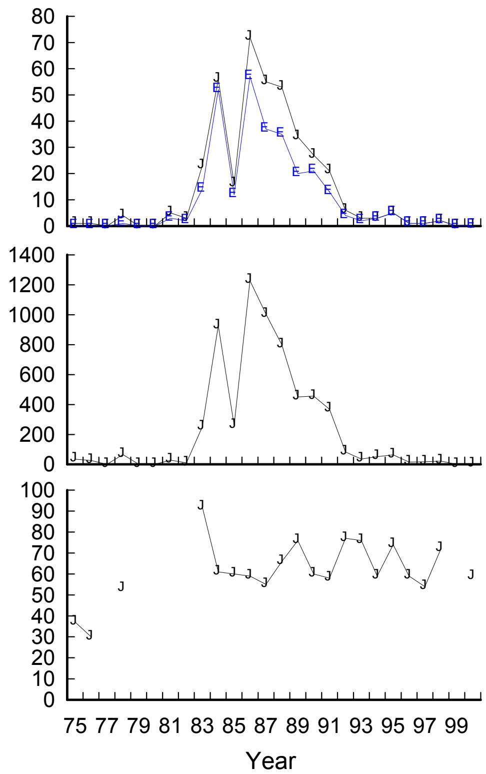
Block 39 (North East)

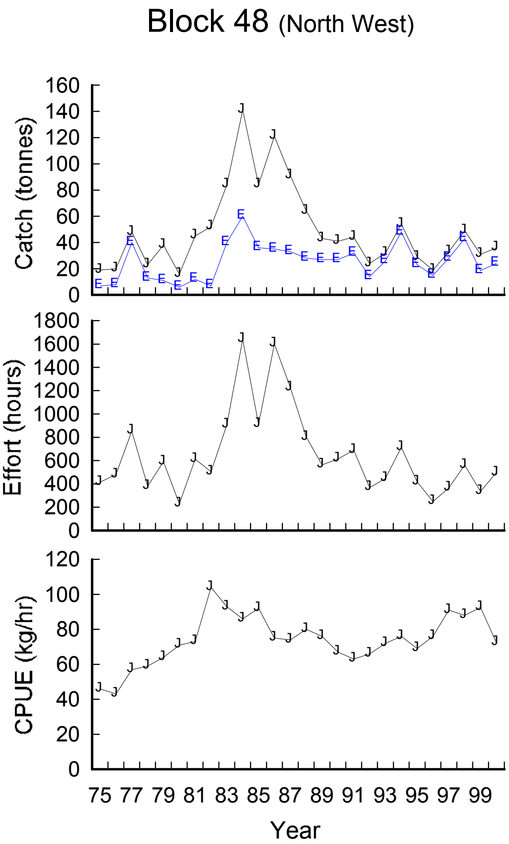


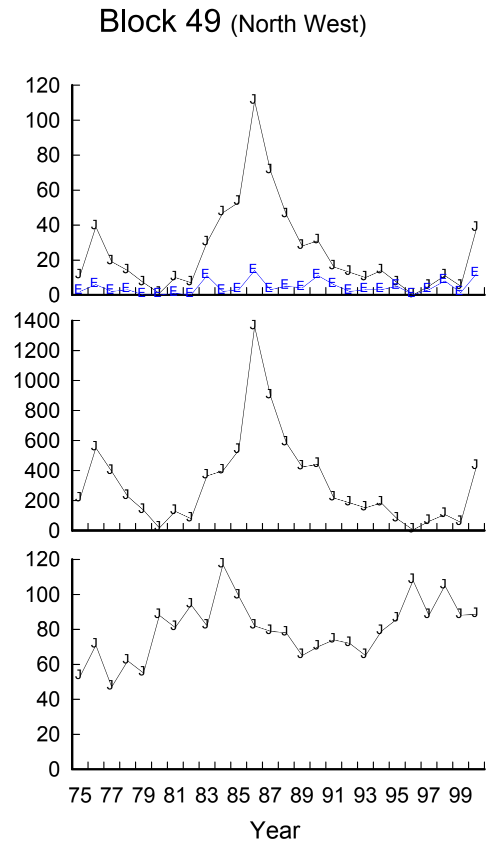
Block 40 (North East)



Block 47 (North West)




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


Block 49 (North West)
Year
75 77 79 81 83 85 87 89 91 93 95 97 99

Appendix 3: Annual Catches From The Eastern Blacklip Fishery 1975 - 2000.

Annual tonnages of blacklip abalone caught within the four regions comprising the Eastern Zone in 2000. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights. The South East also includes catch from the part of Block 13 west of Whale Head that is currently included in the Western Zone. In 2000, the Western Zone component of the Block 13 catch was 12%, or approximately 52 tonnes.

Year	South East	East Coast	North East	Furneaux Group	Total
1975	471	289	80	29	869
1976	509	262	92	8	871
1977	741	286	181	23	1231
1978	789	400	252	21	1462
1979	911	257	172	16	1356
1980	773	512	257	13	1555
1981	863	525	206	11	1605
1982	841	459	224	14	1538
1983	892	562	396	14	1864
1984	957	535	232	12	1736
1985	853	406	263	14	1536
1986	817	369	302	19	1507
1987	676	286	128	14	1104
1988	726	305	196	13	1240
1989	533	170	68	4	775
1990	522	301	75	2	900
1991	540	298	53	3	894
1992	469	280	27	2	778
1993	698	283	30	4	1015
1994	851	275	32	5	1163
1995	902	213	35	1	1151
1996	818	290	49	0	1157
1997	825	453	57	0	1335
1998	885	583	25	2	1495
1999	886	438	55	6	1385
2000	760	364	108	7	1239
Average 1997-1999	865	491	46	3	1405
Average 1975-2000	750	362	138	10	1260

Appendix 4: Annual Catches From The Western Blacklip Fishery 1975 - 2000.

Annual tonnages of blacklip abalone caught within the four regions comprising the Western Zone in 2000. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights. The Western Zone also includes a component of catch from Block 13 in the South East. In 2000, the Western Zone component of the Block 13 catch was 12%, or approximately 52 tonnes.

Year	North West	West & South West	West Coast North	King Island	Total
1975	22	668	149	75	914
1976	46	960	109	98	1213
1977	25	609	101	114	849
1978	24	898	143	105	1170
1979	34	974	197	45	1250
1980	12	1343	288	90	1733
1981	45	1541	377	69	2032
1982	53	955	268	71	1347
1983	72	1206	458	106	1842
1984	128	1590	610	99	2427
1985	103	1142	641	80	1966
1986	198	852	480	76	1606
1987	143	995	382	182	1702
1988	95	805	411	128	1439
1989	53	683	281	37	1054
1990	40	612	279	41	972
1991	30	651	266	53	1000
1992	24	738	342	34	1138
1993	14	654	226	30	924
1994	19	572	131	17	739
1995	8	527	185	26	746
1996	3	515	177	12	707
1997	8	760	154	27	949
1998	10	567	189	6	772
1999	17	729	206	17	969
2000	38	1055	228	20	1341
Average 1997-1999	12	685	183	17	897
Average 1975-2000	49	869	280	64	1262

Appendix 5: Annual Catches From The Greenlip Fishery 1975 - 2000.

Annual tonnages of greenlip abalone caught within the four regions comprising the Greenlip fishery in 2000. These tonnages are derived from estimated weights, which do not correspond exactly with landed weights. The North West also includes a component of catch from Block 5A in the West North West. In 2000, the Block 5A component of the North West greenlip catch was 12.6 tonnes, or approximately 52 tonnes.

Year	King Island	North West	North East	Furneaux Group	Total
1975	4	18	14	177	213
1976	0	29	26	156	211
1977	0	62	21	146	229
1978	6	30	11	147	194
1979	1	21	21	108	151
1980	3	12	12	74	101
1981	17	33	12	99	161
1982	17	11	31	83	142
1983	15	74	27	88	204
1984	14	136	62	120	332
1985	3	58	68	103	232
1986	13	111	56	74	254
1987	212	81	46	93	432
1988	51	79	39	85	254
1989	84	57	30	58	229
1990	68	70	31	50	219
1991	50	63	26	53	192
1992	30	24	25	43	122
1993	28	33	11	42	114
1994	36	63	14	47	160
1995	37	40	34	54	165
1996	82	20	26	64	192
1997	74	38	40	63	215
1998	72	66	21	40	199
1999	58	31	12	42	142
2000	10	49	39	43	140
Average 1997-1999	68	45	24	48	185
Average 1975-2000	38	50	29	83	200

Appendix 6: Preliminary Standardization Of The Tasmanian Abalone Fishery Catch And Effort Data: 1975-2000

Summary

General linear models were used to standardize the commercial catch and effort (CPUE) data for two reporting blocks, 13 and 14, in South East Tasmania. Statistical models were built in a step-wise fashion, and Akaike's Information Criterion (AIC) used as a test statistic to determine the optimal model. Because CPUE data are typically log-normally distributed, a GLM was fitted to the natural logarithm of the CPUE for each record. For Block 13 the optimal model was Model 6, and included the predictor variables: Year, Month, Diver, Boat, and Port. Model 6 described 52.1% of the variation in the catch effort data for Block 13. For Block 14, Model 7 was the optimal model and included all the predictor variables of Model 6 (above), as well as a Processor term. Model 7 described 48.3% of the variation in catch effort data for Block 14.

For both blocks, the standardized *trend* of the optimal model differs little from that of the geometric means; however, the *magnitude* of the change over time has increased. The standardization had little effect on the early years of data, however from 1984 in Block 13, and about 1980 in Block 14, the standardized year indices rose considerably above those for the unstandardized geometric means. This suggests that the actual increase in biomass over time is much greater than that evident by the raw data. The catch rate index for Block 13, in 1996, is about 22% greater than that obtained from the geometric means. Similarly, that for Block 14, in 1998, is about 34% greater. However, the standardization of catch rates for Blocks 13 and 14 do not influence any interpretation of the fishery with respect to the average of the reference periods specified by the management plan.

Background

All modern stock assessment methods require some index of the relative abundance or biomass of the stock through time. While this is preferably attained through fishery independent surveys collected with a standardised procedure, more often than not, scientists must rely on commercial catch per unit effort (CPUE) data. In many fisheries around the world, including the Tasmanian abalone fishery, commercial CPUE data are the only index of stock biomass available. The annual Tasmanian abalone assessment is at present restricted to an analysis of trends in catch per unit effort (CPUE), catches and size composition (see Officer & Tarbath, 2000).

It is one of the most fundamental assumptions in fisheries science that commercial CPUE data reflect stock abundance. Catch per unit effort (CPUE) is usually related to biomass by the classic equation CPUE = qB, where q is the catchability coefficient (the proportion of available fish captured by one unit of effort; assumed constant), and B is the available biomass. If CPUE falls through time this is taken to reflect a decline in the biomass available to the fishery and, conversely, if CPUE increases, an increase in available biomass is predicted. Even for those fisheries where a time series of survey data is available, CPUE data are still used in the assessment modeling process to provide additional information on changes to the population biomass.

There are two major complications in the use and interpretation of CPUE data for abalone fisheries. Firstly, CPUE data displays hyperstable behaviour, meaning that catch rates can be maintained while abundance or biomass declines, possibly leading to serial depletion of stocks. This non-linear relationship between CPUE and the available biomass is due to the non-random distribution of fishing effort caused by patterns in the behaviour of fishers, and is exacerbated by the discrete, sedentary and aggregatory character of abalone populations (Breen, 1992; Prince, 1987). Without fishery independent surveys it is impossible to know the actual form of the relationship, however CPUE is currently still the best (and only) data available for use in the Tasmanian abalone assessment as an index of abundance.

Another major factor that can complicate the use of CPUE as an indicator of abundance is change in catchability (q) through time. Changes in, for example, the divers in the fishery or the seasonality of fishing over years, can alter the effective catchability of abalone, i.e. alter the proportion of available fish captured by one unit of effort. The observed change in CPUE may have nothing to do with change in the stock biomass, instead being related to changes in fleet dynamics and the distribution of fishing effort through time. Such processes are common to many fisheries and, if sufficient supplementary information exists, their effects can be removed by standardizing catch rates.

Standardization attempts to identify the relative contribution of various factors towards the observed trends in CPUE. This is essentially a statistical decomposition of the catchability coefficient (q) into its contributing components. Once the variation due to factors other than ‘year’ is described, the variation associated with a 'year' factor should provide an improved representation of the relative status of the stock upon which the fishery is based. Of course, if significant factors are not included in the analysis (usually because data relating to them is unavailable), then there will still be noise remaining on any signal about the stock size that is present in the CPUE data.

Methods

The Preliminary standardization of the Tasmanian blacklip abalone commercial catch and effort data was investigated for two fishing blocks only. Reporting blocks 13 and 14 in South East Tasmania were selected as they have been, and still are, heavily fished, and have produced very high catch rates. Recently however, managers have listed these blocks as being of high concern. Both fishery dependent and independent (research) data indicate signs of stress in recent years.

Standardization of CPUE is usually achieved by fitting a general linear regression model (GLM), of the form (Eq.1), to estimates of catch rate (Gavaris, 1980; Kimura, 1981).

(Eq.1) $$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots\ldots\ldots + \beta_{p-1} X_{i,p-1} + \varepsilon_i$$

where Y_i is the response variable (in this case the log of catch rate), β_0, β_1, ……, β_{p-1} are the parameters that scale each of the factors, X_{i1},……, $X_{i,p-1}$, which are the predictor variables. The final term, ε_i, represents any residual noise in the data and is described by a standard, normal distribution with mean zero and standard deviation σ^2, i.e. $N(0,\sigma^2)$, (see Neter *et al* 1996 for a more thorough description).

Because CPUE data are typically log-normally distributed, a GLM was fitted to the natural logarithm of the CPUE for each record. The model was built in a step-wise fashion, adding predictor variables, such as port or diver, one by one, so as to monitor any increase in the amount of variation in the catch-effort information described by the linear model. A test statistic, Akaike's Information Criterion (AIC) was used to determine the best statistical model: a compromise between the proportion of the variability in the data described by the linear model and the complexity of the model (Burnham & Anderson, 1998). The statistical model leading to the smallest AIC is selected as being optimal.

In standardizing CPUE, we are interested in the parameters, β_k , estimated for each class of the categorical 'Year' predictor variable. In this instance, we have data from 1975- 2000, and thus there are 26 classes. The parameter estimates indicate the change in CPUE, due to each class of the 'Year' factor, while all other predictor variables are held constant. The standardised indices thus provide an improved representation of the relative status of the stock through time. By including other predictor variables in the model, we are essentially *removing* their effects.

Thus the full general log-linear model used, including all classes of categorical predictor variables tested, was of the form:

(Eq.2)

$$\begin{aligned} Ln(\mathrm{CPUE})_i = {} & Constant \\ & + \beta_1.\mathrm{Year}_{i1} + \ldots\ldots\ldots + \beta_n.\mathrm{Year}_{in} \\ & + \beta_{n+1}.\mathrm{Month}_{i,n+1} + \beta_{n+2}.\mathrm{Month}^2{}_{i,n+2} \\ & + \beta_{n+3}.\mathrm{Diver}_{i,n+3} + \ldots\ldots\ldots + \beta_p.\mathrm{Diver}_{ip} \\ & + \beta_{p+1}.\mathrm{Boat}_{i,p+1} + \ldots\ldots\ldots + \beta_q.\mathrm{Boat}_{iq} \\ & + \beta_{q+1}.\mathrm{Port}_{i,q+1} + \ldots\ldots\ldots + \beta_r.\mathrm{Port}_{ir} \\ & + \beta_{r+1}.\mathrm{Processor}_{i,r+1} + \ldots\ldots\ldots + \beta_s.\mathrm{Processor}_{is} \\ & + \varepsilon_i \end{aligned}$$

Month was modelled as a continuous variable (quadratic function). All other predictor variables were put in as qualitative categorical or dummy variables and therefore have the same number of parameters as classes minus 1, for example, Year has n classes and n-1 parameters are estimated, Boat has q-p classes, and q-p-1 parameters are estimated.

These predictor variables were chosen as the data was easily available, and it seemed reasonable to expect them to exert some influence on catch rates. For example, Month is included in the model to account for changes in the seasonal patterns of fleet dynamics, possibly driven by changing weather patterns, management arrangements and/or market demands. If catchability varies seasonally, then annual changes in CPUE may be due to change in the seasonality of effort exerted, rather than changes in stock biomass. Standardisation removes this effect.

The Processor factor (a code representing the processor the catch is supplied to) attempts to account for any variation in the CPUE data series that may be due to changes in market demand feeding through the processors. For example, the proportion of the catch going to live export and cannery processors may change through time and these processors prefer different size ranges of fish. Catchability when fishing for a specific size range or quality of fish may be quite different to that when any fish (above legal size) can be taken. This may create noise around the catch rate data that has little to do with actual changes in the biomass of the stock.

It is known that catchability can vary between reefs due to habitat heterogeneity, and thus changes in the proportion of effort exerted on each reef, within a reporting block, would influence the overall catch rates observed for that reporting block. Including the port of landing is an attempt to remove variation in catch rates within a statistical block. It is the only information we have available that may reflect the location of the catch at a spatial scale smaller than reporting block (although catches are now reported by sub-block, we do not have this information for all years).

Diver and Boat information allows us to remove variability in the CPUE that is due to change in the divers and vessels fishing. For example, if several divers retired from the fishery, and were replaced by new, inexperienced divers, it could be expected that the overall annual catch rates for the fishery in the next year would drop considerably. This would not however, be reflective of a decline in the stock biomass. Standardization is an attempt to remove this ‘other’ variability.

It should be noted however, that the output from a general linear model does not guarantee that a relation exists between stock size and standardized CPUE. It is possible that factors not included in the model (through no information being available) may still obscure changes in stock biomass. The aim of standardisation is to make the CPUE a 'better' description of the stock dynamics.

Results

Model 1 is essentially the relative unstandardized, or raw, average CPUE per year (geometric mean). However, the mean CPUE for 1975 is set to 1 and all other years are relative to this, so the results shown are CPUE 'indices', not actual values. Each standardized trajectory (Models 2-7) is compared against that for Model 1 to show the effect of the addition of each new factor to the model (Figs 1 and 2). The large amount of catch effort data available means that the statistical power to detect an effect by a predictor variable is substantial, even if the effect is very small. So, while a factor may explain a statistically significant amount of the variation around the catch and effort data, it may have very little influence on the trajectory of standardized CPUE.

For Block 13, Model 6 was the optimal model (Table 1). This included the factors Year, Diver, Boat and Port as categorical variables, and Month included as a quadratic function. Model 6 described 52.1% of the variation in the catch effort data and had the lowest AIC value (Table 1). All variables in the model were significant, however, the inclusion of the term Diver (for the first time in Model 4) resulted in a considerable jump in the variance explained by the model (from 28.5 to 44.7%, Table 1). As each predictor variable is added the trajectory of catch rates also changes, though by different amount for each factor (Fig. 1). For the optimal model, standardization had minimal effect on the trajectory of catch rates over time prior to 1984 (Fig. 1). From 1984 onwards the standardized year indices rose considerably above those for Model 1 (i.e. the unstandardized geometric means).

In Block 14, Model 7 was the optimal model (Table 2), describing 48.3% of the variation in the catch effort data. This model was equivalent to the optimal model for Block 13, but also included a significant Processor term. As in Block 13, the inclusion of the Diver term (for the first time in Model 4) resulted in a considerable jump in the variance explained by the model (from 20.5 to 40.3%, Table 2).

The change in CPUE through time for Block 14 is similar to that for Block 13, as is the effect of the standardisation (Fig. 2). The standardized indices of CPUE (Model 7) deviate from the unstandardized geometric means (Model 1) at about 1980, after which they are considerably higher than those of Model 1(Fig. 2). Interestingly, the inclusion of the Processor term into Model 7 lowers the trajectory, reducing the difference between the Model 1 and standardized indices in the latter years (Fig. 2).

In both blocks the addition of the month term (Models 2 and 3) is statistically significant, but has very little influence on the trajectory (Figs. 1 and 2). Similarly for the Port term (Figs. 1 and 2).

Standardized catch rates, in both blocks, are fairly stable between 1975 and the late 1980's. We then see a rapid increase in CPUE, towards a peak in 1996 for Block 13, about 2.2 times the 1975 average catch rate (Fig. 1), and a peak of 2.2 times that in 1975 for Block 14 (Fig. 2). Both blocks then display declining catch rates between the peak year and 2000.

Table 1. General Linear Model results for Block 13

N is the no. of observations, Var% is the r-squared value, F is the F-statistic from the ANOVA, df Params is the parameter degrees of freedom, df Resids that for the residuals, the Model SS is the model sum of squared residuals, Resid SS is that for the residuals, #Param is the no. of parameters estimated, and AIC is the Akaike's Information Criterion. Model 6 is the optimal model according to AIC. The estimated parameter values for each year are provided. See text for explanation of model.

Model 1	LnCE = Constant + Year
Model 2	LnCE = Constant + Year + Month
Model 3	LnCE = Constant + Year + Month + Month^2
Model 4	LnCE = Constant + Year + Month + Month^2 + Diver
Model 5	LnCE = Constant + Year + Month + Month^2 + Diver + Boat
Model 6	LnCE = Constant + Year + Month + Month^2 + Diver + Boat + Port
Model 7	LnCE = Constant + Year + Month + Month^2 + Diver + Boat + Port + Proc

Model	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
N	25567	25567	25567	25567	25567	25567	25567
Var%	0.276	0.277	0.285	0.447	0.519	0.521	0.520
F	389.9	376.3	377.6	75.8	38.5	37.4	33.6
df Params	25	26	27	270	696	721	776
df Resids	25541	25540	25539	25296	24856	24831	24045
ModelSS	1542.1	1546.3	1592.8	2497.4	2895.5	2905.6	2791.7
Resid SS	4040.6	4036.4	3989.9	3085.3	2685.8	2675.6	2574.5
df Lost	0	0	0	0	14	14	745
# Param	27	28	29	272	712	737	1523
AIC	-47114.6	-47139.2	-47433.5	-53521.2	-56187.1	-56233.7	-55647.3
AIC2	8.306	8.305	8.294	8.056	7.951	7.950	7.973

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
1975	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.941	0.942	0.944	1.024	1.051	1.047	1.062
1977	0.995	0.993	0.996	1.105	1.106	1.104	1.120
1978	0.991	0.991	0.990	1.055	1.068	1.070	1.095
1979	1.029	1.028	1.022	1.045	1.039	1.037	1.054
1980	0.952	0.952	0.945	1.006	1.018	1.008	1.021
1981	0.938	0.939	0.931	0.985	1.008	1.004	1.029
1982	0.978	0.980	0.979	1.015	1.055	1.054	1.083
1983	0.959	0.958	0.956	1.002	1.046	1.039	1.064
1984	1.012	1.012	1.004	1.070	1.142	1.145	1.182
1985	1.040	1.038	1.023	1.141	1.200	1.202	1.250
1986	0.980	0.981	0.978	1.162	1.232	1.231	1.288
1987	0.893	0.894	0.887	1.057	1.130	1.134	1.197
1988	0.884	0.885	0.883	1.050	1.105	1.108	1.162
1989	0.981	0.981	0.966	1.167	1.226	1.236	1.300
1990	1.044	1.046	1.034	1.177	1.294	1.299	1.379
1991	1.033	1.033	1.033	1.188	1.360	1.376	1.463
1992	1.283	1.283	1.269	1.395	1.626	1.625	1.804
1993	1.273	1.274	1.264	1.381	1.616	1.603	1.776
1994	1.495	1.490	1.478	1.654	1.734	1.716	1.888
1995	1.697	1.695	1.668	1.845	1.950	1.945	2.105
1996	1.807	1.802	1.800	2.073	2.184	2.182	2.352
1997	1.688	1.687	1.685	1.991	2.116	2.114	2.307
1998	1.715	1.713	1.697	1.952	2.045	2.042	2.228
1999	1.688	1.688	1.691	1.957	2.022	2.018	2.215
2000	1.527	1.524	1.531	1.782	1.857	1.853	2.036

Table 2. General Linear Model results for Block 14

N is the no. of observations, Var% is the r-squared value, F is the F-statistic from the ANOVA, df Params is the parameter degrees of freedom, df Resids that for the residuals, the Model SS is the model sum of squared residuals, Resid SS is that for the residuals, #Param is the no. of parameters estimated, and AIC is the Akaike's Information Criterion. Model 7 is the optimal model according to AIC. The estimated parameter values for each year are provided. See text for explanation of model.

Model 1	LnCE = Constant + YeaR
Model 2	LnCE = Constant + Year + Month
Model 3	LnCE = Constant + Year + Month + Month^2
Model 4	LnCE = Constant + Year + Month + Month^2 + Diver
Model 5	LnCE = Constant + Year + Month + Month^2 + Diver + Boat
Model 6	LnCE = Constant + Year + Month + Month^2 + Diver + Boat + Port
Model 7	LnCE = Constant + Year + Month + Month^2 + Diver + Boat + Port + Proc

Model	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
N	22418	22418	22418	22418	22418	22418	22418
Var%	0.175	0.179	0.205	0.403	0.476	0.480	0.483
F	190.1	188.3	213.3	54.1	26.7	25.9	24.3
df Params	25	26	27	276	739	771	825
df Resids	22392	22391	22390	22141	21665	21633	21466
Model SS	691.1	708.3	807.4	1590.1	1878.7	1892.9	1886.3
Resid SS	3255.9	3238.7	3139.6	2356.9	2065.4	2051.2	2020.7
df Lost	0	0	0	0	13	13	126
# Param	27	28	29	278	754	786	953
AIC	-43199.0	-43316.0	-44010.8	-49940.7	-51948.5	-52039.2	-52040.9
AIC2	8.091	8.085	8.054	7.790	7.700	7.696	7.696

YEAR	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
1975	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.902	0.896	0.905	0.968	0.932	0.944	0.947
1977	1.194	1.189	1.194	1.138	1.154	1.164	1.125
1978	1.088	1.086	1.096	1.088	1.124	1.132	1.006
1979	1.097	1.093	1.083	1.066	1.113	1.123	0.985
1980	0.970	0.967	0.962	0.974	1.017	1.018	0.889
1981	0.982	0.981	0.974	1.027	1.069	1.079	0.938
1982	1.035	1.033	1.045	1.102	1.132	1.158	1.003
1983	1.066	1.056	1.055	1.124	1.207	1.240	1.079
1984	0.958	0.952	0.945	1.019	1.167	1.192	1.034
1985	1.017	1.015	0.993	1.081	1.262	1.277	1.109
1986	1.031	1.031	1.017	1.169	1.346	1.362	1.183
1987	0.939	0.937	0.931	1.092	1.257	1.271	1.101
1988	0.943	0.937	0.934	1.123	1.313	1.327	1.148
1989	1.009	1.005	0.992	1.212	1.390	1.415	1.223
1990	1.105	1.099	1.089	1.274	1.515	1.520	1.316
1991	1.158	1.159	1.177	1.395	1.652	1.677	1.452
1992	1.163	1.165	1.171	1.430	1.732	1.753	1.543
1993	1.212	1.216	1.219	1.524	1.923	1.941	1.700
1994	1.440	1.429	1.416	1.733	2.133	2.151	1.854
1995	1.666	1.662	1.627	1.929	2.339	2.343	2.013
1996	1.709	1.691	1.690	2.096	2.565	2.557	2.199
1997	1.613	1.611	1.632	2.051	2.461	2.463	2.111
1998	1.739	1.728	1.702	2.222	2.646	2.672	2.324
1999	1.588	1.583	1.605	2.082	2.446	2.455	2.178
2000	1.571	1.547	1.568	1.942	2.284	2.307	2.049

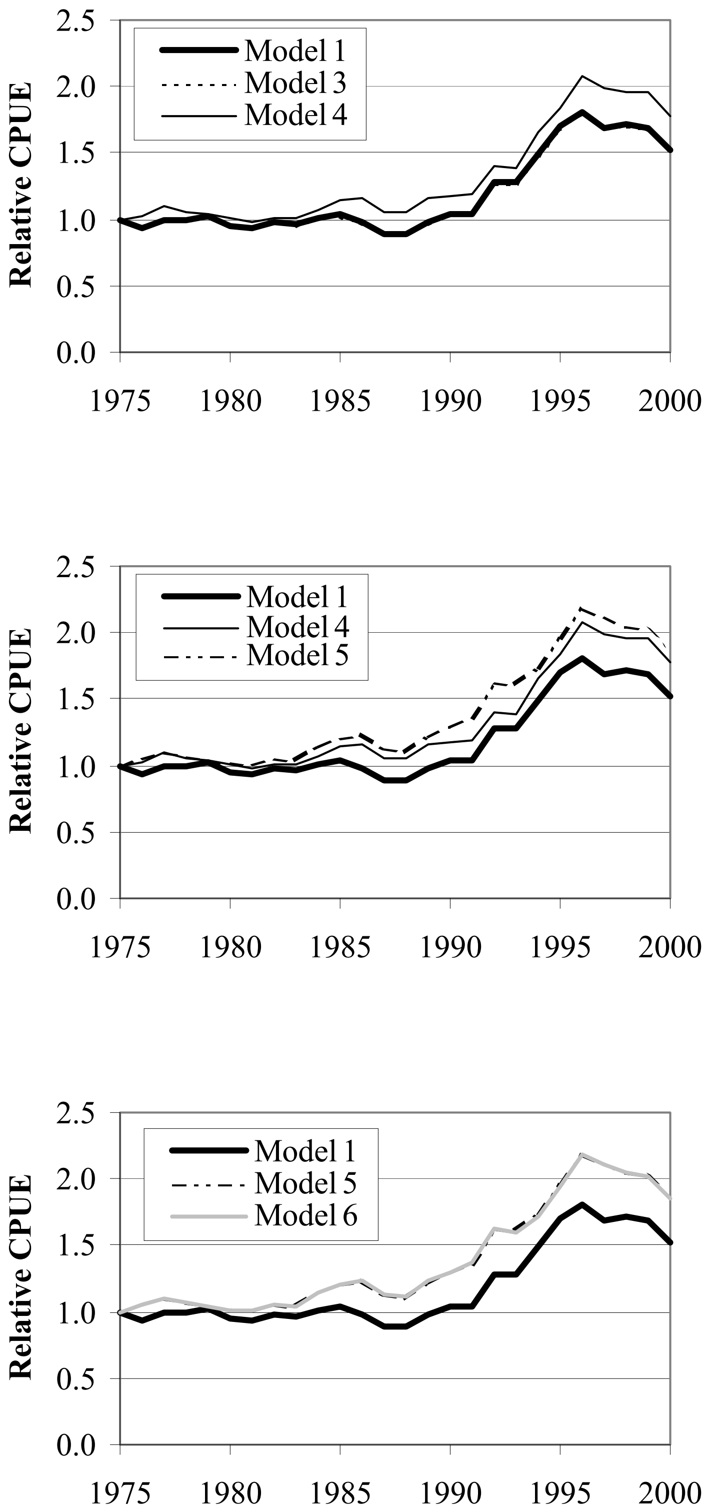


Fig. 1. Relative CPUE indices for Block 13, 1975-2000. Model 6 is the optimal model. For a description of each model see Table 1. The trajectory for Model 1 hides those of Models 2 and 3. Similarly that of Model 6 hides the trajectory of Model 5.

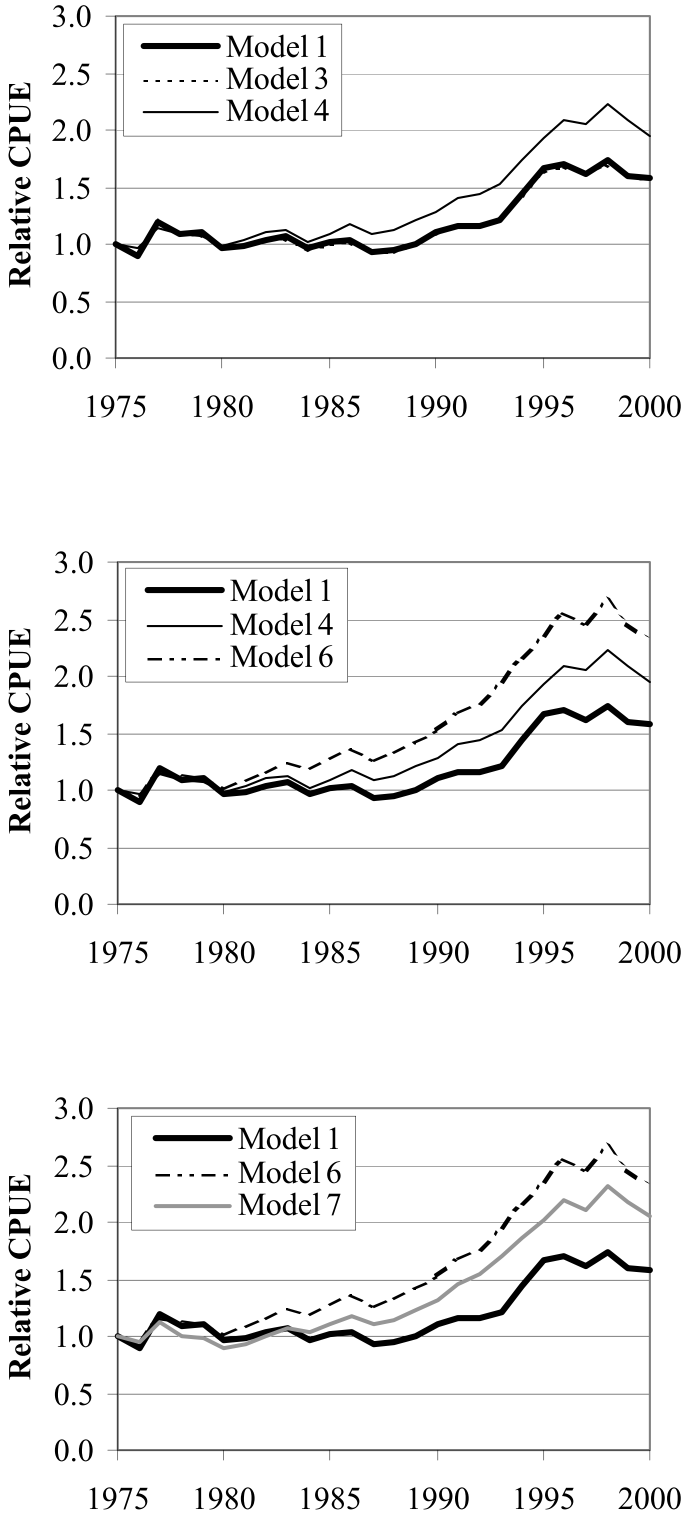


Fig. 2. Relative CPUE indices for Block 14, 1975-2000. Model 7 is the optimal model. For a description of each model see Table 1. The trajectory for Model 1 hides those of Models 2 and 3. Similarly that of Model 6 hides the trajectory of Model 5.

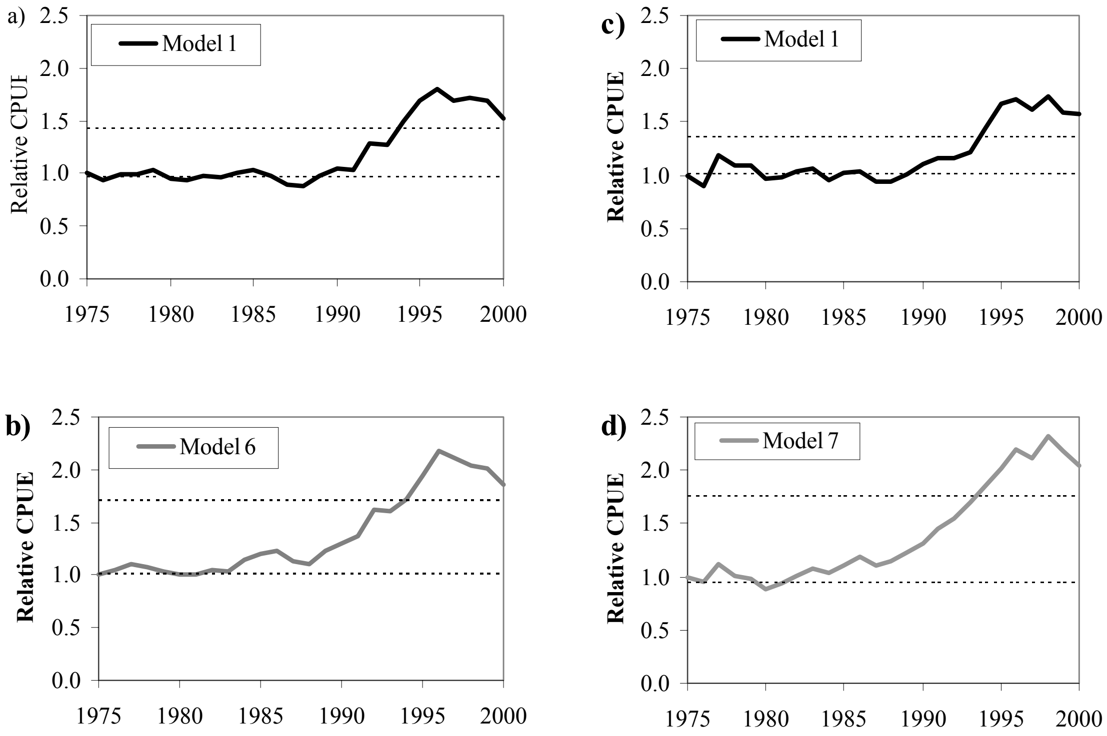


Fig. 3. Relative CPUE indices for: a) Block 13, Model 1, b) Block 13, Model 6, c) Block 14, Model 1, and d) Block 14, Model 7. The horizontal dotted lines indicate the trigger points; the upper line being the average catch rate for the 1992-1995 period, the lower line being that for the 1979-1982 period.

Conclusions

The models used for standardizing catch rates explain 52.1% and 48.3% of the variation in the catch effort data for Blocks 13 and 14 respectively. While the standardized trend differs little from that of the geometric means, the magnitude of the change over time has increased. The catch rate index for Block 13, in 1996, is about 22% greater than that obtained from the geometric means. Similarly, that for Block 14, in 1998, is about 34% greater.

When considered in context of the management of the fishery however, the standardizations for these two blocks have minimal influence. The two reference periods used to assess the current CPUE indices against are 1992-1995, and 1979-1982 (Anonymous, 1997; Officer and Tarbath, 2000). The average catch rate for each of these periods is used as a reference to compare the current index against. The standardization results in a larger change in catch rates over time, reaching a higher maximum than that for the geometric means, but the average values for the reference periods also change (Figs. 3 and 4). Thus, for Block 13, the relative CPUE for the year 2000 is approximately 6% greater than the 1992-1995 reference value regardless of whether the data are standardized. Similarly for Block 14, the 2000 relative catch rate is approximately 15% greater than the 1992-1995 reference value for both models. The standardization therefore would have little influence on the assessment and management of the fishery, in these cases. However, the standardizations are only preliminary and more factors need to be considered.

The standardization was limited by the data available, so it was only possible to include the factors: year, month, diver, vessel, port of landing, and processor, in the models. Several of these factors do not have directly interpretable influences e.g. port of landing, but are instead used as proxies for information we don't have; in this case small scale spatial variability in fishing effort. Similarly, it is not immediately obvious how the specific boat being used when the catch is taken, influences CPUE. The Boat term is also used as a proxy, for example, for the presence or absence of GPS and plotters and other vessel related technology.

It is possible that factors not yet included in the model may obscure the relationship between the standardized catch rates and biomass of the stock. There are many other factors, not included in these models, which are thought to be important, such as, weather conditions, market pressures, management restrictions, and diver experience. Data quantifying these factors are not immediately or readily available and will be pursued for future work. In particular, diver experience is thought to be responsible for a significant amount of the noise around the catch effort data. While the model accounts for the effect of individual divers, the improvement in their efficiency through time has not yet been considered. Finally, we have not yet considered interaction effects but have, instead, assumed that the effects of the predictor variables on the response variable are additive. It seems likely that the effect of one predictor variable, e.g. Diver, would depend on the level of another predictor variable, e.g. Month. This will be investigated in the near future.

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Appendix 7: The Influence Of Effort Creep On The Interpretation Of CPUE Data.

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 = qB, 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 = qB 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, 2000) as guidelines, six plausible scenarios were constructed; continuous annual effort creep between 1975 and 2000 of:

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

effort creep of 5% per annum between 1975 and 1981, consistent with estimates by Harrison (1983), and between 1981 and 2000:

- 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 2000 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, 2000). 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

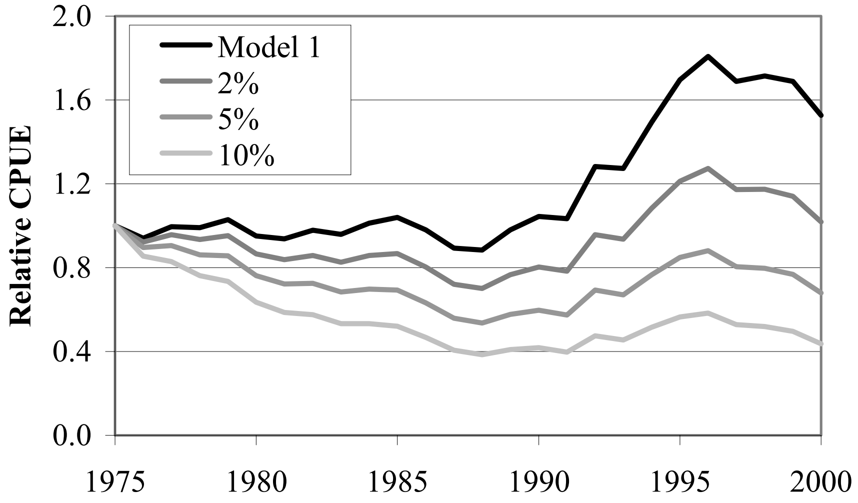

Fig.1. Relative CPUE indices for Block 13, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; and (iii) 10% per annum. All values of CPUE are relative to 1975.

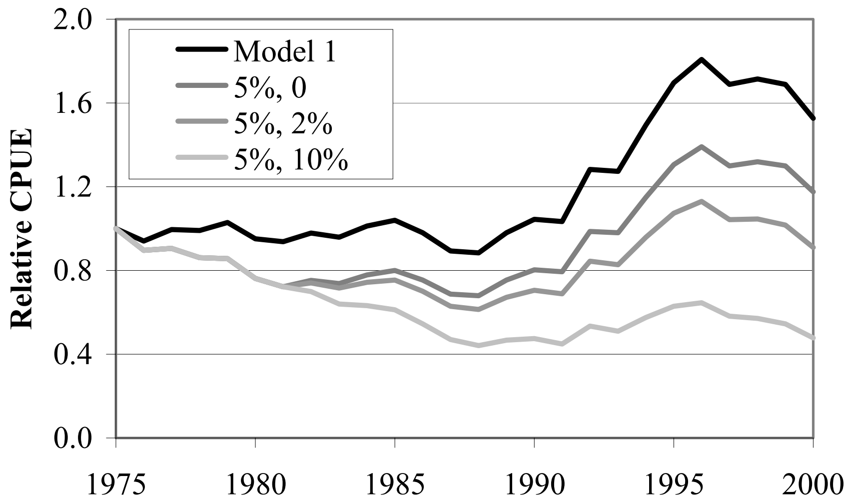

Fig. 2. Relative CPUE indices for Block 13, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 5% per annum until 1981 only; (ii) 5% per annum until 1981, and then 2% per annum until 2000; (iii) 5% per annum until 1981, and then 10% per annum until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

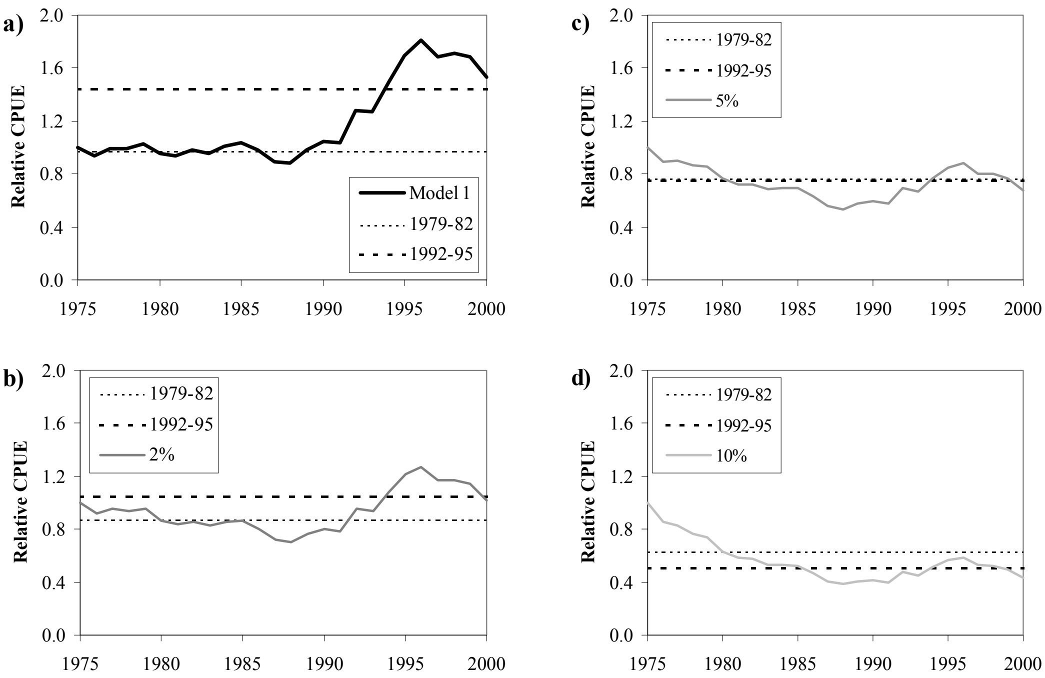

Fig. 3. Relative CPUE indices for Block 13, 1975-2000. Model 1, (a), is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (b) 2% p.a.; (c) 5% p.a.; and (d) 10% p.a. All values of CPUE are relative to 1975. The dotted lines are the mean CPUE for the two assessment reference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

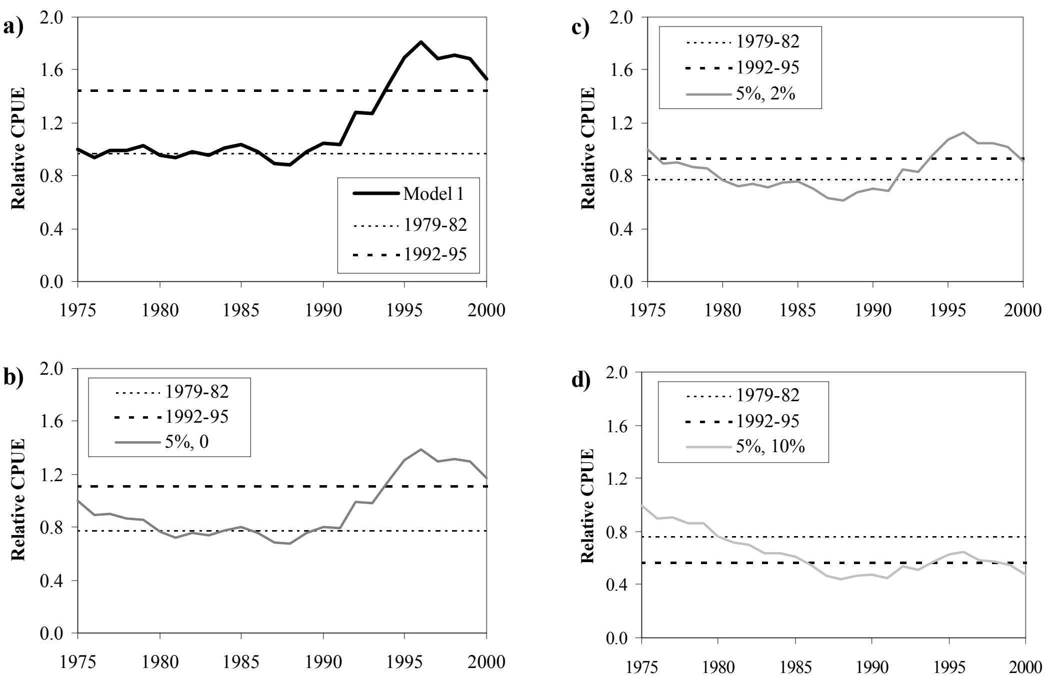

Fig. 4. Relative CPUE indices for Block 13, 1975-2000. Model 1, (a), is the raw geometric mean. The three effort creep scenarios considered are: (b) 5% p.a. until 1981 only; (c) 5% p.a. until 1981; and then 2% p.a. until 2000; (d) 5% p.a. until 1981, and then 10% p.a. until 2000. All values of CPUE are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

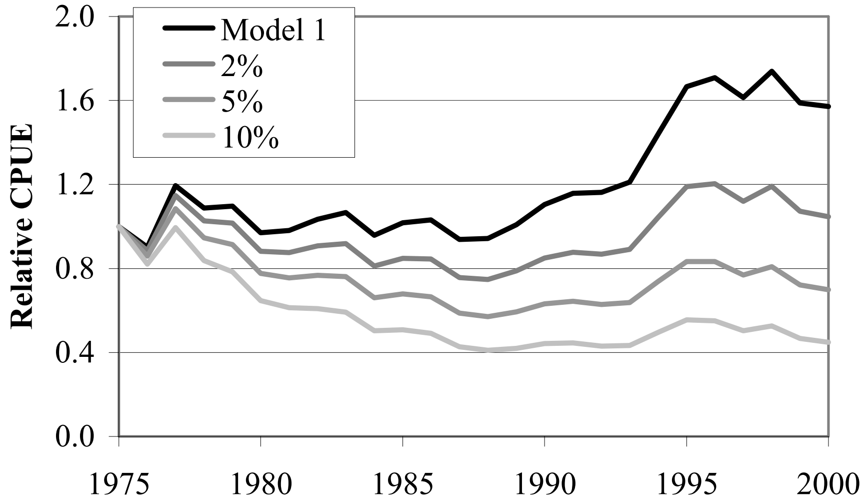

Fig. 5. Relative CPUE indices for Block 14, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 2% per annum; (ii) 5% per annum; and (iii) 10% per annum. All values of CPUE are relative to 1975.

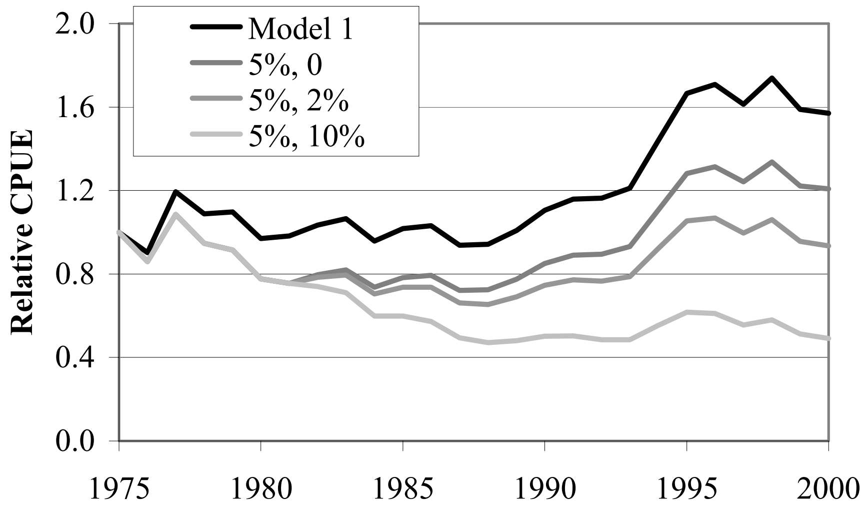

Fig. 6. Relative CPUE indices for Block 14, 1975-2000. Model 1 is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (i) 5% per annum until 1981 only; (ii) 5% per annum until 1981, and then 2% per annum until 2000; (iii) 5% per annum until 1981, and then 10% per annum until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

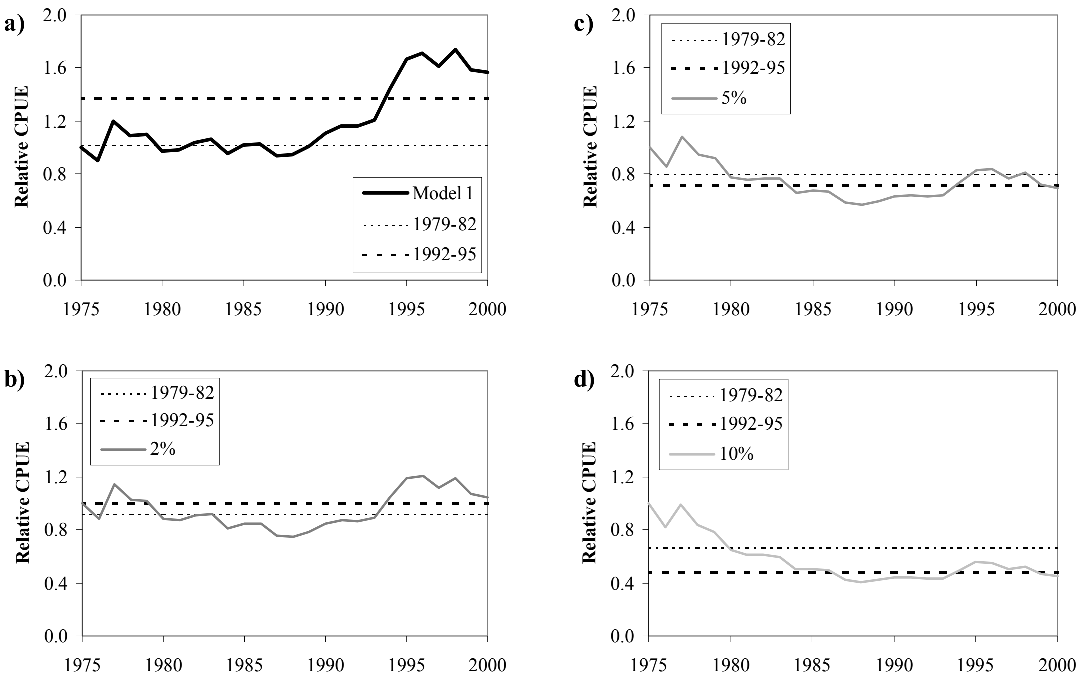

Fig.7. Relative CPUE indices for Block 14, 1975-2000. Model 1, (a), is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (b) 2% p.a.; (c) 5% p.a.; and (d) 10% p.a. All values of CPUE are relative to 1975. The dotted lines are the mean CPUE for the two assessment reference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

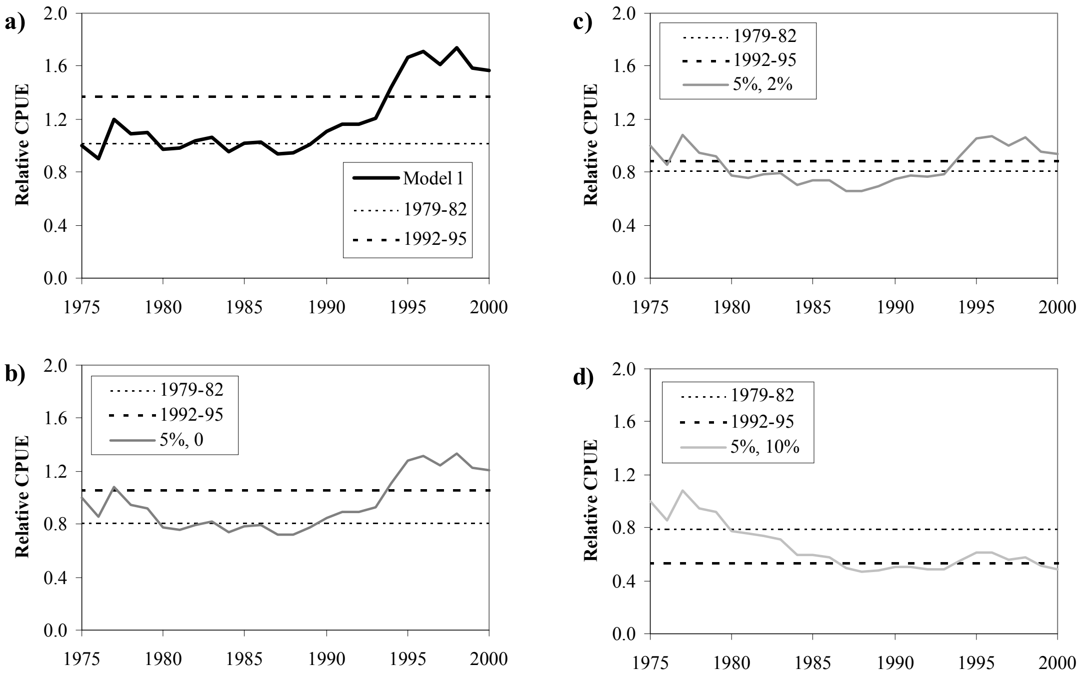

Fig. 8. Relative CPUE indices for Block 14, 1975-2000. Model 1, (a), is the raw geometric mean of CPUE. The three effort creep scenarios considered are: (b) 5% p.a. until 1981 only; (c) 5% p.a. until 1981, and then 2% p.a. until 2000; (d) 5% p.a. until 1981, and then 10% p.a. until 2000. All values of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

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Appendix 8: The TAFI Market-Measuring Program In The Tasmanian Abalone Fishery.

Background

In mid-1998, after a break of several years, TAFI resumed the collection of length-composition data from the commercial fishery. This was initially done using a technique whereby industry participants (primarily licensed divers or their deckhands) take photographic samples of their catch, in conjunction with the recording of details such as the catch date, location and depth. The abalone sampled in this manner are photographed against a calibrated backing sheet, allowing calculation of shell lengths using a graphical software package.

Regression analysis on abalone length data obtained using the photographic technique versus physical measurements revealed a strong, almost 1:1 relationship (1.02:1), with a coefficient of determination (r^2) of 0.98 for abalone over the size range 70 mm to 166 mm (physically measured length) as shown in Fig. 1a. Over the size range 132 mm to 166 mm, the relationship remains strongly at unity, however variance about the line increases a little, with the r^2 value falling to 0.87 (Fig. 1b), indicating a drop in the accuracy of individual measurements.

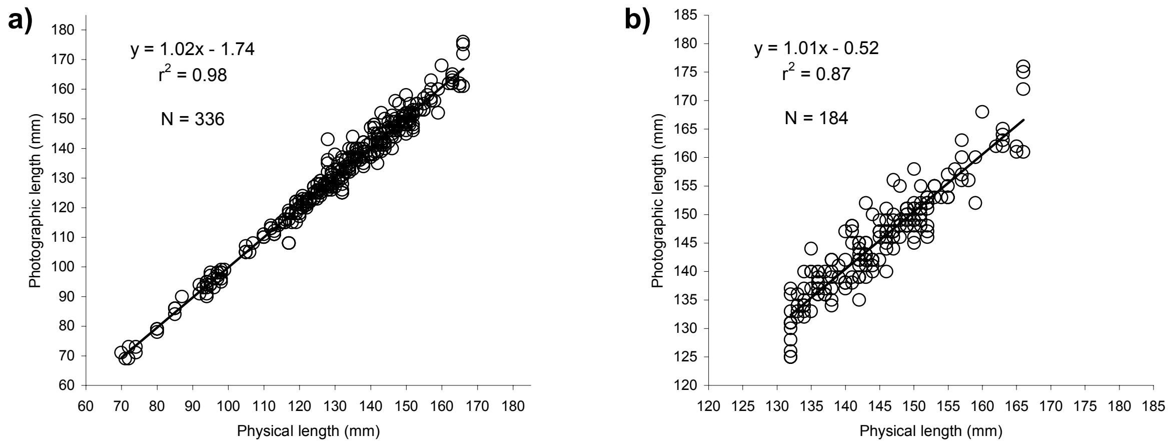

Fig. 1. Regression plots showing length of abalone measured using the photographic technique versus physically measured length for fish **(a)** between 70 mm and 166 mm, and **(b)** between 132 mm and 166 mm physically measured length.

Industry participation in the photographic catch sampling project was relatively high in the initial stages, however participation in the program has waned over time (Table 1), and since September 2000 has apparently all but ceased. It should be noted however, that other samples may have been taken, that are yet to be received.

Table 1. Industry participation in the photographic catch sampling project
Figures for 1998 include preliminary samples gathered in April to June in addition to those gathered since the project was launched in July of that year. Figures for 2001 are for samples received by May 31, 2001.

	1998	**1999**	**2000**	**2001**
Number of Abalone Measured	11919	9968	7908	411
Number of Industry Participants (divers/deckhands)	10	10	6	2
Number of Divers' Catches Sampled	13	11	9	3
Number of Statistical Blocks	20	21	19	4
Statistical Block Numbers	1, 7, 12, 13, 14, 16, 17, 19, 20, 21, 22, 23, 24, 26, 27, 28, 28, 29, 30, 39, 40	1, 2, 4, 6, 12, 13, 14, 16, 19, 20, 21, 22, 23, 24, 27, 28, 29, 32, 33, 35, 40	6, 10, 11, 12, 13, 14, 19, 20, 21, 22, 23, 24, 27, 31, 32, 33, 35, 36, 40	5, 39, 48, 49

Photographic catch sampling has a number of advantages, such as providing precise catch information, a potentially broad geographical coverage, and ease of integration with other work (as samples can be measured by research staff when it is convenient to do so). Several disadvantages however, have become increasingly apparent. One of these is variability in the quality of samples received. Problems with sample quality include poor picture quality (due, for example, to under- and over-exposure or poorly aimed cameras), overcrowding of abalone on the backing sheet and inadequate sample sizes. Errors may also arise when measuring abalone from photographs taken from oblique angles. Although parallax error is largely negated by calibrating separately for each fish measured, the domed shape of abalone shells can obscure the shell edges, making it difficult to obtain accurate measurements. Such variability in sample quality makes the quantitative assessment of error problematical.

Table 1 clearly shows that the photographic program has failed to adequately sample across divers in a representative manner. For example, only 9 of the divers who operated in the 2000 fishery supplied samples. For a number of reasons including difficulties encountered using the equipment and lack of interest, this program has suffered from low rates of industry participation.

The reliance on industry for samples also makes it difficult to control for bias. It is possible, for example, that participants may inadvertently bias data by selectively photographing abalone with particular characteristics (different sizes, clean shells) or preferentially sampling from areas that they feel are important in some way.

In response to these problems, catch sampling methods were re-evaluated in 2000, and TAFI Marine Research Laboratory staff commenced catch sampling at processors' premises in October of that year. This change in the way that size-composition data is collected led to substantial improvements in terms of both the numbers of abalone measured and diver coverage. In the eight months between October 3, 2000 and May 31, 2001, 28338 fish were measured from 67 divers at processing factories, compared to around 30000 measurements from 23 divers in the four years of the photographic project (Fig. 2).

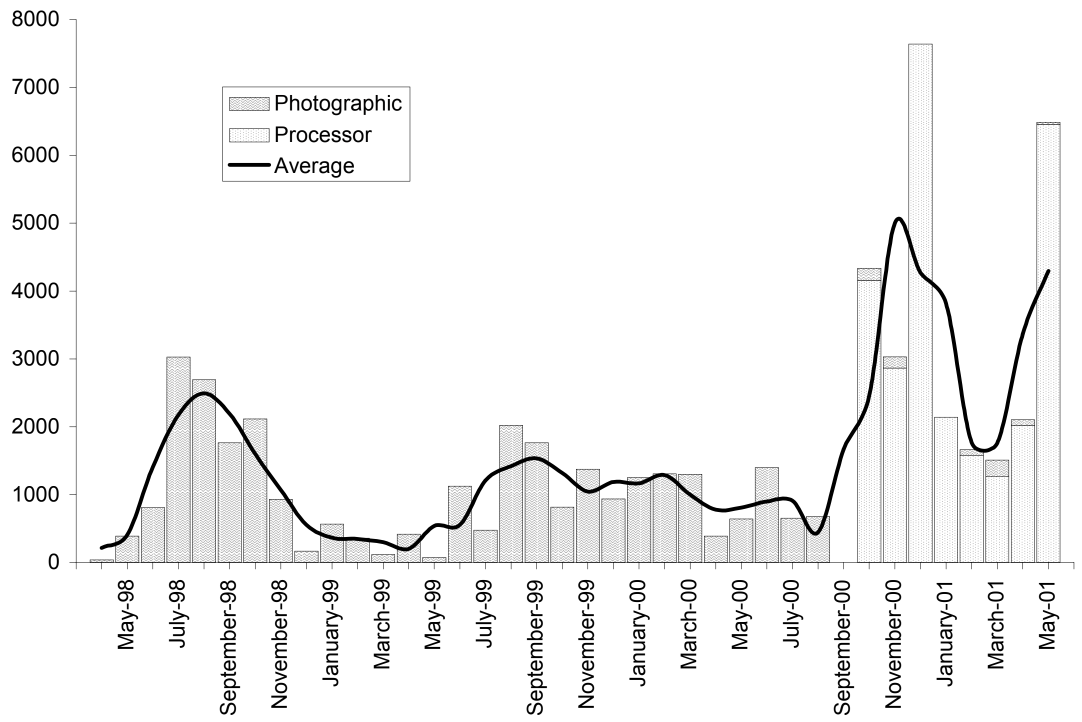

Fig. 2. Number of fish measured per month using the photographic technique and at processors, since resumption of commercial catch sampling in 1998. The trend-line shows the rolling 3-month average number of abalone measured using both methods combined.

Despite these improvements, a number of difficulties with catch sampling at processors, have been encountered. These largely relate to differences in the accessibility of factories (due to their location), or of the fish within those factories. Since the processor catch sampling project, all sampling has been undertaken at factories in the south-east of the state, between Dover and Triabunna (Fig. 3), reflecting their proximity to TAFI's Marine Research Laboratories in Hobart.

Differences exist between various processors in terms of preferred size, species and source location of abalone. Processors dealing in blacklip abalone for the live market for example, tend to require smaller fish, whilst the live greenlip market generally requires larger animals. Because of factors such as the grading of live fish and combining catches from different areas in holding tanks, it is often more difficult to sample from live fish processors (reflected in Fig. 3).

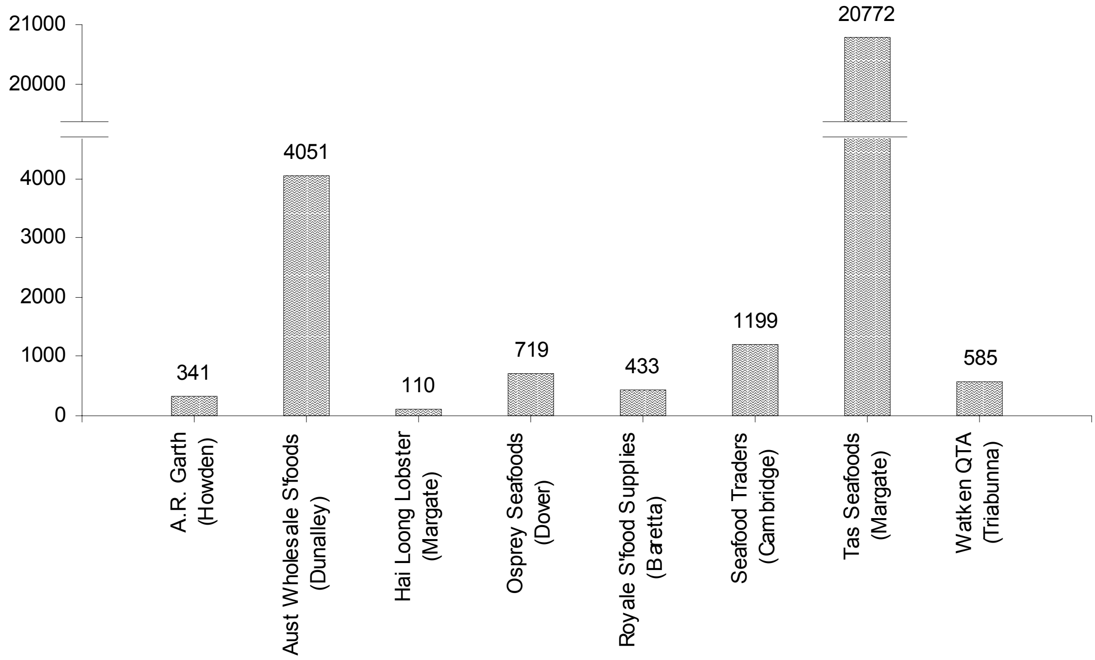

Fig. 3. Number of abalone measured at each processor between October 2000 and May 2001.

The disparity between processors in terms of sampling frequency, is illustrated by the fact that of the 28338 abalone measured at processors between October 2000 and May 2001, 21098 (74.5%) came from Tasmanian Seafoods Pty Ltd (at Margate), and were destined for canning. The next largest contributor to the samples was Australian Wholesale Seafoods Pty Ltd, from which 4051 abalone, or 14.3% of those sampled, were measured (these were destined primarily for the live market). Whilst to some extent, this is representative of the volumes of abalone passing through these processors, it is also strongly reflects differences in accessibility at different processors as described above.

The focus on sampling at processors in the south-east of the state has, to some extent, been reflected in the range of fishing areas represented in the samples – parts of the northern blacklip and greenlip fisheries are under-represented. Notwithstanding this, relatively broad geographical coverage was still achieved from processor sampling, with abalone measured from 24 of the 56 statistical blocks (Fig. 4a). On a per-sample basis however, samples taken from processors have been more restricted in terms of their geographical distribution, than those received through the photographic program. Since its inception in 1998, the approximately 30000 fish measured through the photographic program have come from 33 statistical blocks (Fig. 4b), whilst the 7908 measurements taken in 2000 using this method came from 19 blocks (Table 1, Fig. 4c).

In 2001, it is planned to expand the geographical range and coverage of the fishery to specifically include areas of management concern. As well, greater emphasis will be placed on obtaining size-composition samples from key areas within the new Northern Zone to help monitor the effects of the reduced size-limit. The recent introduction of sub-blocks to the diver catch-dockets books enables more accurate targeting of areas of interest to fishery managers, particularly in the south and east, and more effort will be spent on obtaining samples specifically from heavily fished reefs.

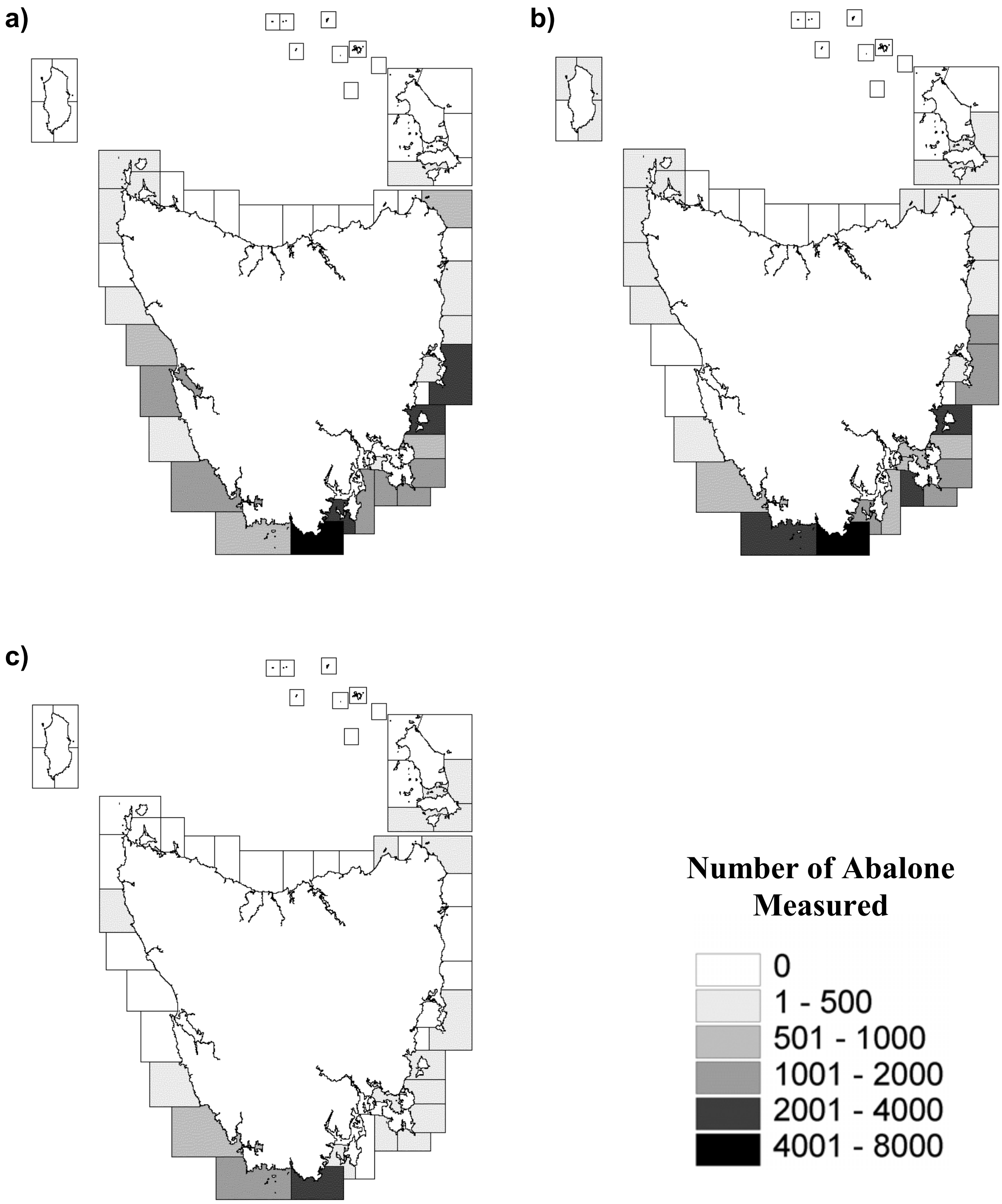

Fig. 4. Distribution of samples obtained through commercial catch sampling: **(a)** at processors between commencement of processor sampling (October 2000) and May 2001 inclusive, **(b)** using the photographic technique since its inception in mid-1998 and **(c)** from the photographic project in 2000.