Australia's National
Science Agency

Final report on the Review of Tasmanian Abalone Harvest Strategy

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Contents

1 Harvest Strategy Background

1.1 What is a harvest strategy?

A harvest strategy outlines management control of a fishery and the reasons for it. Harvest strategies specify active periodic control mechanisms, in contrast to more passive “set-and-forget” management actions such as size limits, and marine reserves. They conceptually sit within a broader fishery management plan, or management strategy. Harvest strategies incorporate data collection procedures, and ultimately specify formal rules for translating data into management actions. They need not apply only to catch controls, and have been successfully applied to input controls, such as effort.

1.1.1 Harvest Strategy

A harvest strategy consists of several core components:

- One or more **operational objectives** including policy and management goals;
- Indicators that measure performance against the objectives, which can include:
    - a specified desired state of a fishery, called a **target reference point**;
    - the bounds of an undesired state, called a **limit reference point**; and
    - an intermediate reference point, called a **trigger** which is intended to prompt a management response.
- A statement defining acceptable levels of risk to meeting the objectives
- A monitoring and data collection strategy and program to capture the state of the fishery or stock;
- An analytical process, including assessment, that translates the data collected from the monitoring program into a management control response;
- A decision rule, called a harvest control rule, representing a control response which acts on catch (output control) or effort (input control) to achieve the operational objective.

1.1.2 Empirical harvest strategies

Empirical harvest strategies use empirically derived indicators such as mean lengths, mean ages, or CPUE, replacing an assessment of stock status based on models (Dowling et al. 2015). Indicators are thus required to reflect stock status in some way, so that changes in them can be used by the harvest strategy to steer the stock towards meeting management objectives.

1.1.3 Evaluation

In addition, before a harvest strategy is implemented, or changes to one are made, best-practice requires simulation testing to ensure the harvest strategy achieves the desired management objectives (Sloane et al. 2014).

2 The Tasmanian Abalone Harvest Strategy

The Tasmanian Abalone Harvest Strategy (Bradshaw, 2018) was implemented in 2018 and was intended to run until 2020, at which point it was to be reviewed. It was previously reviewed in 2015 by Buxton et al. (2015) and in 2019 by Mayfield (2019). This review examines the scientific and operational basis for the harvest strategy, and the TAC setting process, primarily related to the First aim of the Harvest Strategy to *ensure abalone are sustainably harvested*. It does not examine the specific calculations or data analyses, which would require an in-depth knowledge of the data, and management history of the fishery. This information is well-documented, maintained and reported in the annual Tasmanian abalone fishery assessment reports (Mundy and McAllister 2020). This review also does not cover some of the non-technical parts such as the Second Aim to *ensure use of the abalone resource provide appropriate benefits to the community*, the Third Aim *to minimise harmful ecosystem impacts*, or the Fourth Aim to *practise good governance*. These Aims cover strategies relating to non-commercial catch controls, identification and management of harmful diseases, parasites and invasive species. In general, such responsibilities are beyond the concern of a harvest strategy *per se*, but still remain the concern addressed by a broader management strategy, and management agency. In general, national best-practice standards or guidelines for fisheries management have been addressed by Hobday et al. (2019).

The key elements of the Tasmanian Abalone Harvest Strategy (Bradshaw 2018) in the context of a best-practice harvest strategy from Sloane et al. (2014) are presented in Figure 1. The main objectives of the Harvest Strategy relating to its First aim of *ensuring abalone are sustainably harvested* are:

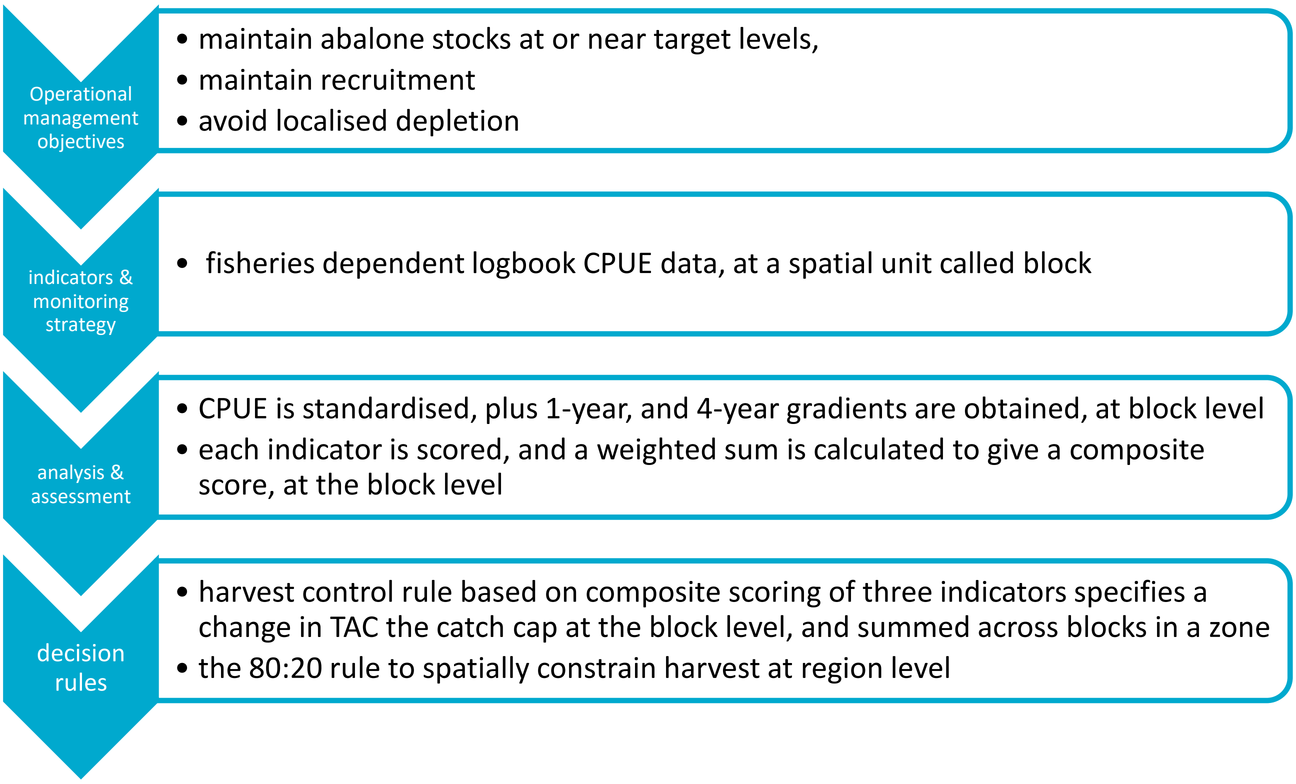
1. to maintain abalone stocks at or near target levels;
2. to maintain recruitment to rebuild or keep stocks at target levels, and
3. avoid localised depletion.

Although Objective 3 of *avoiding localised depletion* is not an explicit objective of the Harvest Strategy, Bradshaw (2018) notes the approach of spatial management is taken to avoid localised depletion (page 18). Thus, it implicitly states that avoiding localised depletion is an objective (to which spatial management is the strategy), and so I have assumed such an objective.

1. **The Harvest Strategy should clarify whether avoiding localised depletion is a management objective.**

Management actions that are set out to achieve these objectives respectively, are:

  a. Set an annual TAC using an empirical harvest strategy;
  b. Set a legal minimum length (LML); and
  c. Ensure spatial catch targets are established and enforced



Operational management objectives

- maintain abalone stocks at or near target levels,
- maintain recruitment
- avoid localised depletion

indicators & monitoring strategy

- fisheries dependent logbook CPUE data, at a spatial unit called block

analysis & assessment

- CPUE is standardised, plus 1-year, and 4-year gradients are obtained, at block level
- each indicator is scored, and a weighted sum is calculated to give a composite score, at the block level

decision rules

- harvest control rule based on composite scoring of three indicators specifies a change in TAC the catch cap at the block level, and summed across blocks in a zone
- the 80:20 rule to spatially constrain harvest at region level

Figure 1 Summary of the Tasmanian Harvest Strategy in the context of a generic harvest strategy (Sloane et al. 2014).

Abalone exist in functionally independent populations with low connectivity (e.g. Mayfield et al. 2014). Blacklip and greenlip abalone co-occur naturally in some areas in northern Tasmania. Greenlip tend to be associated with warm water conditions, high current and low wave action in the north of the state. Blacklip are more thermally tolerant and are found in higher energy environments, across the state. Both species have highly spatial life histories, growth and maturity patterns, and are slow growing. A detailed review of growth and maturity, and the spatial variability of it, was recently conducted by Jones et al. (2020).

In general, a challenge for spatially structured fisheries is balancing the need for, and cost of management at small spatial scales against the pragmatic need to have harvest strategies based on reasonable sets of data, applied over an enforceable area (Sloane et al. 2014). Sloane et al. (2014) recognised that abalone fisheries face challenges because differential growth and productivity at fine (reef-level) scales leads to differential levels of protection across a wider area. They suggest:

1. Objectives be consistent across the wider fishery, but separate reference points be applied at smaller spatial scales.

2. Risk to the fishery should be managed by basing the harvest strategy on the biology of the most vulnerable sub-population, rather than on the average biology across the fish stock or fisheries management unit.

At a broad level the Tasmanian Abalone fishery is divided into zones (Figure 2). Logbook catches and effort are reported at the scale of blocks and sub-blocks. The fact that there are sub-blocks (e.g. 12A, 12B and 12C) implies a process has occurred that has resulted in dividing former blocks. The question thus is why has this been done? The Harvest Strategy does not provide a rationale for what defines a spatial management unit (block, or sub-block), the criteria for defining them, or the process of re-defining them.

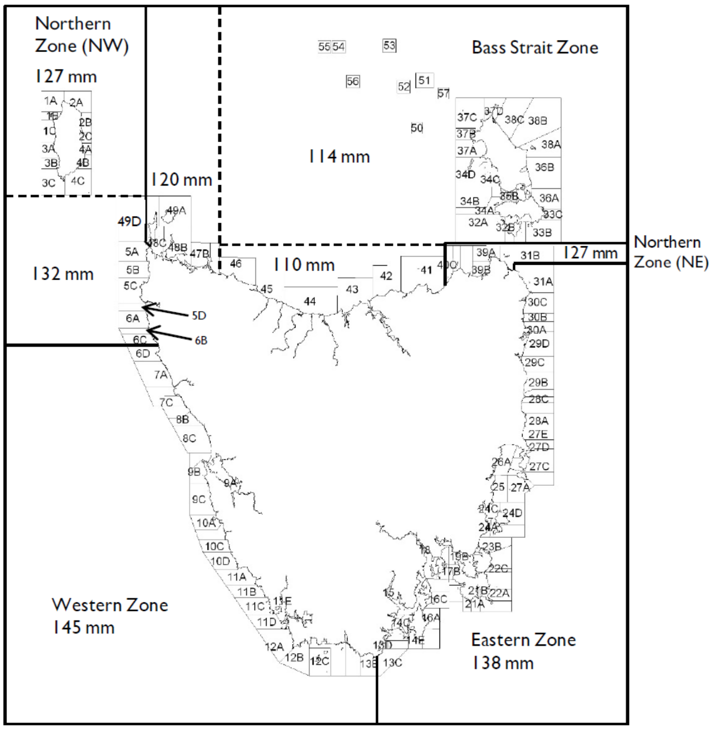


Figure 2 Spatial zones, associated LML and reporting blocks for blacklip abalone in the Tasmanian abalone fishery.

The general concern therefore is that the Harvest Strategy does not specify the spatial scale at which the fishery should be managed. This could lead to uncertainty, confusion and disagreement over application of management actions.

In summary, the Harvest Strategy manages stock size and recruitment (objectives 1 and 2) with TACs and LMLs applied at the zone level. TACs are calculated by summing catch allocations across blocks, and sub-blocks. Catch allocations to blocks are calculated based on scoring three CPUE indicators relative to a target at that scale. A weighted sum of the three scores is calculated and applied to a harvest control rule that specifies whether the individual block catch allocation from the previous year should increase, decrease or stay as it is. Interviews with stakeholders suggested that localised depletion (objective 3) is managed with spatial catch caps applied at a “regional” level, but what a region is defined as is not clear.

2. **The Harvest Strategy should provide greater clarity on the spatial scale(s) at which the fishery is managed, and the criteria of what defines the spatial unit of management.**

2.1 Setting the LML

Legal minimum length (LML) is the component of the Harvest Strategy that attempts to *maintain recruitment to rebuild or keep stocks at or near target levels*. LML is based on growth and maturity and is set to allow 3-years of spawning post maturity, with maturity being defined as the length at which 50% of animals are mature (Lmat50).

Several growth functions have been proposed for abalone. One of the most recently developed, the inverse-logistic (Haddon et al. 2008), is independent of age and specifies an expected growth (length) increment based on current length. Maturity is represented as a logistic function of the proportion of individuals that are mature by length. Combining growth and maturity in a population dynamics model shows the effect of a 140mm LML compared to a 130mm LML in Figure 3. In this example where the harvest rate was set at 0.4, the larger LML results in about 55% more spawners. In terms of biomass protection, Bradshaw (2018) reported that Haddon and Mundy (2016) translate the effect of a 140mm LML as protecting over 10 times more unfished spawning biomass than a 127mm LML (Bradshaw 2018; page 28).

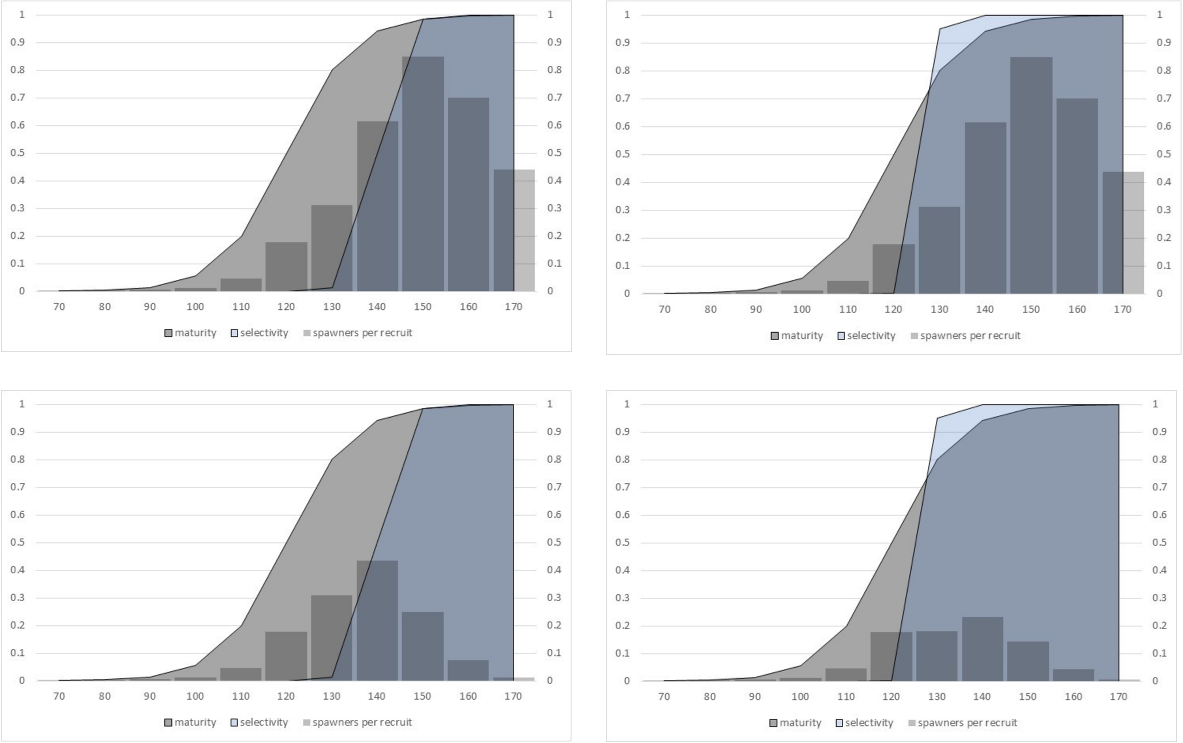


Figure 3 Equilibrium size distribution (grey bars) of mature spawning animals (relative to average number of recruits) subject to inverse-logistic growth under no fishing (top panel) and 0.4 harvest rate (bottom panel), parameterised according to Haddon and Mundy (2016). Grey curve / area represents the proportion of animal of given size that are mature. Blue curve / area represents the proportion of animal of given size that are selected and vulnerable to fishing. Left panels represents LML 140mm, and right panels 130mm.

Calculating LML

The calculation of the LML for blacklip abalone has recently been reviewed by Jones et al. (2020). In general, growth and maturity functions have been estimated at a size resolution greater than that shown in Figure 3 and spatially around the state (Jones et al. 2020; Haddon and Mundy 2016). Growth and maturity data were obtained from two data sets. Inverse-logistic growth functions were fit to data based on measurements from a tag-release-recapture dataset. Maturity was based on data collected from visual examination of gonads and length measurements, collected around the state from 112 sub-blocks with more than 150 observations.

The two datasets were matched according to an assumption that samples taken at the same location, but a year apart would not have differed significantly. A regression of the growth and maturity parameters allowed growth parameters to be allocated to the remaining maturity datasets that did not have corresponding growth data.

Since the population dynamics model of abalone was not dependent on age of animals but rather a growth transition matrix, calculating the effect of different LMLs and survivability 1, 2 and 3-years post-maturity was calculated through simulation. This was done by releasing 1,000 simulated animals at Lmat50 and observing the size distribution 1, 2 and 3 year intervals post-release (Figure 4). Jones et al. (2020) applied this spatially across several blocks in the Eastern, Western and Northern zones relative to their LMLs (and at a size resolution greater than the model represented in Figure 4).

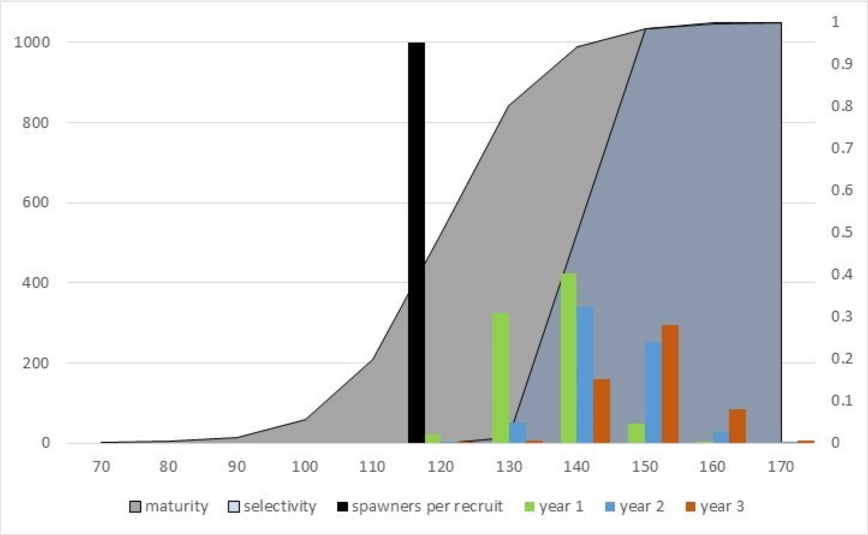


Figure 4 Example of size distribution of 1000 animals (black bar) seeded at Lmat50 of 120mm, 1 (green), 2 (blue) and 3 (orange) -years post-release. Grey curve / area represents the proportion of animal of given size that are mature. Blue curve / area represents the proportion of animal of given size that are selected and vulnerable to fishing. Mean shell lengths (bars) from this model were 136mm, 143mm and 148mm, 1 (green), 2 (blue) and 3 (orange) -years post release, respectively.

They showed that across all blocks and zones almost all fish were below their LML after 1 year of growth. Thus, the LML gives at least 1 year of spawning to all animals. After 2 years of growth the median number of animals in blocks tended to be above the LML in the Western and Northern zones, implying that the LML protects around 50% of animals for 2 years. This was not the case in blocks of the Eastern zone, however. Importantly, within block variation of animal size was large, especially in the Eastern zone, where the median size could be above the LML, but the average size of fish in the block was below.

After 3 years of growth post-maturity, almost all blocks in the Eastern zone had median fish sizes above 145mm, though still some blocks had wide variability in lengths. Fewer blocks were examined by Jones et al. (2020) in the Western and Northern zones. In the Western zone, 3 years of growth post-maturity allowed roughly 95% of animals to be above 140mm. This was generally case in the Northern zone, with some blocks displaying low and variable growth patterns.

Conclusion

These results, particularly from the Eastern zone, point out wide spatial variability both within blocks, and across blocks. An LML of 3-year post maturity, “the 3-year rule” seems to be able to the job it was designed to do, which is to protect a proportion of the spawning biomass of local populations. Not surprisingly, the previous “2-year rule” would also protect spawning individuals, but faster growing blocks could be at risk of localised depletion, as it would allow fewer spawning opportunities.

The question that comes to mind from these results is: is this good enough? Knuckey (2015) asks a similar question: What are the correct LMLs for Tasmania? The answer of course is that it depends on the management objective. The management objective of maintaining levels of recruitment does not provide a quantitative operational measure of success, so it is uncertain whether the “2-year rule” or “3-year rule” is sufficient.

3. **DPIPWE develop a clear operational objective, with performance indicator and target, relating to recruitment and stock level.**

Such an objective could be applied to the stock recruitment, i.e. eggs or larvae.

Box 1.

Harvest Strategy objectives that use recruitment indicators

The WA Dept of Fisheries (2010, 2014) outline an objective for Western Rock Lobster *to ensure that the egg production in the Breeding Stock Management Areas of the Fishery remains above its threshold value for the next five years with a probability greater than 75%.*

The Small Pelagic Fishery (SPF) Harvest Strategy (AFMA 2017b) is based primarily on fishery–independent Daily Egg Production Method (DEPM) surveys. This method generates estimates of spawning stock size based on surveys of eggs during the spawning seasons for four species in the fishery. DEPM estimates are used as absolute estimates of stock size for the purpose of calculating RBCs. The Harvest Strategy sets exploitation rates to *maintain stocks on average at a target DEPM estimate of 50% of unfished levels of spawning stock biomass, with a risk tolerance such that <10% chance over 50 years of falling below a limit reference point of 20% of unfished levels*.

The Harvest Strategy also does not clearly state the risk tolerance of not achieving this objective. Such statements of acceptable risk are a key feature of harvest strategies (Sloan et al. 2014). In the Commonwealth Harvest Strategy policy (DAWR 2018) for example, all commercial fish stocks are required to maintain biomass above the limit reference point with at least 90% assurance.

4. **Levels of risk tolerance should be specified for all management objectives.**

2.2 Empirical harvest strategy

The Harvest Strategy uses an empirical harvest strategy to *maintain abalone stocks at or near target levels*. Empirical harvest strategies use empirically derived indicators such as mean lengths, mean ages, or CPUE, to reflect stock status in some way, so that changes in them can be used by the harvest strategy to steer the stock towards meeting management objectives. The Harvest Strategy does not explicitly state the indicator or the target. Additionally, several interviews discussed the need for the fishery to recover from an overfished state. If this is an objective of management, it should be made explicit.

5. **It is recommended that in stating the objective to maintain stocks at target levels, DPIPWE explicitly state the target, and the indicator. If rebuilding is an objective, DPIPWE should state the rebuilding target. As previously indicated, the spatial scale at which targets are applied should also be explicitly stated.**

Buxton et al. (2015) recommended that desired rates of rebuilding be built into the operational management objectives. The Harvest Strategy (Bradshaw 2018) does not define how rebuilding should occur other than in reference to setting the LML. The need for rebuilding implies the fishery is in an undesirable state but this state i.e. the limit reference point has not been defined.

6. **Limit reference points should define undesirable states of the fishery, and the harvest control rule should define the course of action under such conditions.**

2.2.1 Indicators and Monitoring

The empirical harvest strategy relies principally on fishery-dependent catch rate (CPUE). Three indicators of CPUE measure fishery performance:

1. The current standardised CPUE;

2. the gradient of change in CPUE in the past 12 months (current year over the previous

one year); and

3. the gradient of change in CPUE over the past four years including year to date.

These indicators are calculated for each of the 155 management (sub-)blocks in the fishery.

1. **CPUE**

Standardised CPUE is used is used as one indicator in the empirical harvest strategy and is measured against a target CPUE. Some stakeholders understand the purpose and process of CPUE standardisation, but uncertainty exists about the factors considered in that analysis, reasons for perceived changes in it.

7. **The factors and process of CPUE standardisation should be documented in the Harvest Strategy, and suggested changes should be conducted in consultation with management and stakeholders.**

Consultation with stakeholders is a highly desirable feature for managing fisheries, because it provides opportunity for stakeholders to provide insight, clarification and explanation of fishery trends, as well as take-away an understanding of the scientific process and management decisions. Care must be taken however, that consultation does not evolve into a negotiated process, as this could compromise the management objective in the Harvest Strategy of *using best available scientific advice*.

The target CPUE is defined for each block as the 55th percentile of CPUE observations in a reference period between 1992 and the previous year of assessment. The intention of targeting CPUE above the median value (55th percentile) is precautionary (Bradshaw 2018). Interview discussions with stakeholders raised the issue of the choice of reference period, which excludes a period of low CPUE prior to 1992 (Bradshaw 2018), when effort reporting requirements are known to have changed. The criteria and justification for the choice of reference period should be made explicit. It is clear also that blocks have different catch histories, which raises the question: why do blocks with different catch histories have the same reference period? One option could be to allow blocks to have different reference periods.

The use of a reference period that moves in time has the potential to be unstable, and crucially could lead to high-risk activity. In a declining fishery, for example, as CPUE and available biomass decline, so will the target. A lower target means the indicator decline would be moderated, thus potentially masking the degree of decline in stock status in the longer-term. A retrospective analysis showing how the CPUE and target CPUE have changed in time would be able to show this effect. Previous Management Strategy Evaluation (MSE) of the Harvest Strategy (Haddon and Mundy,

2016) did not examine the potential effect of a moving target and it is strongly recommended that this be evaluated.

8. **It is strongly recommended that a fixed reference period be considered, or that the dynamic reference period is simulation tested. It is also recommended that the choice of reference period be justified (see box 1) and consistent with management objectives. A retrospective analysis showing how CPUE and targets have changed relative to each other would show the extent of risk that the stock has been subject to by a moving reference period.**

The original reason for using a moving reference period was to allow consideration of the potential environmental effects of regime shift or climate change. For such an approach to work however, environmental change would need to be gradual or continual. In contrast, the current approach allows the effects of episodic events such as recruitment pulses, storms or marine heat waves, to be entrenched in the reference period and target calculation in subsequent years, even after a system returns to normal.

The problem also with using a moving reference period to account for environmental trends is that any supposed climate effect is confounded with the effects of the fishery. Several stakeholder interviews suggested the possibility that other indicators could be included in the MCDA, including weather, and formalised diver input.

9. **The Harvest Strategy should consider objective climate and environmental indicators to factor the effects of long-term climate change and short-term episodic events into the TAC setting process.**

Box 2.

Reference period specification for the SESSF Tier 4 assessment

The Tier 4 assessment and harvest control rule for the Australian SESSF is an empirical harvest strategy, that uses CPUE as indicator targeting the average catch and CPUE (biomass) in a fixed reference period to calculate reference points. A full CPUE time series back to the start of fishing is mostly unavailable in the fishery, so it was necessary to choose a reference period from the data series. The default period is 1986-1995, but other periods are used for some species which were not fully developed in 1986.

The assumption is that the reference period represented a time that produced a sustainable yield at a relatively constant CPUE across species (Little et al. 2011), and corresponds as a proxy target reference point for BMEY (the Biomass at Maximum [sustainable] Economic Yield), which by default in the fishery is the spawning biomass of 48 per cent of unfished levels. (It is also recognised that the Tier 4 method is based on catch rates and thus relates to exploitable biomass and not spawning biomass.)

Most SESSF species are considered to be fully exploited by the time data began to be collected in 1986. However, if a stock was considered unexploited or lightly fished in 1986, then the initial CPUE level then would correspond to the unexploited biomass or B0, and the reference points considered as fractions of this (AFMA 2017).

In its current form, the empirical harvest strategy used in the Tasmanian abalone fishery is a form of proportional–integral–derivative control (PID controller). Such controllers are broadly applicable and rely on the response of a measured process variable (such as catch per unit effort; CPUE), not on knowledge or a model of the underlying process (e.g. a stock assessment model). In such cases there can be an increased risk of unstable dynamics, especially when there are long measurement lags.

Because abalone are relatively sessile animals, and slow to move and mix, the use of CPUE as a fishery indicator can be seen more as a measure of prior abundance than current abundance. As a result, responses to management actions are not immediately obvious. Indeed, with a lag of 3-4 years for animals to mature (Haddon and Mundy 2016) and another 3 years to become available to the fishery, the lag effect of management on CPUE would be approximately 6 years. The use of a leading indicator such as a pre-recruit survey would shorten this interval. Buxton et al. (2015) highlighted the importance of a leading indicator, and support was indicated during stakeholder consultation.

10. **The fishery (industry, management, scientists) consider pre-recruit surveys as an indicator to reduce lagged observation effects, with the potential of incorporating such an indicator into the TAC setting process and harvest control rule. Given the potential costs of such widespread functionally independent populations, costs may be a constraining factor.**

Suggested candidate indicators are the experimental Abalone Recruitment Modules (ARMs) that have been deployed to six locations (Mundy and McAllister 2020).

In a risk-cost-catch trade-off (DAWR 2018b, Dichmont 2017), greater certainty in stock status can reduce the risk of over-fishing and allow greater catches. It requires however increased management or monitoring, which adds to costs (Little et al. 2015). The Tasmanian abalone fishery is a 70M AUD fishery, and the resources used to manage it should be put into a cost-benefit context.

11. **DPIPWE consider performing an economic analysis of management costs and benefits according to risk-cost-catch framework, benchmarked nationally and globally.**

Several interviewees stressed not only the lack of mixing and slow growing nature of abalone, but also hyperstability of CPUE. Hyperstability results when catch rates remain constant while the actual fish population declines and is often the result of aggregating behaviour, of fishers and fish. Hyperstability creates an illusion that population levels are stable, potentially masking fishery declines. This has important implications. First, it means fishery-dependent data usually will not detect the changes in abundance, or density in areas beyond where the fishery is looking. Second, it also means that the abundance seen by the fishery, and industry, is not indicative of the broader stock abundance, setting up potential tension and disagreement between scientists, managers and stakeholders.

In general, abalone ranges expand and contract, either by fishing or by physical and environmentally mediated factors. Thus, densities, abundances and catch rates might remain constant in a particular area but change over a broader area. Such hyperstability and the reliability of CPUE as an indicator of stock status in Tasmanian abalone fisheries have long been recognised (Environment Australia 2001), but there is no explicit strategy to manage it in the fishery.

12. **It is strongly recommended that DPIPWE incorporate an objective and outline a strategy to manage hyperstability of CPUE in the fishery.**

Several options exist. One option would be to employ a fishery-independent survey. Such a survey would have a fixed sampling regime that would provide abundance estimates across an entire area, without the bias of sampling only where the fish are. Another option would be to use logger data more effectively to capture fish per unit area from catch bag lifts or something similar.

2. Gradient indicators

The gradient or rate of change of CPUE over a 4-year period is the indicator that provides long-term stability to the controller. The gradient indicator over a 1-year period stabilises short-term changes in CPUE. Both gradient indicators target a gradient of 0 (or a ratio of CPUE at time *t*, to previous CPUE intervals of 1).

2.2.2 Analysis and assessment

A score between 0 and 10 is assigned on a linear scale based on each of the three indicators (Figure 5). The target score is 5, and a higher score contributes to higher TACs in the harvest control rule (HCR). A score of 5 for the CPUE corresponds to a target CPUE defined as the 55th percentile of the CPUE distribution during the reference period. A score of 5 from the gradient indicators correspond to a CPUE gradient of 0 (or a ratio of CPUE at time t: CPUE the previous interval, equal to 1).

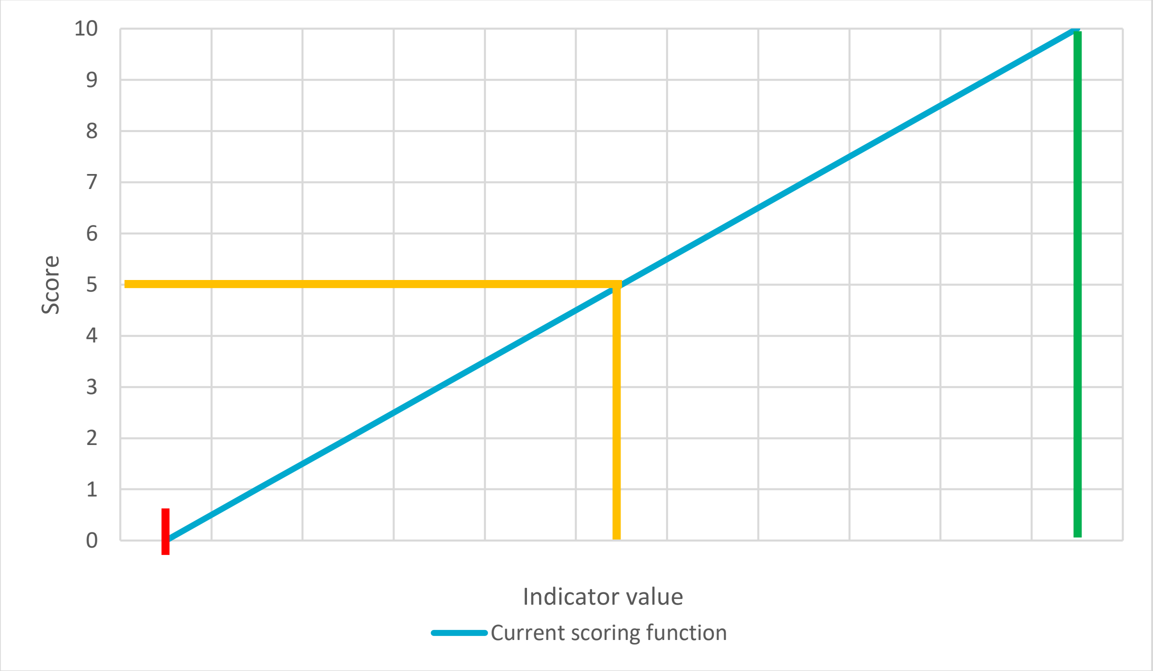


Figure 5 Current (linear: Bradshaw 2018) scoring function scaling an indicator level to a score value. Yellow line represents the target indicator value. Red line represents 90% of the minimum historical value of the indicator (since 1992). Green line represents the value of the indicator 10% above the maximum historical value of the indicator (since 1992)

The current scoring function in Figure 5 corresponds to Bradshaw (2018), and is defined by the equation:

$$score = \frac{11}{\Delta CE}\left[CE_{b,y} - CE_{b,T}\right] + 5 \qquad \text{EQ 1}$$

Where ΔCE is the difference between the upper and lower range of the CPUE distribution over the reference period (i.e. between 10% above the maximum value, i.e. 1.1 X 100th percentile, and 10%

below the minimum, i.e. 0.9 X 0th percentile). $CE_{b,y}$ and $CE_{b,T}$ are respectively the CPUE in block *b* year *y*, and the target CPUE in block *b*. I note that this is not the linear function that was evaluation tested by Haddon and Mundy (2016)

$$score = \frac{5}{\Delta CE}\left[CE_{b,y} - CE_{b,T}\right] + 5 \qquad \text{EQ 2}$$

The scoring function is dependent and potentially sensitive to the historical variability of CPUE, (ΔCE), and a few concerns with it should be clarified, confirmed and simulation tested. First, the use of maximum and minimum values sampled (0th and 100th percentiles) could represent a problem for the Harvest Strategy as these statistics are well known to be unreliably estimated and highly sensitive to outliers[1]. The scoring function is also highly sensitive to the range between these statistics, ΔCE. For example, under a target CPUE, $CE_{b,T} = 100$, an observed catch rate $CE_{b,y} = 99$, generates a score value, $score = 4.89$ under $\Delta CE = 100$, but a substantially lower value, $score = 2.8$ under $\Delta CE = 5$. It is unclear whether this was a design feature of the Harvest Strategy, but a simple prediction of this effect would be that across blocks there is an inverse relationship between the CPUE variability, which is reflected in ΔCE, and TAC variability, which is reflected in the scores. Other factors are likely to play an effect, but a relatively simple analysis could be conducted to show the extent of these potential effects.

Additionally, the linear scoring function (Figure 5) assumes that the indicator distribution is relatively symmetric. In a situation where the distribution of the indicator is highly skewed, the expected outcome could be far from the target, and result in dynamic instabilities and uncertainty in outcome.

The 1-year and 4-year gradient indicators are parameterised similar to the CPUE, but it is unclear whether their values are log-transformed in the analysis. In general, such a transformation would be required if the harvest strategy sought to preserve a given *percentage* change in CPUE, at either a 1-year or 4-year interval, on the scoring function.

13. **The current indicator scoring function should be published in a public document, and simulation tested. I also suggest**
    a. **a retrospective analysis be conducted across blocks showing the extent and potential effect of ΔCE on the corresponding scores and TACs; and**
    b. **an investigation into the extent and potential effect of skewness in the indicator distributions.**

    Log-transformations of the gradient indicators in the analysis should also be confirmed or clarified.

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[1] One need go no further than Wikipedia to see that Extreme Value Theory is the branch of statistics dealing with extreme deviations from the median of a probability distribution, seeking to calculate the probability of events that are more extreme than any previously observed.

2.2.3 Harvest control rule (HCR)

Figure 6 outlines the TAC setting process scaled up from the block-level catch allocations. A catch allocation for each block is determined based on a percentage change from the previous year TAC. There is no target catch or yield such as MSY, or MEY as recommended by Buxton et al. (2015).

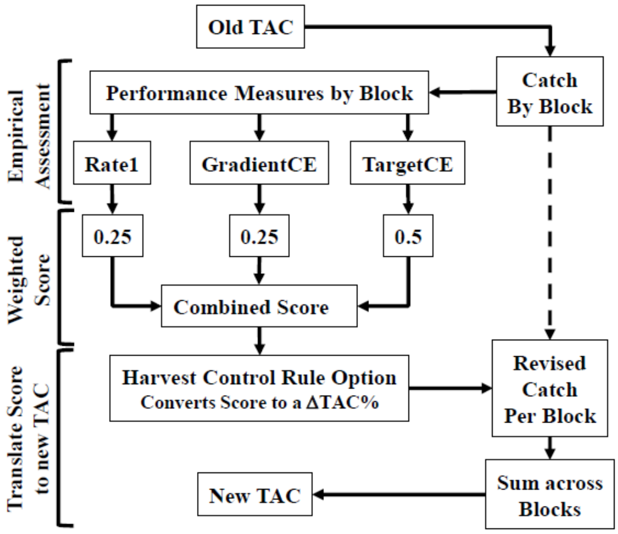

Figure 6 TAC setting process from Haddon and Mundy 2016.

The harvest control rule (HCR) shown in Table 1 Figure 7 uses the weighted sum of the three indicators to adjust the TAC from the previous year. The indicator weights currently used are 0.65:0.25:0.10 (target CPUE: 1-year gradient: 4-year gradient). Haddon and Mundy (2016) examined a wide range of weights, but the decision on which the current weights were made is not clear. The current HCR is risk averse (conservative) in that no change in TAC would eventuate in CPUE scores near the 65th percentile (i.e. at scores ≥5.0 but <6.0) of the reference period. I note that the risk strategy as noted by Mayfield (2019) is captured, and could be modified, through both the scoring function (Figure 5) and the harvest control rule (Figure 7).

Table 1 The current harvest control rule (HCR).

Composite score	<1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9
Catch allocation adjustment	-75%	-25%	-20%	-15%	-10%	No change	+5%	+10%	15%	20%

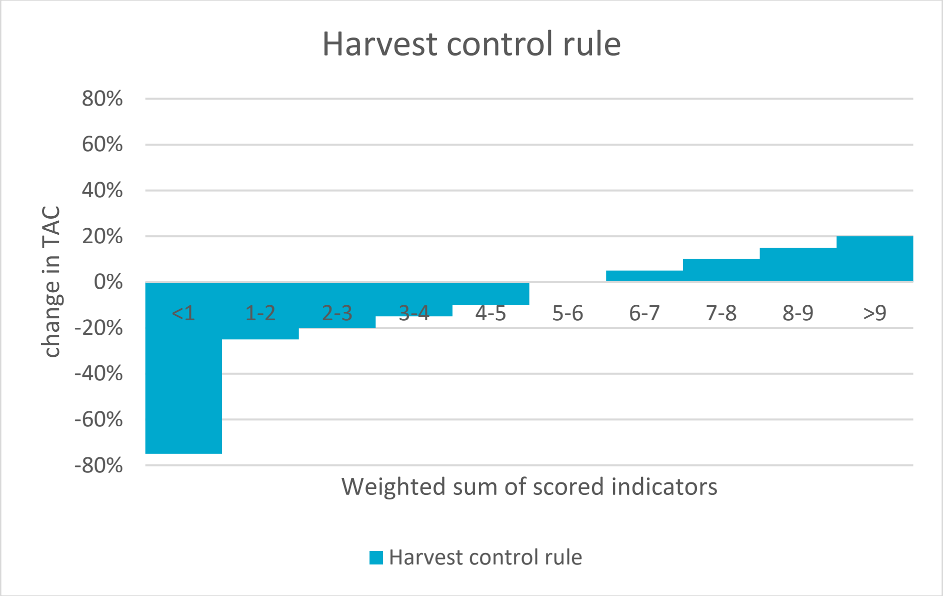

Figure 7 Harvest control rule based on weighted sum of indicators.

2.2.4 Empirical Harvest Strategy evaluation

Models are helpful in evaluating the ability of a harvest strategy to achieve desired outcomes. The general rule is that if they are unable to achieve the desired outcome in the computer, they are unlikely to do so in reality. Realism is an important feature in simulation models used to evaluate harvest strategies. Realistic models however, can be complicated and difficult to understand. Understanding is often achieved by using simplified models. Two separate simplified models were used for this review to understand the effects of the empirical Harvest Strategy. These models showed that it had the potential to produce stable biomass and catches, but with a risk of large amplitude limit cycles. The moving CPUE target meant the outcome depended on the initial biomass and catches, and the outcome could be biased towards being overly conservative, by producing relatively high biomass levels, and relatively low TACs. It is not clear whether this was an intended precautionary goal and design feature, but the simplified models highlight that further evaluation against the management objectives using more realistic models is needed.

Haddon and Mundy (2016) tested an early version of the Harvest Strategy, including the weightings of the indicators to the composite scoring. This exercise however did not evaluate the current harvest strategy in terms of the dynamic target reference point, or achievement of the 55th percentile of CPUE in the reference period. It is not clear whether the evaluation also explored the range of uncertainty in the fishery that exists or existed at the time.

14. **The current and potential future Harvest Strategies should be simulation tested. Any suggested changes to the Harvest Strategy should be similarly simulation tested, and range of uncertainty captured.**

A recently commenced *FRDC project 2019-118: Drawing strength from each other: simulation testing of Australia's abalone harvest strategies*, could provide the basis for evaluating the Harvest Strategy. The objectives of this project are:

1. Undertake Management Strategy Evaluation (MSE) testing of each jurisdiction's current abalone harvest strategies in Australia.

2. Contrast harvest strategy performance under a common dynamic range of stock types, with and without conflicting indicators.

3. Provide guidance on what constitutes best approaches to using empirical abalone harvest strategies

4. Provide fully documented open-source R package for other MSE expert's use

5. Provide advice on how best to include additional indicators

2.2.5 Meta-rules

Meta-rules have been developed to prevent unwanted outcomes in the harvest control rule. If for example, a CPUE has risen off a very low base for successive 4 years, but is still below the target CPUE, then a meta-rule is used to prevent large increases in block catch allocation unless the CPUE indicator has been above the target for more than 2 years. Likewise, reductions are ignored if the CPUE indicator has been increasing for two years.

15. **An attempt should be made to simulation test the meta-rules.**

2.2.6 Interaction between the LML and the empirical Harvest Strategy

The Harvest Strategy has no spawning biomass indicator to signal recruitment to the population, and, as already highlighted, no pre-recruitment indicator to signal recruitment to the fishery. The principal management indicator is CPUE, which reflects the biomass available to the fishery (i.e. exploitable biomass above the LML). Changing the LML changes the biomass available to the fishery and thus also affects the ability to catch a TAC. Bradshaw (2018) started to recognise this by showing the effect of LML on protecting mature and exploitable biomass in an unfished population (page 28). What is not clear is the combined effect of fishing (i.e. the TAC) and different LMLs have on the exploitable biomass and the probability of catching the TAC. Indeed, LMLs have changed in the past and the effect that such a change has had on CPUE, CPUE standardisation, and target CPUE calculation is not clear. The relationship between LML and TAC is fundamental, and there are likely trade-offs and interaction effects. Determining how the LML works with the TAC setting process in the empirical harvest strategy to achieve the target CPUE is needed.

16. **A simulation test showing the effects that changing LML and TAC have on stock level, CPUE and ability to achieve the CPUE target would be helpful for understanding the interaction and balance between the management levers.**

It was noted also in interviews and in Bradshaw (2018) that size data are being collected from processors. It was unclear the amount of data and the extent to which they are used in the Harvest Strategy, but such information as '% of abalone *x* mm above the LML' by spatial area could be a valuable indicator of exploitable biomass, and fishing mortality in the absence of pre-recruit surveys.

17. **Effort should be made to incorporate a size indicator into the Harvest Strategy. Such an indicator could provide an additional score to the empirical harvest control rule.**

2.3 Sustainable catch targets

The Harvest Strategy recognises the spatial nature of the fishery, and that fishing effort needs to be widely distributed to avoid localised depletion. To address the aggregation of effort (and thus catch), catches are monitored closely through the year. This is done at a higher scale than blocks, but below zone. Catch targets or allocations are calculated as summed TACs across a group of blocks informally called a “region”.

When catch in a region is 80% filled it is reviewed with an aim to limit catch in the region to 20% above its allocation. The review takes account of diver feedback as to how the area is fishing, catch rates, in consultation with the industry and scientists. The degree of subjectivity in this process is unclear, as is whether this management component is voluntary.

18. **The rules and decision-making process for reviewing spatial catch allocations should be formalised and made explicit to ensure transparency and reduce subjectivity.**

This element of the Harvest Strategy has not been simulation tested. To do this, however, might require the ability to simulate the fishing effort dynamics, the behaviour of fishers, and the choices they make on where to fish, when to fish, or even whether to fish. In general, understanding the behaviour of a fishing fleet can provide useful information on the effectiveness of management measures.

19. **The spatial catch allocation rule should be simulation tested, and if needed a model of the effort dynamics or fishing behaviour should be developed.**

3 Summary

Empirical harvest strategies are difficult to design because there is no underlying dynamical process model assumed, and no statistical estimation process. The trade-off is that MSE testing under a wide range of scenarios is even more critical, and I encourage a comprehensive update of Haddon and Mundy (2016). Consideration should be made of the interacting nature of the Harvest Strategy objectives and strategies to achieve them, namely the LML and the TAC setting process. The use of fishery dependent indicators complicates matters, but this situation is not unique to the fishery. Given the biological nature of abalone, consideration should be made for hyperstability of the stock, and CPUE indicator.

The current Harvest Strategy has made steps to best practice, but there are a few current practices that I think should be reviewed in more detail. Those practices include the effect of a moving reference period (recommendation 8), and the scoring function (recommendation 13). Hyperstability is also not surprisingly a concern (recommendation 12). Most of the recommendations in this review are not new, but shared by Buxton et al. (2015), Knuckey (2019) and Mayfield (2019). In the future, I suggest DPIPWE and AbFAC formally respond to them, and if acceptable provide progress updates.

20. **DPIPWE and AbFAC formally respond to the recommendations.**

4 Recommendations

1. **The Harvest Strategy should clarify whether avoiding localised depletion is a management objective.**
2. **The Harvest Strategy should provide greater clarity on the spatial scale(s) at which the fishery is managed, and the criteria of what defines the spatial unit of management.**
3. **DPIPWE develop a clear operational objective, with performance indicator and target, relating to recruitment and stock level.**
4. **Levels of risk tolerance should be specified for all management objectives.**
5. **It is recommended that in stating the objective to maintain stocks at target levels, DPIPWE explicitly state the target, and the indicator. If rebuilding is an objective, DPIPWE should state the rebuilding target. As previously indicated, the spatial scale at which targets are applied should also be explicitly stated.**
6. **Limit reference points should define undesirable states of the fishery, and the harvest control rule should define the course of action under such conditions.**
7. **The factors and process of CPUE standardisation should be documented in the Harvest Strategy, and suggested changes should be conducted in consultation with management and stakeholders.**
8. **It is strongly recommended that a fixed reference period be considered, or that the dynamic reference period is simulation tested. It is also recommended that the choice of reference period be justified (see box 1) and consistent with management objectives. A retrospective analysis showing how CPUE and targets have changed relative to each other would show the extent of risk that the stock has been subject to by a moving reference period.**
9. **The Harvest Strategy should consider objective climate and environmental indicators to factor the effects of long-term climate change and short-term episodic events into the TAC setting process.**
10. **The fishery (industry, management, scientists) consider pre-recruit surveys as an indicator to reduce lagged observation effects, with the potential of incorporating such an indicator into the TAC setting process and harvest control rule. Given the potential costs of such widespread functionally independent populations, costs may be a constraining factor.**
11. **DPIPWE consider performing an economic analysis of management costs and benefits according to risk-cost-catch framework, benchmarked nationally and globally.**
12. **It is strongly recommended that DPIPWE incorporate an objective and outline a strategy to manage hyperstability of CPUE in the fishery.**
13. **The current indicator scoring function should be published in a public document, and simulation tested. I also suggest**
    a. **a retrospective analysis be conducted across blocks showing the extent and potential effect of ΔCE on the corresponding scores and TACs; and**

   b. **an investigation into the extent and potential effect of skewness in the indicator distributions.**

   Log-transformations of the gradient indicators in the analysis should also be confirmed or clarified.

14. **The current and potential future Harvest Strategies should be simulation tested. Any suggested changes to the Harvest Strategy should be similarly simulation tested, and range of uncertainty captured.**
15. **An attempt should be made to simulation test the meta-rules.**
16. **A simulation test showing the effects that changing LML and TAC have on stock level, CPUE and ability to achieve the CPUE target would be helpful for understanding the interaction and balance between the management levers.**
17. **Effort should be made to incorporate a size indicator into the Harvest Strategy. Such an indicator could provide an additional score to the empirical harvest control rule.**
18. **The rules and decision-making process for reviewing spatial catch allocations should be formalised and made explicit to ensure transparency and reduce subjectivity.**
19. **The spatial catch allocation rule should be simulation tested, and if needed a model of the effort dynamics or fishing behaviour should be developed.**
20. **DPIPWE and AbFAC formally respond to the recommendations.**

5 Consultation

I am grateful to the following individuals for their time, advice and analyses.

5.1 IMAS

Craig Mundy

5.2 DPIPWE

Matt Bradshaw, Ian Dutton

5.3 Industry

Sean Larby, Sue Forward, Dean Lisson, Greg Woodham, Darvin Hansen, Rob Royal, Beth Mathison, Paul Richardson, Ruben Bock, Joey McKibben, Allison Anderson

5.4 Other

Ian Cartwright, Malcolm Haddon, Keith Sainsbury, Bruce Mapstone, Tony Smith, Cathy Dichmont, Ian Knuckey, John Parslow

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