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Performance indicators, biological reference points and decision rules for Western Australian abalone fisheries (*Haliotis* sp.): (1) Standardised catch per unit effort

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Executive Summary

This report summarises the performance indicators (PIs) and biological reference points (BRPs) developed from standardised catch per unit effort (SCPUE) models of the Western Australian abalone fisheries. It also outlines analysis and consultation processes used to construct these indicators. Other PIs, such as those relating to harvest rate and recruitment, will be developed when more fishery independent data becomes available.

A comprehensive 7-step process was utilised to develop PIs. 1) The Abalone Management and Advisory Committee (AbMac) considered options and advised that in the short-term, catch and effort trends be reviewed with other potential indicators to be considered at a future date. 2) A phone questionnaire was to obtain information on factors that affect fishing efficiency was completed. 3) Feedback from this questionnaire was used to develop a preliminary SCPUE model for each fishery. This was undertaken using a Generalised Linear Model (GLM) analysis of fishers' daily catch rate (catch per hour) taking into account factors, year, month, sub-area, diver, GPS technology, and internet weather prediction services. The least-squares mean for the year effects provided the SCPUE. 4) A second questionnaire detailed the preliminary PIs, and biological reference points. Feedback from this 2nd questionnaire was coordinated though the Performance Indicator Reference Group (PIRG). 5) Three technical briefings were held for stakeholders who raised concerns and suggested changes to the SCPUE model to make the indicators, and the reference points arising from them, more robust. 6) The final system, with the proposed amendments to the SCPUE models, were applied in the 2008/09 TAC assessment process as a test, and compared with existing performance indicators. 7) The PIRG reviewed the PIs in February 2008, and recommended to AbMac they be adopted in-principle as tools to assist in TAC assessment and management, providing that the limitations continued to be recognised, and subject to regular (3-year) review. A description of the performance indicators (PIs) and reference points (BRPs) is summarised below, and in Figure 1.

1) The PI for each fishery is a 3-year running mean of standardised CPUE to determine the trends in abundance. Standardised CPUE models are specific to each fishery, and can be adapted or changed over time to account for varying environmental and technological factors, and changes in harvesting practices.

2) Each PI has three BRPs (limit, threshold, and target). These have been based on the trend and variability in the 15-year time series of the SCPUE (Fig. 1; Table 1).

3) Each BRP has a management decision rule associated with it (Table 1).

If performance indicators and decision rules are to be used in managing a fishery they need to be sufficiently robust to assist in stock management decisions. The decision rules also need to cover most of the management scenarios predicted to arise. However they specifically reflect a stock maintenance objective in fully exploited fisheries, i.e., to maintain stock biomass to enable harvesting of the average long-term sustainable TAC. If the management objective were to alter, a different set of decision rules may be required.

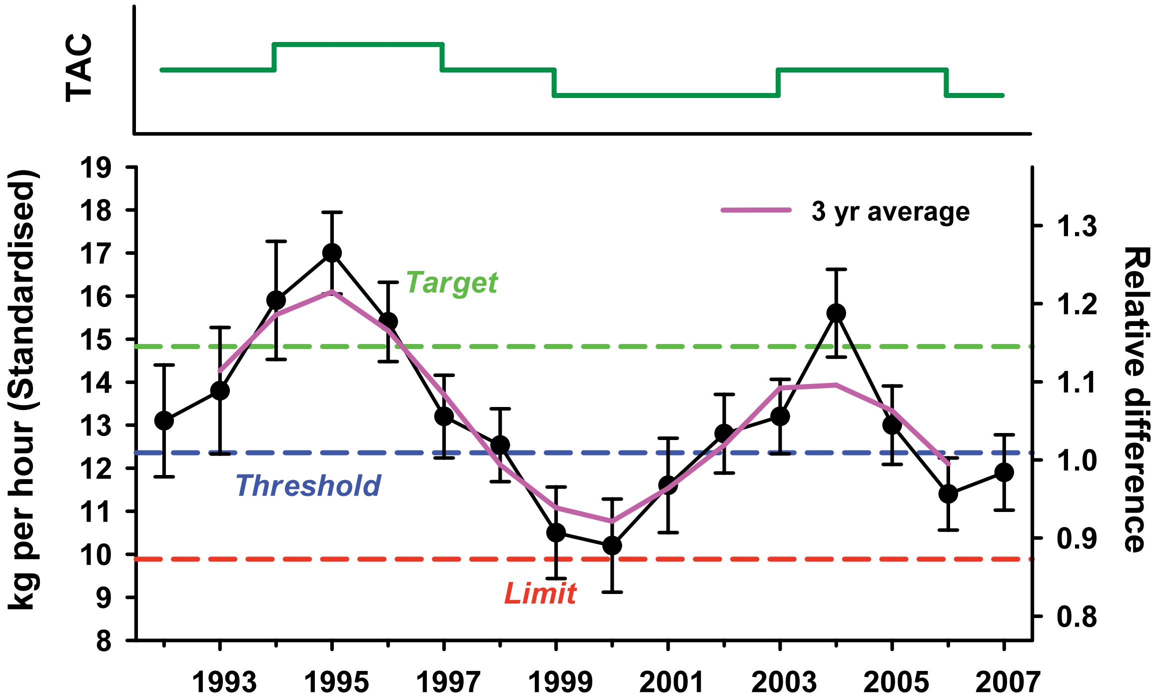

Figure 1. Example of performance indicator (pink line) and biological reference points (Target, Limit, Threshold) for a hypothetical Greenlip abalone fishery, and a schematic of how TAC might vary over time. Yearly data are standardised CPUE (± 95% CLs), and relative differences (to the threshold BRP) are on the right axis.

Table 1. Management decision rules in relation to defined biological reference points (BRPs) for Western Australian Abalone Fisheries. See Figure 1 for the relationship between the performance indicator and biological reference points.

BRPs	Description	Decision Rule
Target	20% above Threshold	Minimum of 10% TAC increase if PI is above the target BRP
Threshold	upper end of the bottom 30% of the historical variability in the PI	a) Maintain TAC at long-term sustainable level if PI is above threshold and below target BRP b) 10% TAC decrease (below long-term sustainable level) if PI is below threshold and above limit BRP
Limit	20% below Threshold	Minimum of 30% TAC decrease if PI is below limit BRP

1.0 Catch Per Unit Effort Standardization

1.1 Introduction

Western Australian abalone fisheries are based on three species (*Haliotis laevigata, H. roei,* and *H. conicopora*) that are harvested from a number of different management areas (Fig. 2 and Fig. 3). Management of these fisheries is currently based on trends derived from catch and effort data for each management area, and existing performance indicators have been developed using the raw CPUE data. Other data sets, such as fishery independent stock surveys to estimate current and future recruitment to the fishery, and catch sampling programs to estimate fishing mortality are currently under development, but lack sufficient time-series of information to be useful to management.

CPUE data can be biased as an index of abundance because of changes in a number of factors such as fishing efficiency, time of year, industry divers, and other technology factors, such as the availability of long-range Internet Weather Prediction services. Consequently, this section examines the relative impact of these factors and the value of developing an annual standardised CPUE (SCPUE) index that would take into account these factors (e.g. month, sub-area, diver and technology). In the next section (Section 2) the SCPUE index is used to develop performance indicators (PIs) and biological reference points (BRPs), which are incorporated into a decision rule framework for management.

1.2 Methods

1.2.1 Estimation of the effect of technology factors on fishing efficiency

1.2.1.1 GPS (Global Positioning System)

Being able to accurately pinpoint the spatial location of abalone reefs using the newly developed GPS technology in the early to mid-1990s was a major technological development in the Greenlip and Brownlip abalone fishery. This wasn't considered a significant factor for the Roe's abalone fishery however, because it operates in shallow water.

To estimate the effect of GPS technology on fishing efficiency in the Greenlip Brownlip abalone fisheries, a variable was created that had a value of zero for the years before GPS was introduced, and one for the years after GPS was introduced. Such an approach will give an overall estimate of the effect of GPS in proportional terms, and is an established technique in applied regression analysis (Kleinbaum et al., 1988; Cohen, 1968). A similar method has been successfully used to estimate the effect of GPS on pot efficiency in the western rock lobster fishery (Brown et al., 1995).

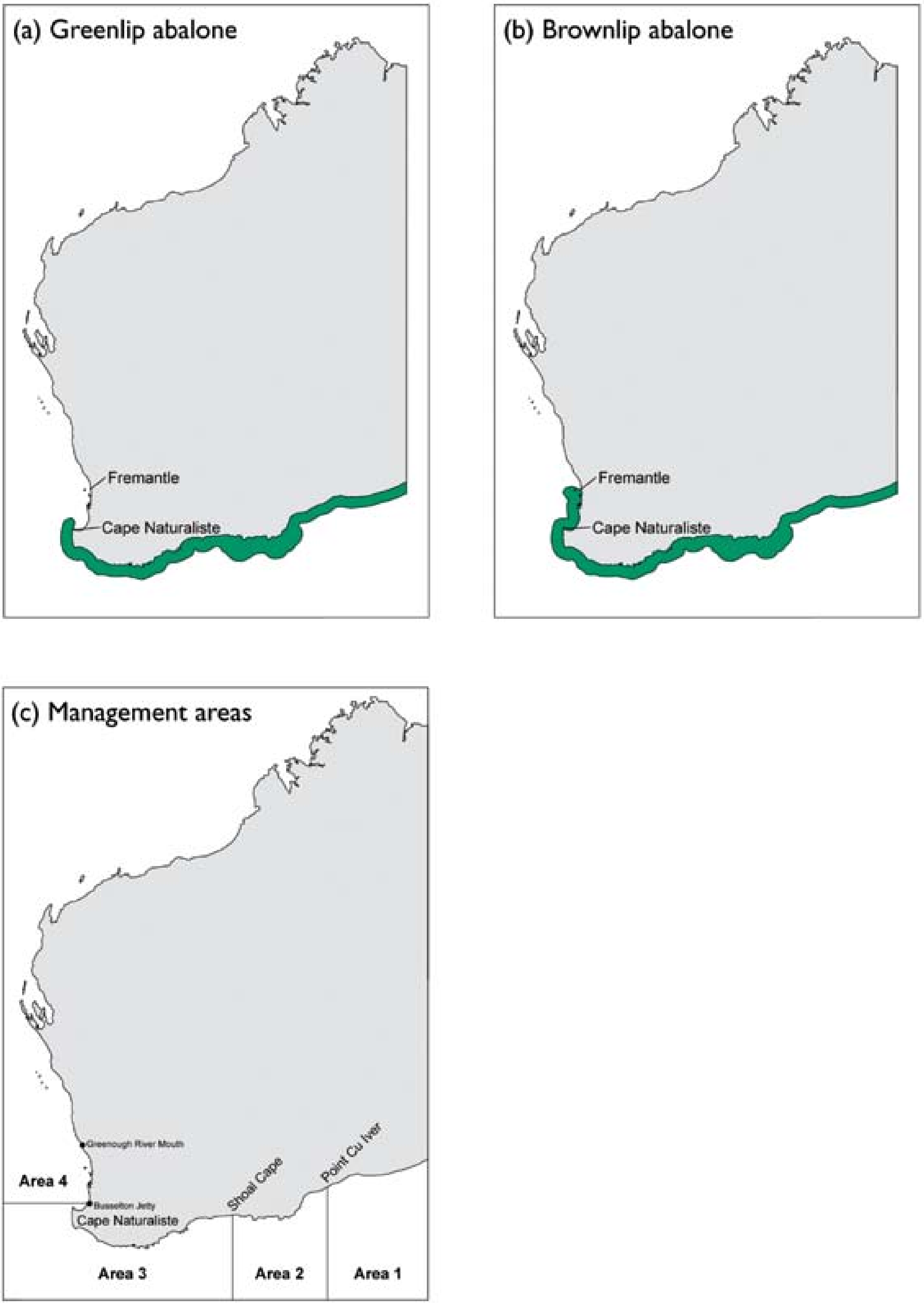

Figure 2. Maps showing the distribution of (a) Greenlip and (b) Brownlip abalone in Western Australia, and (c) the management areas used to set quotas for the commercial fishery.

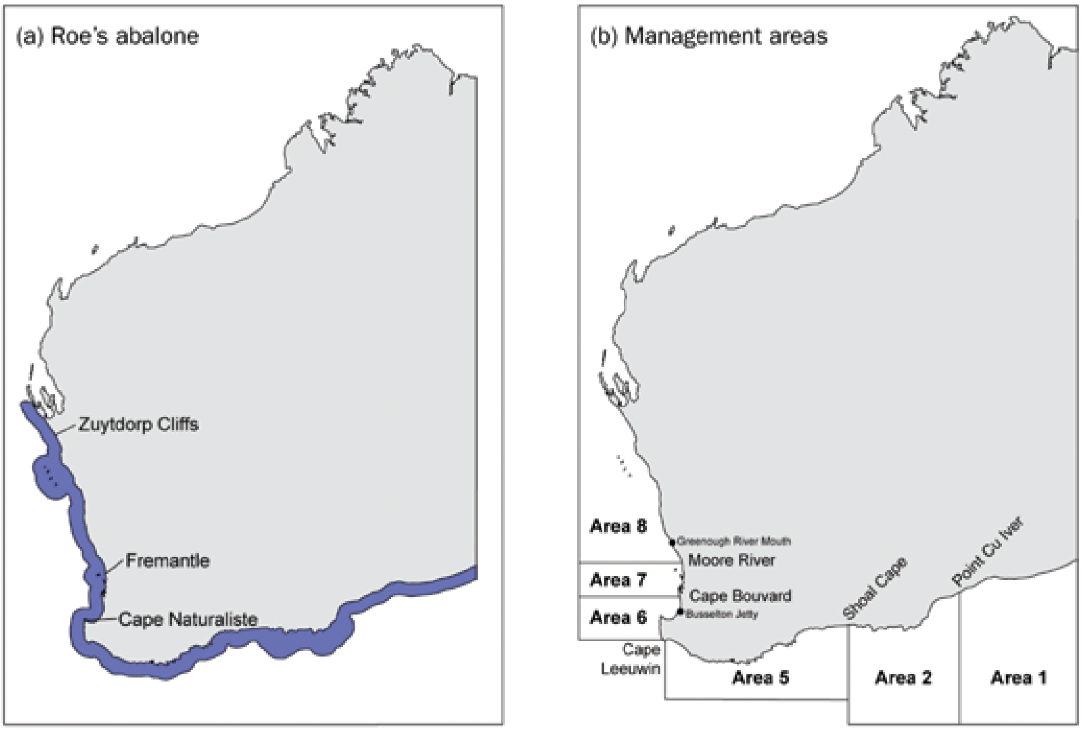

Figure 3. Maps showing (a) the distribution of Roe's abalone in Western Australia, and (b) the management areas used to set quotas for the commercial fishery.

The dataset chosen for the GPS effect analysis included the four years immediately prior (1990-1993), and post (1995-1998) to the introduction of GPS. This was done to smooth out any annual changes in abundance that might affect estimation of the GPS effect, as well as account for a variable implementation of this technology across different years and fishers. Only those divers who fished at least 6 of the 8 years were included which resulted in 4 divers from Area 2 and 9 divers from Area 3 being included in the analysis.

After final selection of variables, a logarithmic transformation of raw data was undertaken to take into account the skewed distribution associated with CPUE.

The GLM model used to estimate the GPS effect was:

$$Ln(CPUE+1) = \mu + \beta_1(month) + \beta_2(subarea) + \beta_3(Diver) + \beta_4(GPS) + \varepsilon$$

CPUE is the raw CPUE data (kg/hr) from each fishing day of an abalone diver

$\beta_1(month)$ is the effect of monthly variation in the fishing efficiency arising from changes in seasonally varying factors, such as meat condition, swell, visibility

$\beta_2(subarea)$ is the effect of spatial differences on abundance of abalone

$\beta_3(Diver)$ is the effect of diver differences on the catch rate of abalone

$\beta_4(GPS)$ is the effect of GPS on the fishing efficiency of divers.
ε is the error term (assumed to be normally distributed with a mean of 0 and constant variance).

Estimates of $\beta_4(GPS)$ were obtained by comparing the least squares means from the "0" code (before GPS introduction) with the "1" code (after GPS introduction) using the eight years of data 1990-1998. The correction factor arising from this estimate was applied to the raw data in the final GLM models used to standardise CPUE (see section 2.3, Table 2).

1.2.1.2 IWP (Internet Weather Prediction)

Internet weather prediction is a recent development that allows industry divers to use swell and wind prediction services available on the Internet to plan their harvesting activities up to 7 days in advance. This enables them to maximise the daily catch rates during the good weather days and was identified as reasonably important in the Greenlip abalone fishery, and critically important factor in the Roe's abalone fishery (see Appendix 6.1).

The data selection and analysis procedures used to estimate the IWP effect was similar to that used for GPS estimation. The dataset chosen included the 4 years immediately prior (2000-2003), and post (2004-2007) to the introduction of IWP. Further selection was made for only those divers who fished during at least 6 of the 8 years.

The GLM model used to estimate this effect was:

$$Ln(CPUE+1) = \mu + \beta_1(month) + \beta_2(subarea) + \beta_3(Diver) + \beta_4(IWP) + \varepsilon$$

CPUE is the raw CPUE data (kg/hr) from each fishing day of an abalone diver;

$\beta_1(month)$ is the effect of monthly variation in the fishing efficiency arising from changes in seasonally varying factors, such as meat condition, swell, visibility;

$\beta_2(subarea)$ is the effect of spatial differences on abundance of abalone;

$\beta_3(Diver)$ is the effect of diver differences on the catch rate of abalone;

$\beta_4(IWP)$ is the effect of Internet Weather Prediction on the fishing efficiency of divers; and
ε is the error term (assumed to be normally distributed with a mean of 0 and constant variance).

$$Ln(CPUE+1) = \mu + \beta_1(month) + \beta_2(subarea) +$$
$$\beta_3(Diver) + \beta_4(IWP) + \varepsilon$$

1.2.2 Data validation and selection procedures for the GLM models

The final GLM models chosen for each management area were dependent on a few different variables, including feedback from fishers/stakeholders regarding which factors were relevant, important, or could be omitted or changed. For example, initial analyses suggested that the IWP (Internet Weather Prediction) efficiency increase in the Area 2 Roe's abalone fishery was as high as 19%. However subsequent discussions with stakeholders and the PIRG (Performance Indicator Reference Group) suggested the actual increase was probably closer to 15%, and this was chosen for the final model (Table 2).

1.2.3 Separation of effort between species

In the early years (1990-1999) of the daily catch and effort logbooks, effort was not separated between different species for each fishing day. This was not an issue for Roe's only divers, however for Greenlip Brownlip divers, adjustments had to be made to ensure that effort for Greenlip abalone was properly accounted for, as these divers occasionally fished all three species on one day, and regularly fished Greenlip and Brownlip abalone on the same day. The final selection criteria chosen was that the SCPUE dataset only included those fishing days where >5 kg of Greenlip and < 10 kg Brownlip were caught (Table 2). The reasoning being that it is extremely unlikely to have 0 kg catch for an entire days worth of fishing if Greenlip is specifically targeted, and any catch < 10 kg of Brownlip was perceived as incidental, and not the result of specific Brownlip targeting that may bias the estimates of Greenlip effort.

1.2.4 Selection of divers and CPUE outliers

During initial analyses, the individual diver was often shown to be the most important contributor to variability in the standardised CPUE (SCPUE) trends. The basis for choosing which divers were to be included, and which to be excluded, came down to a measure of years of experience. In general, divers were included if they had 2+ years and/or a minimum of 100 days fishing experience, and excluded from the analyses if they had less than this. There were some instances where divers had 3+ years of experience, but less than 100 days fishing time and these were also included.

Examination of the raw CPUE data distributions identified CPUE of >100 kg per hour in the Greenlip fishery, and 120 kg per hour in the Roes' abalone fishery to be clearly outliers caused by human error. These were excluded from the analyses. Data grooming and variable section criteria applied to the GLM models are summarised in Table 2.

Table 2. Data and variable selection criteria applied to the GLM models for standardised CPUE in the different management areas. IWP – Internet Weather Prediction.

Area	Data selection criteria	Variable selection	Technology Correction factors
Area 2 Greenlip	Greenlip catch >5 kg Brownlip catch <10 kg Roe's catch < 5 kg CPUE < 100 kg/hr	Years: 1992+ Months: All months Diver: 11 divers Subareas: West, Town, Dukes, Arid, Israelite	GPS: 9% efficiency increase 1994+
Area 3 Greenlip	Greenlip catch >5 kg Brownlip catch <10 kg Roe's catch < 5 kg CPUE < 100 kg/hr	Years: 1992+ Months: All months Diver: 12 divers Subareas: Albany, Augusta, Hopetoun, Windy Harbour	GPS: 8% efficiency increase 1994+
Area 2 Roe's	Roei only divers Roe's catch > 5 kg CPUE < 120 kg/hr	Years: 1992+ Months: Jul, Aug, Sep omitted Diver: 8 divers Subareas: West, Town, Dukes, Arid	IWP: 15% efficiency increase 2004+
Area 5 Roe's	Roe's catch > 5 kg CPUE < 120 kg/hr	Years: 1992+ Months: July omitted Diver: 15 divers Subareas: Albany, Augusta, Hopetoun, Windy Harbour	IWP: 12% efficiency increase 2004+
Area 6 Roe's	Roe's catch > 5 kg CPUE < 120 kg/hr	Years: 1992+ Months: Jun, Jul, Aug, Sep omitted Diver: 10 divers Subareas: Capes North, Capes South	IWP: 17% efficiency increase 2004+
Area 7 Roe's	Roe's catch > 5 kg CPUE < 120 kg/hr	Years: 1992+ Months: July omitted Diver: 16 divers Subareas: None	IWP: 10% efficiency increase 2004+
Area 8 Roe's	Roe's catch > 5 kg CPUE < 120 kg/hr	Years: 1992+ Months: All months Diver: 8 divers Subareas: 6 main sequence numbers (10, 11, 12, 13, 14, 21)	IWP: 10% efficiency increase 2004+

1.2.5 Standardised catch per unit effort models

Estimates of standardised CPUE for each management area were derived from GLM analysis of the catch per unit effort data (kg per hour diving), taking into account various factors that significantly influence fishing efficiency. The analysis was carried out in S_Plus®.

Estimates of technology correction factors (GPS, IWP) were obtained as described in section 1.2.1 and this correction factor was applied to the raw CPUE data prior to the GLM analysis.

After final selection of variables, a logarithmic transformation of raw data was undertaken to take into account the skewed distribution associated with CPUE.

SCPUE model:

$$Ln(CPUE+1) = \mu + \beta_1(Year) + \beta_2(month) + \beta_3(subarea) + \beta_4(Diver) + \varepsilon$$

Estimation of the standardised yearly CPUE for each fishery was undertaken in two steps.

1) A GLM modelling approach was applied to the available information in order to estimate μ, β, and ε.
2) The least squares mean of the factor Year was used to produce an index of the relative abundance (standardised CPUE) for each year.

1.3 Results

1.3.1 Estimation of technology effects

Estimates of the GPS and IWP technology correction factors on CPUE are given in Table 3. In most cases these correction factors were applied to the final GLM models, however in some instances, e.g. the Area 7 and Area 5 Roe's abalone fishery, the estimates were modified after discussion with stakeholders. These modified estimates (Table 3) were then used as the correction factors in the final GLM analysis. No correction factor for IWP was applied to Greenlip fisheries, however a significant effect was estimated for the Area 2 fishery, but not Area 3 (Table 3).

Table 3. Model estimates of the effect of technology on CPUE in abalone fisheries (β_4), and the correction factor (β) used in the final model. GPS – Global Positioning System; IWP – Internet Weather Prediction; ns – non-significant.

Area	Technology factor	Model Estimates of β_4	β used in final GLM model
Area 2 Greenlip	GPS	1.094 (9%)	1.094 (9%)
	IWP	1.134 (13%)$	
Area 3 Greenlip	GPS	1.079 (8%)	1.079 (8%)
	IWP	ns (0%)$	
Area 2 Roe's	IWP	1.192 (19%)	1.15 (15%)*
Area 5 Roe's	IWP	1.091 (9%)	1.12 (12%)*
Area 6 Roe's	IWP	1.168 (17%)	1.168 (17%)
Area 7 Roe's	IWP	1.151 (15%)	1.10 (10%)*
Area 8 Roe's	IWP	1.10 (10%)	1.10 (10%)
Average of GPS (Greenlip) (± SE)	1.087 (0.01)		
Average of IWP (Roe's) (± SE)	1.140 (0.02)		

* final chosen values of β modified from model estimates after discussion with stakeholders about how IWP is used in each of the areas.

$ as a result of uncertain model outputs and after discussions with stakeholders, no correction factor for IWP was applied to Greenlip fisheries.

1.3.2 Standardised CPUE Model Outputs

Results of the GLM model for SCPUE are summarised in Table 4 for the Area 3 Greenlip abalone fishery, and Table 5 for the Area 7 Roe's abalone fishery. These have been chosen as examples as they are representative of the results obtained from other areas.

1.3.2.1 Example 1: Area 3 Greenlip fishery

In the Area 3 Greenlip fishery, all tested variables had a significant influence on CPUE, however according to the mean-square effect, the most important of these was Sub-area (Table 4). Taking into account all other factors, there was a 50 % difference in standardised CPUE between Augusta and Albany stocks (Fig. 4). Variation in CPUE due to month was cyclical with a difference of 35% from the lowest (February) to highest month, May (Fig. 5). Variation in CPUE due to diver differences was 40% from the lowest (Diver 4) to highest diver, Diver 7 (Fig. 6).

Year-to-year variation in standardised CPUE is shown in Fig. 7. Over the 15 year period, there has been a 40% variation in CPUE from the lowest year (1995) to the highest year (2000).

Table 4. GLM results for the effect of Year, Month, Subarea, and Diver on Area 3 Greenlip CPUE (shells caught per diver hour) from 1992 to 2007. Data has been ln (x +1) transformed and adjusted for the GPS effect.

Source of variability	d.f	Mean Square	F	P
Year	15	5.37	32.5	< 0.001
Month	11	5.47	33.1	< 0.001
Subarea	3	36.46	220.5	< 0.001
Diver	11	5.78	34.9	< 0.001
Residual	5,787			

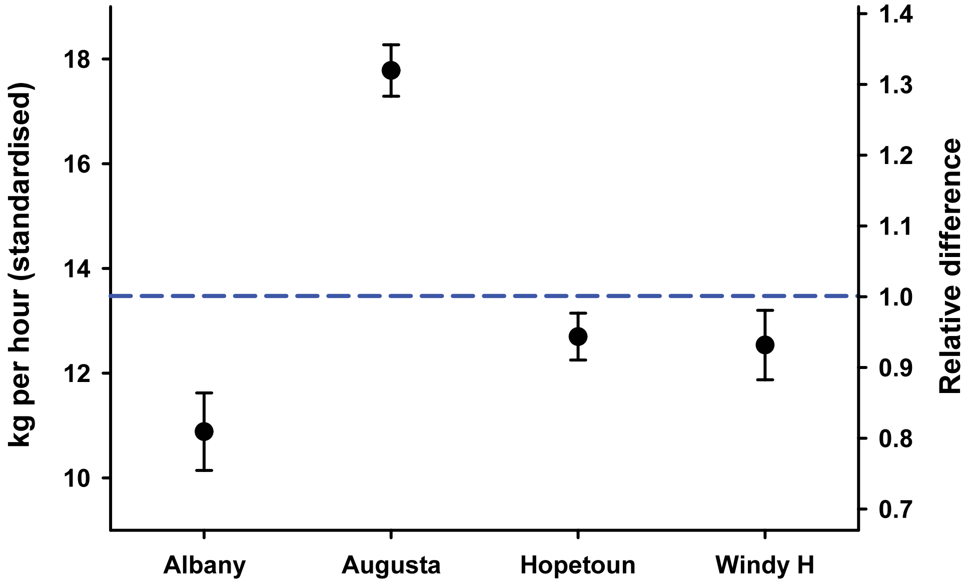

Figure 4. Least squares mean Greenlip CPUE (± 95% CL) in different subareas of the Area 3 Greenlip fishery. Relative differences (to the mean) are shown on the right axis.

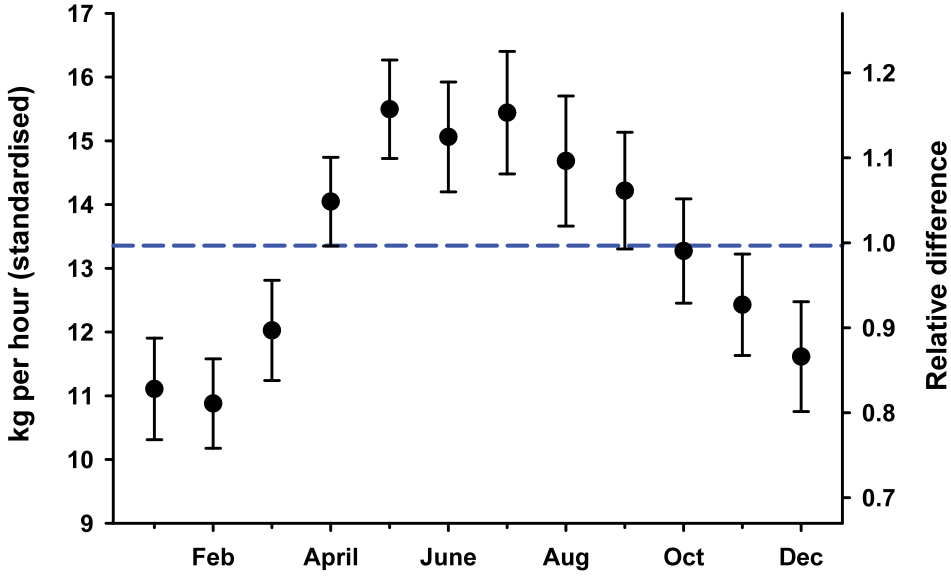

Figure 5. Monthly variation in least squares mean Greenlip CPUE (± 95% CL) in the Area 3 Greenlip fishery. Relative differences (to the mean) are shown on the right axis.

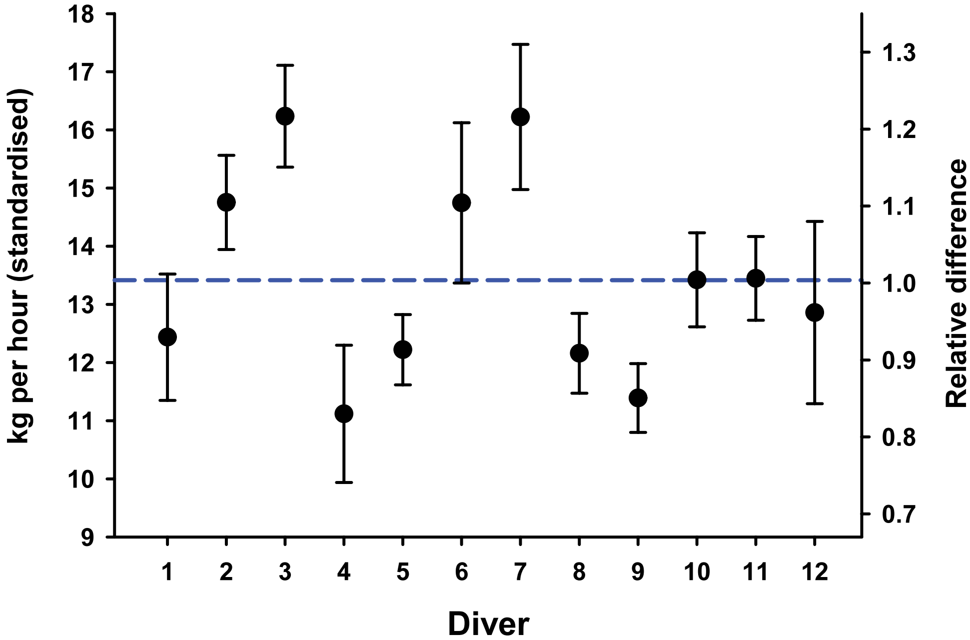

Figure 6. Diver variation in least squares mean Greenlip CPUE (± 95% CL) in the Area 3 Greenlip fishery. Relative differences (to the mean) are shown on the right axis.

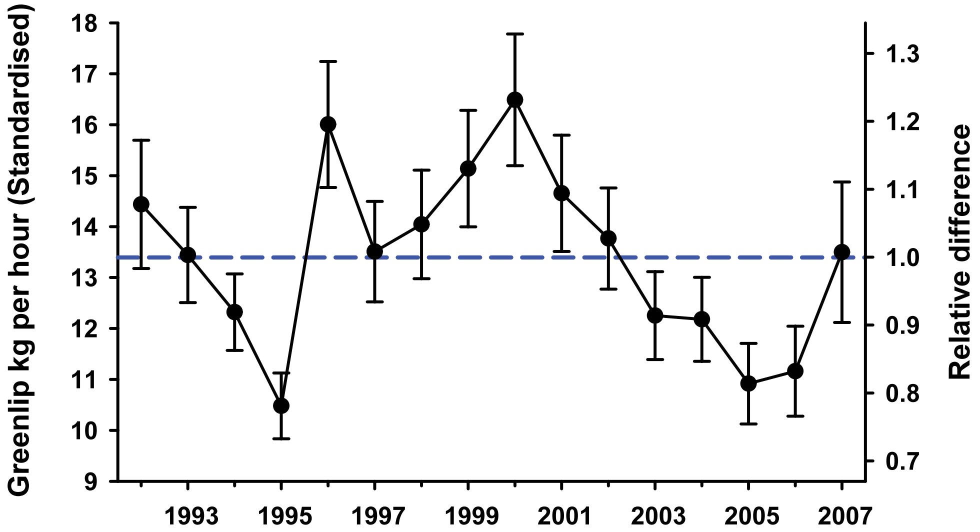

Figure 7. Yearly variation in least squares mean Greenlip CPUE (± 95% CL) in the Area 3 Greenlip fishery. Relative differences (to the mean) are shown on the right axis.

1.3.2.2 Example 2: *Area 7 Roe's abalone fishery*

In the Area 7 Roe's abalone fishery, all variables had a significant influence on CPUE, however according to the mean square effect, the most important of these was Diver (Table 5). It is worth noting in this fishery that the sub-area effect was insignificant in the initial analysis, and was also considered unimportant by industry divers. Consequently the sub-area variable was removed from the model (Table 5).

Taking into account all other factors, there was a 50 % difference in standardised CPUE from the highest (Diver 4) to lowest (Diver 2) diver (Fig. 8). Variation in CPUE due to month was 50% from the lowest (March) to the highest, April (Fig. 9).

Year-to-year variation standardised CPUE in Area 7 is shown in Fig. 10. Over the 15 year period, there has been a 40% variation in CPUE from the lowest year (1995) to the highest year (2000).

Table 5. GLM Results for the effect of Year, Month, and Diver on Area 7 Roe's abalone CPUE (shells caught per diver hour) from 1992 to 2007. Data has been ln (x +1) transformed.

Source of variability	d.f	Mean Square	F	P
Year	15	2.16	19.2	< 0.001
Month	10	1.37	12.2	< 0.001
Diver	15	6.64	59.2	< 0.001
Residual	3574	0.11		

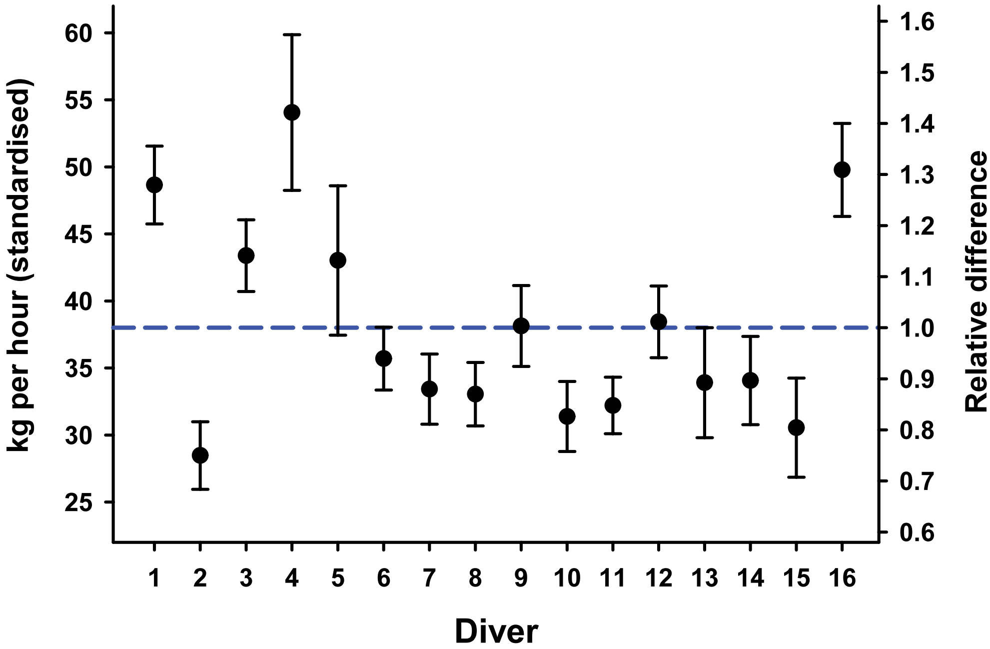

Figure 8. Diver variation in least squares mean Roe's CPUE (± 95% CL) in the Area 7 Roe's abalone fishery. Relative differences (to the mean) are shown on the right axis.

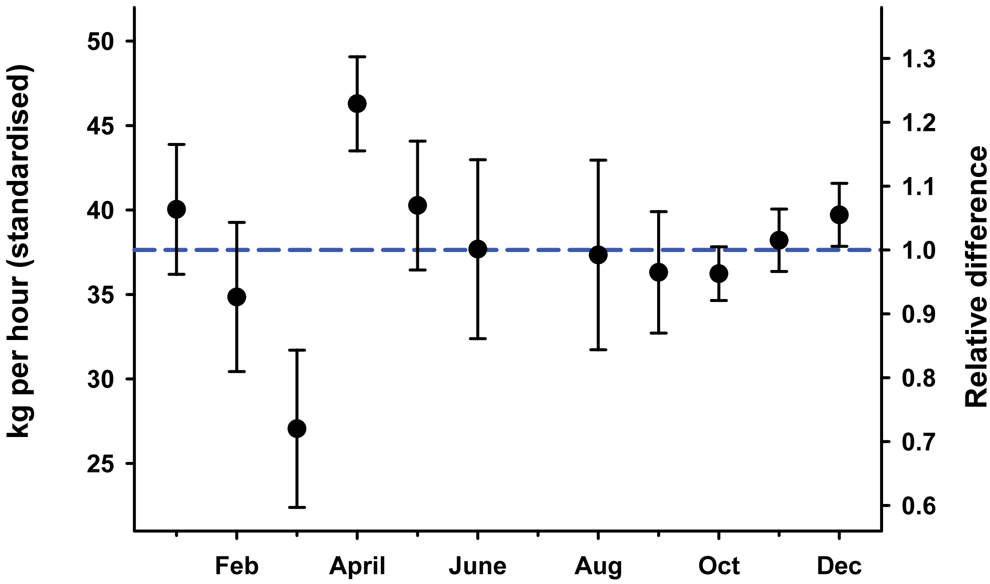

Figure 9. Monthly variation in least squares mean Roe's CPUE (± 95% CL) in the Area 7 Roe's abalone fishery. Relative differences (to the mean) are shown on the right axis.

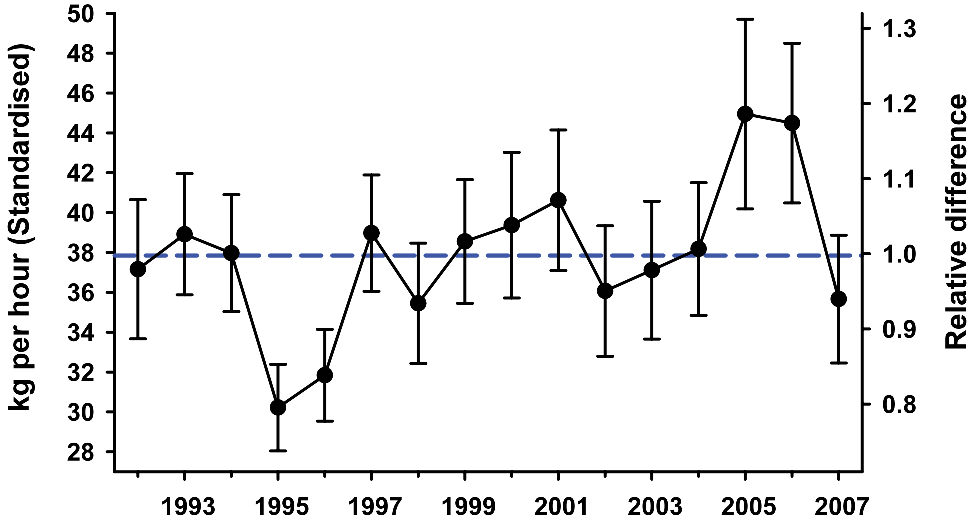

Figure 10. Yearly variation in least squares mean CPUE (± 95% CL) in the Area 7 Roe's abalone fishery. Relative differences (to the mean) are shown on the right axis.

2.0 Performance Indicators, Biological Reference Points, and Decision Rules

2.1 Introduction and Conceptual Definitions

Performance indicators (PIs) and biological reference points (BRPs) are necessary components of harvest control strategy in fisheries (Anon, 2007). They provide a level of certainty around management decisions, and stakeholders can play an active role in their development.

Under the harvest strategy policy guidelines for Commonwealth fisheries, terms such as "performance measures", "indicators", and "reference points" encapsulate the management system (Anon, 2007). Using Figure 11 as a guide, a brief summary of these is as follows: a performance measure defines progress against a management objective, and is the measure of where a PI sits in relation to a BRP (Figure 11). The PI can be a direct observation such as CPUE or another index of density, or it may be an output of an assessment model, such as breeding stock biomass. BRPs define particular levels of an indicator, in this case, the limit is where you don't want to be, the threshold is the minimum level above which the performance indicators need to be, whereas the target defines an optimum state of the fishery.

Progress against management objectives is captured by the performance measure, which feeds into the management decision rules (Figure 11). These decision rules can take many forms, in their simplest role they will suggest a change in harvest strategy, such as lowering the Total Allowable Catch, in response to the performance measure.

Under the Commonwealth guidelines the biological reference points (Limit, Threshold, Target) have particular minimum standards (Anon, 2007). For example, the limit reference point (B_{LIM}) or its proxy value, must be greater than 0.5 B_{MSY}, or its proxy value. B_{LIM} corresponds to the biomass level at which the risk to the stock is unacceptably high, and recruitment overfishing likely to occur (Myers et al., 1994), and B_{MSY} is the biomass that gives the maximum sustainable yield.

In the absence of sufficiently robust estimates of B_{LIM} and B_{MSY}, as is the case for the Western Australian abalone fisheries, BRPs can still be obtained by analysing the variability in catch per unit effort (CPUE) from a time period over which the fishery has been considered sustainable. In this study, estimates of B_{LIM} are not as closely related to biological sustainability as recommended under the Commonwealth guidelines, instead being more aligned with an economic B_{LIM}, i.e. the level below which it becomes economically unviable to fish.

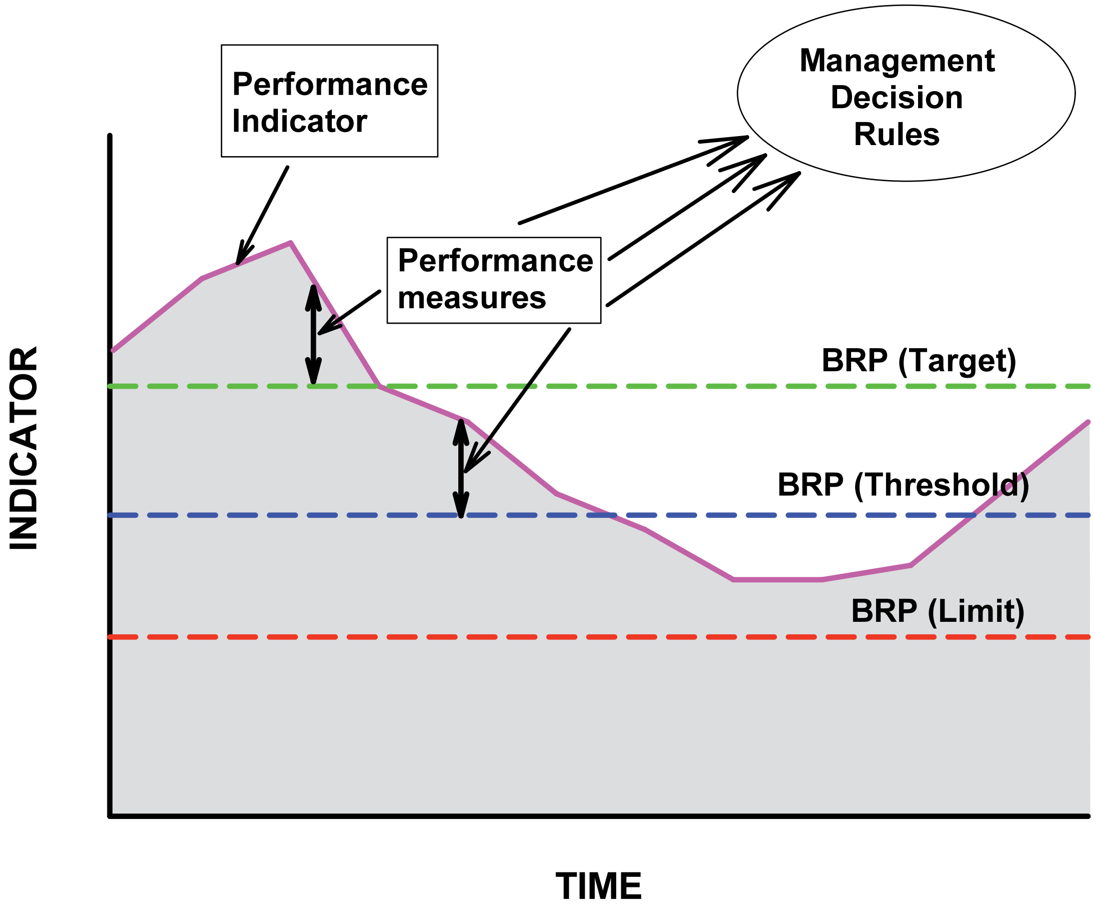

Figure 11. Conceptual definition of performance indicators, performance measures, biological reference points and their relation to management decision rules (Adapted from Commonwealth Policy Guidelines – Anon, 2007).

2.2 Performance Indicators

The performance indicators (PIs) for each abalone fishery were estimated as the 3-year running mean of the standardised yearly CPUE. The running mean enables a better estimate of the trend of the time series and removes the variation associated with annual variation that may be driven by environmental conditions. Estimates of standardised yearly CPUE were derived from the model described in Section 1.2.5.

2.3 Biological Reference Points and sustainable TACCs

A summary of the biological reference points (BRPs) for each management area is provided in Table 6.

BRPs have been defined in relation to PIs estimated from the standardised catch per unit effort (SCPUE) models, and their values are critically dependent on the models, which may change over time. The key element in the setting of BRPs is the threshold reference year (Table 6). Setting a reference year allows for a relative comparison of abundance across the entire history of the fishery, regardless of the model used.

The rationale for choosing the reference year was to first, estimate the threshold value using the criteria developed in Table 7. Second, identify the year in which the standardised CPUE was closest to this value. The target and limit BRP were then chosen relative to the threshold BRP.

A graphical representation of the BRPs in relation to SCPUE and the performance indicator (3 year average) for the Area 2 Greenlip abalone fishery is given Figure 12. Performance indicators and BRPs for all areas are summarised in Appendix 6.2.

Table 6. Biological Reference Points (BRPs) and sustainable TACs for management areas and species in the Western Australian abalone fisheries.

Area	Species	Threshold Reference Year	Sustainable TAC (t)	Biological Reference Points		
				Threshold Value* (kg/hr)	Limit value (20% below Threshold)	Target value (20% above Threshold
2	*H. laevigata*	2005	30.0#	12.09 (1.0)	9.89 (0.8)	14.83 (1.2)
3	*H. laevigata*	2004	35.0	12.24 (1.0)	9.74 (0.8)	14.62 (1.2)
2	*H. roei*	1995	19.8@	25.52 (1.0)	20.44 (0.8)	30.66 (1.2)
5	*H. roei*	1993	20.0	23.42 (1.0)	17.60 (0.8)	26.40 (1.2)
6	*H. roei*	1993	12.0	21.69 (1.0)	17.09 (0.8)	25.63 (1.2)
7	*H. roei*	1998	36.0	35.24 (1.0)	26.56 (0.8)	40.10 (1.2)
8	*H. roei*	1998	12.0	20.17 (1.0)	16.20 (0.8)	24.30 (1.2)

H. laevigata TAC in meat weight; @ *H. roei* TAC in whole weight

* current threshold value (as of Dec 2008)

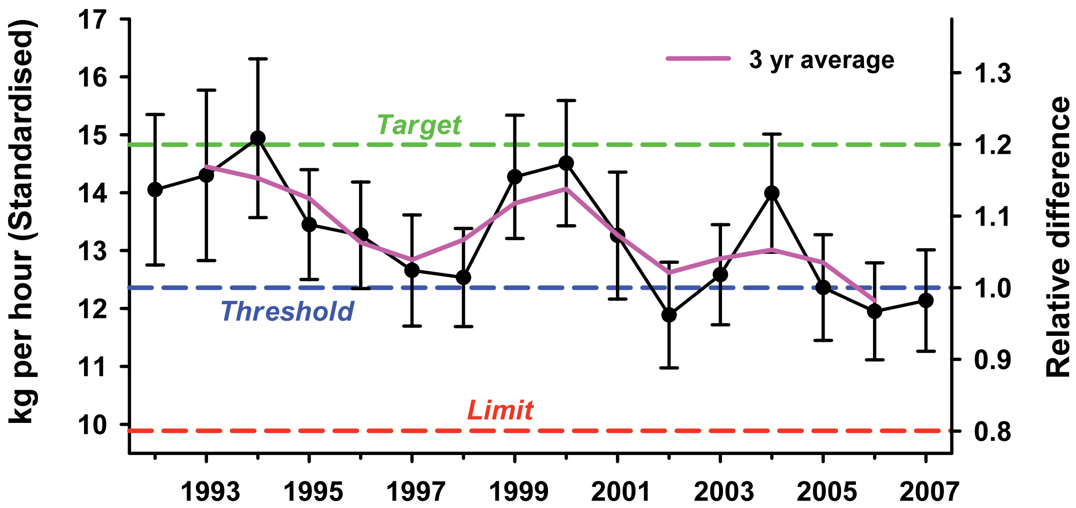

Figure 12. Example of performance indicator (pink line) and biological reference points (Target, Limit, Threshold) for the Area 2 Greenlip abalone fishery. Yearly data are least squares means (± 95% CLs), and relative differences (to the reference year / threshold BRP) are on the right axis.

The long-term sustainable TAC was estimated for each area by calculating the average catch over the years 1992 – 2006. The TAC is maintained if the PI remains between the target and threshold, or recommended for change if the PI is outside this range (Table 7, Fig. 12).

2.4 Management Decision Rules

The decision rules adjust TAC in specified amounts depending on the performance measure, as summarised in Table 7. They are designed to capture most management scenarios predicted to arise from our historical observations of the behaviour of the SCPUE trends. However they specifically reflect a stock maintenance objective in fully exploited fisheries, i.e., to maintain stock biomass to enable harvesting of the average long-term sustainable TAC. Should a rebuilding or other strategy be required a different set of rules may be adopted.

Table 7. Management decision rules in relation to defined biological reference points (BRPs) for Western Australian Abalone Fisheries. Refer to Figure 12 for the relationship between the performance indicator and biological reference points.

BRPs	Description	Decision Rule
Target	20% above Threshold	Minimum of 10% TAC increase if PI is above the target BRP
Threshold	upper end of the bottom 30% of the historical variability in the PI	a) Maintain TAC at long-term sustainable level if PI is above threshold and below target BRP b) 10% TAC decrease (below long-term sustainable level) if PI is below threshold and above limit BRP
Limit	20% below Threshold	Minimum of 30% TAC decrease if PI is below limit BRP

3.0 Discussion

If performance indicators and decision rules are to be used in managing a fishery they need to be sufficiently robust to assist in stock management decisions. The decision rules also need to cover most of the management scenarios predicted to arise. The current rules specifically reflect a stock maintenance objective in fully exploited fisheries, i.e., to maintain stock biomass to enable harvesting of the average long-term sustainable TAC. If the management objective were to alter, a different set of decision rules may be required.

Improvements to the GLM models in explaining the variability in CPUE may further improve the performance indicators. For example, a potential effort correction factor not explored in this report, but which is a valid exercise for abalone fisheries, is to separate out searching time from handling time (Beinssen, 1979). Abalone diver effort consists of two components, searching time (S), and handling time (h). Searching time is the effective measure of effort, whereas handling time is the time spent handling the abalone. As abundance increases, searching time decreases and handling time increases and vice versa. This procedure is used to adjust effort estimates obtained from research diver surveys on both Greenlip abalone populations in South Australia (Dowling et al., 2004), and New Zealand paua (Breen and Kim, 2005). However it has not been applied to commercial abalone fishery data to date because of lack of knowledge of total number of abalone caught. These data (total number of abalone caught) are recorded for the Greenlip and Brownlip fisheries in Western Australia and could be used at a future date to get a better estimate of effort.

Other improvements will be the inclusion of environmental factors that significantly impact on CPUE such as swell and wind, and identifying changes in harvest practices (e.g. targeting larger sizes) that affect CPUE data. These will be incorporated into the models as data becomes available.

3.1 Future directions for performance indicators

In the long-term the performance indicators for the stock will be improved by research in the following areas.

- Harvest rate analysis (e.g. from commercial catch sampling)
- Catch prediction (e.g. with data obtained from fishery independent surveys)
- Fishery independent surveys' using a combination of industry video surveys and research diver transects.
- Estimates of key parameters such as B_{LIM}, the biomass limit reference point, and B_{MSY}, the biomass that gives the maximum sustainable yield, and B_{MEY}, the biomass that gives the maximum economic yield, derived from a formal assessment model of the fishery.
- Research into the biological and economic basis for setting the BRPs
- Environmental factors affecting CPUE
- Identification of changes in fishers' harvesting practices
- Assessment of the time taken to achieve the brownlip quota, relative to the GL quota

In particular, catch predictions enable the TAC to be set on the actual abundance of abalone in the year of fishing, rather than the average abundance 1 to 3 years previously.

Ideally, a decision-rule framework that incorporates knowledge of stock biomass and harvest rate can be developed. Such a framework is outlined in Figure 13. The advantage of this approach is that it integrates biological knowledge with fishing behaviour of the fleet into a coherent management system.

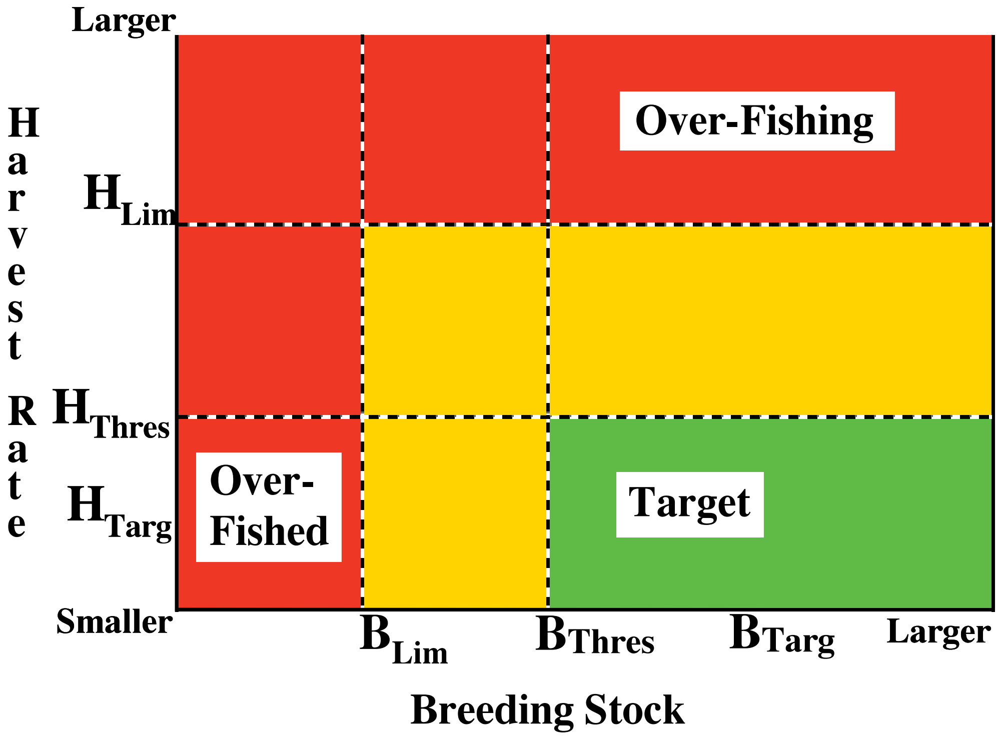

Figure 13. Biological Reference Points (BRPs) based on the relationship between Harvest Rate and Breeding stock (Adopted from Anon, 2007).

4.0 Acknowledgements

This review benefited from many parties. Our first thanks go to the abalone industry licensees divers for responding in-depth to the various questionnaires, and attending the numerous technical presentations as well as critiquing the analyses. AbMac members are thanked for their strategic actions in recommending this review be undertaken. The performance indicator reference group (PIRG) consisted of Kerry Rowe, Allan Wilson, Brad Adams, John South, and Dave Sutcliff, and they provided constructive criticism to proposed models. Finally we thank DoF statisticians Mr Brent Wise, and Mr Adrian Thompson for critically reviewing the manuscript.

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6.0 Appendices

6.1 Fishing efficiency and technology questionnaire

Aim

In September 2007, a diver phone questionnaire was developed to gather data that was used as an aid in the process of commercial abalone logbook CPUE standardisation (for performance indicator appraisal and potential selection).

Method

The questionnaire incorporated questions on diver gear development and questions about the weather and weather prediction (Figure 13). Both greenlip/brownlip and roei zone III divers were canvassed over the phone and asked if they used certain technological developments and if so, what year they began to use the technology. Divers were then asked to rate the importance of the use of the technology in catching their quota, 1 being of no importance and 5 being critical.

Results

Eight greenlip/brownlip divers and seven roei commercial abalone divers participated in the questionnaire during September and October 2007. The results of the greenlip/brownlip questionnaire are found in Table 1 and the results of the roei questionnaire are found in Table 2.

On average, greenlip/brownlip divers rated GPS, depth sounders, scooters/cages, hot water systems (HWS) and internet weather predictions (IWP) technology in the reasonably important to critical categories. In contrast, roei divers, on average, rated the use of IWP in the very important to critical category.

Nitrox and oxygen for decompression were used by very few greenlip/ brownlip divers, however, those divers that used this technology rated the technology as very important to critical.

HWS, nitrox, oxygen for decompression and scooters/cages were not used by roei divers who participated in the survey. However, two roei divers used GPS and sounders but rated their use as of little importance in catching their quota.

Greenlip/brownlip divers were willing to work in onshore conditions to an average wind speed of 25 knots and a maximum swell of 3.5m. Roei divers were willing to work in onshore conditions to an average wind speed of 19 knots and a average maximum swell of 1.5m.

Discussion

It is clear from the response of divers that a number of technology developments within the commercial abalone fishery have increased their ability to catch their quota (efficiency). Both the greenlip/brownlip and roei divers rate the use of internet weather predictions from reasonably important to critical. It is useful to take this technological development into consideration when standardising for CPUE. Similarly, other gear used by the greenlip/brownlip divers including GPS, depth sounders and scooters/cages are also most certainly increasing catching efficiencies and need to be considered also.

Table 1. Greenlip/brownlip diver questionnaire results.

Technology	Year	Average Importance/Conditions
GPS	1995	Reasonably to very important
Depth sounder	1993	Very important to critical
Scooter/Cage	1996	Very important to critical
HWS	2000	Very important
IWP	2003	Reasonably important
Max wind speed (onshore)	-	25 knots
Max swell	-	3.5m

Table 2. Roes diver questionnaire results.

Technology	Year	Average Importance/Conditions
IWP	2002	Very important to critical
Max wind speed (onshore)	-	19 knots
Max swell	-	1.9m

Diver Gear Technology and Weather Questionnaire, September 2007

Diver Name: **Date:**

Gear Technology

1a Do you use **GPS**?
1b What year did you start this technology?
1c How important is the use of GPS in catching your quota?

2a Do you use **depth sounder**?
2b What year did you start this technology?
2c How important is the use of a depth sounder in catching your quota?

3a Do you use **scooter/cage**?
3b What year did you start this technology?
3c How important is the use of a scooter/cage in catching your quota?

4a Do you use a **hot water system** to keep warm?
4b What year did you start this technology?
4c How important is the use of hot water in catching your quota?

5a Do you use **oxygen for decompression**?
5b What year did you start this technology?
5c How important is the use of hot water in catching your quota?

6a Do you **nitrox**?
6b What year did you start this technology?
6c What percentage of your total dive time do you use nitrox?
6d How important is the use nitrox in catching your quota?

7a Do you use **the internet for weather predications**?
7b What year did you start this technology?
7c How important is the use of **the internet for weather predications** in catching your quota?

Weather

8a What are the most favourable **wind directions** for fishing this area?

8b On average, what strength **wind** will prevent you from going to work?
8c On average, what size **swell** will prevent you from going to work?

Diver rating scale (part c)		
	1	No importance
	2	Little importance
	3	Reasonably important
	4	Very important
	5	Critical

Figure 14. Technology and fishing efficiency questionnaire design.

6.2 Performance indicators and biological reference points for each management area and species

6.2.1 Area 1 Greenlip and Roe's abalone fishery

Area 1 is remote and inaccessible, being principally stationed below the Nullabor Cliffs (see Figs. 2 & 3) and fishing is generally of an exploratory nature. Consequently, the historical time series of catch per unit effort for both Greenlip and Roe's abalone was too variable to be used to develop PI's. TAC assessment and management in this region will continue to be based largely on raw data trends and feedback from industry divers as to their own harvest plans.

6.2.2 Area 2 Roe's abalone fishery

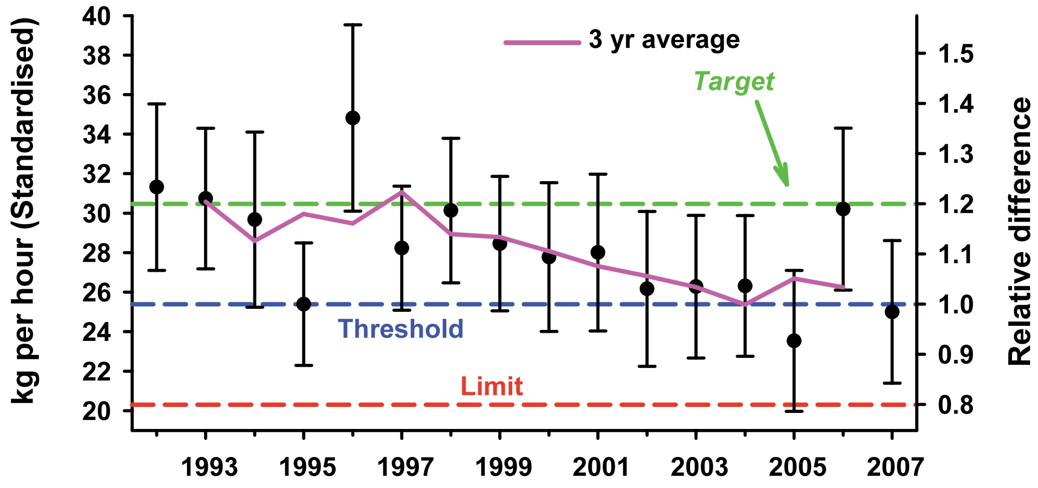
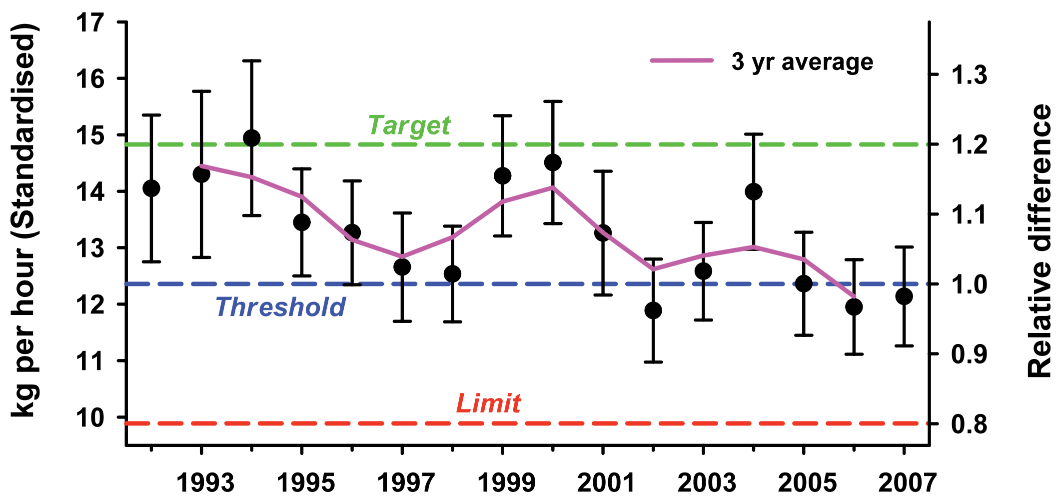
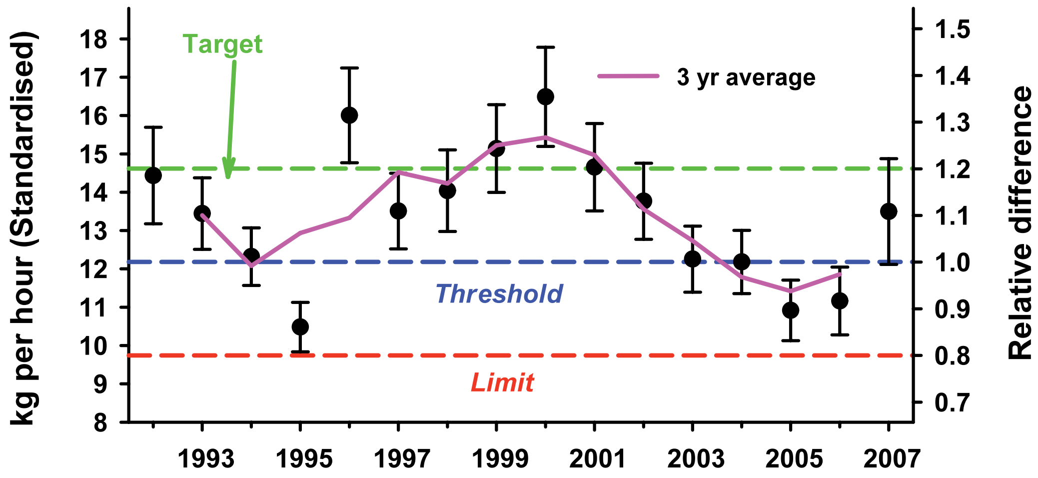


Figure 15. Example of performance indicator (pink line) and biological reference points (Target, Limit, Threshold) for the Area 2 Roe's abalone fishery. Yearly data are least squares means (± 95% CLs), and relative differences (to the reference year / threshold BRP) are on the right axis.

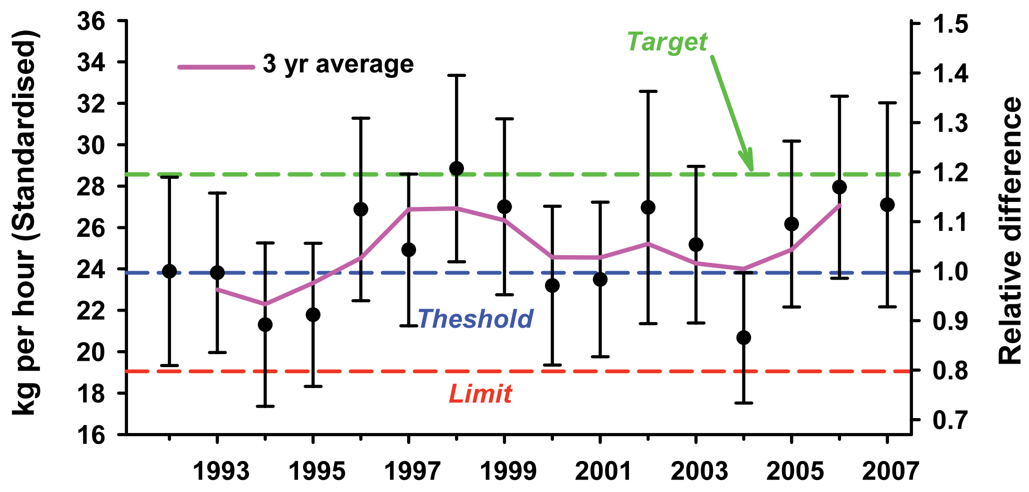
6.2.3 Area 2 Greenlip abalone fishery



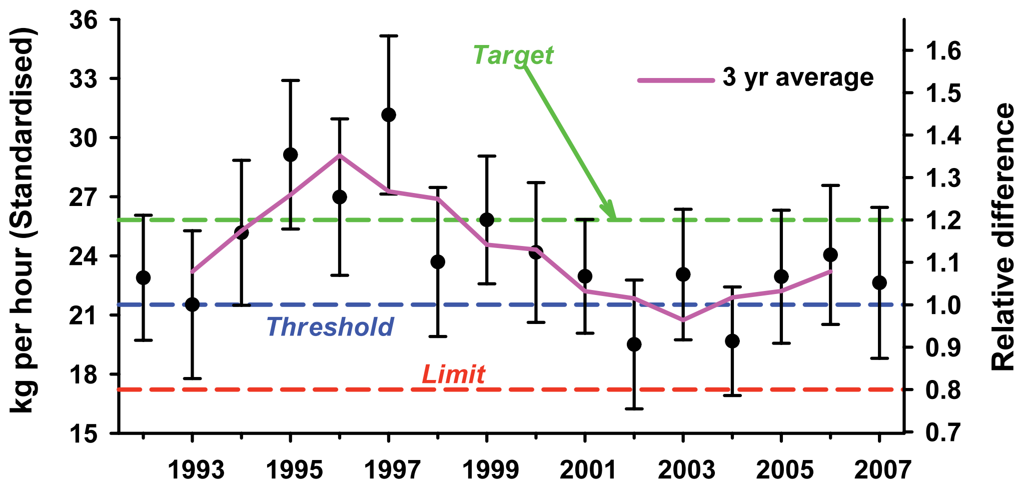
6.2.4 Area 3 Greenlip abalone fishery



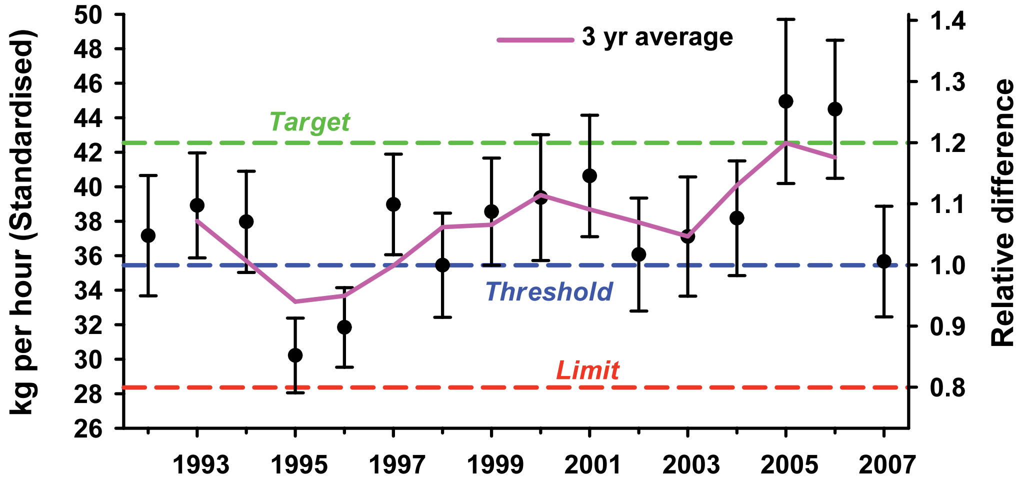
6.2.5 Area 5 Roe's abalone fishery



6.2.6 Area 6 Roe's abalone fishery



6.2.7 Area 7 Roe's abalone fishery



6.2.8 Area 8 Roe's abalone fishery