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Western Zone Blacklip Abalone (*Haliotis rubra*) Fishery (Region A)

B. Stobart, S. Mayfield, J. Dent and D.J. Matthews

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SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

October 2013

Fishery Stock Assessment Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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EXECUTIVE SUMMARY

This report provides an assessment of the current status of blacklip abalone *Haliotis rubra* (hereafter referred to as blacklip) stocks in Region A of the Western Zone Abalone Fishery.

This assessment was informed by the harvest strategy in the Abalone Fishery Management Plan (PIRSA 2012) and the traditional, weight-of-evidence assessment. Comparison between these has identified several potential improvements to the harvest strategy.

Data spanning two spatial scales were integrated in this assessment: Region A and the spatial assessment units (SAUs) defined in the harvest strategy.

Blacklip abalone comprises 57% of the combined Region A abalone total allowable commercial catch (TACC). Total catches were relatively stable from 1989 to 2009 (293.3 t). Recent catches have been lower (2010-2012: 276 t).

The catch per unit effort (CPUE) in 2012 was similar to that in the mid to late 1990s. However, the current harvestable biomass may be lower due to the high propensity for catch rates on abalone to exhibit hyperstability.

The spatial distribution of catch has changed since 2009. Catches from traditional SAUs such as Ward Island and Hotspot have declined to the lowest level in more than 20 years, while catches from other traditional SAUs (e.g. Drummond, Sheringa, Avoid Bay and Reef Head) have increased.

The increased catches from these other traditional SAUs (Drummond, Sheringa, Avoid Bay and Reef Head) are unlikely to be sustainable because recent catch rates in these SAUs are low and/or declining. These areas contributed >60% of the blacklip catch in 2012.

This weight-of-evidence assessment suggests that the harvestable biomass of blacklip in Region A has declined substantially over recent years and is likely to be lower than that observed in the 1990s, prior to an extended period of elevated blacklip abundance.

This outcome was similar to that obtained from the harvest strategy: (1) the zonal stock status value decreased between 2011 (-0.083) and 2012 (-0.414) and, despite the fishery being categorised as sustainably-fished, the value in 2012 only marginally exceeded the value of the upper limit for the over-fished category (-0.5); (2) six of the 13 high or medium importance SAUs had a red or yellow risk-of-overfishing category (high risk); and (3) no SAUs were assigned a blue or light blue (low risk) risk-of-overfishing category.

The TACC was reduced by 6% from 2010 and a further 5% from 2013. However, it is unclear whether these reductions are adequate to arrest the ongoing declines and facilitate stock rebuilding.

Consequently, additional management measures for this fishery may warrant consideration. These could include (1) further lowering the TACC or introducing closed seasons to reduce the exploitation rate, (2) redistributing catches into non-traditional fishing grounds without compromising the stocks in those areas, and/or (3) spatial management, including catch caps and varying minimum legal lengths.

Ongoing monitoring, stock assessment and application of the harvest strategy will be crucial for (1) evaluating the sustainability of current catches of blacklip abalone in key SAUs, particularly those where catch has recently increased as CPUE decreased; (2) documenting changes in abalone abundance at SAUs such as Ward Island and Hotspot from which current catches are among the lowest on record; and (3) assessing the suitability of the current and future TACCs.

1. INTRODUCTION

1.1. Overview

This fishery assessment report for Region A of the South Australian Western Zone Abalone Fishery (WZAF), hereafter referred to as Region A (see Figure 1.1), updates previous fishery assessment and status reports for this region (Chick *et al.* 2006; 2008; 2009; Stobart *et al.* 2011; 2012b). The report provides an analysis of the fishery-dependent (FD) and fishery-independent (FI) data for blacklip abalone (*Haliotis rubra*), hereafter referred to as blacklip, in the WZ for the period from 1 January 1968 to 31 December 2012 and is part of the South Australian Research and Development Institute (SARDI) Aquatic Sciences' ongoing assessment program for the blacklip fishery in this zone. It also includes a formal analysis of the fishery's performance and stock status based on the harvest strategy described in the Management Plan (PIRSA 2012), which determines the risk that stocks in the high and medium spatial assessment units (SAUs) are overfished and zonal stock status. In the discussion, we assess the current status of the blacklip stocks in Region A comparing the harvest strategy and traditional weight-of-evidence assessments.

The aims of the report are to (1) document the current status of the resource; (2) identify the uncertainty associated with the assessment; (3) evaluate the new harvest strategy for the fishery; (4) detail the methodology followed to assess the fishery; (5) provide summaries of biological knowledge; (6) describe the recreational and illegal, unregulated and unreported (IUU) fisheries in this zone; and (7) identify future research needs.

The report is divided into four sections. This introduction (Section 1) provides (1) a general overview of the report; (2) the history and a description of the fishery, including the management plan and; (3) information on blacklip biology. Section 2 details the methods used in this assessment. Section 3 is the results and provides an assessment of FD and FI data for blacklip abalone. Where appropriate, this includes spatial and temporal analyses of catch (tonnes shell weight; t), effort (days), catch-per-unit-effort (CPUE; $kg.hr^{-1}$), commercial catch size-structure, FI survey data and application of the harvest strategy that determines the risk that stocks within SAUs are overfished and the status of the blacklip fishery in Region A. Finally, in Section 4, the discussion, uncertainties in the assessment are identified, a synthesis of the information and a summary of the current status of the fishery are provided, the harvest strategy is evaluated, and future research needs for the fishery considered.

1.2. History and description of the fishery

1.2.1. Commercial fishery

The South Australian Abalone Fishery (SAAF) has evolved since its inception in 1964. It includes the Western Zone, Central Zone and Southern Zone fisheries. Entrants to the fishery increased in the late 1960s, and exceeded 100 entrants state-wide by 1970. Licences were made non-transferable in 1971 to reduce the number of operators in the fishery. By 1976, the number of operators in the Western Zone Abalone Fishery (WZAF) had reduced to 30 and an additional 5 licences were issued. These 35 licences remain in 2013. A review of the management history for South Australia's abalone fisheries is provided by Shepherd and Rodda (2001) and Mayfield *et al.* (2012), with major management milestones relevant to the WZAF listed in Table 1.1. Summaries of the fisheries can be found in Prince and Shepherd (1992), Keesing *et al.* (1995), Zacharin (1997), Nobes *et al*. (2004) and Mayfield *et al.* (2012).

Table 1.1. Management milestones in the Western Zone of the South Australian Abalone Fisheries.

Date	Milestone
1964	Fishery started
1971	Licences made non-transferable
	Fishery divided into three zones (western, central and southern)
	Minimum legal length (MLL) set at 130 mm for both species
1976	30 Licences remained; 5 additional licences issued
1978	Sub-zones and fishing blocks replaced by map numbers and codes
1980	Licences became transferable
1984	Greenlip minimum legal length amended to 145 mm in the Western Zone
1985	Western Zone divided into Regions A and B
	Quota introduced to Region A in the Western Zone (293.25 t blacklip; 293.25 t greenlip)
1989	TACC in Western Zone Region A greenlip fishery reduced to 207 t
1991	Quota introduced to Region B in the Western Zone (27.6 t both species)
1993	Abolition of owner-operator regulation
	TACC in Western Zone Region B increased to 34.5 t
1994	TACC in Western Zone Region B increased to 41.4 t
1996	TACC in Western Zone Region A blacklip fishery decreased to 258 t
1997	Management Plan implemented (Zacharin 1997)
	TACC in Western Zone Region A blacklip fishery increased to 293.25 t
2004	Management Plan reviewed (Nobes *et al.* 2004)
2006	TACC in Western Zone Region A greenlip fishery increased to 227.7 t
2010	TACC in Western Zone Region A blacklip fishery decreased to 276 t
	TACC in Western Zone Region A greenlip fishery decreased to 207 t
2012	New management plan including harvest strategy
2013	TACC in Western Zone Region A blacklip fishery decreased to 262.2 t

In 1971, the SAAF was divided into three zones (Western (WZ), Central and Southern) to facilitate more effective management (Figure 1.1). The WZ includes all coastal

waters of South Australia between the Western Australian/South Australian border and the eastern Eyre Peninsula (Figure 1.1). This zone was further subdivided into Region A and Region B in 1985. The fishing season in both these regions extends from 1 January to 31 December each year.

To monitor catches and facilitate compliance with quota limits, fishers must complete a 'Catch and Disposal Record' form upon landing. In addition, a commercial logbook must be completed for each fishing day and submitted to SARDI Aquatic Sciences at the end of each month. Commercial catch and effort data on this fishery have been collected since 1968. These data are used by SARDI to provide analyses of catch, effort and catch per unit effort (CPUE) in stock assessment or status reports for each zone for Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture.

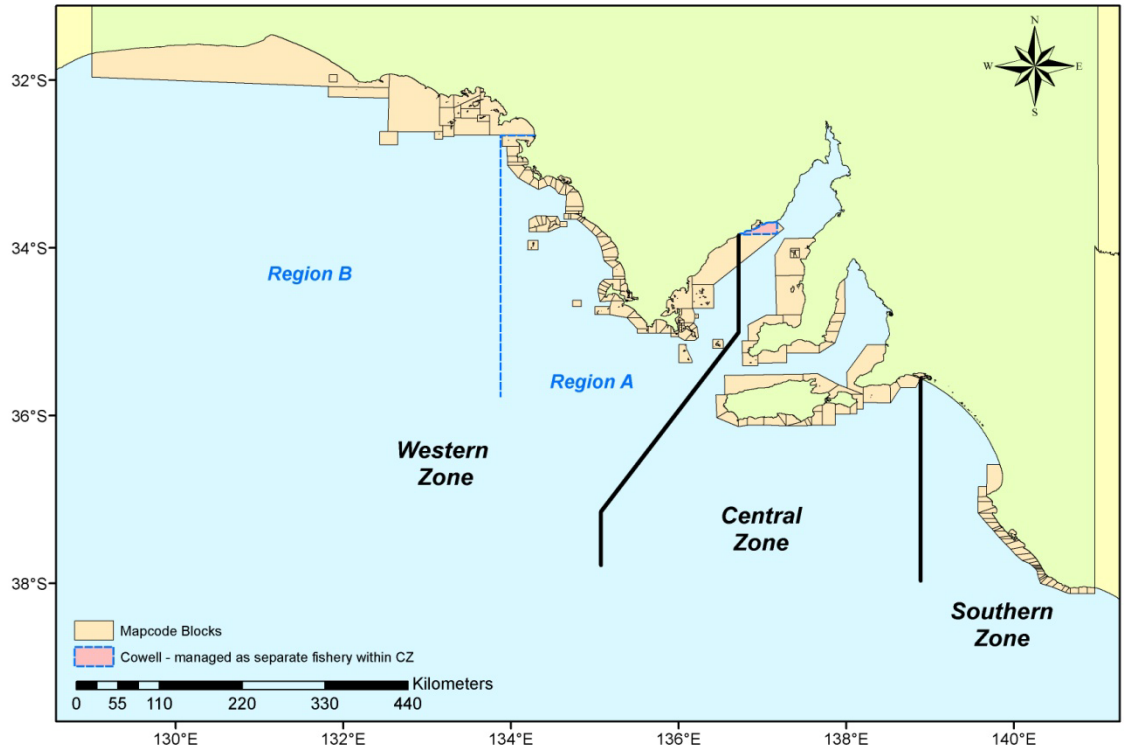

Figure 1.1. Fishing zones of the South Australian Abalone Fishery.

In Region A, quota management arrangements were introduced for blacklip in 1985 and amended to the calendar year fishing season from 1989 (Nobes *et al.* 2004). The Total Allowable Commercial Catch (TACC) for blacklip in Region A was 293.25 t shell weight from 1989 to 2009, with the exception of a 35.25 t (12%) reduction to 258 t for the 1996 quota period due to infection of blacklip with *Perkinsus* sp. in Thorny Passage (Nobes *et al.* 2004) and a reduction of 17.25 t (6%) since 2010 (276 t) driven by licence holders concern for the stock.

Since 1997, the fishery has operated under the control of formal management plans (Zacharin 1997; Nobes *et al.* 2004; PIRSA 2012). These plans encourage management of the fishery through a regime of input (e.g. limited entry) and output (e.g. minimum legal lengths, MLLs, and quota) controls. The current management arrangements in the WZ are summarised in Table 1.2. A MLL of 130 mm shell length (SL) was introduced for blacklip in 1971 and has remained unchanged (Table 1.1).

Table 1.2. Summary of the current management arrangements for the Western Zone commercial abalone fishery.

Management strategy	Western Zone management arrangements
Licence holders	23
Target species	*Haliotis rubra* (blacklip) and *H. laevigata* (greenlip)
Minimum legal length (MLL)	Blacklip 130 mm SL, Greenlip 145 mm SL
Quota year	1 January to 31 December
Quota transferability	Yes
Other species permitted	*H. roei*, *H. scalaris*, *H. cyclobates* when SL >130 mm
Method of capture	By hand – dive fishery
By-catch	Negligible

1.2.2. Recreational fishery

The total recreational blacklip abalone catch in South Australia was estimated at 1,685 individuals for the 12 month period from November 2007 to October 2008 (Jones 2009). Of these, an estimated 10% (168) were caught in the WZ and equate to 24 kg meat weight (based on average weight of 140 g per abalone).

1.2.3. Illegal, unregulated and unreported catch

Accurate estimation of illegal, unregulated and unreported (IUU) catch is difficult, as many information reports cannot be validated. During 2012, PIRSA received 74 information reports relevant to the Western Zone. PIRSA identified that, through six of these reports, at least 1,489 kg (meat weight) of abalone were taken illegally (mean: 248 kg.report^{-1}). Applying this value to the 74 information reports received, the estimated illegal catch of abalone in the WZ equates to about 18.3 t (meat weight), which equates to 11% of the TACC. This estimate excludes IUU take where a caution, expiation or brief has been compiled (PIRSA Fisheries and Aquaculture). It would be expected that PIRSA would not have been notified of all reports alleging that abalone theft had occurred within the WZ during 2012, so the actual extent of IUU take of abalone is likely to have been higher.

1.3. Management plan

The second management plan for the SAAF (Nobes *et al.* 2004) was reviewed and replaced in 2012 (PIRSA 2012). The most recent management plan stipulates the management goals and objectives for the fishery that reflect current policy drivers

including Section 7 of the *Fisheries Management Act 2007,* Ecologically Sustainable Development and the precautionary principle.

The four management goals are to ensure (1) the abalone resource is sustainably harvested; (2) optimal economic utilisation and equitable distribution of the abalone resource; (3) impacts on the ecosystem are minimised; and (4) cost effective and participative management of the fishery. This report is directly relevant to the first goal, for which the objectives are to (1) maintain the stocks above ecologically sustainable levels; and (2) ensure sufficient data and information are available to undertake the harvest strategy which underpins the management decisions.

The harvest strategy is the primary tool used to achieve the goal of sustainably harvesting the abalone resource and has been well described elsewhere (Chick and Mayfield 2012; PIRSA 2012; Stobart *et al.* 2012a; 2012b; Mayfield *et al.* 2013). It is both species and spatially-explicit with SAUs as the spatial scale at which monitoring and assessments are undertaken (Figure 1.2). The harvest strategy comprises two key components. These are (1) determining the risk that each SAU is overfished and the overall status (depleted, overfished, sustainably fished, under fished or lightly fished) of each species in each zone of the SAAF, based on the summed performance indicator score (Figure 1.3); and (2) the decision-making process which integrates information from multiple sources (e.g. divers, licence holders, fishery managers, compliance officers, researchers) to make management decisions for each SAU. The range of management decisions for each SAU is constrained by explicit decision rules based on the assigned risk-of-overfishing category (Table 1.3). These harvest-decision rules guide determination of future catch contributions from each SAU in the fishery, which are then summed by species for each zone and used to adjust annual TACCs.

1.4. Blacklip biology

Abalone (Family: Haliotidae; Genus: *Haliotis*) are marine gastropods inhabiting near-shore reefs (Day and Shepherd 1995) from the shallow sub-tidal zone to depths around 200 m (Geiger 2000). They have a world-wide distribution in tropical and temperate waters with the richest abalone faunas found in Australia, Japan and South Africa (Geiger 2000). Over 50 species of abalone are currently recognised (Geiger 2000).

Blacklip are contiguous throughout southern Australia between Coffs Harbour (New South Wales) and Rottnest Island (Western Australia). Adults commonly occur in crevices and caves, or at the bottom of steep rock faces, of topographically complex rocky reefs (1-30 m depth).

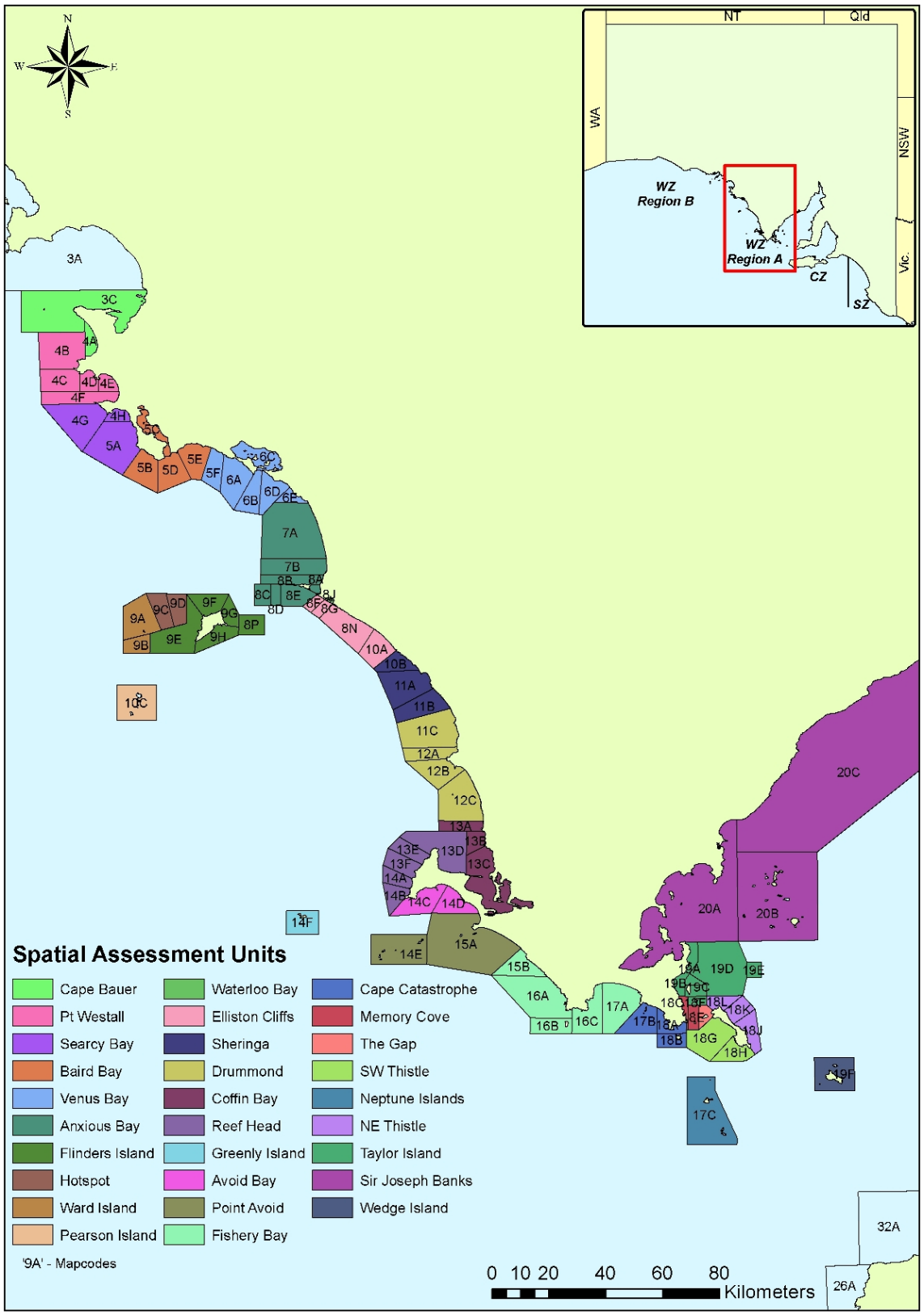

Figure 1.2. Spatial assessment units (SAUs) and map codes in Region A of the Western Zone South Australian Abalone Fishery.

Blacklip have a broad-scale population structure (Brown 1991). However, significant genetic differentiation can occur between sites less than 15 km apart (Shepherd and Brown 1993; Temby *et al.* 2007; Miller *et al.* 2009), suggesting limited dispersal among 'metapopulations' (Fleming 1997; Miller *et al.* 2009). Blacklip have separate sexes and spawn during summer and autumn, though spawning may not be synchronous (Shepherd and Laws 1974; Keesing *et al.* 1995; Rodda *et al.* 1997). The annual spawning cycle may be driven by seasonal variation in water temperature (Shepherd and Laws 1974). Their size at sexual maturity varies substantially among areas. In the WZ, the length at which 50% of individuals are sexually mature (L_{50}) varies between 82.3 mm (Hotspot, 2004) and 103.0 mm SL (Tungketta, 2004; Appendix 1, Table A1.1). Fecundity of 130 mm SL blacklip ranges from 0.81 to 1.7 million eggs (Table A1.2).

Abalone growth rates are highly variable and largely dependent on water temperature, water movement and the quantity and species of macro algae available for consumption (Day and Fleming 1992; Zacharin 1997). Initial rates of growth of settled larvae are high and can be length-dependent (Shepherd 1988). Typically, growth rates are described by a von Bertalanffy model (Shepherd and Hearn 1983), although more complex models are being used (Haddon *et al.* 2008). The growth rates of adult blacklip can be represented by the von Bertalanffy growth equation, k (yr^{-1}) and L_∞ (mm SL). In the WZ, k ranged from 0.078 yr^{-1} at West Bay (2001) to 0.406 yr^{-1} at Waterloo Bay (1969), while L_∞ ranged between 132.8 mm SL at Reef Head and 244.0 mm SL at West Bay (Appendix A.1, Table A1.3). The length-weight relationships for blacklip in Region A are generally well established (Appendix A.1, Table A1.4).

Through their ontogeny the diet shifts from crustose coralline algae (individuals 5-10 mm SL) to drift algae in adults (Shepherd and Cannon 1988). In some species, including blacklip, brown algae and detritus make up a high proportion of the diet (Guest *et al.* 2008). Other abundant algae may be largely avoided, ostensibly due to non-palatability. Small abalone are preyed upon by a range of predators, including fish, crabs, lobsters, starfish and octopus. Shells are frequently bored by whelks that then feed on the foot muscle. Boring polychaetes also erode the shells and spire (Shepherd 1973).

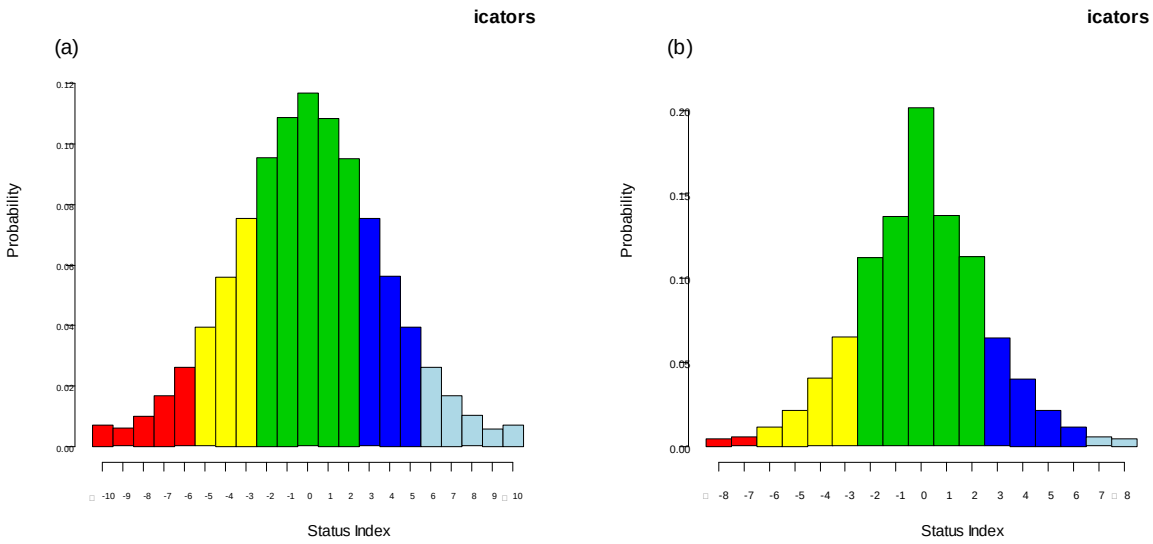

Figure 1.3. Histograms showing the probability distributions of obtaining total scores across (a) six performance indicators (PIs) for SAUs of high importance and (b) three PIs for SAUs of medium importance. Probabilities above and below ±10 (High) and ±8 (Medium) were accummulated in these upper and lower bin classes, respectively, for each of the six and three PIs distributions.

Table 1.3. Range of harvest decision rules (% change in catch contribution) following identification of the risk of overfishing category by the harvest strategy.

Risk-of-overfishing	Harvest decision rule
	At least 30% reduction
	10-30% reduction
	10% reduction to 10% increase
	Up to 30% increase
	Up to 50% increase

1.5. Previous stock assessments

The first assessment of the South Australian abalone resource was published by the South Australian Department of Fisheries in 1984 (Lewis *et al.* 1984). In 1996, the abalone research arrangements were comprehensively reviewed (Andrew 1996) following which fishery assessment reports for each management zone of the SAAF were produced annually between 1998 and 2000 (Rodda *et al.* 1998; Shepherd *et al.* 1999; Rodda *et al.* 2000). The 2001 stock assessment report provided fishery statistics for all three zones of the SAAF (Mayfield *et al.* 2001). The first dedicated WZ report (Mayfield *et al.* 2002) synthesised relevant fisheries data from 1968 to 2001. Stock assessment reports were updated annually to 2006 (Mayfield *et al.* 2003; 2004; 2005; Chick *et al.* 2006). Subsequent fishery assessment and status reports for Regions A

and B of the WZ have been provided to PIRSA in alternate years (Chick *et al.* 2007; 2008; 2009; Stobart *et al.* 2010; 2011). In the most recent reports, rapid changes in blacklip CPUE (Stobart *et al.* 2011; 2012b) and mean daily catch (Stobart *et al.* 2011) over the past decade were identified, and these changes were ascribed to an increased abundance of legal-sized blacklip abalone between 2000 and 2008 following elevated, zone-wide recruitment levels in the mid-late 1990s.

The 2012 assessment (Stobart *et al.* 2012b) concluded that (1) the harvestable biomass was either similar to (based on the assumption that catch rates are not hyperstable) or below (assuming catch rates are hyperstable) that prior to the recruitment pulse in the 1990s; and (2) catches from four fishing areas (FAs 11-14), from which recent catch rates were low or declining, were unlikely to be sustainable. Importantly, maintenance of the current TACC appeared reliant on catches from FAs 11-14 being redistributed, without overfishing blacklip stocks elsewhere.

2. METHODS

This assessment relies on analyses of fishery-dependent and fishery-independent data for blacklip in the WZ. Fishery-dependent data consists of catch and effort data for a 45-year period from 1 January 1968 to 31 December 2012 and, with the exception of 2001 and 2010 when no shells were measured, commercial shell measurements from 1999 to 2012. The fishery-independent data consists of estimates of density derived from cross drop surveys conducted periodically at selected SAUs from 2005 to 2012. During these surveys, population length-frequency distributions were also obtained at the same locations.

Data were analysed at two spatial scales: (1) the whole of Region A; and (2) the spatial assessment units (SAUs) defined in the harvest strategy. For historical reference catch and effort data are also provided by fishing area (Appendix A.2; Figures A2.1 and A2.2). The importance of each blacklip SAU in the WZ is based on the relative contribution to total catch of abalone (i.e. combined catch of greenlip and blacklip and combined Regions A and B) over the ten-year period ending with the year being assessed (i.e. the current year). Thus, for this assessment, importance was determined using data from 2003 to 2012. Three importance categories are defined – high, medium and low – based on the percentage contribution to total catch. SAUs from which the cumulative catch harvested reaches 50% are deemed of high importance. Medium importance SAUs comprise those which, cumulatively, bring the total catch to >80% of the combined TACC when added to the catch from high importance SAUs. All remaining SAUs are classified as being of low importance.

2.1. Catch and effort

Commercial catch and effort data have been collected since 1968 in the form of daily entries to commercial logbooks submitted to SARDI, allowing spatial and temporal analyses of catch (t, shell weight), effort (days) and mean CPUE ± standard error (se). Multi-dimensional scaling (MDS) was used to evaluate temporal changes in the distribution of catch among SAUs, where proximity between years indicates their similarity. MDS results were further interpreted with similarity percentage (SIMPER) analysis which calculates the percentage each SAU contributes to the difference between each year pair (i.e. which SAUs are contributing most to the differences).

The mean CPUE was computed using the catch-weighted mean of daily CPUE (Burch *et al.* 2011). Prior to calculation of CPUE, daily data were filtered to remove records where catch was >900 kg, effort was <3 and >8 hours, the ratio of total catch over total hours was >150 $kg.hr^{-1}$ or blacklip comprised <30% of catch. The minimum sample size

was 10 fishing records, therefore the absence of data for this measure in any one year indicates fewer records were available.

For historical comparison, mean values of key measures of fishery performance are provided both in text and as dashed lines on graphs. These are the (1) proportion of the blacklip TACC harvested from each SAU for the 10-yr period between 2003 and 2012 ($C_{03\text{-}12}$); and (2) mean annual CPUE for the 20-yr period between 1990 and 2009 ($CPUE_{90\text{-}09}$). Ranking of SAUs refer first to the rank within the ten-year period ($C_{03\text{-}12}$), followed by the rank in 2012 separated by a hyphen (e.g. 1-5 had rank 1 over the 10-yr period and rank 5 in 2012).

2.2. Commercial catch sampling

Data on the length-frequency distribution of the commercial catch were obtained by measuring samples provided to SARDI by commercial fishers (1999 – 30 June 2005) and subsequently data provided by the Abalone Industry Association of South Australia (AIASA) from 1 July 2005 to 17 April 2008. Following this, in 2009, one sample from Neptune Islands was measured by SARDI who have also undertaken limited 'at-sea' sampling (Reef Head in 2011 and Drummond in 2011 and 2012). From 1 January 2012, AIASA resumed provision of data from commercial fishers who were requested to measure the first five blacklip from each catch bag obtained in high and medium importance SAUs. The length-frequency data are used to estimate the proportion of large blacklip in the commercial catch (PropLge), defined as the ratio of 'large' shells (>165 mm SL) to all commercial SL measurements (minimum sample size = 100) with SL measurements >5 mm below the MLL (130 mm SL) excluded.

The quality of length-frequency data obtained varied considerably between years with substantially more representative data (21% of fishing days sampled) obtained in 2012 than in the period from 2009-2011 (Figure 2.1; range <1% to 12%). However, the limited historical information continues to impede interpretation of the data and data provided in 2012 remains well below the 70% of fishing days required (Burch *et al.* 2010; Stobart *et al.* 2012b). Thus, although the data are excluded from the weight-of-evidence analyses on stock status, they are presented for completeness in Section 3 and Appendix A.3 because they conform to current rules describing data utilisation in the harvest strategy (Appendix A.3; Table A3.1). Consequently, despite their identified weakness, they are scored and used to determine stock status in accordance with the management plan for the fishery.

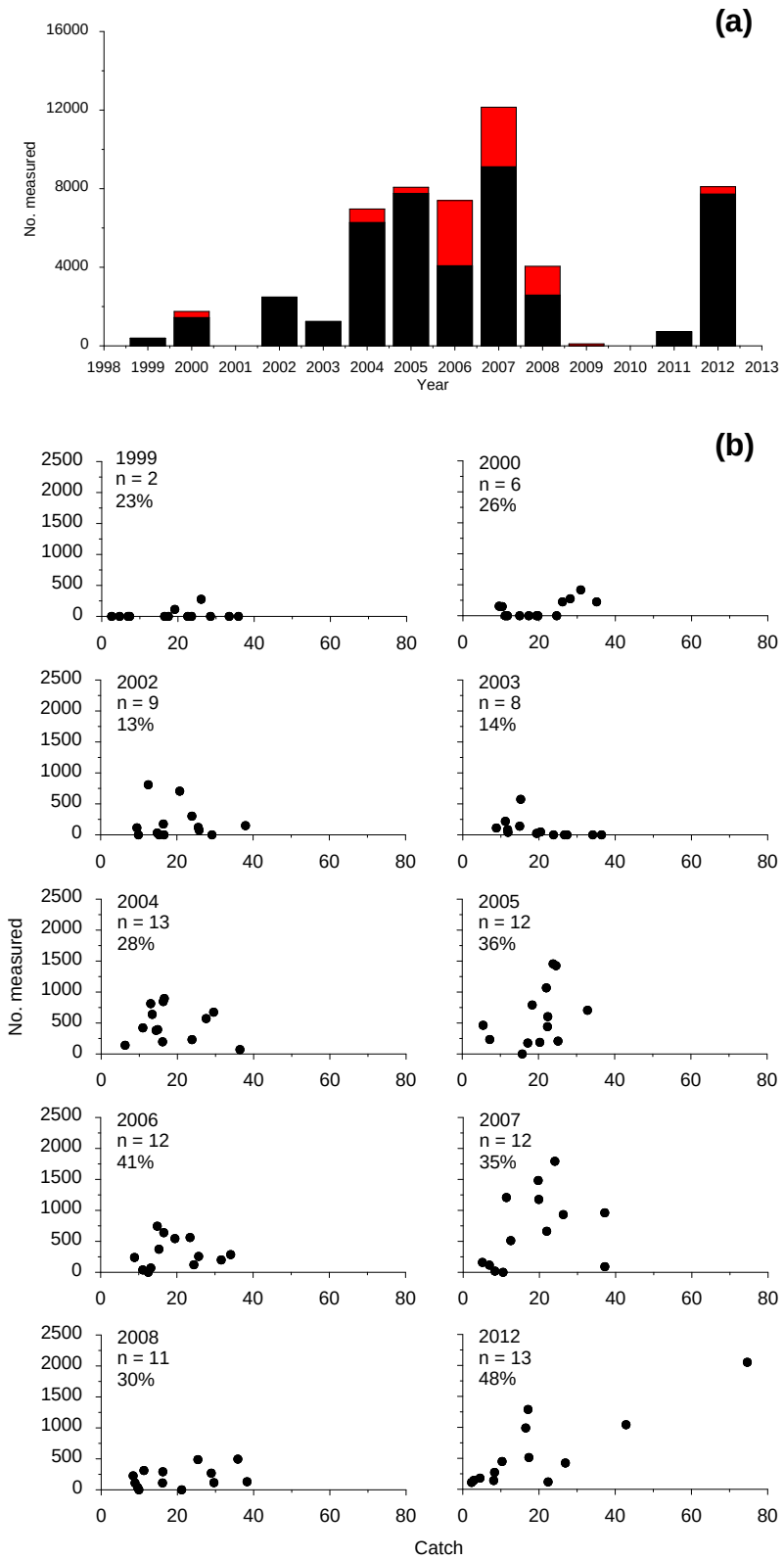

Figure 2.1. Number of blacklip measured by the commercial fishery from 1999 to 2012 by (a) year (black = high and medium, red = low importance SAUs; and (b) catch (t, shell weight). Information on graphs indicates: year = year of sampling; n = number of medium and high importance SAUs in which measurements were made; and % = percentage of licences measuring shells in high and medium importance SAUs (based on SAU importance defined in this report).

2.3. Fishery-independent surveys

Blacklip abundance and population size structure were obtained from SARDI fishery independent (FI) surveys which, in recent years, have been undertaken bi-enially as part of an overall rationalisation of the research program. The FI information provided includes length-frequency distributions and mean density ± standard error (se) of legal and sub-legal-sized blacklip. These are primarily obtained from high importance SAUs. In 2013, data were available for four of the nine high importance SAUs. One medium importance SAU, Hotspot, was also surveyed in 2013 to maintain the historical record, as this site previously yielded higher catches and has been categorised as a high importance SAU historically. In order to aid the interpretation of the length-frequency distributions, the percentage of large blacklip (LARGE) from FI survey length-frequency distributions was defined as the ratio of 'large' blacklip (≥ 145 mm SL) to all legal-sized (i.e. ≥ 130 mm SL) measurements. The percentage of small blacklip (SMALL) was defined as the ratio of 'small' blacklip (< 100 mm SL) to all sub-legal-sized blacklip (i.e. ≥ 100 mm to < 130mm SL). Density was estimated using cross drops (Chick and Mayfield 2006; Chick *et al.* 2012).

Survey design was reviewed in 2013. Alterations to existing surveys included changes to survey areas, survey boxes and the number/location of cross drops, notably at Drummond and Ward Island. However, the method has been changed without compromising the results evidenced by the strong positive correlations between the densities of legal-sized and sub-legal-sized blacklip from the old and new survey design ($r>0.94$; $p<0.05$).

2.4. Harvest strategy

The harvest strategy integrates catch and effort, commercial catch sampling and FI data to determine the risk that individual SAUs are overfished and a zonal stock status. The methodology used to calculate, score and interpret high and medium importance SAU PIs for the harvest strategy is detailed in Stobart *et al.* (2012b) and the Management Plan (PIRSA 2012).

2.5. Quality Assurance

Quality assurance systems form an integral part of stock assessments undertaken by SARDI. These systems are designed to ensure high quality project planning, data collection and storage, analyses, interpretation of results and report writing.

2.5.1. Research planning

The requirements of PIRSA Fisheries and Aquaculture were discussed in December 2012 and subsequently provided to representatives of the WZ abalone fishery to confirm their understanding of proposed deliverables. This ensures that the research

undertaken and deliverables provided are consistent with the needs of PIRSA Fisheries and Aquaculture to meet their obligations under the *Fisheries Management Act 2007.*

2.5.2. Data collection

Commercial fishers are advised on the procedures and requirements for commercial catch sampling and completion of the required fishing logbook on a regular basis, usually at the commencement of each fishing season. The data provided by commercial fishers are checked by SARDI prior to acceptance and potential errors corrected through direct correspondence with individual commercial fishers. SARDI staff are trained to undertake fishery-independent data collection using the standardised method described in the SARDI Abalone Research Group Quality Assurance and Fishery-Independent Survey Manual (QAFISM).

2.5.3. Data entry, validation, storage and security

All logbook data are entered and validated according to the quality assurance protocols identified for the abalone fisheries in the SARDI Information Systems Quality Assurance and Data Integrity Report. The data are stored in an Oracle database, backed up daily, with access restricted to SARDI Information Systems staff. Copies of the database are provided to SARDI abalone researchers on request. All FI data are entered into Excel spreadsheets. A subset of the data (20%) is checked against the original data sheets in accordance with the Abalone Data Library Management Protocol (DLMP). Once validated, data are uploaded to an Access database stored on the network drive in Port Lincoln. The database is regularly backed up to an external hard drive and to Objective.

2.5.4. Data and statistical analyses

Data are extracted from the databases using established protocols. A subset (10%) of data extractions are checked to ensure extraction accuracy. This occurs in two ways. First, data are compared to those extracted previously. Second, the data extractions are undertaken by two SARDI researchers and subsequently compared. Most of the data are analysed using the open source software R. A subset (~10%) of the outputs from R are compared against estimates made in an alternative package (e.g. Excel).

2.5.5. Data interpretation and report writing

The results, their interpretation and conclusions provided in the reports are discussed with peers, PIRSA Fisheries and Aquaculture and abalone licence holders. All co-authors review the report prior to the report being formally reviewed by two independent scientists at SARDI in accordance with the SARDI report review process. Following necessary revision, the report is reviewed by PIRSA Fisheries and Aquaculture to ensure it is consistent with their needs and objectives for the fishery.

3. RESULTS

3.1. Region A

Total catches were relatively stable (293 t) from the introduction of the quota management arrangements in 1985, with the exception of a temporary reduction to 258 t in 1996 and, from 2010, a 10% lower catch at ~276 t, reflecting the reduction in TACC (Figure 3.1). Total effort was relatively stable from 1989 to 2000, decreased to a recent historical minimum in 2006, but has since increased. These temporal changes in effort were strongly reflected in CPUE which increased rapidly from 2000 to 2006 (78 kg.hr^{-1}), whereafter it has declined. In 2012, CPUE was 64.2 kg.hr^{-1}. This was 7% below $CPUE_{90\text{-}09}$, but equivalent to the mean CPUE of 64.6 kg.hr^{-1} between 1992 and 2000 (the period prior to the increased abundance between 2001 and 2008).

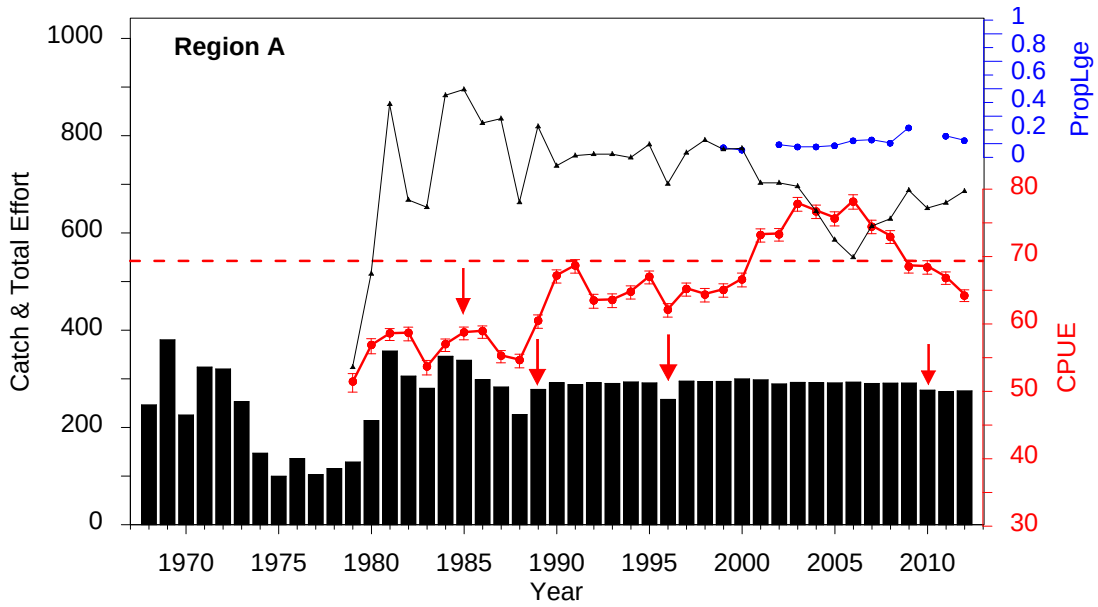

Figure 3.1. Catch (t, shell weight; black bars) of blacklip from Region A from 1968 to 2012. Total effort (days), CPUE ± se (kg.hr^{-1}) and PropLge are shown in black, red and blue lines, respectively. Red dashed line is $CPUE_{90\text{-}09}$. Red arrows indicate implementation (1985) and amendment (1989, 1996 and 2010) of TACC.

3.2. Spatial assessment units

For the ten year period ending 31 December 2012, there were 12 high and 14 medium importance SAUs in the WZ (Figure 3.2). Of these, 9 high (75%; Drummond, Sheringa, Avoid Bay, Point Westall, Searcy Bay, Ward Island, Reef Head, Venus Bay and Anxious Bay) and 4 medium (29%; Hotspot, Point Avoid, Baird Bay and Flinders Island) importance blacklip SAUs were located in Region A. The only change in importance rating between 2011 and 2012 was for Reef Head for which relatively high catches over recent years have led to a change in its status from medium importance in the 2011 assessment (Stobart *et al.* 2012b) to high importance in this assessment.

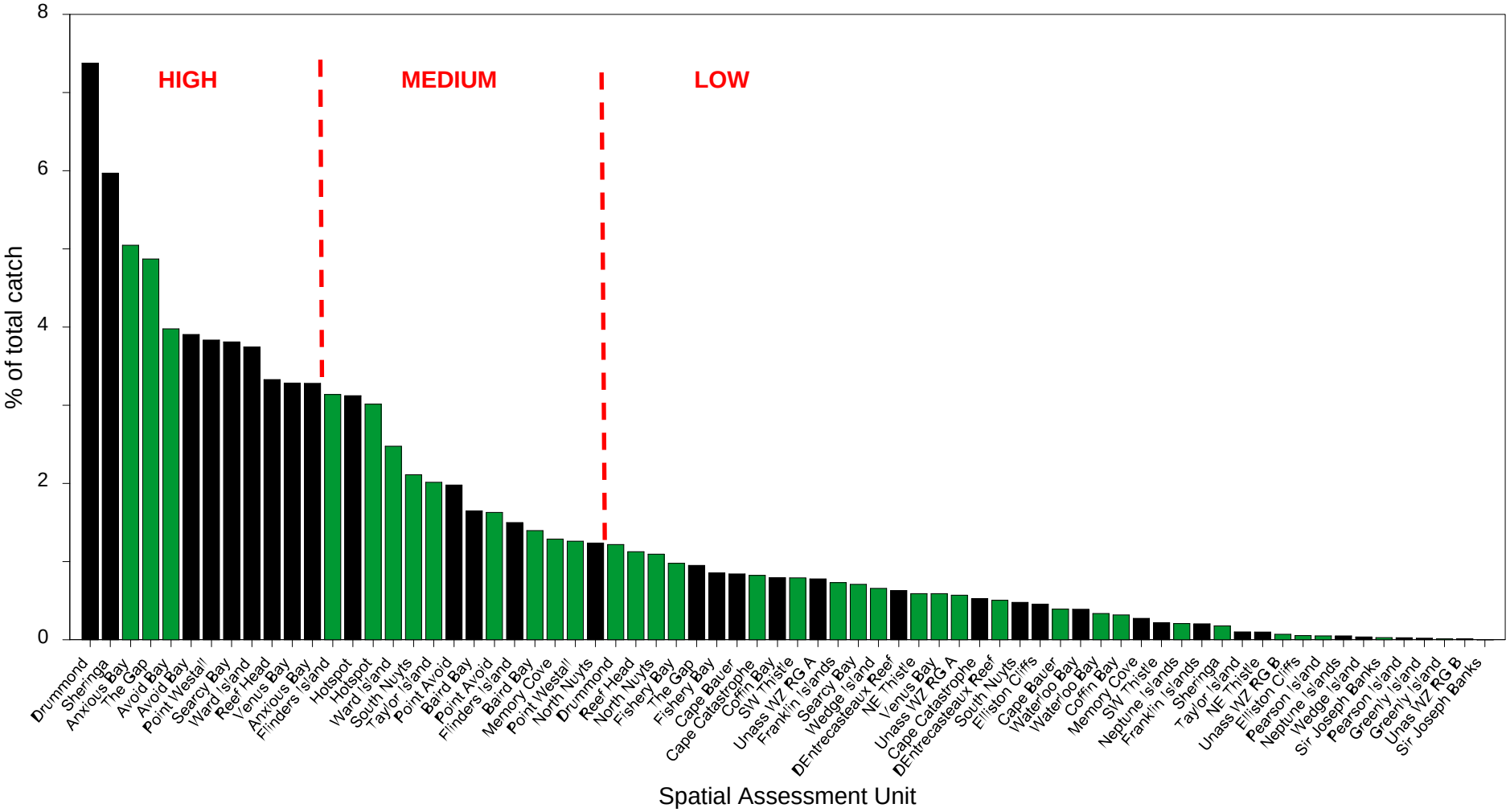

Figure 3.2. Relative importance (% of catch) of each blacklip (black bars) and greenlip (green bars) SAU. Note each SAU is ranked twice, once for blacklip and once for greenlip. Red text and dotted lines indicate SAU importance category and division. Note abbreviations for cape (Cp), island (Isl), Joseph Banks (JB) and Unass RG A or Unass RG B (unassigned Region A or Region B, respectively).

3.2.1. Distribution of catch among spatial assessment units

In 2012, SAUs from which more than 5% of the total blacklip catch for Region A was harvested were Drummond (27.1%), Sheringa (15.6%), Reef Head (9.8%), Avoid Bay (8.1%), Anxious Bay (6.3%), Searcy Bay (6.2%) and Point Westall (6.0%; Figure 3.3). Cumulatively, these represent 79% of the catch, a 4% increase over that in 2011. The distribution of catch among SAUs remained similar between 2011 and 2012, although there were considerable increases at Drummond (65.6 t; 24% to 74.7 t; 27%) and Avoid Bay (18.1 t; 7% to 22.4 t; 8%) and decreases at Point Avoid (13.1 t; 5% to 10.3 t; 4%), Venus Bay (12.0 t; 4% to 8.3 t; 3%) and Hotspot (4.0 t; 2% to 2.3 t; 1%).

The MDS plot shows a cluster of years (1993-2009) in which, with the exception of 2007, the distribution of catch among SAUs was similar, suggesting a period of relative stability in the fishery (Figure 3.4). During this period of relative stability, catch was more evenly distributed among SAUs and changed less abruptly between years (Figure 3.5). More recently, between 2009 and 2012, the distribution of catch among years has varied substantially, with the spatial distribution of catch in 2012 being most similar to that from 2011 and 1980 (Figure 3.4). Within this three-year period the greatest change occurred from 2010 to 2011 and was most strongly influenced by the increase in catch from Drummond and decreases from Hotspot and Ward Island. The smaller difference between 2011 and 2012 was primarily attributed to increased catch from Pearson Island and Drummond, along with decreases from Venus Bay and Waterloo Bay.

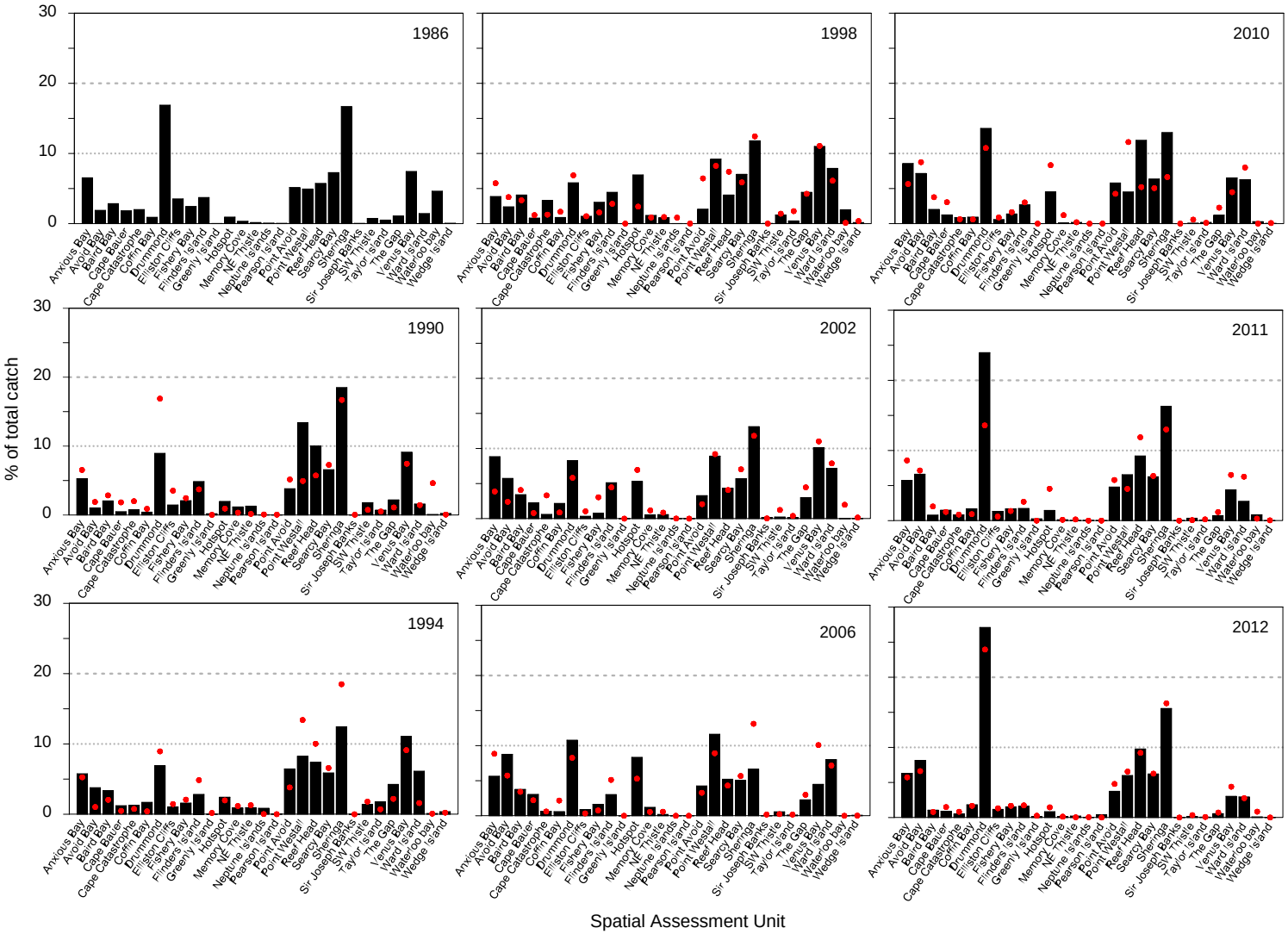

Figure 3.3. Spatial distribution of the blacklip catch (% of total catch) among each of the SAUs in Region A at 4-yearly intervals from 1986 to 2010, and annually thereafter. Red dots represent catches from previous period.

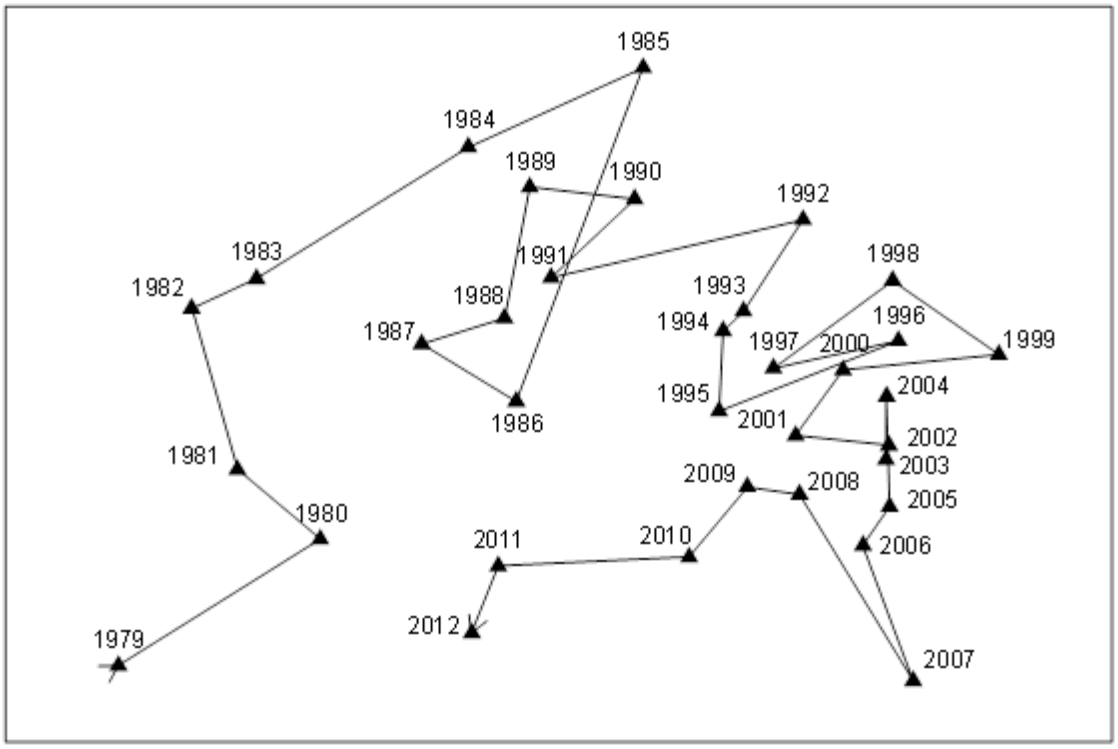

Figure 3.4. Multi-dimensional scaling (MDS) plot for SAUs showing similarity among years based on blacklip catch from Region A from 1979 to 2012. 2D stress = 0.15.

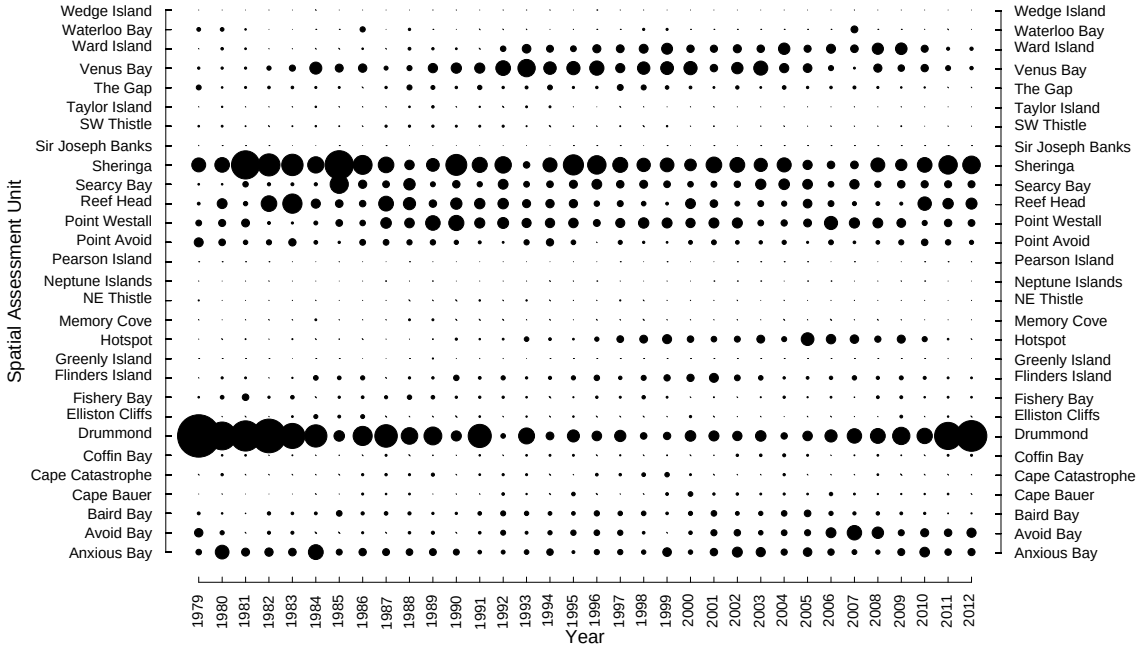

Figure 3.5. Bubble plot showing blacklip catch (% of total catch) among each of the SAUs in Region A from 1979 to 2012.

3.2.2. Temporal patterns in high importance spatial assessment units

Drummond (Rank 1-1; 13.9% $C_{03\text{-}12}$)

Drummond is the most important blacklip SAU in Region A. Catch decreased from a historic high in 1981 to substantially lower, but relatively stable catches between 1994 and 2005. Subsequently, catches from this SAU have increased substantially with the greatest increase (74%) occurring between 2010 (38 t) and 2011 (66 t), to a level similar to that recorded in the early 1980s. Catch also increased between 2011 and 2012 to 75 t (Figure 3.6). This represented 27% of the 2012 Region A blacklip catch (Figure 3.3) and was the highest catch from this SAU since 1982 and the third highest catch since 1979. CPUE generally increased from 1979 (57 kg.hr^{-1}) to the maximum in 2006 (88 kg.hr^{-1}). However, it has subsequently declined and, in 2012 (64 kg.hr^{-1}), was (1) 27% below that in 2006; (2) at the lowest level since 1996; and (3) 16% below $CPUE_{90\text{-}09}$.

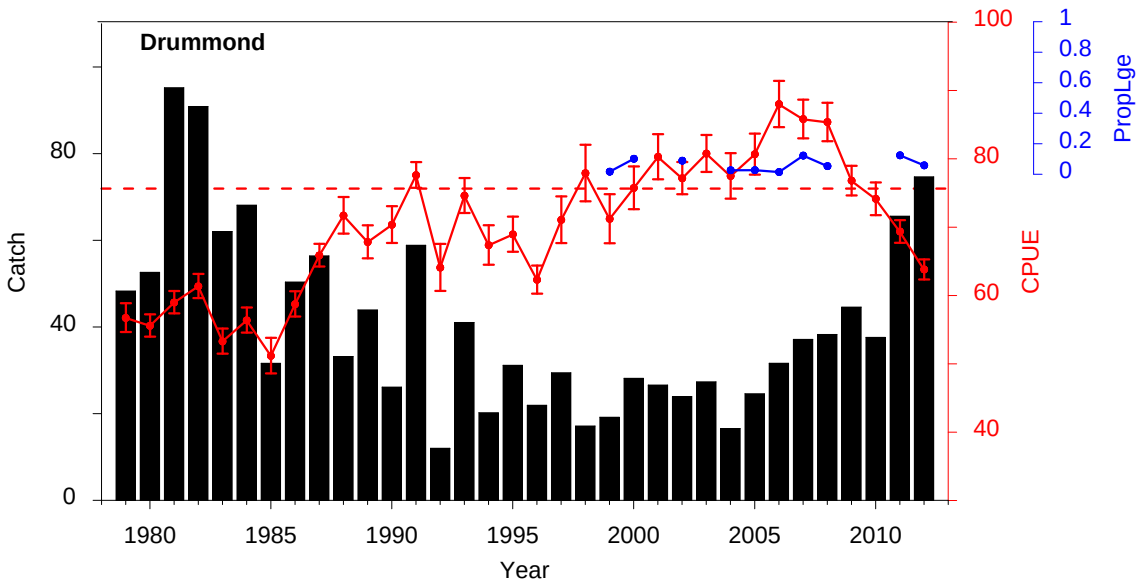

Figure 3.6. Catch (t, shell weight; black bars) of blacklip from Drummond from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90\text{-}09}$.

FI surveys at Drummond indicated that the percentage of LARGE blacklip varied between years (range: 12-27%), with most size classes represented in all years (Figure 3.7). The percentage of SMALL blacklip was low in 2006 and 2013 (10%) in contrast with 2008, 2009 (30%) and 2011 (20%). Density of legal-size and sub-legal-size blacklip have remained similar since surveys began in 2005 (Figure 3.8) and unchanged between surveys in 2011 and 2013.

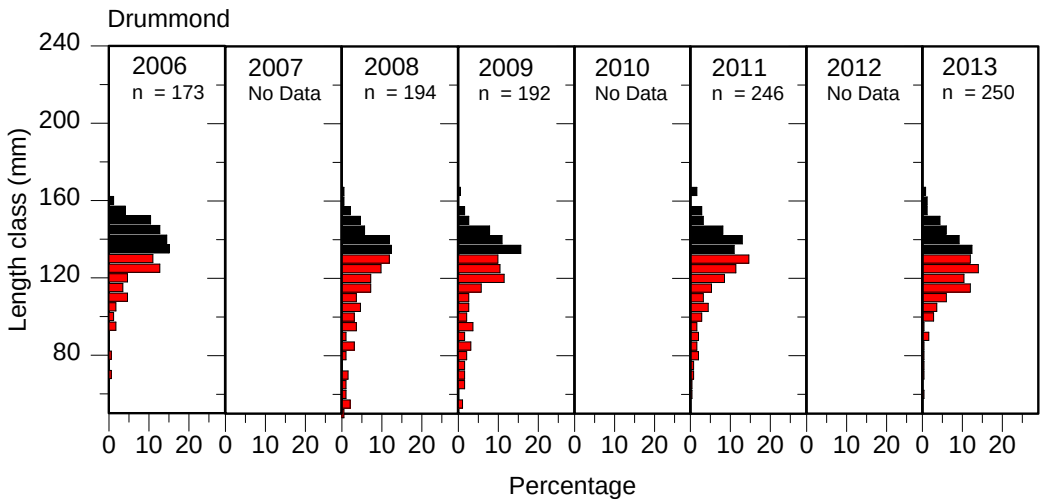

Figure 3.7. Length-frequency distributions of legal-sized (black bars) and sub-legal-sized (red bars) blacklip at Drummond (map-code 12B) observed on fishery-independent surveys from 2006 to 2013. Length classes represent the upper length of each 5 mm bin. n = number of blacklip measured. Bin classes < 50 mm pooled.

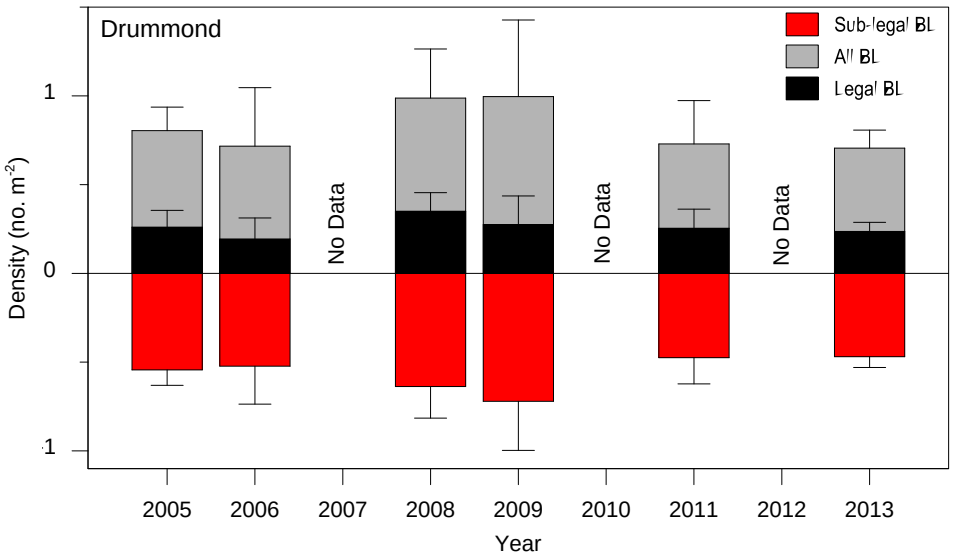

Figure 3.8. Mean density ± se (abalone.m^{-2}) of all, legal-sized and sub-legal sized (see legend) blacklip at Drummond (estimated from six cross drops; map-code 12B) from 2005 to 2013.

Sheringa (Rank 2-2; 11.2% C_{03-12})

Catches from Sheringa have oscillated among years with substantially larger catches harvested from this SAU in 1981 and 1985 (Figure 3.9). Lower catches from 2005 to 2007 were the consequence of industry agreeing with PIRSA to reduce the level of catch from this SAU for this period. Since 2007, catches have increased and, in 2011 and 2012 (45 and 43 t, respectively), were at the highest level since 1995, constituting, in both years, 16% of the blacklip catch from Region A (Figure 3.3). With the exception of a high value in 2006, CPUE remained relatively stable from 1990 to 2010. However, it decreased between 2010 (89 kg.hr^{-1}) and 2011 (83 kg.hr^{-1}), to the lowest level since 1989 and, in 2012 remained at 8% below $CPUE_{90-09}$.

While no FI surveys were available for Sheringa in 2013, previous surveys at Sheringa indicated that the percentage of LARGE blacklip varied considerably between 2005 and 2011 (range: 44-81%), with the largest size classes evident in all years (Figure 3.10). However, the density of legal-sized blacklip halved between 2008 and 2009, and remained low during 2011 (Figure 3.11). Similarly, the density of sub-legal-sized blacklip was lowest in 2009 and remained relatively low in 2011.

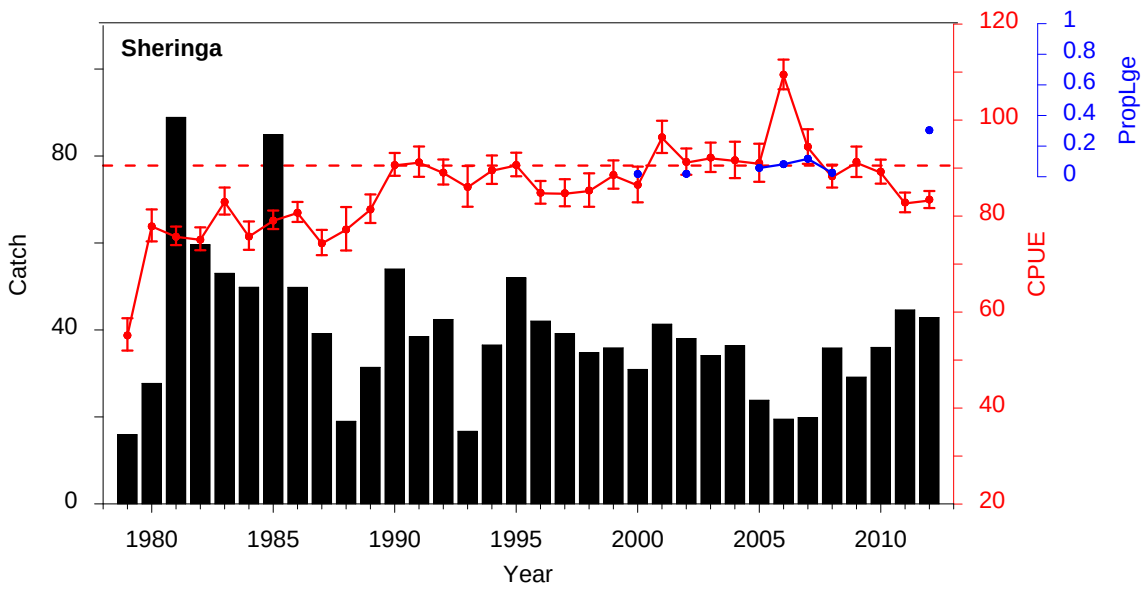

Figure 3.9. Catch (t, shell weight; black bars) of blacklip from Sheringa from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90-09}$.

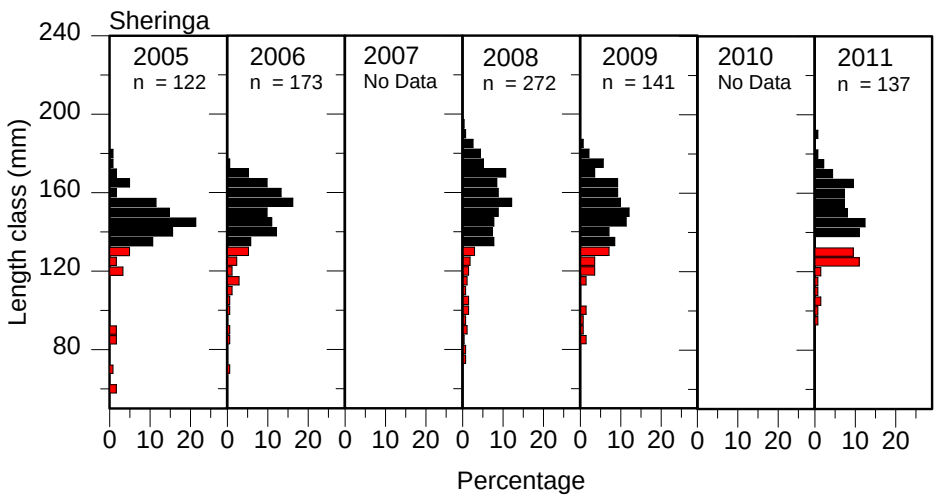

Figure 3.10. Length-frequency distributions of legal-sized (black bars) and sub-legal-sized (red bars) blacklip at Sheringa (map-code 11A) observed on fishery-independent surveys from 2005 to 2011. Length classes represent the upper length of each 5 mm bin. n = number of blacklip measured. Bin classes < 50 mm SL pooled.

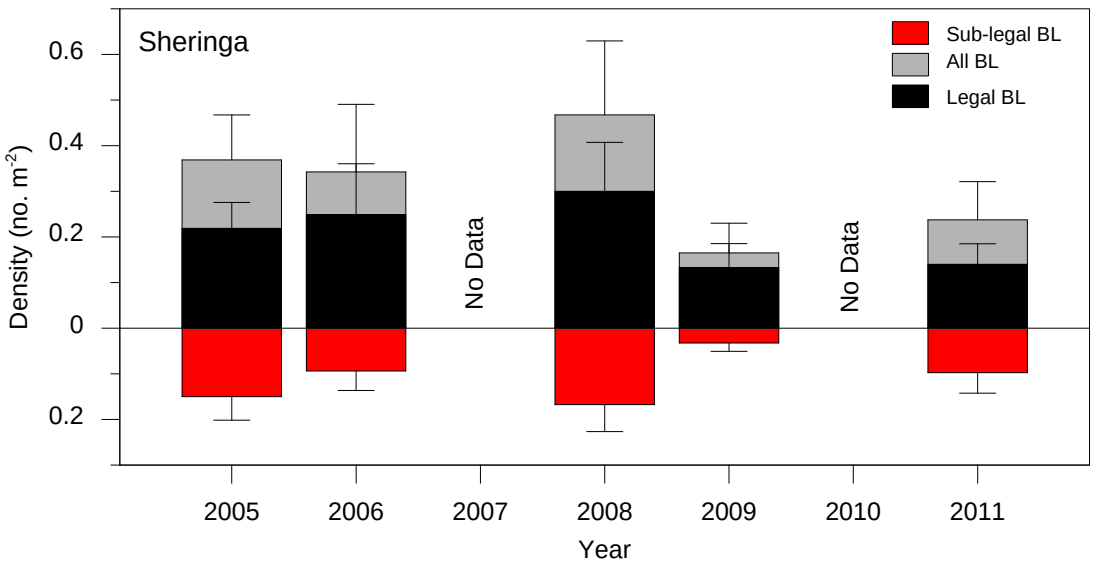

Figure 3.11. Mean density ± se (abalone.m^{-2}) of all, legal-sized and sub-legal sized (see legend) blacklip at Sheringa (cross drops; map-code 11A) from 2005 to 2011.

Avoid Bay (Rank 3-4; 7.3% C_{03-12})

Catch from Avoid Bay was relatively stable between 1979 and 2005, ranging between about 5 and 15 t.yr^{-1} (Figure 3.12). Substantially larger catches were obtained from this SAU between 2006 and 2008, while more recently catch has increased from 16 t.yr^{-1} in 2009 to 22 t.yr^{-1} in 2012. CPUE has been substantially lower over recent years, declining from a recent maximum in 2007 (79 kg.hr^{-1}) to 55 kg.hr^{-1} in 2012. This was the lowest level since 1998 and 15% below $CPUE_{90-09}$.

FI surveys at Avoid Bay (at Black Rocks, map-code 14D) began in 2009 and, with the exception of a relatively low percentage of LARGE blacklip in 2011 (30%), this metric has remained relatively stable (range: 38-44%). However, no blacklip >164 mm SL were observed in 2011 and 2013 (Figure 3.13). Density estimates of legal-sized blacklip have reduced to less than half between 2009 and 2013 (Figure 3.14), and the density of sub-legal blacklip has declined between 2010 and 2013.

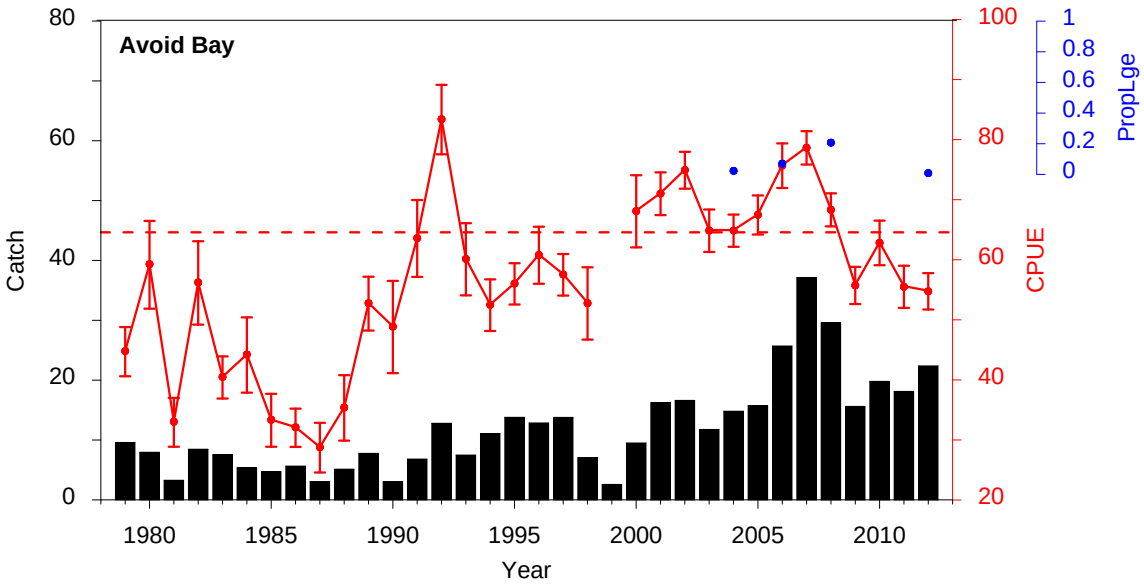

Figure 3.12. Catch (t, shell weight; black bars) of blacklip from Avoid Bay from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90-09}$.

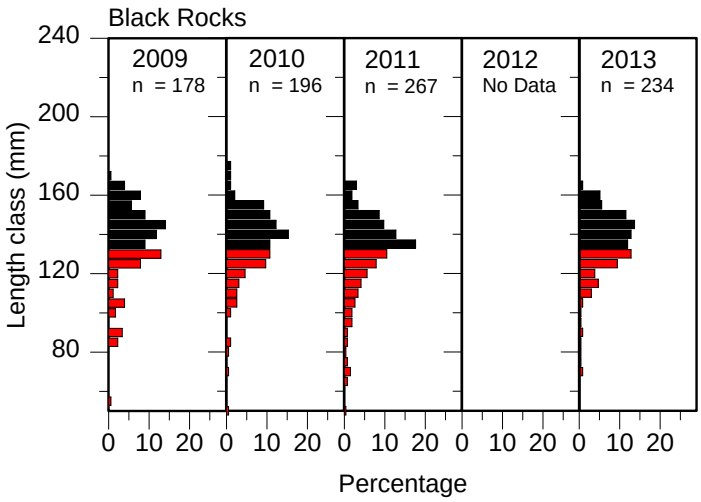

Figure 3.13. Length-frequency distributions of legal-sized (black bars) and sub-legal-sized (red bars) blacklip at Black Rocks (map-code 14D) observed on fishery-independent surveys from 2009 to 2013. Length classes represent the upper length of each 5 mm bin. n = number of blacklip measured. Bin classes < 50 mm SL pooled.

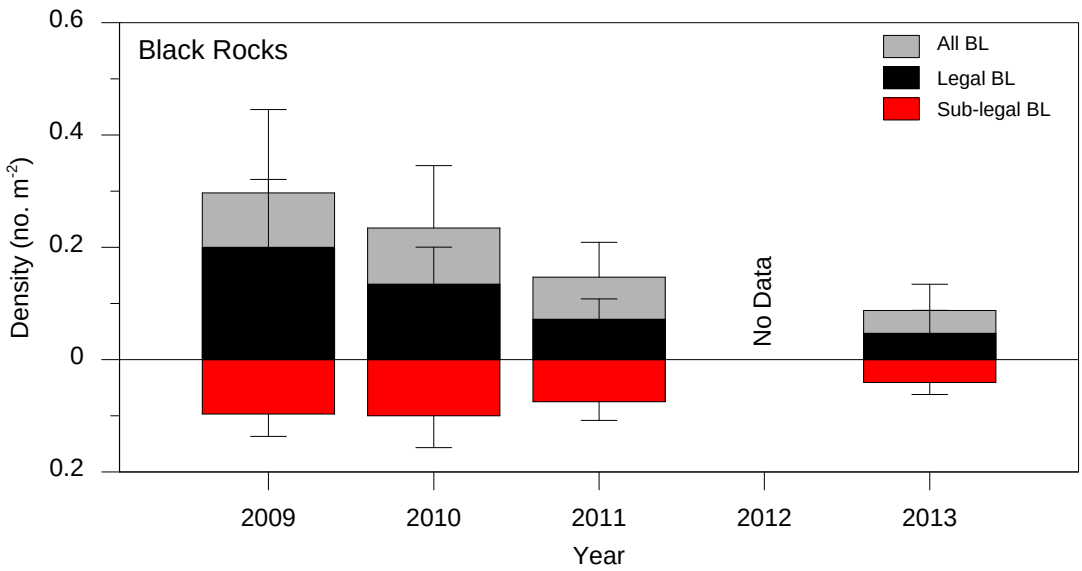

Figure 3.14. Mean density ± se (abalone.m^{-2}) of all, legal-sized and sub-legal sized (see legend) blacklip at Black Rocks (cross drops; map-code 14D) from 2009 to 2013.

Point Westall (Rank 4-7; 7.2% $C_{03\text{-}12}$)

Following modest catches in the 1980s, annual catches from Point Westall have been relatively stable, varying between about 13 and 28 t.yr^{-1} with a peak of 34 t in 2006 (Figure 3.15). However, catches have decreased since 2006 and, in 2012 catch was relatively low. Similarly, CPUE fell from a recent peak in 2006 (90 kg.hr^{-1}) and, in 2012 (62 kg.hr^{-1}), was at the lowest level since 1998 and 9% below $CPUE_{90\text{-}09}$.

FI surveys at Point Westall (at Granites, map-code 4B) indicated that the percentage of LARGE blacklip has been relatively stable since 2005 (range: 17–25%; Figure 3.16) and, in 2013, was similar to that observed between 2005 and 2007 (24%). However, while there has been good representation of sub-legal (Figure 3.16) and consistent densities of sub-legal-sized blacklip since surveys began in 2005 (Figure 3.17), the density of legal-sized blacklip in 2013 was the lowest on record, 50% below that recorded in 2009.

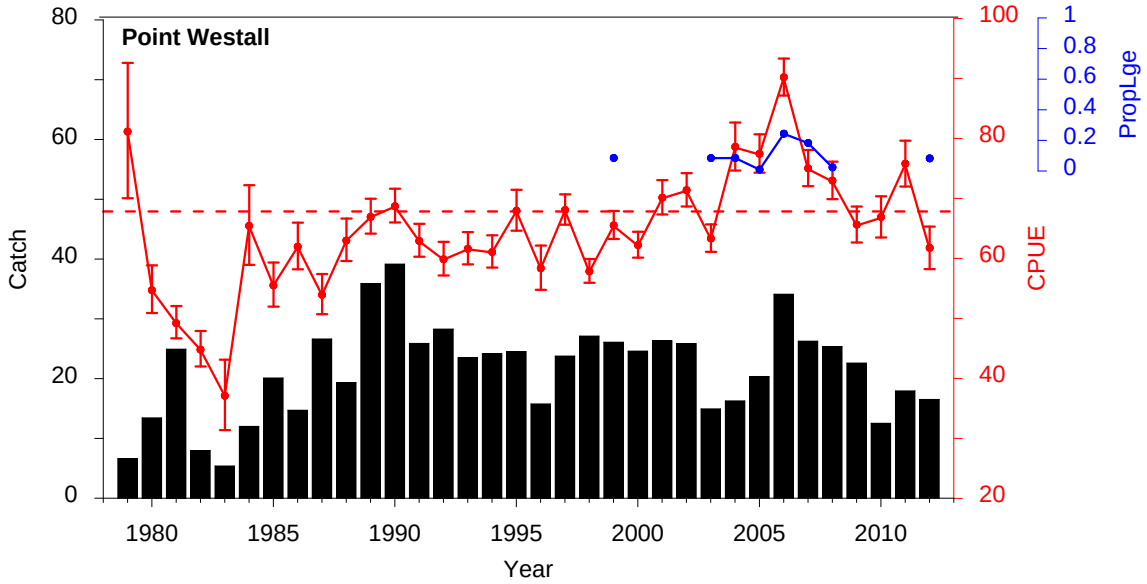

Figure 3.15. Catch (t, shell weight; black bars) of blacklip from Point Westall from 1979 to 2012. CPUE ± se (kg.hr-1) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90\text{-}09}$.

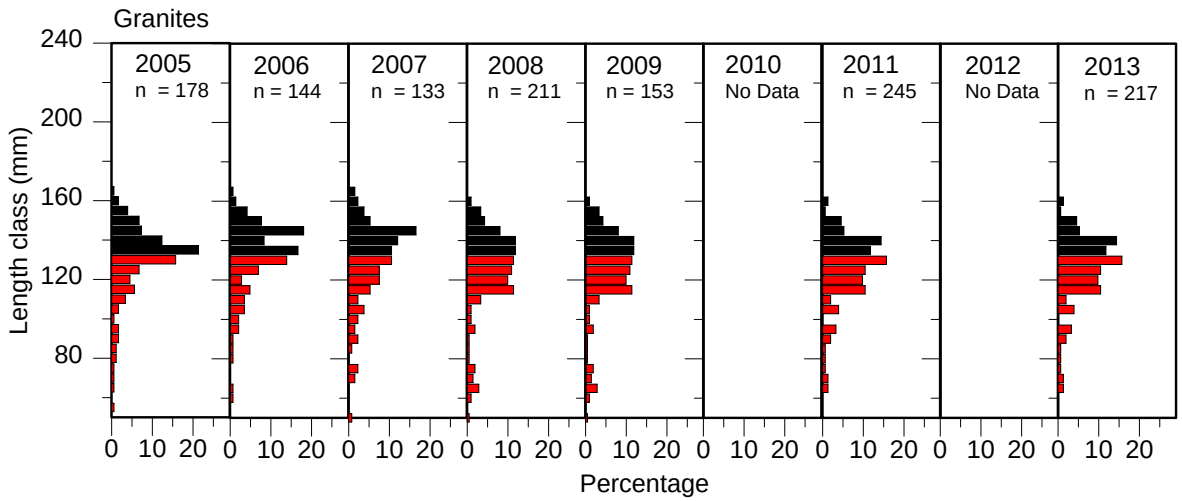

Figure 3.16. Length-frequency distributions of legal-sized (black bars) and sub-legal-sized (red bars) blacklip at Point Westall (Granites map-code 4B) observed on fishery-independent surveys from 2005 to 2013. Length classes represent the upper length of each 5 mm bin. n = number of blacklip measured. Bin classes < 50 mm SL pooled.

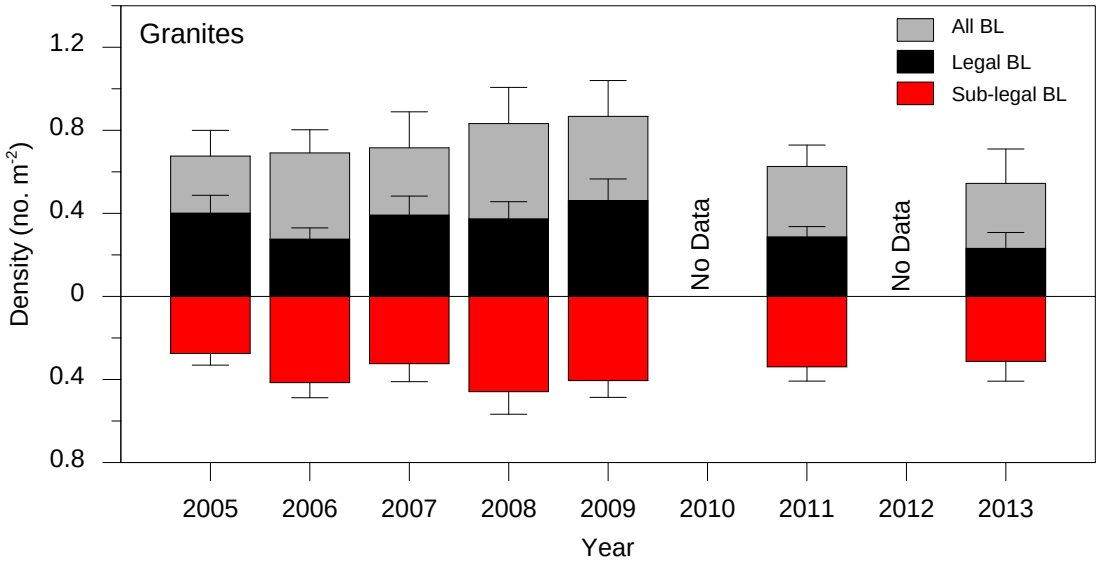

Figure 3.17. Mean density ± se (abalone.m^{-2}) of all, legal-sized and sub-legal sized (see legend) blacklip at Point Westall (cross drops; Granites map-code 4B) from 2005 to 2013.

Searcy Bay (Rank 5-6; 7.2% $C_{03\text{-}12}$)

Since 1985, when the catch from this SAU was 54 t, annual catches from Searcy Bay have been relatively stable, ranging between about 15 and 25 t.yr^{-1} (Figure 3.18). CPUE has fluctuated among years and, following a relatively low estimate in 2009, has remained similar to $CPUE_{90\text{-}09}$ between 2010 and 2012.

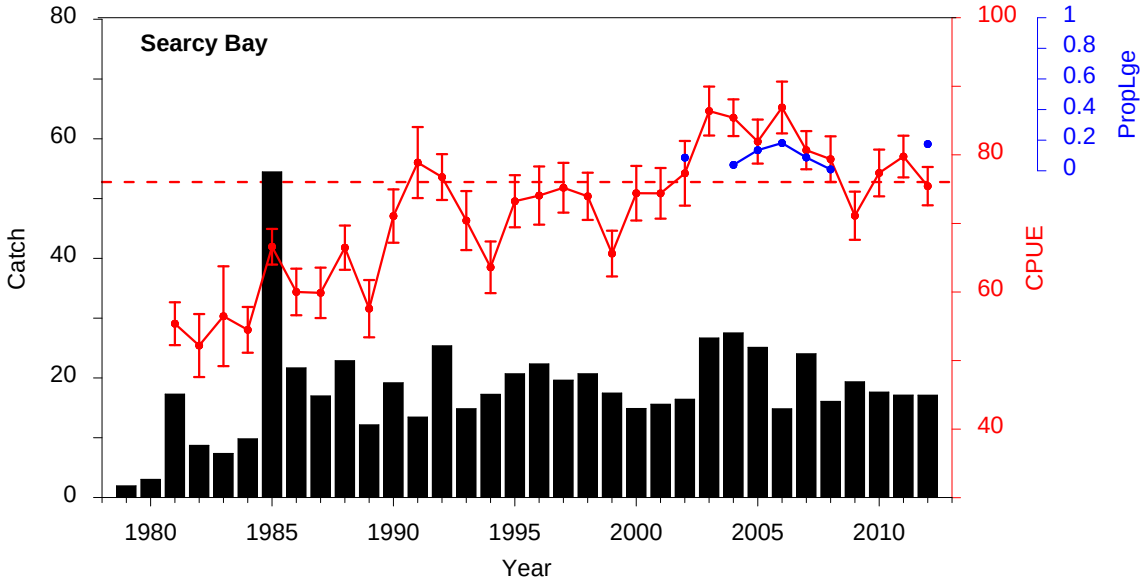

Figure 3.18. Catch (t, shell weight; black bars) of blacklip from Searcy Bay from 1979 to 2012. CPUE ± se (kg.hr-1) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90\text{-}09}$.

Ward Island (Rank 6-10; 7.0% C_{03-12})

Between 1979 and 1991, catch from Ward Island was less than 6 t. Following this, catch more than doubled, remaining stable at about 21 t.yr^{-1} from 1993 to 2010 (Figure 3.19). However, in 2011, catch decreased by 56% to the lowest level since 1991 (7.6 t), and remained low in 2012 (8.1 t). CPUE was relatively stable between 1992 and 2010, although substantially higher in 2003 and 2004, then declined substantially between 2010 and 2011 (78 to 61 kg.hr^{-1}). The CPUE in 2012 (63 kg.hr^{-1}) was similar to that in 2011 with both among the lowest on record for this SAU and 16% below $CPUE_{90-09}$.

FI surveys at Ward Island indicated that the percentage of LARGE blacklip varied between 48% and 62% prior to 2009 but, in 2011 and 2013, decreased to 24% and 21%, respectively, with no blacklip >165 mm SL observed in either year (Figure 3.20). The density of legal-sized blacklip in 2013 was 14% lower than the mean density between 2005 and 2011, but increased by 38% between the 2011 and 2013 surveys (Figure 3.21).

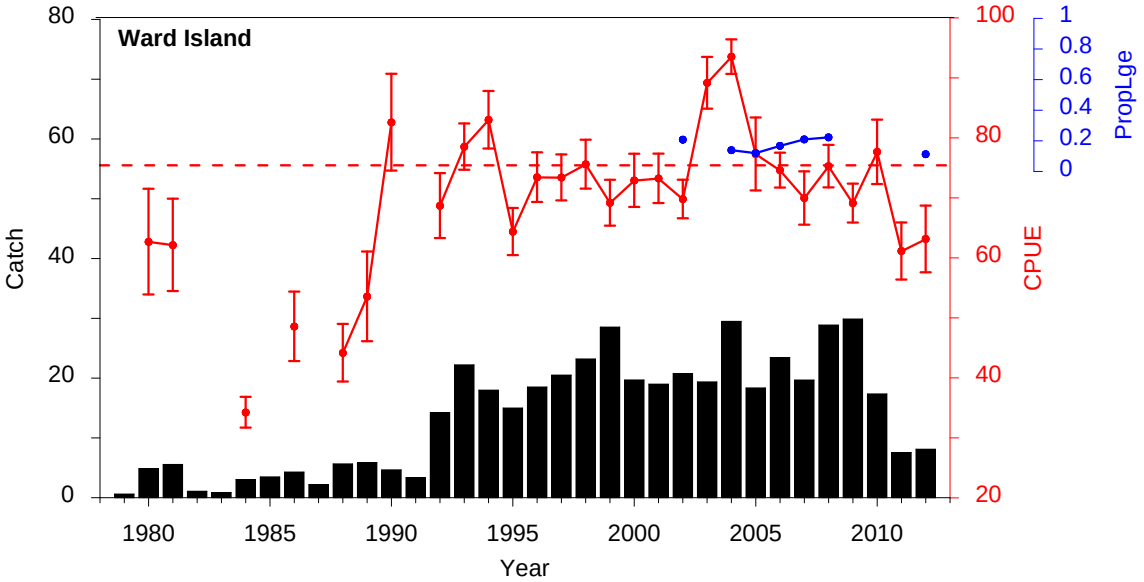

Figure 3.19. Catch (t, shell weight; black bars) of blacklip from Ward Island from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90-09}$.

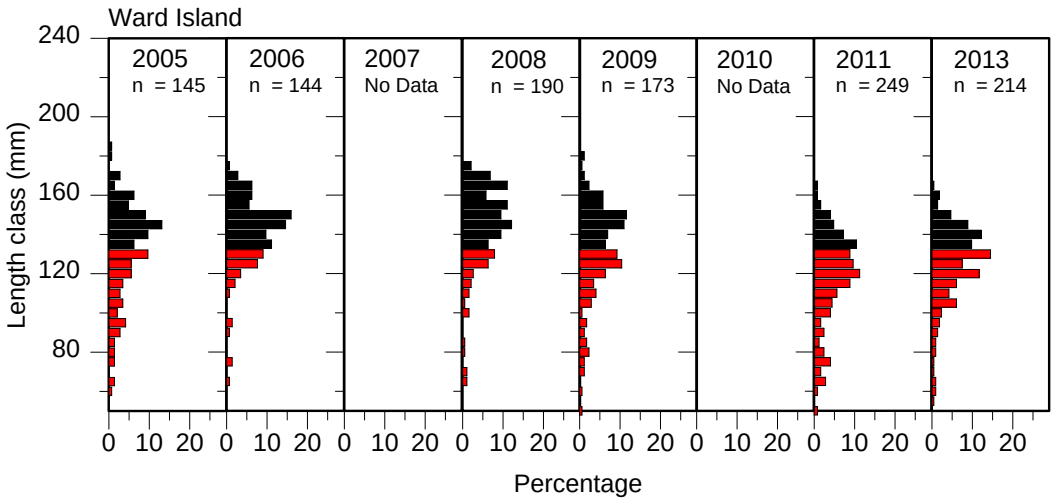

Figure 3.20. Length-frequency distributions of legal-sized (black bars) and sub-legal-sized (red bars) blacklip at Ward Island (map-code 9A) observed on fishery-independent surveys from 2005 to 2013. Length classes represent the upper length of each 5 mm bin. n = number of blacklip measured. Bin classes < 50 mm SL pooled.

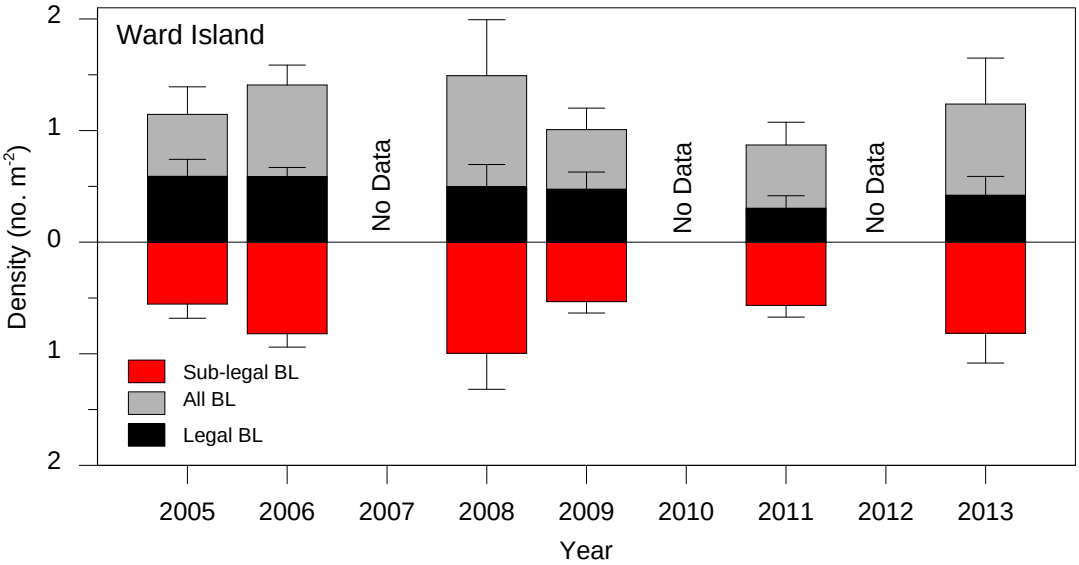

Figure 3.21. Mean density ± se (abalone.m^{-2}) of all, legal-sized and sub-legal sized (see legend) blacklip at Ward Island (cross drops; map-code 9A) from 2005 to 2013.

Reef Head (Rank 7-3; 6.3% C_{03-12})

Annual catch from Reef Head generally declined between 1983 and 2009. Catches from 2010 to 2012 were substantially greater than those caught in the previous nine years and similar to those harvested from this SAU in the early 1980s (Figure 3.22). However, CPUE has declined from the maximum level in 2005 (73 kg.hr^{-1}) and, in 2012 (54 kg.hr^{-1}) was amongst the lowest on record and 13% below $CPUE_{90-09}$. There are no FI survey data for this high-importance SAU.

Venus Bay (Rank 8-9; 6.2% C_{03-12})

Catch from Venus Bay increased considerably from 1979 to 1984, then oscillated among years up to 2003, and subsequently declined (Figure 3.22). In 2012, catch from this SAU was amongst the lowest on record (8 t), representing 3% of the blacklip catch from Region A. CPUE was relatively stable between 1989 and 2002, following which it increased to a historic high in 2006 (89 kg.hr^{-1}). Between 2006 and 2007 (70 kg.hr^{-1}), there was a large (21%) decrease in CPUE, which has subsequently stabilised at approximately 8% below $CPUE_{90-09}$. The CPUE in 2012 (71 kg.hr^{-1}) was 8% below $CPUE_{90-09}$. There are no FI survey data for this high-importance SAU.

Anxious Bay (Rank 9-5; 6.2% C_{03-12})

With the exception of a high catch in 1984, annual catches from Anxious Bay have been relatively stable among years, ranging between about 8 and 26 t.yr^{-1} (Figure 3.22). CPUE remained relatively stable between 1980 and 2000, whereafter it increased to a historic high in 2007 (81 kg.hr^{-1}) and subsequently decreased rapidly between 2007 and 2010 (52 kg.hr^{-1}). Between 2010 and 2012, the CPUE has increased and, in 2012 (67 kg.hr^{-1}), was 4% above $CPUE_{90-09}$. There are no FI survey data for this high-importance SAU.

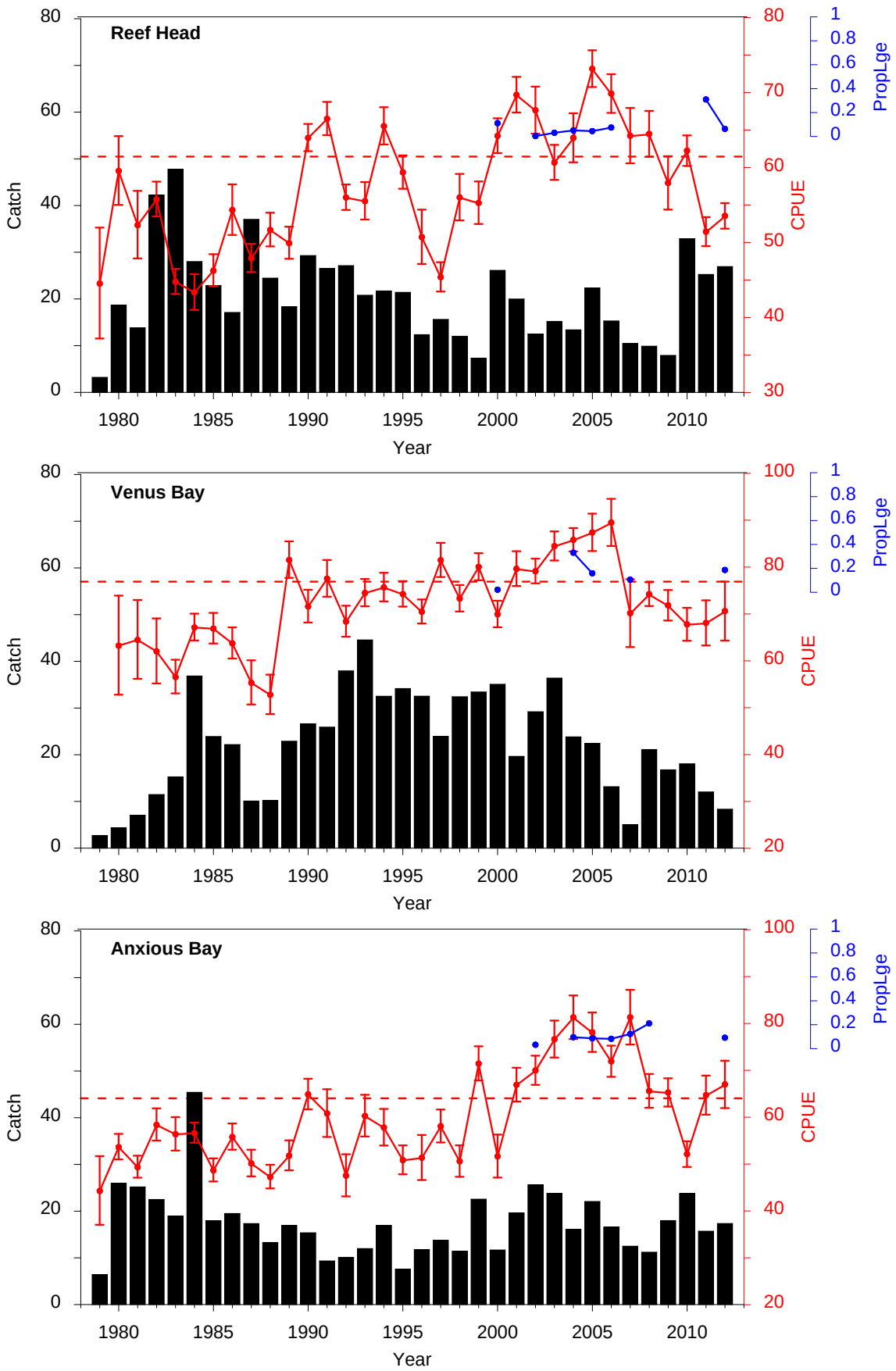

Figure 3.22. Catch (t, shell weight; black bars) of blacklip from SAUs Reef Head, Venus Bay and Anxious Bay from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90\text{-}09}$.

3.2.3. Temporal patterns in medium importance spatial assessment units

Hotspot (Rank 10-17; 5.9% C_{03-12})

Annual catch from Hotspot was relatively low until 1996, whereafter it increased considerably and ranged from about 18 to 22 t.yr^{-1} between 1997 and 2009, with a historic high of 33 t in 2005. Catch has subsequently declined and, in 2012, was at the lowest level since 1989 (2 t), representing 0.8% of the blacklip catch from Region A (Figure 3.23). CPUE has fluctuated considerably among years but has generally declined since 2005. In 2011 (57 kg.hr^{-1}), it was 5% below $CPUE_{90-09}$ and, in 2012, could not be calculated due to insufficient data.

With the exception of a very low value of 12% in 2009 and data in 2011 that were too limited for interpretation, the percentage of LARGE blacklip observed on FI surveys at Hotspot ranged from 24%-41% between 2005 and 2013 (Figure 3.24). In 2013, the percentage of LARGE blacklip was 33%. Densities of legal-sized blacklip decreased considerably from 2006 to 2008 and have remained low during subsequent surveys in 2009, 2011 and 2013 (Figure 3.25), suggesting high exploitation rates. The density of sub-legal-sized blacklip remained relatively stable between 2005 and 2009 but, in 2011, declined to the lowest level recorded since surveys began, remaining at a similarly low level in 2013.

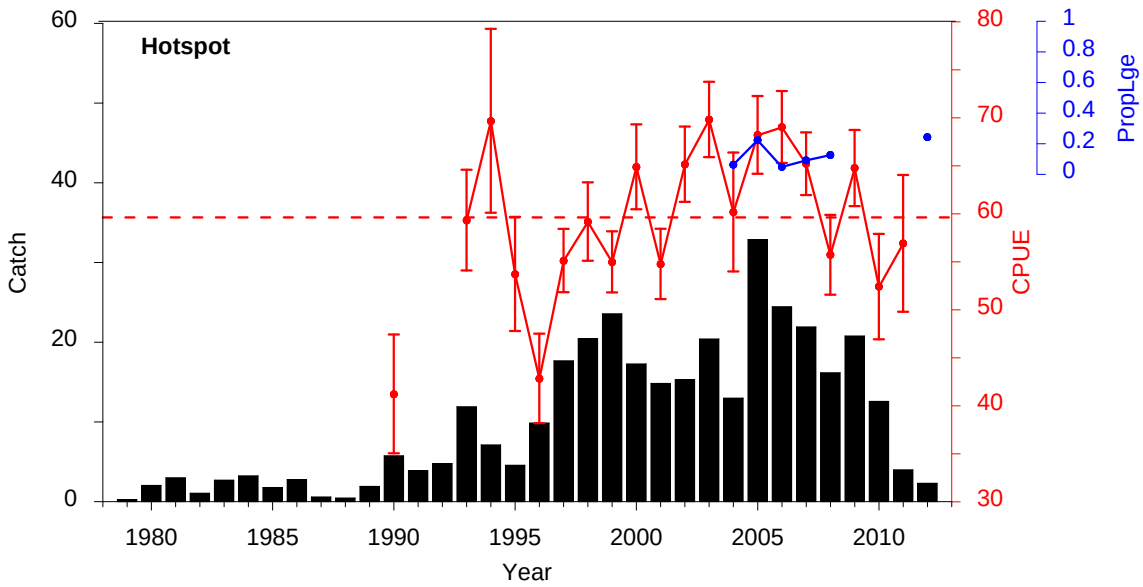

Figure 3.23. Catch (t, shell weight; black bars) of blacklip from SAUs Hotspot from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90-09}$.

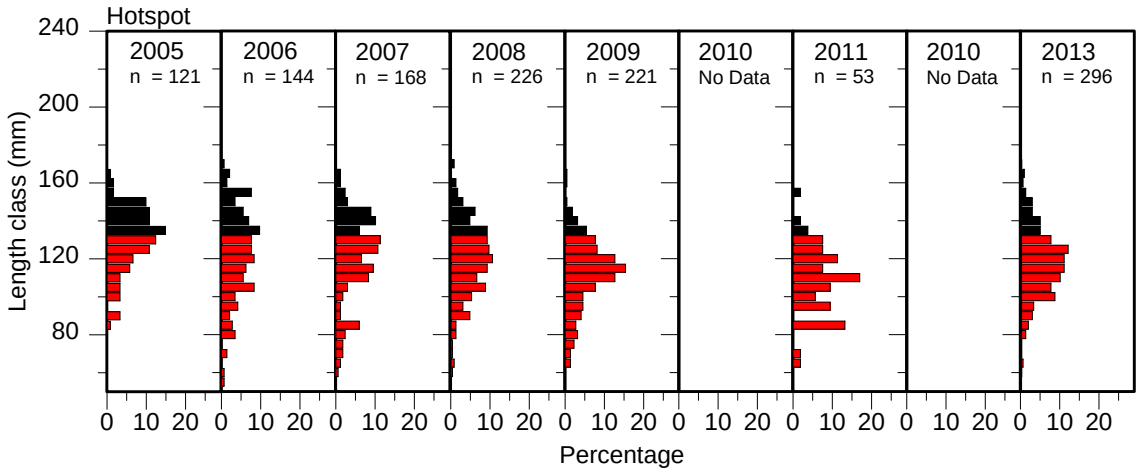

Figure 3.24. Length-frequency distributions of legal-sized (black bars) and sub-legal-sized (red bars) blacklip at Hotspot (map-code 9D) observed on fishery-independent surveys from 2005 to 2013. Length classes represent the upper length of each 5 mm bin. n = number of blacklip measured. Bin classes < 50 mm SL pooled.

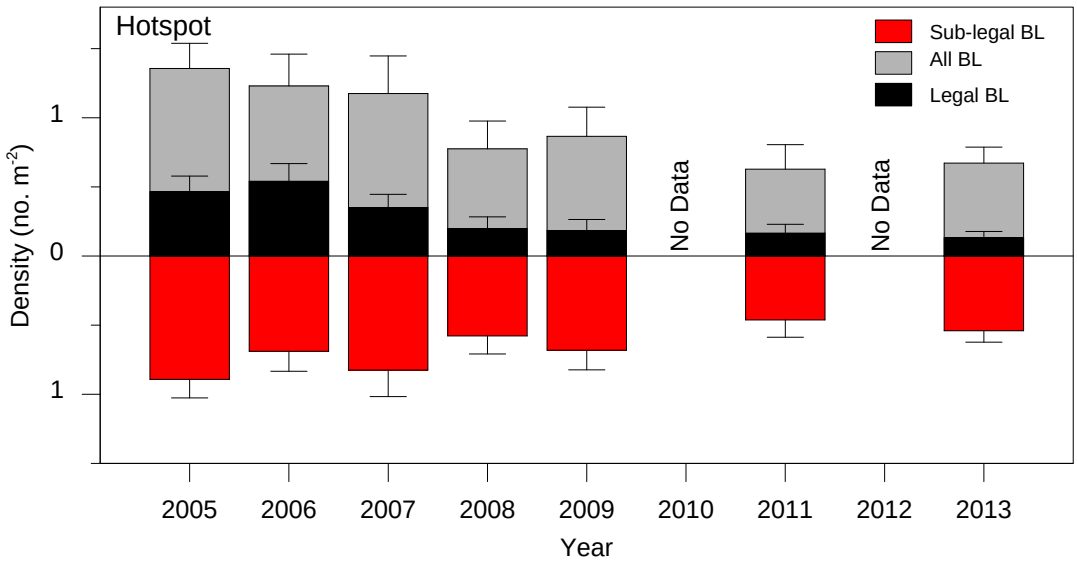

Figure 3.25. Mean density ± se (abalone.m^{-2}) of all, legal-sized and sub-legal sized (see legend) blacklip at Hotspot (cross drops; map-code 9D) from 2005 to 2013.

Point Avoid (Rank 11-8; 3.7% C_{03-12})

Annual catches from Point Avoid have been relatively stable since 1979. Catch in 2012 (10 t) was similar to C_{03-12} (11 t.yr^{-1}; Figure 3.26) and represented 4% of the blacklip catch for Region A. CPUE has fluctuated considerably among years, but gradually increased to 2006. However, over the last decade it has declined from historical peaks observed in 2003 and 2006. In 2012, CPUE (51 kg.hr^{-1}) was at the lowest level since 1999 and 18% below $CPUE_{90-09}$.

Baird Bay (Rank 12-15; 3.1% C_{03-12})

Catches from Baird Bay were stable at about 10 t.yr^{-1} between 1982 and 2005, whereafter they have declined progressively. In 2012, the catch (3 t) from this SAU was the lowest level since 1981 (3 t) and equated to 1% of the blacklip catch for Region A (Figure 3.26). CPUE has varied considerably among years; due to limited data, it was not estimable in 2011 or 2012.

Flinders Island (Rank 13-12; 2.8% C_{03-12})

Annual catch from Flinders Island, while variable, increased gradually between 1980 and 2001, whereafter it has declined. In 2011 and 2012, the catch from this SAU was among the lowest on record (5 t; Figure 3.26). CPUE was relatively low between 1991 and 2000 and high from 2001 to 2012. In 2012 CPUE (63 kg.hr^{-1}) was similar to $CPUE_{90-09}$.

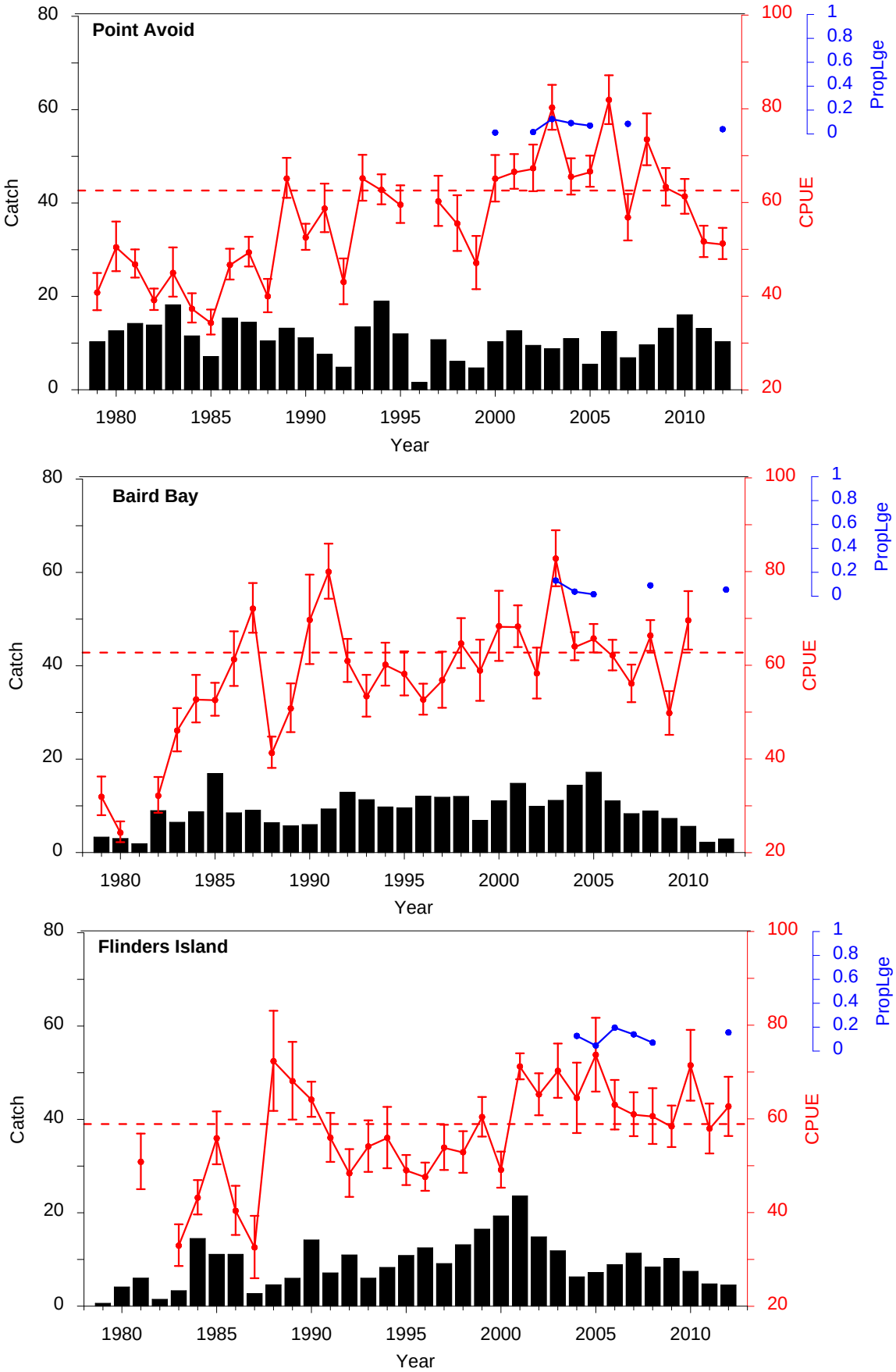

Figure 3.26. Catch (t, shell weight; black bars) of blacklip from SAUs Point Avoid, Baird Bay and Flinders Island from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Red dashed line shows $CPUE_{90\text{-}09}$.

3.3. Risk-of-overfishing in SAUs and zonal stock status

There were nine high and four medium importance SAUs for blacklip in Region A in 2012, with all remaining SAUs being of low importance (Table 3.1, Appendix A3.1–A3.12). It was possible to determine the risk of being overfished for 11 (85%) of these 13 SAUs. The inability to estimate CPUE on blacklip in two medium importance SAUs in 2012 (Hotspot and Baird Bay), due to insufficient data, resulted in the blacklip stocks in these SAUs being categorised as uncertain (Table 3.1; Appendix A3.10).

Summed PI scores ranged between -15 (Ward Island) and +2 (Drummond and Reef Head; Table 3.1). Five of the nine high-importance SAUs (Drummond, Sheringa, Searcy Bay, Reef Head and Anxious Bay) were assigned to a green, one (Avoid Bay) to a yellow, and three to a red (Point Westall, Ward Island and Venus Bay) risk-of-overfishing category (Table 3.1; Appendix A.3). The two assessable medium importance SAUs were both assigned a yellow risk-of-overfishing category (Point Avoid and Flinders Island). Low importance SAUs were not assessed against the PIs. The catch-weighted, zonal score was -0.414, defining a zonal stock status for blacklip in Region A of sustainably fished (Table 3.1).

Table 3.**1**. Outcome from application of the harvest strategy described in the Management Plan for the SAAF against the blacklip fishery in Region A of the Western Zone. Grey shading identifies the performance indicators and their respective scores. ND indicates no data.

Spatial assessment unit	%Contribution to mean total catch (WZ) over last 10 years (2003-2012)	Importance	%Contribution to catch from high & medium SAU in 2012	CPUE	%TACC	PropLge	Pre-recruit Density	Legal Density	Mortality	Combined PI score	Risk of overfishing	Catch-weighted contribution to zonal score
Drummond	7.4	High	30.0	-3	7	0	-3	-1	2	2	0	0.00
Sheringa	6.0	High	17.2	-4	2	2	-1	0	-1	-2	0	0.00
Avoid Bay	3.9	High	9.0	-2	3	-1	-2	-2	0	-4	-1	-0.09
Point Westall	3.8	High	6.6	-1	-6	-1	-3	-2	1	-12	-2	-0.13
Searcy Bay	3.8	High	6.9	0	0	1	ND	ND	ND	1	0	0.00
Ward Island	3.7	High	3.3	-4	-4	-2	0	-2	-3	-15	-2	-0.07
Reef Head	3.3	High	10.8	-4	6	0	ND	ND	ND	2	0	0.00
Venus Bay	3.3	High	3.3	-5	-6	1	ND	ND	ND	-10	-2	-0.07
Anxious Bay	3.3	High	7.0	0	1	0	ND	ND	ND	1	0	0.00
Hotspot	3.1	Medium	-	ND	-4	2	-	-	-	Uncertain	Not assigned	-
Point Avoid	2.0	Medium	4.1	-4	0	0	-	-	-	-4	-1	-0.04
Baird Bay	1.6	Medium	-	ND	-7	0	-	-	-	Uncertain	Not assigned	-
Flinders Island	1.5	Medium	1.8	0	-5	1	-	-	-	-4	-1	-0.02
The_Gap	1.0	Low		-	-	-	-	-	-	-	Not assessed	
Fishery_Bay	0.9	Low		-	-	-	-	-	-	-	Not assessed	
Cape_Bauer	0.8	Low		-	-	-	-	-	-	-	Not assessed	
Coffin_Bay	0.8	Low		-	-	-	-	-	-	-	Not assessed	
Unassigned_WZ_RG_A	0.8	Low		-	-	-	-	-	-	-	Not assessed	
Cape_Catastrophe	0.5	Low		-	-	-	-	-	-	-	Not assessed	
Elliston_Cliffs	0.5	Low		-	-	-	-	-	-	-	Not assessed	
Waterloo_Bay	0.4	Low		-	-	-	-	-	-	-	Not assessed	
Memory_Cove	0.3	Low		-	-	-	-	-	-	-	Not assessed	
SW_Thistle	0.2	Low		-	-	-	-	-	-	-	Not assessed	
Taylors_Island	0.1	Low		-	-	-	-	-	-	-	Not assessed	
NE_Thistle	0.1	Low		-	-	-	-	-	-	-	Not assessed	
Neptune_Islands	0.0	Low		-	-	-	-	-	-	-	Not assessed	
Wedge_Island	0.0	Low		-	-	-	-	-	-	-	Not assessed	
Pearson_Island	0.0	Low		-	-	-	-	-	-	-	Not assessed	
Greenly_Island	0.0	Low		-	-	-	-	-	-	-	Not assessed	
Sir_Joseph_Banks	0.0	Low		-	-	-	-	-	-	-	Not assessed	
Sum	**53.2**		**100.0**									**-0.414**

4. DISCUSSION

4.1. Information, data gaps and uncertainty in the assessment

Substantial information was available to assess the blacklip stocks in the WZ including (1) a well-documented history of the management of the fishery; (2) fine-scale, fishery-dependent, catch and effort data; (3) fishery-independent survey data for blacklip population size-frequency and density at five sites; and (4) biological data. Limited information was also available on recreational and IUU catch. In addition, this fishery assessment report for Region A provides a quantitative measure of fishery status via the harvest strategy, based on an integrated suite of performance indicators within a risk analysis framework, in accordance with the Management Plan (PIRSA 2012). In 2012, application of the harvest strategy to determine stock status was based on 13 SAUs distributed throughout the fishery, thus better representing the fished stocks when compared with other zones that rely on fewer SAUs for the assessment (e.g. Blacklip in the Central Zone abalone fishery; Chick and Mayfield 2012).

There were, however, several limitations to this assessment. First, there were no FI survey data for four (Venus Bay, Anxious Bay, Searcy Bay and Reef Head) of the nine high-importance blacklip SAUs as these had not been surveyed previously. This limits application of the harvest strategy to determine the risk-of-overfishing category for these SAUs to FD data and, consequently, reduces the available information for determining overall stock status. Data from future FI surveys in these SAUs will overcome this limitation.

Second, decision rules are applied to the data and designed to exclude outliers from analyses and ensure minimum data standards are applied. In the case of CPUE, decision rules are also used to enable its estimation from data which does not distinguish between effort apportioned to the harvest of blacklip and greenlip within a fishing day. Different methods of estimating CPUE have been examined by Burch *et al.* (2011) who showed that temporal trends in CPUE obtained across methods were highly correlated. While the previous decision rules were sufficiently robust for assessment of the stocks in Region A (Stobart *et al.* 2011), Burch *et al.* (2011) recommended that a catch-weighted mean of daily CPUE would be more appropriate to estimate CPUE as it (1) weights each daily catch and effort record objectively; (2) removes the need to subjectively ‘subset’ the data; and (3) can be applied consistently to greenlip and blacklip abalone at multiple spatial scales across the fishery. As a result of these recommendations, catch-weighted mean daily CPUE has been adopted as the standard method for estimation of this statistic since 2012 (Stobart *et al.* 2012b).

Third, while analyses of the catch and effort data provide useful information on the spatial and temporal distribution of catch within individual fishing areas (Chick *et al.* 2006; 2008; Mayfield and Saunders 2008; Mayfield *et al.* 2009), interpreting these patterns is complicated because fishers may move among areas to maintain, or increase, their expected levels of catch for a range of plausible reasons. These could include technological changes in the fishing fleet (e.g. trends to larger or smaller vessels, increased use of motorised dive cages) that may restrict or increase the number of access points along the coast, increasing fishing efficiency (effort creep), market demands for particular product types (e.g. smaller or larger size abalone), changes in diver demographics, diver preference and habit, convenience, rotation of fishing grounds by divers and changes in abalone abundance. Therefore, while we use CPUE to assess stock status, based on the assumption that changes in this measure reflect changes in the relative abundance of the fishable stock (Tarbath *et al.* 2005), we note CPUE can be strongly influenced by numerous factors which may be unrelated to, or lag, changes in abundance. Consequently this measure is often viewed as a biased index of relative abundance (Harrison 1983; Breen 1992; Prince and Shepherd 1992; Gorfine *et al.* 2002). For example, catch rates may remain high as a result of re-aggregation of abalone or improved knowledge of fishing areas by fishers, thereby masking fluctuations in population size arising from local depletion (Officer *et al.* 2001). This is likely because catch rates in dive fisheries can be hyperstable as a result of divers targeting remnant aggregations (Shepherd and Rodda 2001; Dowling *et al.* 2004). For greenlip, there is some evidence that catch rates are decreasing at a slower rate than the legal-sized biomass in Region A of the WZ (Stobart *et al.* 2012b) and in the CZ (Chick and Mayfield 2012). This indicates that catch rates on greenlip in these two fisheries exhibit hyperstability. If catch rates on blacklip in the WZ are similarly hyperstable, declines in CPUE will be smaller than those of the harvested stocks. The relationship between relative abundance and CPUE is also not likely to be consistent over time as factors influencing CPUE vary among years (e.g. effort creep and changes in market demand). However, decreases in CPUE in abalone fisheries are generally considered to be a reliable indicator of declines in abalone abundance, particularly where effort is consistently applied (Tarbath *et al.* 2005).

Fourth, we were unable to use length-frequency data to determine temporal changes in the length structure and mean length of the commercial catch in the blacklip fishery through time in a way similar to that employed in Tasmania (Tarbath and Gardner 2011) and previously in NSW (Andrew and Chen 1997). This was because interpreting the length-frequency data in this assessment was complicated by the limited degree to which

the available data are considered representative of either the stocks or the fishery. The lack of robust, representative, commercial, length-frequency data increases the uncertainty in the assessment of stock status (Burch *et al.* 2010). This difficulty could be overcome by measuring five abalone from each catch bag on 70% of fishing days (Burch *et al.* 2010).

Finally, the accuracy and precision of estimates of IUU catches are unknown, difficult to estimate and may change over time if the level of fisheries enforcement is not constant. This prevents reliable estimates of the total catch and, hence, impedes this assessment. Development of alternative methods for estimation of IUU extractions may reduce this uncertainty. Similarly, recreational catch is unknown, although it is estimated to be very low in the WZ (Section 1.2.2).

4.2. Status of blacklip in Region A

Blacklip comprises 57% (276 $t.yr^{-1}$) of the combined abalone TACC (i.e. blacklip and greenlip) in Region A. Total annual catch has been relatively stable since 1989, but the TACC was reduced by 6% from 2010 (293.3 t to 276 t) and a further 5% from 2013 (276 t to 262.2 t) following concern for the stock.

Previous reports used CPUE data as evidence that the abundance of legal-sized blacklip increased rapidly between 2000 and 2006 (Chick *et al.* 2006; 2008) then declined sharply from 2006 to 2009 (Chick *et al.* 2009). These recent, spatially-consistent, rapid increases and decreases in CPUE between the early 2000s and the present are most likely the result of a widespread, strong recruitment pulse in the mid-1990s that elevated the abundance of legal-sized blacklip 6-10 years later (Stobart *et al.* 2011; 2012b). Similar trends were also evident during the same period on greenlip in the WZ (Stobart *et al.* 2012b) and the Central Zone of the SAAF (Mayfield *et al.* 2010), with long-term FI data for greenlip providing some evidence of elevated recruitment in the mid-late 1990s (Stobart *et al.* 2012b).

Data presented in the previous report (Stobart *et al.* 2012b) suggested that the rapid reductions in blacklip abundance observed between 2006 and 2009 in Region A had almost stopped because the CPUEs for Region A in 2009, 2010 and 2011, the principal relative index of blacklip abalone abundance, were similar. However, there was a small decline in CPUE between 2010 and 2011 (2%) which doubled between 2011 and 2012 (4%), suggesting the reductions in harvestable biomass have not abated. The CPUE in 2012 was the lowest since 1996. Furthermore, while the estimate of CPUE in 2012 was equivalent to that in the late 1990s before the likely recruitment pulse, catch rates on abalone are prone to hyperstability (Shepherd and Rodda 2001; Dowling *et al.* 2004;

Stobart *et al.* 2012b) and thus the harvestable biomass of legal-sized blacklip in 2012 is likely to be below that in the late 1990s.

Declining harvestable biomass over recent years is consistent with the reduction in the zonal stock status value for blacklip between 2011 (-0.083) and 2012 (-0.414). Although the stock in 2012 was categorised as sustainably fished, the 2012 value was close to the upper limit of the overfished category (≤ -0.5). This was similar to the conclusion of the weight-of-evidence assessment and indicates that the harvestable biomass is decreasing in most key blacklip fishing grounds. This trend is likely to continue unless the exploitation rate is reduced or catches can be re-distributed away from traditional and into alternative fishing grounds without compromising the stocks in those areas. Consideration of spatial and/or temporal management arrangements, including catch caps, varying MLLs and closed seasons (Stobart *et al*. in review), may also warrant consideration. The evidence supporting this assertion includes (1) recent, re-distribution of the blacklip catch among traditionally fished SAUs, with decreases at Ward Island and Hotspot and increases at other traditionally fished SAUs (Drummond, Sheringa, Avoid Bay and Reef Head) in which CPUE is also currently low and/or declining relative to $CPUE_{90\text{-}09}$; and (2) long-term reductions in CPUE and estimates of density from FI surveys in most key fishing grounds.

The recent changes to the spatial distribution of blacklip catch among SAUs were clearly evident using the MDS ordination technique, which indicated that the fishery has transitioned from a decade of relative stability between 1993 and 2009. The primary drivers of these changes were the substantial decrease in catch from Ward Island and Hotspot from 2009 to 2011, and significant increases from Drummond, Reef Head and Sheringa during the same period. The transition from a broad distribution of catch between SAUs for the period 1993 to 2009 to fewer SAUs from 2010 to 2012 indicates an apparent reliance on the Drummond, Reef Head and Sheringa fishing grounds in recent years. However, while analyses of catch using methods such as MDS and bubble plots yields valuable information for fishery assessment, these methods do not identify the causes of changing patterns. These recent changes in the spatial distribution of catch are most likely due to declines in the harvestable biomass of blacklip in several SAUs (Stobart *et al.* 2012b), forcing divers to harvest from fishing grounds in remaining SAUs. However, the apparent dependence on Drummond, Reef Head and Sheringa may reflect a preference for fishing grounds closer to Port Lincoln (lower fishing costs given recent, reduced profitability) rather than a zone-wide contraction in harvestable biomass.

For Ward Island, the weight-of-evidence conclusion that the harvestable biomass has declined was consistent with the outcome from the harvest strategy, which was a 'red'

risk-of-overfishing category. This indicates that there is a high probability that the stocks in this SAU are overfished. Application of the harvest-decision rules to a 'red' risk-of-overfishing category specifies a minimum 30% reduction in the catch contribution from this SAU to the TACC, based on the mean catch over the last four years (i.e. 2009-2012). If this decision rule was implemented, the catch contribution from the Ward Island SAU (15.7 t) to the blacklip TACC for Region A would be reduced by >5 t to 11 t. However, as the CPUE on blacklip in this SAU in 2012 remained among the lowest on record and the combined PI score declined from -9 in 2011 to -15 in 2012, a reduction of more than 30% may be warranted. For Hotspot, the harvest strategy resulted in blacklip stocks in this SAU being categorised as ‘uncertain’ due to the lack of CPUE data in 2012. Although the lack of a CPUE estimate for 2012 also hinders the weight-of-evidence assessment, the low number of fishing days which resulted in the CPUE not being estimated and the FI survey density at this SAU remaining low in 2013, suggest that a decrease in catch contribution from this SAU to the TACC is also appropriate.

In response to declining catches from Ward Island and Hotspot, catches from the Drummond, Sheringa and Reef Head SAUs have increased substantially over the last 2-3 years, whilst that from Avoid Bay rose modestly. However, much of the evidence available for these four SAUs suggests that the current higher catches may not be sustainable. For example, the CPUE in 2012 in each of these SAUs was 16%, 8%, 13% and 15% below $CPUE_{90\text{-}09}$, respectively. Furthermore, there was also no evidence that the rate of decline in CPUE at Drummond, the blacklip SAU with the highest catch contribution in Region A (14% $C_{03\text{-}12}$), was slowing.

These outcomes contrast with those from applying the harvest strategy to the blacklip stocks in the Drummond, Sheringa and Reef Head SAUs (‘green’ risk-of-overfishing category). For the Drummond and Reef Head SAUs, their ‘green’ risk-of-overfishing category score was most strongly positively influenced by the PI value for catch as a percentage of the TACC, while the score and category for Sheringa were equally effected by the PI value for catch and PropLge. Application of the harvest strategy decision rules to SAUs with ‘green' risk-of-overfishing category permits an increase or decrease in their catch contribution to the TACC of up to 10% of their mean catch over the last four years. Given that (1) the CPUE in 2012 was below $CPUE_{90\text{-}09}$ for all of these SAUs; (2) the risk-of-overfishing category changed from blue in 2011 to green in 2012; and (3) CPUE declined substantially at Drummond from 2011 to 2012, an increased catch contribution to the TACC from these SAUs would be difficult to support.

For Avoid Bay, the weight-of-evidence assessment was consistent with the outcome of the harvest strategy, i.e. a ‘yellow’ risk-of-overfishing category, for which the specified

decrease in contribution from this SAU to the TACC of more than 10% appears justified. Decreases in catch contribution would also be justified for Venus Bay and Point Westall, which were assigned a 'red' risk-of-overfishing category and Point Avoid which was assigned a 'yellow' risk-of-overfishing category. Flinders Island was also assigned a 'yellow' risk-of-overfishing category due to lower catch between 2010 and 2012, and thus at least a greater than 10% reduction in contribution is required for this SAU. However the CPUE in 2012 was above $CPUE_{90\text{-}09}$ suggesting the current catch from this SAU is sustainable.

The previous stock assessment report for Region A (Stobart *et al.* 2012b) identified three SAUs (Searcy Bay, Point Westall and Baird Bay) from which it may have been possible to harvest additional catches because current catches were low in a historical context and/or CPUEs remained substantially above $CPUE_{90\text{-}09}$. However, the density of legal-sized blacklip has halved at Point Westall between surveys in 2009 and 2013 and CPUE has decreased at both Point Westall and Searcy Bay between 2011 and 2012, suggesting additional harvest from these SAUs would no longer be justifiable. In contrast, it may still be possible to obtain additional blacklip catches from the Baird Bay SAU as, although the lack of data prevented allocation of a risk-of-overfishing category in both 2011 and 2012, the CPUE in this SAU in 2010 was above $CPUE_{90\text{-}09}$ and catches have remained low. However, the recent voluntary cessation of fishing in this SAU due to the detection of *Perkinsus* may also now exclude this option. Higher catch contributions to the TACC, however, could be considered for several low importance SAUs, particularly The Gap, SW Thistle and Taylor Island, which historically have provided higher catches, though the necessity to land blacklip in the shell from these areas, due to the prevalence of *Perkinsus*, may make this a less suitable option for fishers. This may require spatial management, on either a voluntary or regulated basis, to ensure catches are obtained from the SAUs for which higher catches are allocated.

The continuing decline in CPUE across Region A and in the individual SAUs, and the decrease in overall stock status value, suggest that the harvestable biomass of blacklip in Region A has most likely not stabilised in response to the 6% TACC reduction from 2010 to 2012. Based on the preliminary 2012 data, provided to PIRSA Fisheries and Aquaculture and Industry in November 2012, the TACC was pre-emptively reduced by 5% from 2013. This equates to a total TACC reduction of 11% resulting in the lowest catch since 1996. While a 10% reduction to the TACC in the Eastern Zone of Tasmania led to an increase in CPUE (Tarbath and Gardner 2012), the 11% reduction on blacklip in Region A may be insufficient to arrest and reverse the decrease in harvestable biomass because experience from other abalone fisheries suggests small reductions

may be inadequate to reverse declining abundance. For example, a recent 33% reduction in the Western Zone Region B TACC did not arrest falling CPUE, prompting a further reduction in 2012 (Stobart *et al.* 2012a). Similarly a reduction of ~50% was required in New South Wales between 2002 and 2005 to reverse a downward trend in CPUE (TAC Committee 2012). Other factors may also be reducing the effectiveness of TACC controls, including lower recent recruitment and IUU fishing. FI survey estimates of pre-recruit numbers have decreased in recent years at Sheringa, Hotspot and Avoid Bay, but not at Drummond, Granites and Ward Island, suggesting that declines in recruitment are not widespread. In contrast, estimates reported of IUU extractions have increased substantially from 2% in 2006 (Chick *et al.* 2006) to 8% in 2011 (Stobart *et al.* 2012b) and 11% in 2012 (Section 1.2.3). If this information is accurate, IUU fishing will be contributing to reductions in harvestable biomass. However, the reliability of the information available is unknown as many information reports cannot be validated.

In summary, there is strong evidence that the harvestable biomass of blacklip in Region A has declined substantially over recent years, is likely to be lower than that observed in the late 1990s, prior to an extended period of elevated blacklip abundance, and may not be able to support the current TACC. The evidence supporting this assertion includes low and declining CPUE across region A and in many SAUs. This includes those SAUs from which most of the blacklip catch has been harvested over recent years. Increases in catch from several of these SAUs have occurred in conjunction with reductions in CPUE. These increases in catch have likely occurred because blacklip abundance in some traditionally important fishing grounds has declined substantially since 2009. Notably, six of the 13 high or medium importance SAUs assessed in this report had a ‘red’ or ‘yellow’ risk-of-overfishing category and the zonal stock status value has declined substantially between 2011 and 2012. In 2012, it was -0.414, which only marginally exceeds the upper bound value of the overfished zonal stock status category. Whilst the TACC has been reduced by 11% since 2010, it is unclear whether this reduction will be adequate to arrest the ongoing declines and facilitate stock rebuilding. Consequently, additional management measures for this fishery may warrant consideration. These could include (1) lowering the TACC or introducing closed seasons to reduce the exploitation rate, (2) redistributing catches into non-traditional fishing grounds without compromising the stocks in those areas, and/or (3) spatial management, including catch caps and varying MLLs, as recently implemented in the Southern Zone. Ongoing monitoring, stock assessment and objective application of the harvest strategy will be crucial for (1) evaluating the sustainability of current catches in key SAUs, particularly those where catch has recently increased as CPUE decreased; (2) documenting changes in abalone

abundance at SAUs such as Ward Island and Hotspot from which current catches are among the lowest on record; and (3) assessing the suitability of the current and future TACCs.

4.3. Harvest strategy for the Region A abalone fishery

There were several difficulties with implementation of the harvest strategy for blacklip in Region A. First, there were several problems associated with the PI related to catch because, to avoid TACC changes driving positive or negative scores for catch, the PI for catch was selected as the proportion of the TACC harvested from that SAU. This means that SAUs from which recent, unusually high proportions of the TACC were harvested were allocated positive scores which can substantially influence the total score for that SAU. For example, in this assessment, scores of 7 and -3 were assigned for the catch and CPUE PIs, respectively, for blacklip in the Drummond SAU, which resulted in a total score of 2 and a 'green' risk-of-overfishing category. This was a more optimistic interpretation of stock status in this SAU than was derived through the weight-of-evidence assessment. The same problems were also evident for blacklip in the Reef Head and, to a lesser extent, Sheringa SAUs. There are several possible solutions to this problem including; (1) weighting the PIs, with higher weighting allocated to CPUE and FI survey abundance; (2) allocating negative scores when the proportion of the TACC harvested from an SAU exceeds the upper target reference point or upper limit reference point; (3) using supplementary decision rules that prevent an increase in catch contribution to future TACCs when the score for CPUE is negative; and (4) scoring the catch PI consistently with the CPUE PI (or on the cumulative scores of remaining PIs). Thus, where the CPUE PI is scored positively (≥ 0), high proportions of the TACC (i.e. PI for catch) would similarly receive positive scores (Stobart *et al.* 2012b).

Second, there are a range of complexities associated with the use of PropLge as one of the three FD PIs in the harvest strategy, suggesting the use of this PI should be carefully evaluated when the harvest strategy is next reviewed. One of the primary limitations is the degree to which the commercial catch sampling data, used for determining PropLge, are representative of the fished stocks and the fishery (e.g. differences in fishing practices and knowledge between divers may strongly influence estimates of PropLge). For example, sampling was sporadic from 1999 to 2011 and limited to a few days and licence holders. Even in 2012, which had the most representative sampling to date, measurements were only provided from 21% of fishing days and approximately 50% of licences, thus falling below the minimums of sampling requirements identified by Burch *et al.* (2010; five blacklip from every catch-bag on at least 70% of fishing days). Thus, the available data are not readily comparable among years which make interpreting temporal

trends difficult. Furthermore, estimates of PropLge may also be influenced by external factors such as a change in market demand towards large or small abalone which would result in changes to the value of the PI that would not reflect a change in stock status.

This highlights the need for appropriate decision rules defining the inclusion of data and related levels of sampling. The current rule, which requires a minimum of 100 shells per high and medium importance SAU (Table A3.1), is not adequate. While Burch *et al*. (2010) identified that more than 70% of fishing days need to be sampled, it is also critical that a high proportion of licences (e.g. 80%) contribute data. Even if sampling conformed to this requirement it would still be necessary to (1) evaluate the suitability of the historical data in generating reference points for this performance indicator, and (2) review the lower limit reference point because from years when no measured abalone were large, the lower limit reference point will be zero. Thus the minimum score in any one year will become -1. One solution to this problem may be to exclude such years from the setting of reference points. If these conditions are unachievable then it may be necessary to identify an alternative PI when the management plan is reviewed. One option would be for blacklip to be graded to the same standard as greenlip (Mayfield 2010).

Finally, there were no FI survey data for blacklip in four high-importance SAUs: Venus Bay, Anxious Bay, Searcy Bay and Reef Head. Thus, for these SAUs, application of the harvest strategy to determine the risk-of-overfishing category relied on FD data only. This reduced the information available for categorising the risk that the stocks in these five SAUs are overfished and, subsequently, the overall stock status. To overcome this limitation, FI surveys are planned for the Reef Head, Venus Bay, Anxious Bay and Searcy Bay SAUs in coming years (see Section 4.4).

4.4. Future research needs

The most pressing need for this fishery is to evaluate the effectiveness of the new harvest strategy. This should include identifying limitations and potential improvements to inform the pending review of the management plan, ongoing comparison between the weight-of-evidence approach and the outputs from the harvest strategy and testing the performance of the harvest strategy using a management strategy evaluation procedure. The formal review should also be used to link the harvest strategy more closely with the national fishery status reporting framework (Flood *et al.* 2012).

Identification and testing of a process to formally include industry information into the application of the harvest decision rules for determining TACCs is also a key research need. This is because (1) changes in the value of PIs through time may not be directly

related to stock status and their interpretation can be informed by credible, structured information (e.g. market demand, weather patterns, changing diver demography); and (2) abalone divers directly observe abalone stocks through their harvesting process. The latter is different to nearly all other fisheries where fishers typically use fishing methods (e.g. traps, nets, lines) that do not readily facilitate direct observations on the distribution, abundance and population structure of the target species.

The FI survey program for blacklip in Region A should also be reviewed. This review should include (1) optimising their benefit to the harvest strategy and weight of evidence assessments; (2) survey continuity; and (3) a cost-benefit analysis. Amongst others, this could be achieved by re-evaluating the criteria for identifying survey sites and optimising the number of sites to maximise survey reliability. For example, consideration should be given to continuing FI surveys in medium-importance SAUs with a long series of survey data such as Hotspot, as cessation of surveys diminishes the value of invested effort in that SAU. Similarly, the relative cost-benefit of establishing FI surveys in high-importance SAUs that have not previously been surveyed needs to be evaluated as several years of data are required before the information obtained can be used for assessment of the fishery. The outcomes from the review could be incorporated in the revised management plan for the fishery.

Assessment of abalone in the WZ would also benefit from (1) analysing external influences (e.g. diver, dive location, month, and loss of access) on CPUE through standardisation; (2) improved estimates of the magnitude and trends in IUU catch; (3) assessment of direct and indirect effects of commercial harvest on the ecosystem; and (4) obtaining information on abalone population age structures. Supplementing current data for assessment of stock status with population age structures would enhance interpretation of the patterns in the length-frequency distributions of the commercial catches. While these data can be obtained from stable oxygen isotope analyses (Gurney *et al.* 2005), research effort should be directed towards exploring the relationships between telomere length and age as this is a considerably cheaper analytical technique (Dr Craig Mundy, University of Tasmania, personal communication).

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6. APPENDIX

A.1 BLACKLIP BIOLOGY

Table A1.1. Size at L_{50} (mm, shell length) for blacklip at different sites in the Western Zone. Parameters (a and b) describe the proportion of mature blacklip. The equation is of the form $f(x) = a/(1+\exp(-(x-L_{50})/b)$. N = total number sampled, n = number of abalone sampled within period of maturity transition.

Site	Year	Month	a	b	L_{50}	*N*	n	Reference
Anxious Bay	2013	5	0.9947	4.67	88.1	150	60	SARDI unpublished
Avoid Bay	2012	7	0.9867	0.892	92.0	108	16	SARDI unpublished
Hotspot	2004	5	1.0042	7.495	82.3	124	31	SARDI unpublished
Hotspot	2005	5	1.0094	5.359	94.3	192	32	SARDI unpublished
Reef Head	2001	5	0.9979	6.784	87.7	189	126	SARDI unpublished
Pt Drummond	2011	6	0.9923	6.253	99.3	222	102	SARDI unpublished
Sheringa	2004	5	1.0022	5.369	97.3	130	46	SARDI unpublished
Tungketta	2004	5	0.9942	8.135	103.0	88	37	SARDI unpublished
Ward Island	2001	5	1.0353	10.720	92.0	65	36	SARDI unpublished
Ward Island	2005	5	1.0000	0.333	91.8	145	7	SARDI unpublished
West Bay	2001	6	0.9917	7.040	96.1	222	185	SARDI unpublished

Table A1.2. Relationships between shell length (SL, mm) and fecundity (F, millions of eggs) for legal sized (130 mm SL) blacklip at different sites in the Western Zone. The equation is of the form $F = aSL^b$. * indicates calculations based on anterior counts only.

Site	Year	a	b	r	n	SL	F	Reference
Avoid Bay	2010	1.01E+01	2.46	0.49	15	130	1.60E+06	SARDI unpublished
Hotspot*	2005	2.00E-04	4.58	0.83	22	130	9.47E+05	SARDI unpublished
Point Drummond	2011	2.07E-02	3.59	0.70	20	130	8.07E+05	SARDI unpublished
Ward Island*	2005	1.87E-01	3.29	0.70	27	130	1.68E+06	SARDI unpublished

Table A1.3. Growth rate, k (yr^{-1}) and L_∞ (mm SL), for tagged blacklip at different sites in the Western Zone. Size ranges are shell length at time of tagging for recaptured abalone (mm), n is the number of recaptures. * indicates uncertainty over the time at liberty, therefore k and L_∞ may not represent annual growth (Geibel *et al.* 2010).

Site (Year recovered)	Year tagged	r^2	k	L_∞	Size range	n	Reference
Avoid Bay (2012)	2012	0.462	0.236	156.3	56-170	113	SARDI unpublished
Reef Head (2002)	2001	0.176	0.102	153.6	52-116	29	SARDI unpublished
Reef Head (2003)	2002	0.404	0.177	132.8	66-133	58	SARDI unpublished
Sheringa (2004)	2002	0.571	0.190	152.4	54-135	20	SARDI unpublished
Venus Bay (2002)	2001	0.448	0.295	152.7	66-124	54	SARDI unpublished
Venus Bay (2003)	2001	0.369	0.155	167.9	62-117	34	SARDI unpublished
Ward Is. (2001)	2000	0.053	0.086	217.4	57-135	27	SARDI unpublished
Ward Is. (2002)	2000	0.182	0.139	150.2	67-129	18	SARDI unpublished
Ward Is. (2002)	2001	0.244	0.180	152.5	58-117	24	SARDI unpublished
Ward Is. (2005)	2004	0.363	0.172	167.4	40-153	24	SARDI unpublished
Waterloo Bay*	1969	0.911	0.406	144.0	57-150	52	(Shepherd and Hearn 1983)
West Bay (2001)	2000	0.078	0.078	244.0	59-127	53	SARDI unpublished

Table A1.4. Relationships between shell length (SL, mm) and total weight (TW, g) of blacklip abalone at various sites in the Western Zone. TW is calculated total weight for 130 mm legal-sized blacklip. The equation is of the form $TW = aSL^b$.

Site	Year	a	b	TW	r	n	Reference
Avoid Bay	2012	3.0E-04	2.90	405	0.95	204	SARDI unpublished
Flinders Island	1998	6.7E-05	3.16	321	0.95	85	SARDI unpublished
Hotspot	2004	7.1E-05	3.19	391	0.98	124	SARDI unpublished
Hotspot	2005	3.0E-04	2.90	399	0.98	192	SARDI unpublished
Kiana	1999	3.2E-02	1.93	378	0.73	46	SARDI unpublished
Drummond Point	1998	6.2E-05	3.21	370	0.94	54	SARDI unpublished
Drummond Point	2011	6.4E-05	3.20	377	0.98	222	SARDI unpublished
Point Labatt	1999	1.4E-03	2.58	396	0.85	102	SARDI unpublished
Point Whidbey	1998	4.9E-05	3.26	387	0.97	49	SARDI unpublished
Price Island	1999	5.3E-04	2.75	345	0.83	50	SARDI unpublished
Reef Head	1999	1.1E-02	2.16	411	0.79	44	SARDI unpublished
Reef Head	2004	6.0E-04	2.72	345	0.94	63	SARDI unpublished
Sheringa	2004	2.0E-05	3.44	379	0.98	130	SARDI unpublished
Smoothpool	1999	6.0E-04	2.72	340	0.92	127	SARDI unpublished
Tungketta	2004	9.8E-05	3.12	395	0.98	88	SARDI unpublished
Waldegrave Island	1998	1.0E-04	3.05	274	0.94	100	SARDI unpublished
Waldegrave Island	2005	1.0E-04	3.06	294	0.98	94	SARDI unpublished
Waterloo Bay	2005	5.0E-04	2.77	362	0.94	162	SARDI unpublished
Ward Island	1998	3.0E-04	2.90	399	0.92	100	SARDI unpublished
Ward Island	2005	3.0E-04	2.86	329	0.98	145	SARDI unpublished
West Bay	1998	2.0E-04	2.94	331	0.95	99	SARDI unpublished
West Bay	1999	7.0E-04	2.72	386	0.89	99	SARDI unpublished

A.2 CATCH AND CPUE IN FISHING AREAS

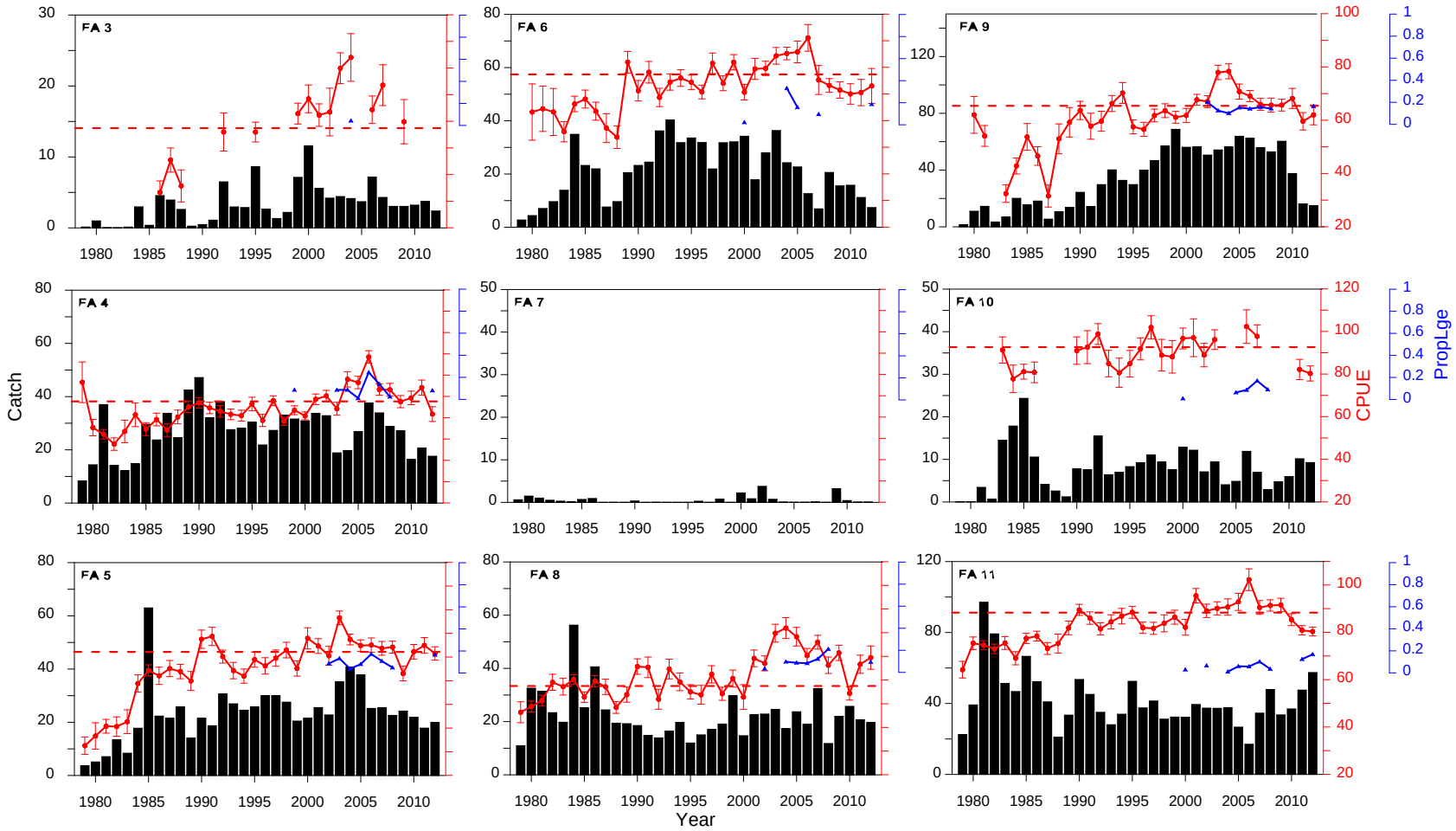

Figure A2.1. Catch (t, shell weight; black bars) of blacklip from FA 3 to FA 11 from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Where applicable, red dashed lines show $CPUE_{90\text{-}09}$. Note catch scales vary among graphs.

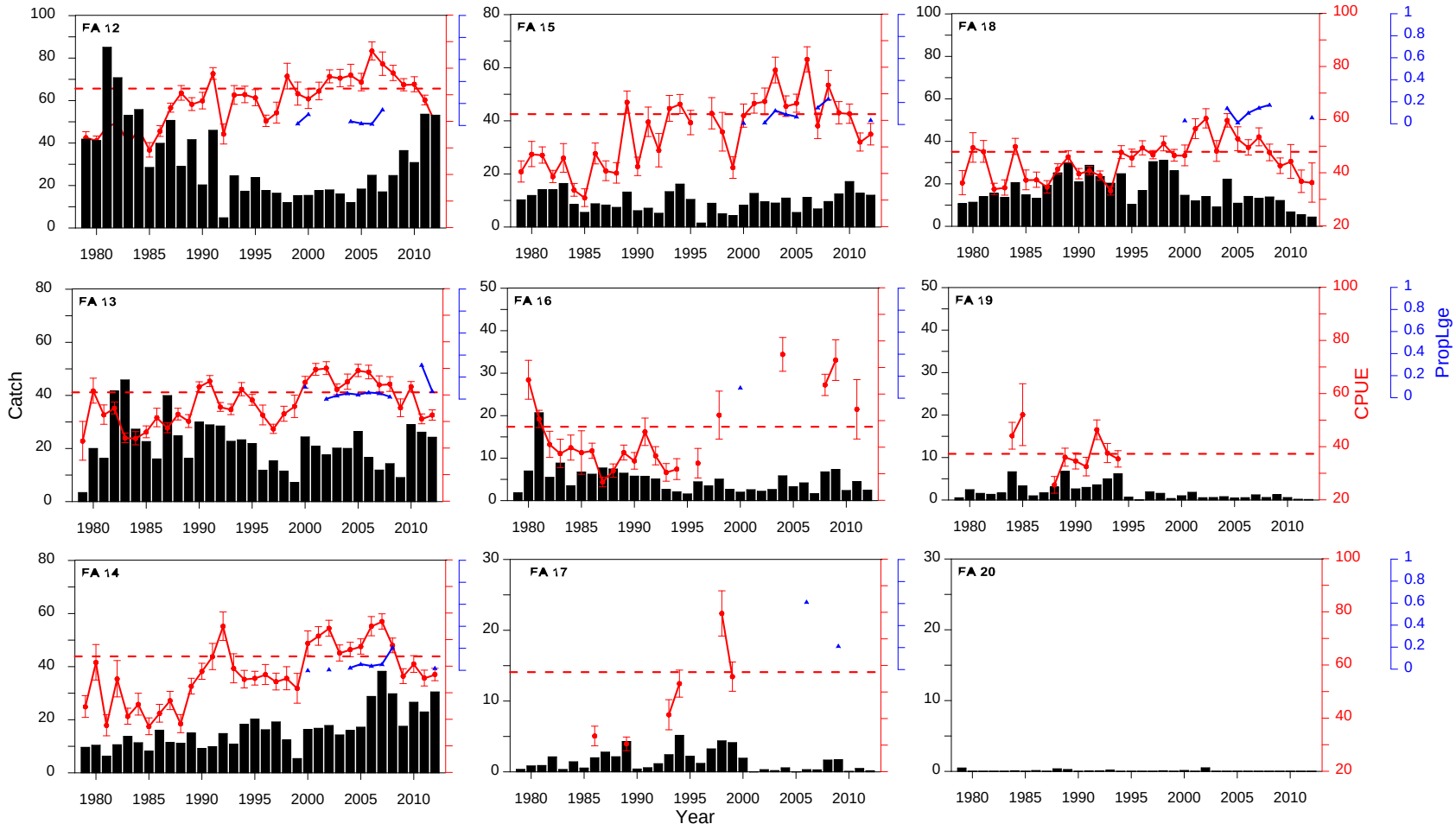

Figure A2.2. Catch (t, shell weight; black bars) of blacklip from FA 12 to FA 20 from 1979 to 2012. CPUE ± se (kg.hr^{-1}) and PropLge are shown in red and blue, respectively. Where applicable, red dashed lines show $CPUE_{90\text{-}09}$. Note catch scales vary among graphs.

A.3 BLACKLIP PERFORMANCE INDICATORS

Table A3.1. Summary of the PIs and the formulae and data constraints underpinning their utilisation in the harvest strategy.

Performance indicator	Description	Formulae	Data constraints
Catch	Total catch, expressed as a percentage of the combined TACC	$\text{Catch} = \frac{\sum \text{Species Catch (t)}}{\text{TACC}}.$	None
Proportion large (blacklip) or Proportion Grade 1 (greenlip)	Proportion of large (or Grade 1) abalone in the commercial catch	$\text{PropLge} = \frac{\text{N Large}}{\text{Total N}},$ or $\text{PropG1} = \frac{\sum \text{Grade 1 Meats (kg)}}{\sum \text{Meats (kg)}}.$	All measurements >5 mm SL below the MLL excluded; Minimum sample size (N): 100 measurements Blacklip >165 mm SL defined as large or All records where the total catch was >1% different from the sum of the three weight-grade categories were excluded; Records with zero catch were excluded. Minimum sample size: 10 records
CPUE	Commercial catch-per-unit effort (kg.hr^{-1})	$CPUE_{Wt} = \frac{\sum_{i=1}^{n} w_i \frac{C_{PSi}}{E_i}}{\sum_{i=1}^{n} w_i},$	All records where: total catch was >900 kg; CPUE (total catch/total effort) was >150 kg.hr^{-1}; fishing effort was >8 hr.; fishing effort was <3 hr.; the reported catch of both species was zero; or the catch of the species for which CPUE was being estimated was <30% of the total catch were excluded. Minimum sample size: 10 records
$\text{Density}_{\text{legal}}$	Density of legal-sized abalone on surveys	$\text{Density}_{\text{Legal}} = \frac{\sum \text{Legal counted}}{\text{Total area surveyed}}$	>90% of survey completed Blacklip ≥130 mm SL defined as legal-sized Greenlip ≥145 mm SL defined as legal-sized
$\text{Density}_{\text{pre-recruit}}$	Density of pre-recruit (i.e. those that will exceed MLL within ~2 yrs.) abalone on surveys	$\text{Density}_{\text{Pre-recruit}} = \frac{\sum \text{Pre-recruit counted}}{\text{Total area surveyed}}$	>90% of survey completed Blacklip 90 to <130 mm SL defined as pre-recruits Greenlip 105 to <145 mm SL defined as pre-recruits
Total mortality	Measure of the difference between the MLL and the mean length of legal-sized abalone. For consistency with other PIs, it is expressed as 1/total mortality	$Z = K \frac{(L_\infty - \bar{L})}{(\bar{L} - \text{MLL})},$	Minimum sample size: 100 measurements

High importance SAUs

Drummond

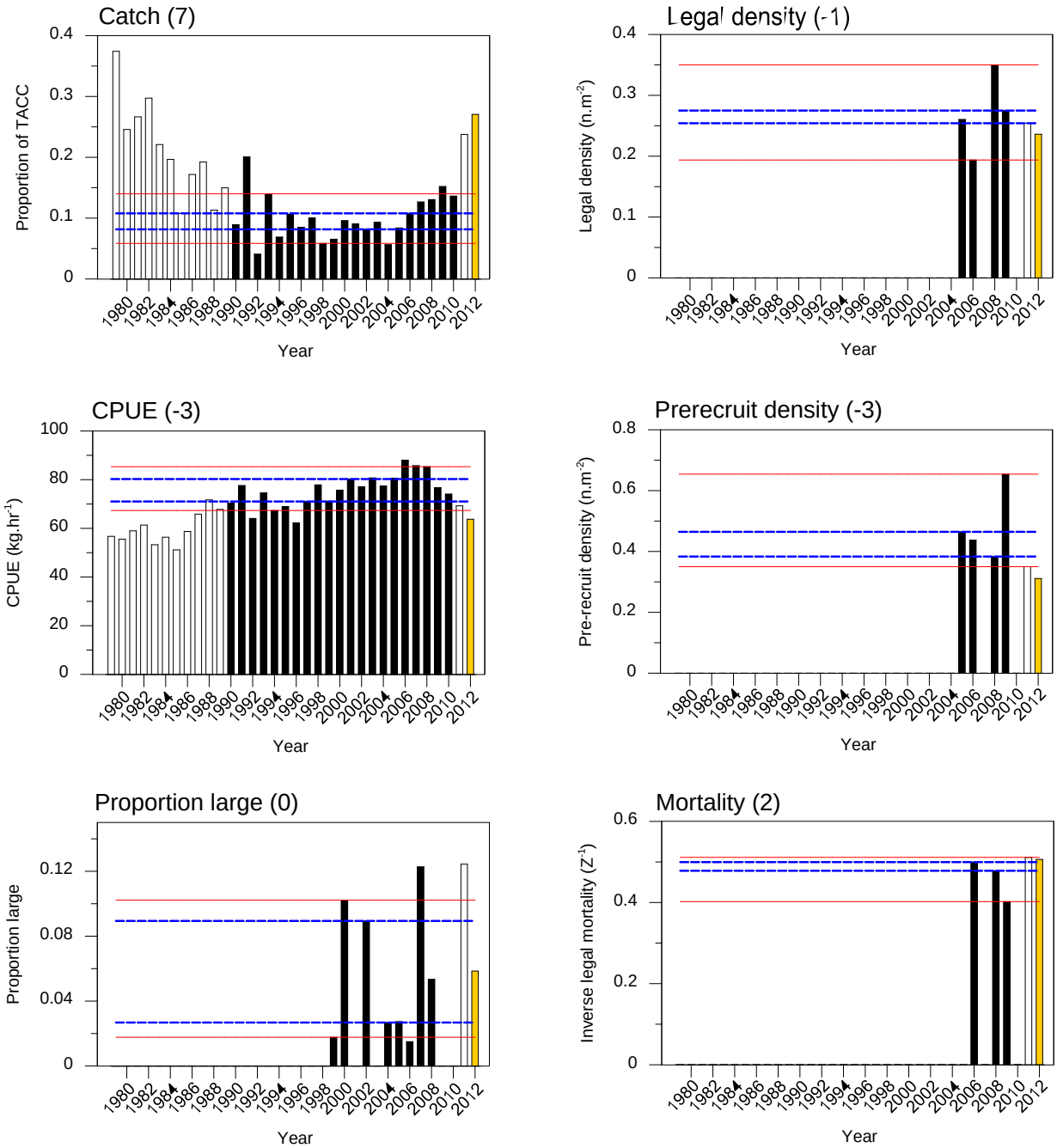

Figure A3.1. Drummond (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Sheringa

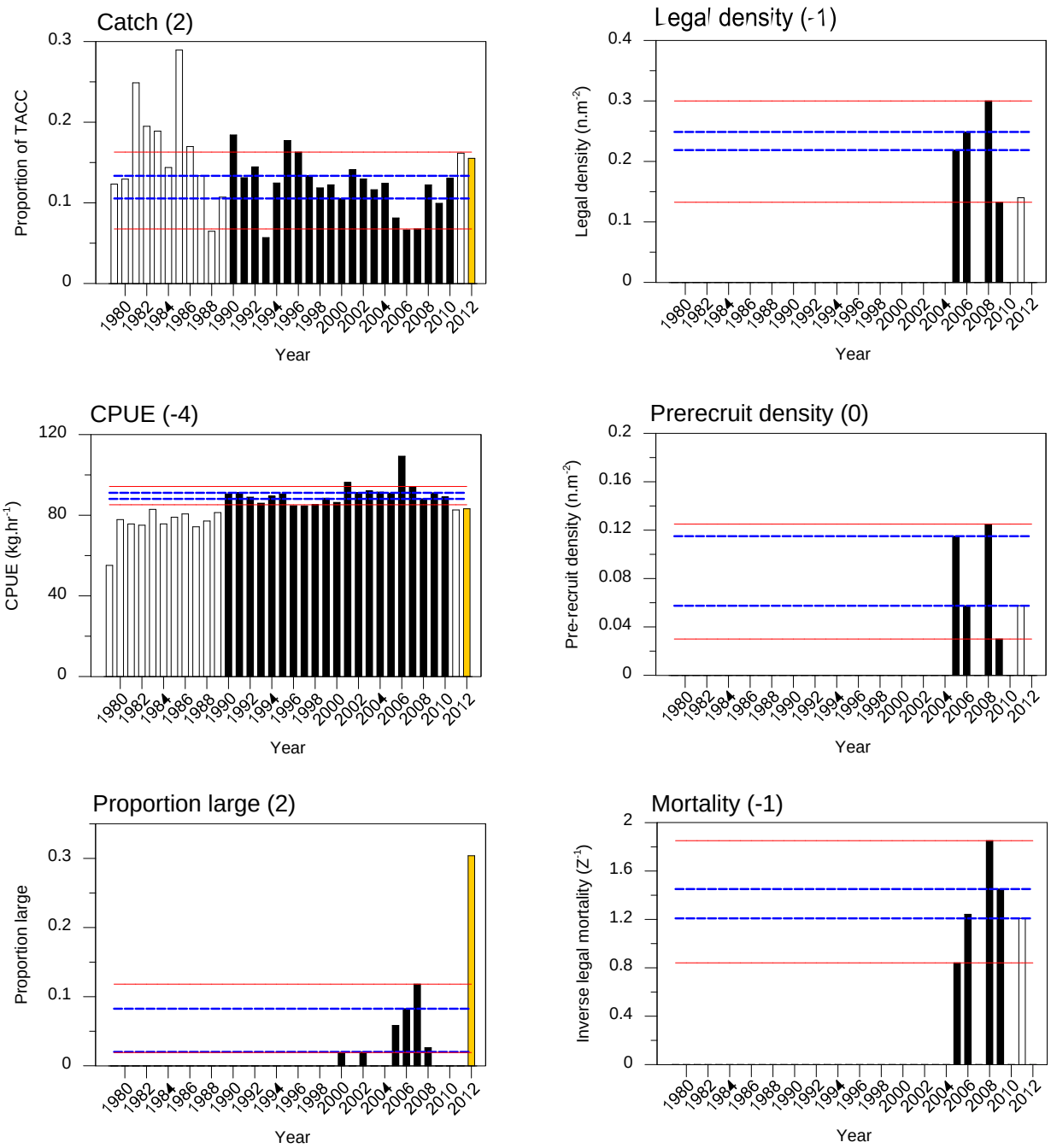

Figure A3.2. Sheringa (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Avoid Bay

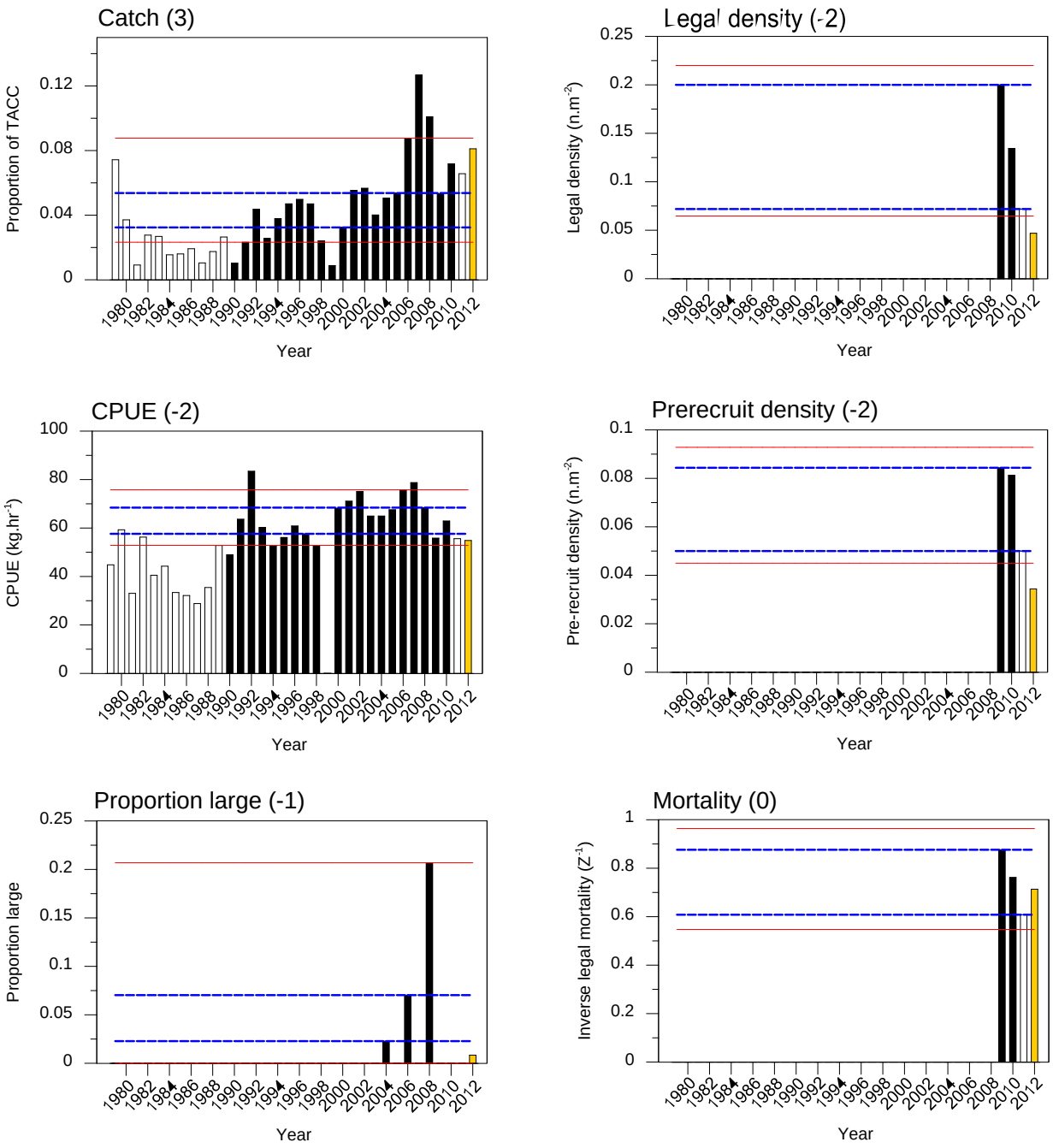

Figure A3.3. Avoid Bay (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Point Westall

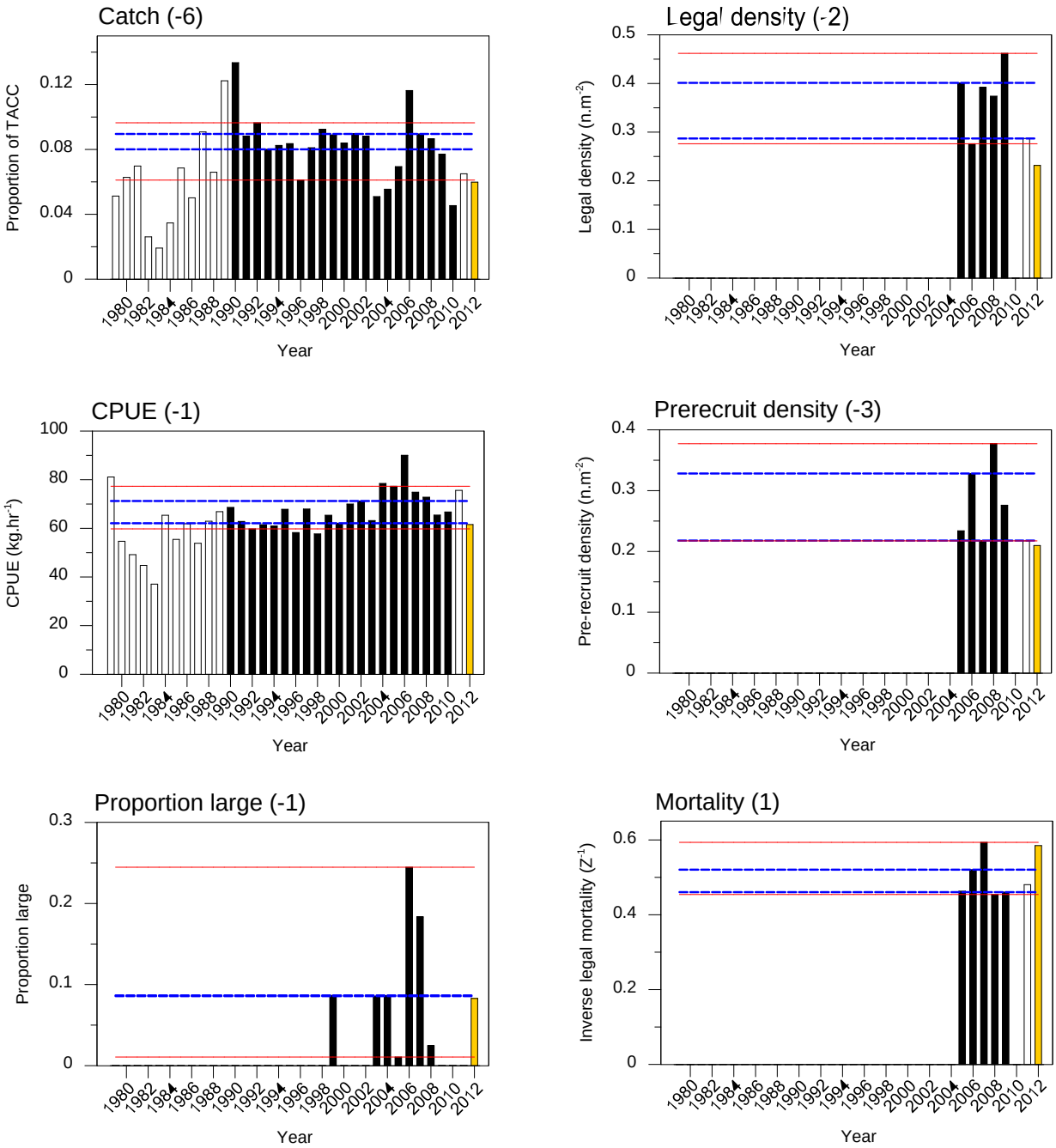

Figure A3.4. Point Westall (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Searcy Bay

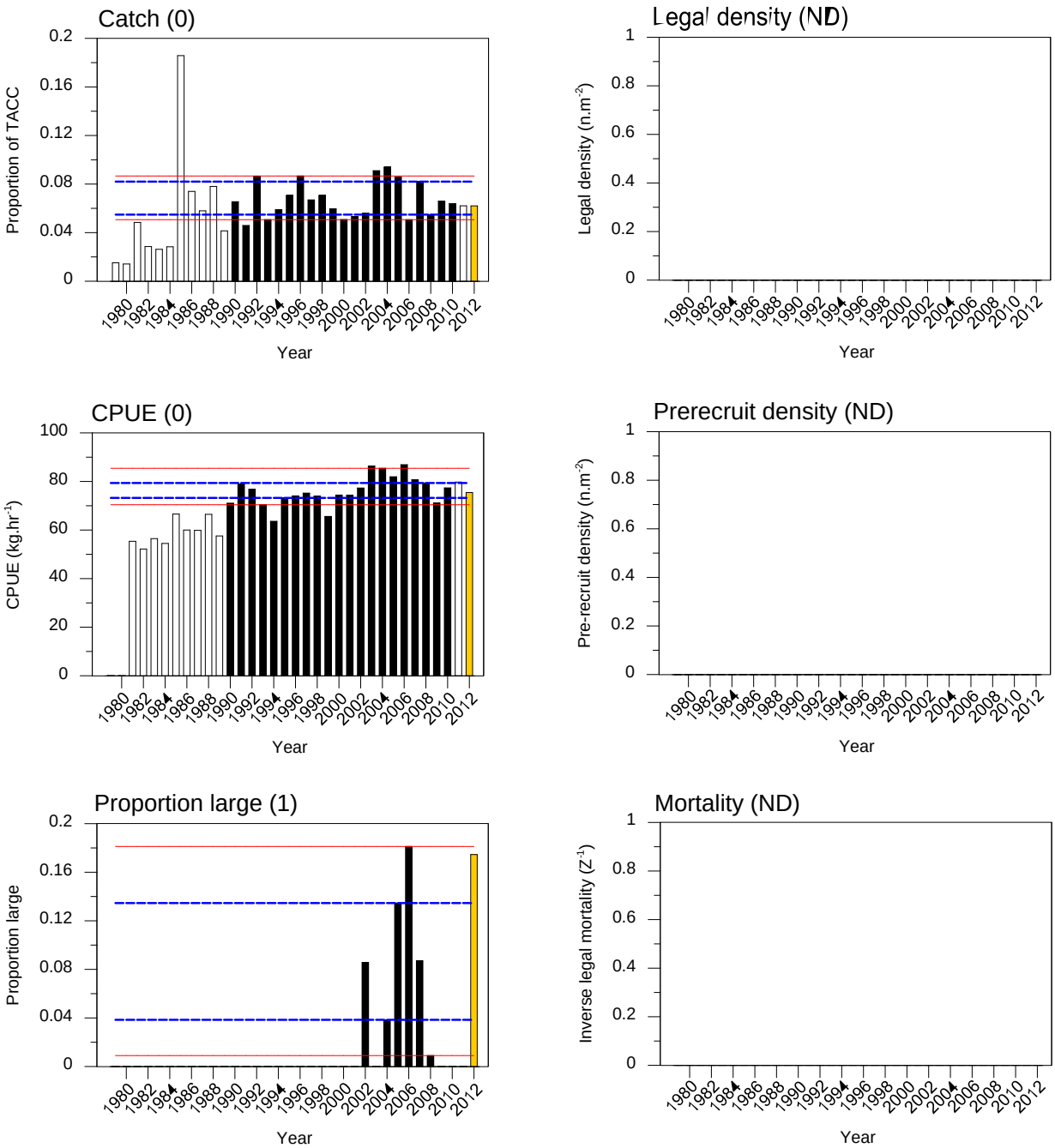

Figure A3.5. Searcy Bay (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year. ND indicates no data.

Ward Island

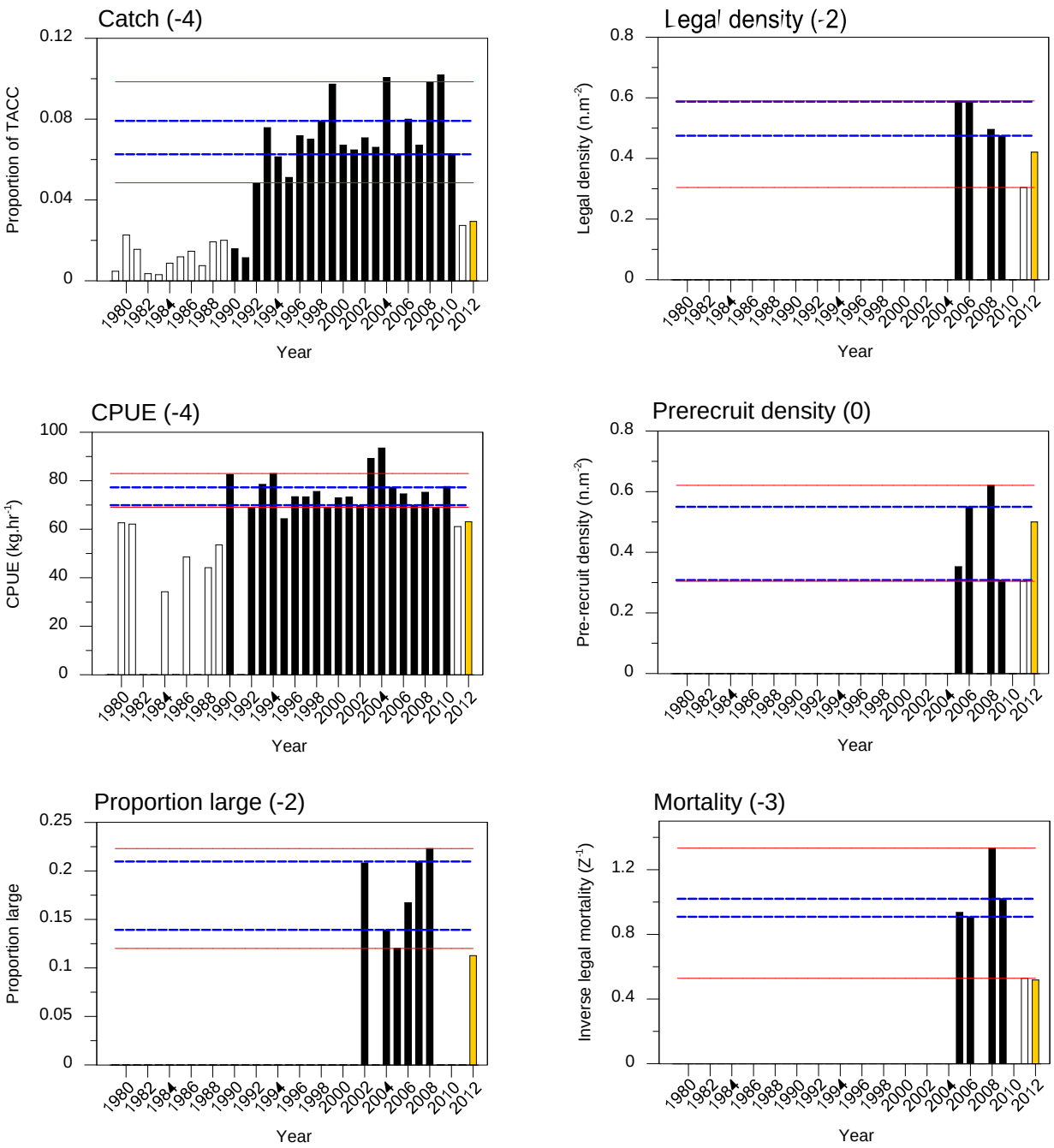

Figure A3.6. Ward Island (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Reef Head

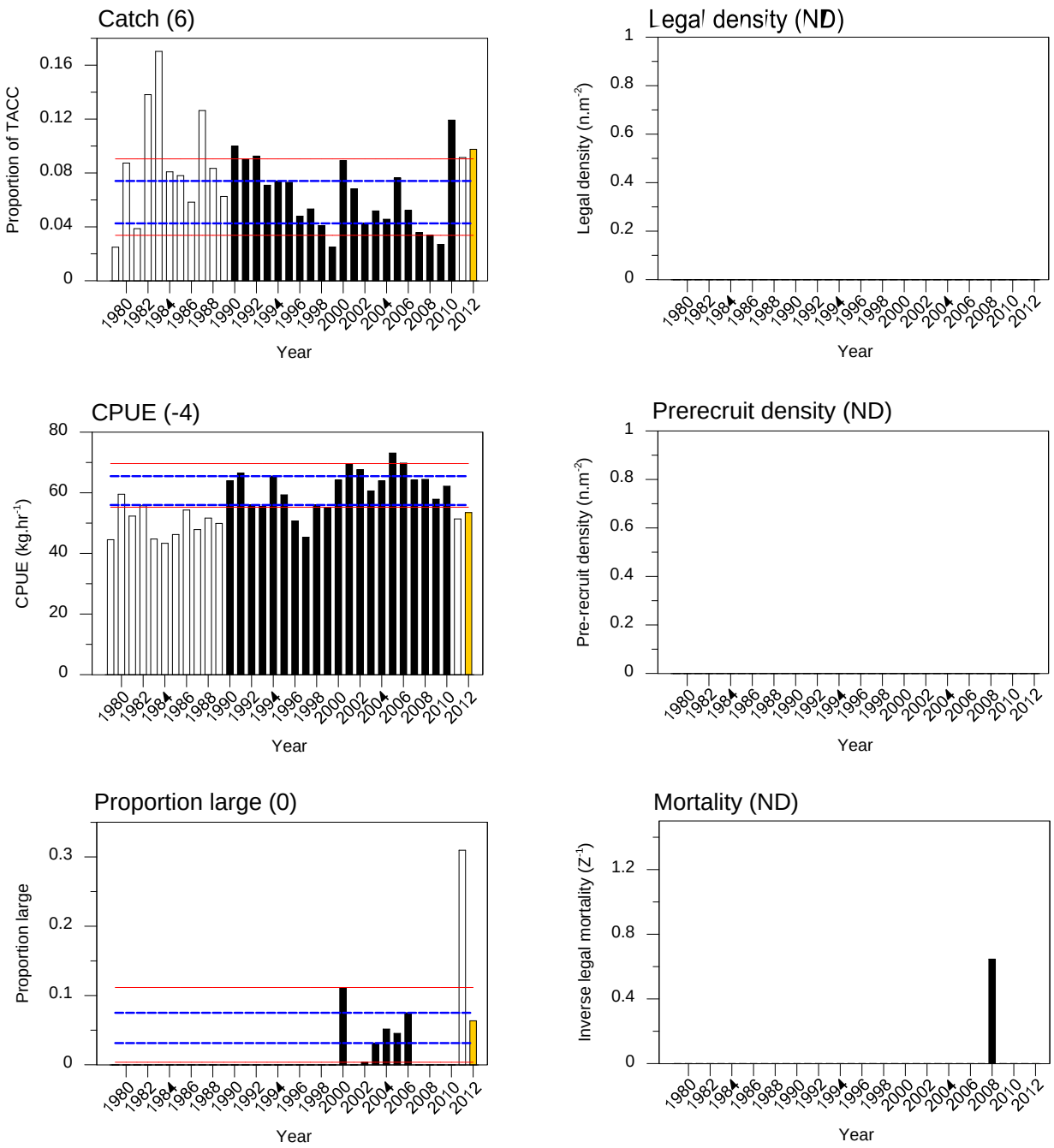

Figure A3.7. Reef Head (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Venus Bay

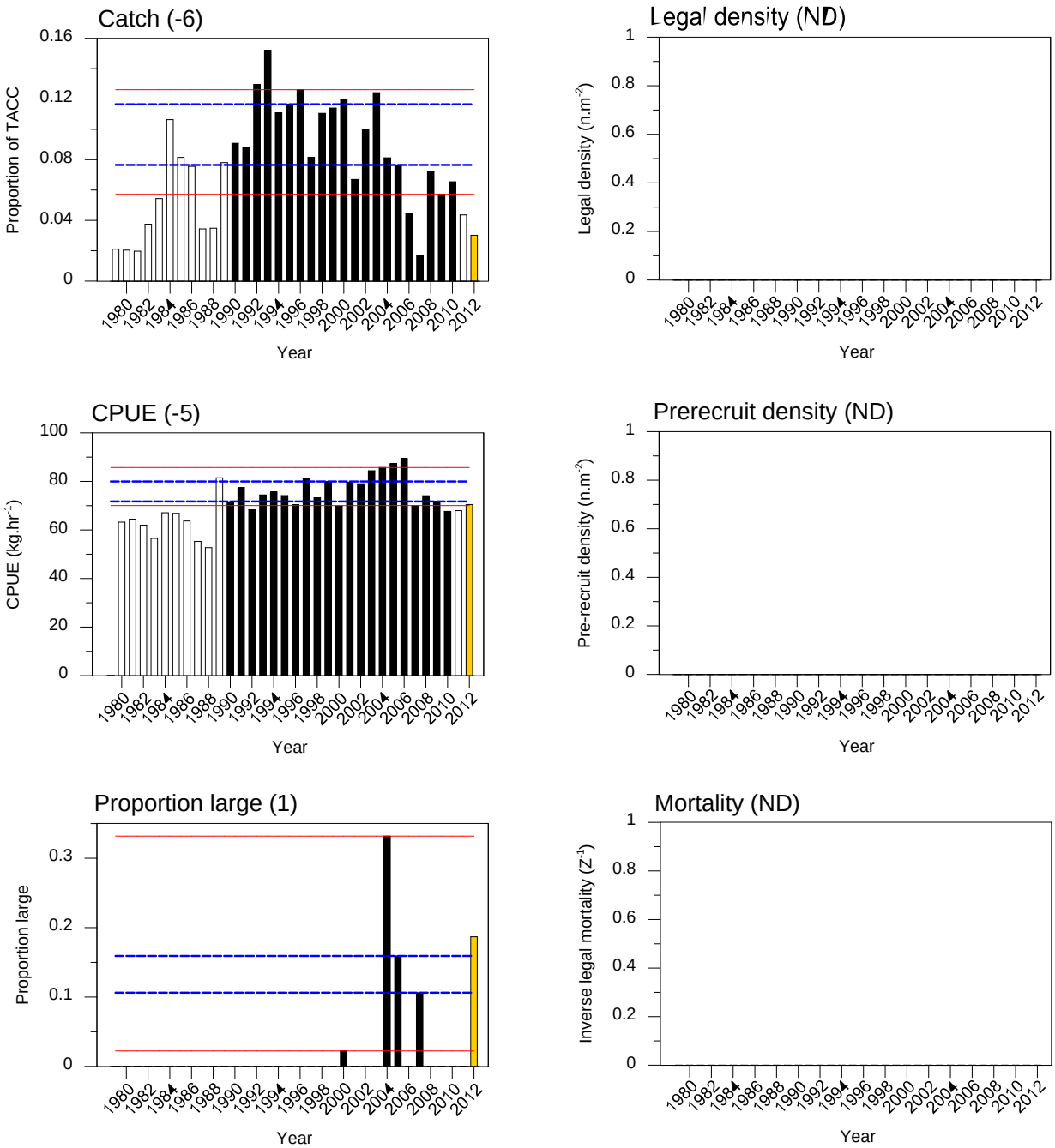

Figure A3.8. Venus Bay (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year. ND indicates no data.

Anxious Bay

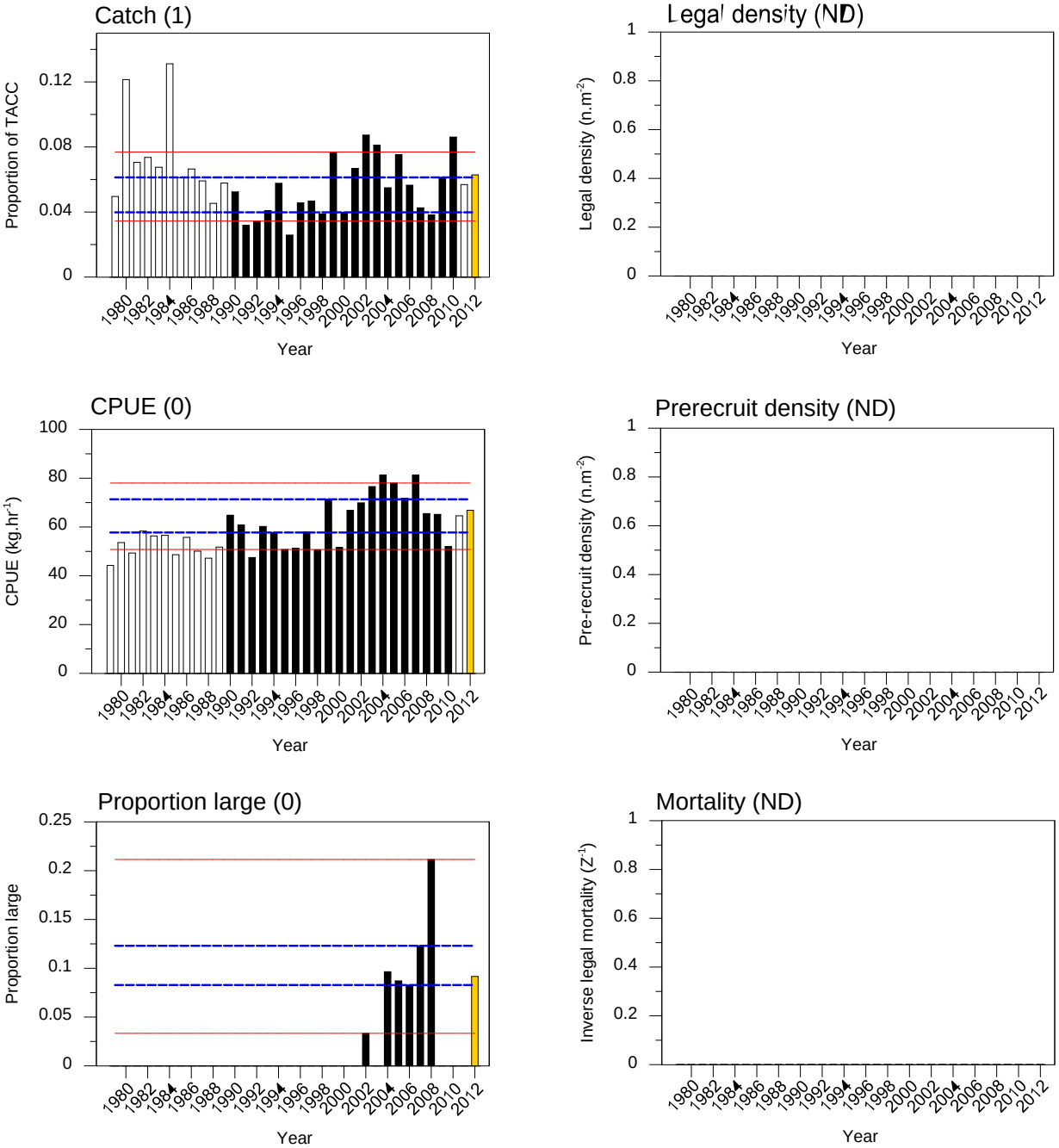

Figure A3.9. Anxious Bay (high importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge, legal density (n.m^{-2}), pre-recruit density (n.m^{-2}), mortality (Z) and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year. ND indicates no data.

Medium importance SAUs

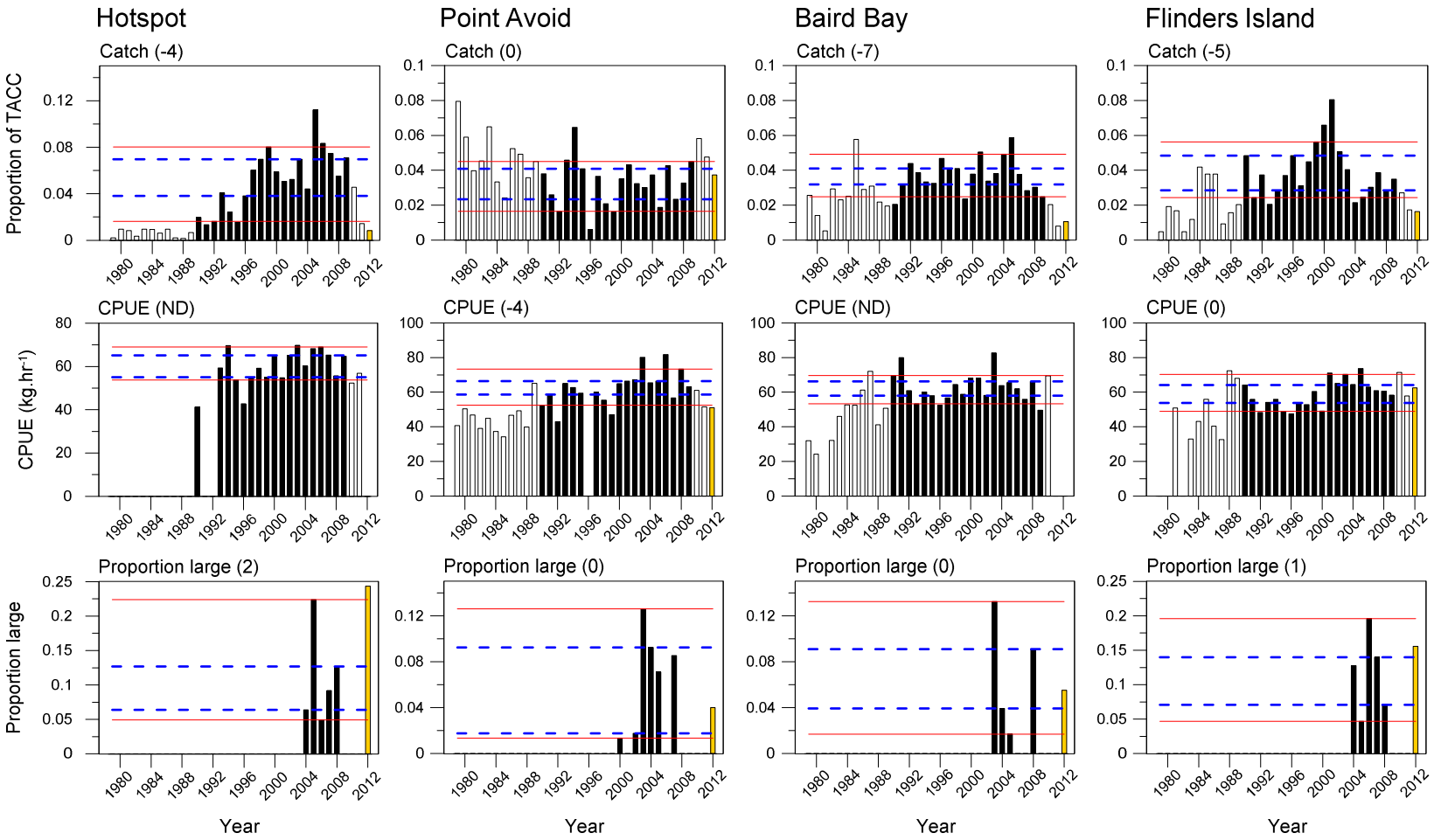

Figure A3.10. Hotspot, Point Avoid, Baird Bay and Flinders Island SAUs (medium importance). Performance indicators catch (Proportion of TACC), CPUE (kg.hr^{-1}), PropLge and scores from the harvest strategy. Red and blue lines are upper and lower limit and target reference points, respectively. Black bars describe the data and time over which the reference points were calculated, open bars describe the measures of the PI outside the reference period and orange bars the data and year subject to assessment for each PI, i.e. the score-year.

Low importance SAUs

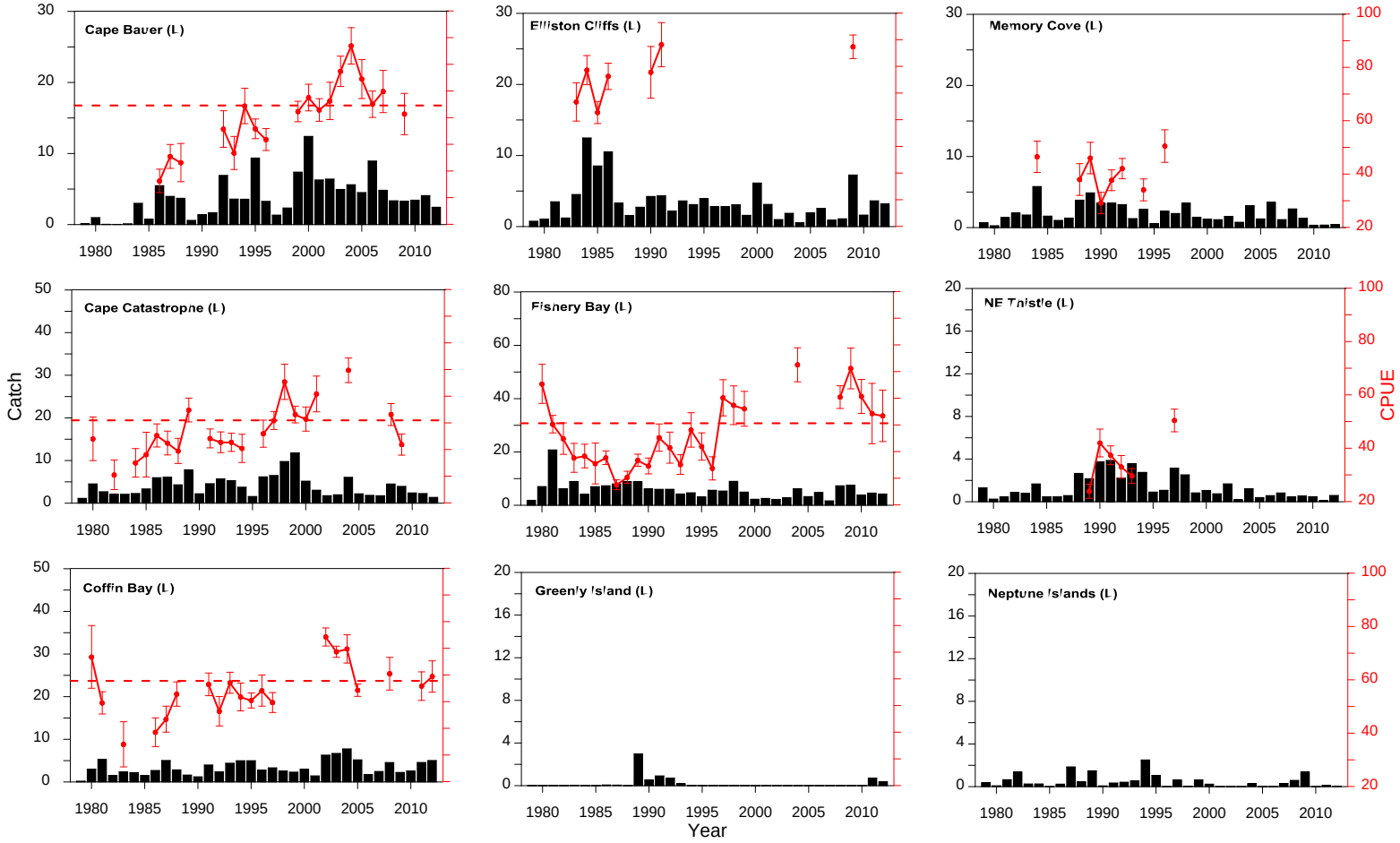

Figure A3.11. Catch (t, shell weight; black bars) of blacklip from low importance SAUs Cape Bauer, Cape Catastrophe, Coffin Bay, Elliston Cliffs, Fishery Bay, Greenly Island, Memory Cove, NE Thistle and Neptune Islands from 1979 to 2012. CPUE ± se (kg.hr^{-1}) is shown in red. Red dashed lines show $CPUE_{90\text{-}09}$ where applicable. Note catch scales vary among graphs.

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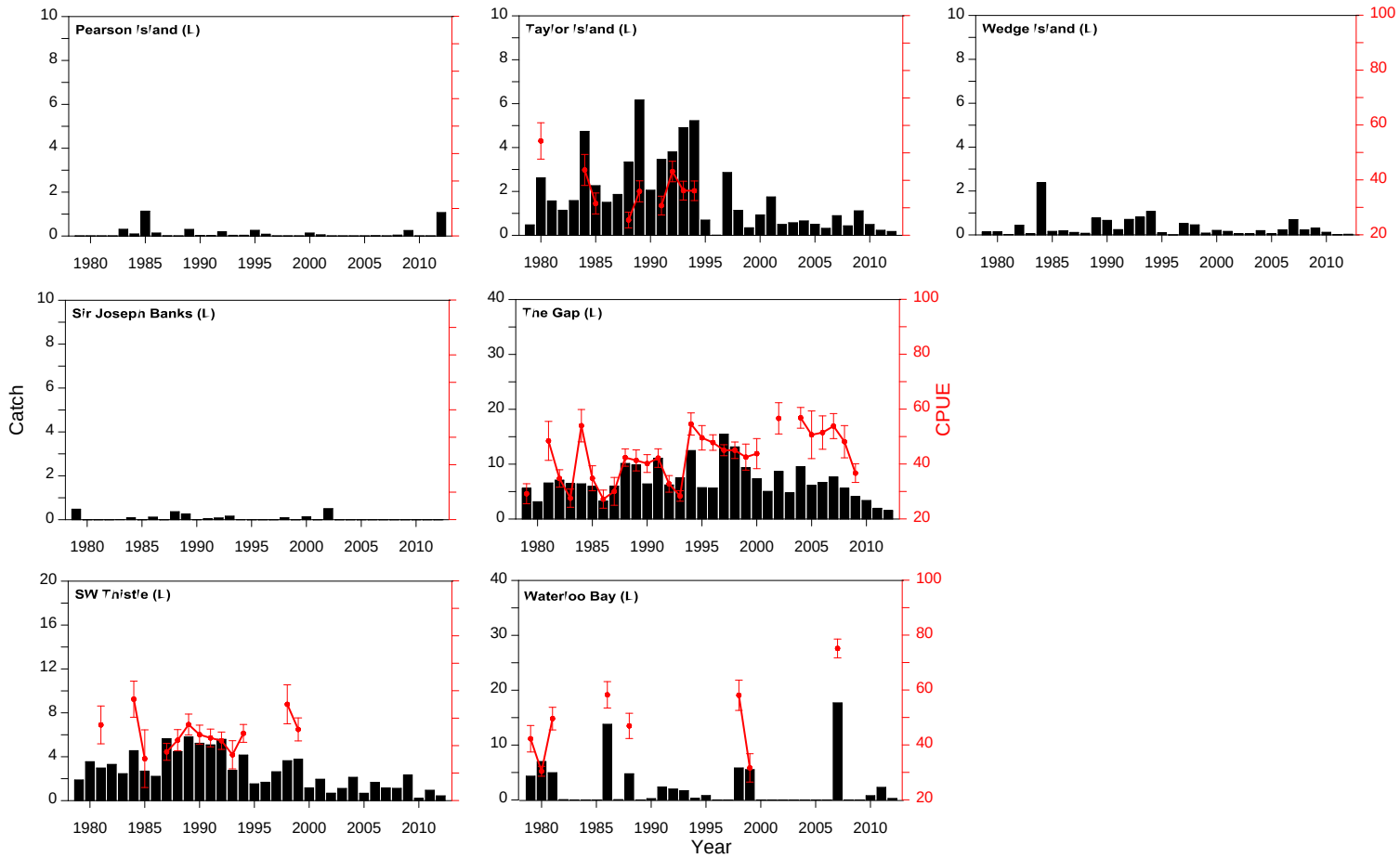

Figure A3.12. Catch (t, shell weight; black bars) of blacklip from low importance SAUs Pearson Island, Sir Joseph Banks, SW Thistle, Taylor Island, The Gap, Waterloo Bay and Wedge Island from 1979 to 2012. CPUE ± se (kg.hr^{-1}) is shown in red. Red dashed lines show $CPUE_{90\text{-}09}$ where applicable. Note catch scales vary among graphs.

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