Section 2: Methods

Section 2A. Proposed de minimis management strategy

Outlook on management strategy design

When data limitations preclude quantitative stock assessment as the basis for management decisions, management strategies rely instead on simpler indicators derived from monitoring data that can be used to inform decision-making (Prince et al. 2008, Butterworth et al. 2010, Dowling et al. 2015). A management strategy consists of three parts: the suite of data streams that comprise the monitoring program, the data analysis used to calculate indicator values, and a harvest control rule that is used to interpret indicator values within a pre-agreed decision framework and produce a recommended management action. Within the realm of data-limited management strategies, there is an extraordinarily diverse array of nuanced approaches, with a key challenge involving designing an approach that is most suitable to the fishery in question (Apostolaki and Hillary 2009, Carruthers et al. 2014, Geromont and Butterworth 2015, Newman et al. 2015, Dowling et al. 2019).

With respect to the red abalone fishery of northern California, a variety of considerations related to data quantity and quality have constrained management strategy design in some important ways. First, fine-scale spatial stock structure of red abalone is at odds with feasible scales of data collection and the large number of landing sites that exist along the coastline. This constraint on data quantity requires a management strategy that is designed to accommodate site-specific signals about resource changes where this information is available, while also attempting to guide decision-making at much larger spatial scales. Second, each of several data streams that have been identified (e.g., density, length frequencies distributions, kelp abundance, sea urchin density, ocean temperature, body condition) emphasizes a somewhat disparate aspect of the biological and ecological condition of red abalone, thus requiring consideration of how multiple indicators can function cohesively to support scientifically sound management decisions (OST 2018). Third, and perhaps most challenging, is the various ways that each data stream is limited in its information content. Information content is a key consideration, as even in instances where fisheries are considered to be data-rich, in actuality, these same fisheries can be information-poor in terms of data reliability for supporting decision-making (Magnusson and Hilborn 2007, Carruthers et al. 2014, Dowling et al. 2015, Harford and Babcock 2016). For red abalone density surveys, the precision with which this quantity can be estimated has been called into question, and directly reflects its information content (OST 2014). For length frequency distributions, sampling precision appears adequate; however, information content reflects the uncertain reliability of life history information used in analyzing this data stream and a persistent information lag between changes to spawning condition and subsequent detection of this change (Bellquist n.d., Prince 2016, OST 2018). For ecological or environmental indicators, despite the intuitive nature of these indicators, implicit mechanistic linkages between red abalone biology and environmental conditions are typically difficult to verify, and more broadly, simulation testing of other fisheries has failed to demonstrate improved management performance through inclusion of such indicators in harvest control rules, except when mechanistic relationships are clearly understood (A’mar et al. 2010, Punt et al. 2014).

These broad considerations affect management strategy design, as do several additional conditions stressed by the peer review of two previous management strategy proposals, direction from the California Fish and Game Commission, and discussions involving the Project Team (CFGC 2018, OST 2018). Peer review urged integration of indicators from two separate proposals as well as a focus on developing rebuilding criteria. The Commission also recommended integrating aspects of both strategies, and emphasized that the operation of a de minimis fishery (during rebuilding) should require triggers for its initiation. Among the diverse array of topics discussed by the Project Team, their views have influenced management strategy design in terms of the need for multiple indicators, designs that emphasize opportunities for fishing, frequency of decision-making (i.e., annual application of management strategy), and enabling citizen scientists to continue to engage in data collection.

Given the above stated constraints on management strategy design, a two-part management strategy is proposed that is applied annually (recursively, through time) as a means to guide decision-making towards the objective of enabling open fishery status. In summary, Part A reflects a Project Team recommendation to require examination of the state of the northern California environment and the productivity of red abalone for exceptional circumstances or emergency circumstances. Part A provides an opportunity to consider whether exceptional circumstances are occurring in a variety of indicators (e.g., kelp abundance, sea urchin density, ocean temperature, body condition, gonad condition). If exceptional circumstances are deemed to be occurring and may impede initiation or continuation of a fishery, then direction is sought from the Commission and/or the Department. Where no exceptional circumstances are found, Part B follows. Part B is a two-indicator approach (i.e., indicators derived from density and length frequency data streams) where each indicator contributes to annual decision-making. These two indicators are assigned a color category that is determined by comparing the indicator value against pre-agreed reference points. Red indicates a dangerous condition, far from achievement of the management objective. Yellow reflects unsatisfactory conditions, occurring during transition from red to green. Green reflects satisfactory conditions aligned with the management objective. Having assigned color categories to both indicators, a harvest control rule in the form of a set of decision trees is then used to interpret indicator color combinations and produce a recommended management action.

Part B described above is a type of management strategy design that is known as a ‘traffic light method’ and provides a single framework within which each of the above stated constraints can be addressed (Fig. 1; Caddy 2002). The traffic light method enables a coarse characterization of a defined geographic region according to the measurement of prevailing conditions (via indicators), which is consistent with the need to guide decision-making at spatial scales larger than the specific sites that are subject to field sampling. The traffic light method enables multiple indicators to inform decision-making, each according to the biological or ecological qualities to which the indicator is most responsive. Finally, the traffic light method establishes a harvest control rule that integrates indicators into decision-making according to their known information limitations. The traffic light method has been implemented in various forms (Caddy 1999, 2015, Caddy et al. 2005), and offers several benefits in addressing the management circumstances facing red abalone. It simplifies data into a set of value judgements, presented in an understandable form, and enables uncertainty in indicators to be embraced while providing a basis for coarse adjustment to management status (Mangel and Levin 2005, Caddy 2015).

A detailed description of the entire management strategy follows. The reader is encouraged to examine the management strategy in the order it is presented, concluding with the technical summary of how indicators are calculated. Then, given an understanding of indicator calculations, work backwards and re-visit the other components of the strategy to understand how data quality and quantity influence the defined structure of the management strategy.

Management strategy components

Component #1: Fishing Zones

The management strategy relies on the concept of management according to fishing zones, which are geographic areas of the coastline comprising several of the formerly defined abalone report card sites. This strategy is designed to unify regulatory decisions and enforcement (notwithstanding marine protected area sites). Zoning is also designed to rely on established sampling programs and to help to ensure a pragmatic approach to coordination of data collection and application of indicators and corresponding reference points.

Through consultation with the Project Team, requests were made to consider up to four zones (i.e., separate zones for Marin, Sonoma, Mendocino, and Humboldt + Del Norte counties, and combinations thereof), as well as requests to consider report card site-specific management strategies. The use of site-specific management strategies were not further considered in this report for the following reasons. While it is plausible that a set of criteria could be constructed for implementing de minimis fishery triggers at various report card sites, shifting of resources towards continual monitoring of sites where a de minimis fishery is operating while also attempting to ensure that coast-wide monitoring coverage remained sufficient to inform actions related to a broader fishery opening appears intractable. Secondarily, serial depletion could be more problematic when fishing is concentrated at only a few sites, depending on the magnitude of catches, in comparison to dispersing fishing effort across many sites (Post 2013).

Now shifting focus to fishing zones encompassing several report card sites, data limitations constrain how fishing zones can be currently delineated. The use of multiple indicators presents a complex challenge for treating the combined Humboldt and Del Norte counties as a unique fishing zone because there is no historical baseline sampling on which to gauge the suitability of density reference points. In the absence of a historical baseline, an idea was considered of a measuring a contemporary density baseline through a concerted sampling effort to occur in the near future (prior to implementation of any management strategy). This idea was met by some opposition from the Project Team, but was also viewed as potentially problematic for an additional reason. The challenge with using a contemporary baseline lies in understanding whether this baseline is a suitable target or limit reference point. Such a baseline could be conservatively regarded as a limit reference point (where the management objective is to keep density above this density limit); however, it is uncertain whether this baseline might even be too low to ensure fishery sustainability. Furthermore, it is unclear whether sufficient length frequency data could be collected from the combined Humboldt and Del Norte counties to support use of this information.

But the idea of maintaining Humboldt and Del Norte counties as separate from Mendocino county, and likewise separating Marin county from Sonoma county, should not be readily dismissed. Each fishing zone should be designed such that information streams are utilized in a manner that describes a defined fishing zone as completely as possible. Also, extensive natural heterogeneity in ecological characteristics within a zone will negatively affect the ability for the management strategy to correctly guide regulatory adjustments. This problem is acute for the use of density as an indicator. Density reference points are chosen based on several criteria (described later) and are compared to historical densities to ensure that they are chosen sensibly. But because historical sampling has occurred in California only as far north as Glass Beach, near Fort Bragg, it is currently unclear how to specify such reference points for Humboldt and Del Norte counties. These circumstances suggest two alternative zoning options as it relates to Humboldt and Del Norte counties. The first alternative is that a special initiative could be carried out to produce an appropriate sampling design for a separate fishing zone consisting of

Humboldt and Del Norte counties. In this case, if Humboldt and Del Norte counties have naturally lower densities or represent a distinct ecological region in comparison to sites further south in Mendocino county, then it may advisable to consider separating Humboldt and Del Norte counties from Mendocino county. This separation is advised because introducing density measurements from Humboldt and Del Norte (in a genuine effort to more effectively cover the coastline) into a fishing zone consisting of Mendocino, Humboldt and Del Norte, may inadvertently prevent the density indicator from crossing above pre-determined reference points. The second alternative is that a lack of data on which to base decision-making does not necessarily preclude the specification of Humboldt and Del Norte counties as a separate zone, where a highly limited fishery could occur with a catch limit equivalent to biological sampling needs for research or other management purposes. Neither of these two alternatives are further developed here, nor are they subject to MSE testing. However, the fishing zones that are specified in this report could also be considered as an interim approach, to be modified to reflect a separate Humboldt and Del Norte fishing zone once an alternative strategy for that zone is developed, and after consideration by the Fish and Game Commission.

For the purpose of testing via management strategy evaluation (MSE), the modeling team identified two fishing zones, as follows:

- **Zone 1: Mendocino, Humboldt and del Norte counties.**
- **Zone 2: Marin and Sonoma counties.**

The most pressing constraint leading to this zone configuration is reliance on established sampling programs, which is viewed as a necessity to ensure that the operation of a de minimis fishery is based on data-driven information triggers. Further, the modeling team did not consider a MSE-based comparison to be feasible between the two zone configuration and the three zone alternative consisting of Humboldt and Del Norte counties as a biological sampling fishery. The infeasibility of this comparison, using MSE, stems from the very low catch levels associated with biological sampling alternative. The effect of these very low catch levels is unlikely to be captured by MSE in a scientifically rigorous way, thus preventing a meaningful comparison against the two zone configuration.

Condition #2: Management status definitions

The management strategy proposed here is used to determine when changes to the management status of each zone should take place via an indicator-based harvest control rule. Differences between each management status reflect the degree of access restriction in the form of total allowable catch (TAC). There are three types of management status: closed, de minimis fishery, open fishery. The management status of closed has no access; a TAC of zero. The management status of de minimis fishery ranges between a small level of take that has no effect on recovery to a TAC level that is anticipated to have a minimal effect on the recovery of the resource. The lowest level of de minimis TAC allows a fishery for abalone but requires presenting abalone to CDFW to collect data first before abalone are retained by the fisher. An open fishery is still a restricted access fishery in that it has a TAC, but which is higher and occurs once the resource is considered to have recovered.

TACs for each management status are to be defined according to fishing zone, thus it is possible that each fishing zone may have different magnitude TACs. Guidance on determination of de minimis TAC size is to be examined via MSE. In a subsequent section, we describe regulatory tactics to occur during open status.

Criteria #3: Allocation of individual take limits (ITLs)

An allocation program for individual take limits (ITLs) must be developed to annually distribute any specified TAC. Allocation to individuals and/or user groups is not covered here, although Project Team discussions have highlighted the desire to allocate any TAC among subsistence and recreational uses. Once allocation is determined, the proposed strategy relies on the assumption that dispersal of fishing across several sites within a zone will occur (notwithstanding marine protected areas or any other closed sites). Thus, allocation of TACs among individuals should not restrict where harvest occurs, except that it occurs within the defined fishing zone and no catches within MPAs or other closed sites. This criterion is intended to disperse the effects of fishing across the entire zone, at least to the extent possible given user preferences.

Criteria #4: Additional and existing regulations

This management strategy is expected to function in conjunction with other existing regulations. Those existing regulations include at least the following: 7-inch size limit; report cards that establish individual take limits (ITLs) and require documentation of prescribed data (date of effort, catch, location, etc.); ban on scuba; no taking abalone for someone else; no high grading, taking a larger abalone and putting a smaller one back; no co-mingling abalone with another fisher; uniform start time for fishery; and other existing CDFW regulations.

Application of the management strategy

The management strategy is applied in two parts. Part A addresses exceptional circumstances and has conditions that must be satisfied before moving to Part B. Part B determines management status via an indicator-based harvest control rule. Parts A and B are applied to each zone separately:

- **Zone 1: Apply Part A. If no exceptional circumstances are triggered, then apply Part B to determine management status and to determine the type of fishery and its corresponding TAC.**
- **Zone 2: Apply Part A. If no exceptional circumstances are triggered, then apply Part B to determine management status and to determine the type of fishery and its corresponding TAC.**

The management strategy is based on a set of decision trees that delineate how data-driven triggers enable transitions between closed, de minimis, and open status. The decision tree is always applied separately to each zone, thus, each zone can have a different management status from its neighboring zone at any given time. Each time the decision tree is used to determine current status, it is possible that the current status may differ from the previous status. Change in status is limited to one step in the positive direction (i.e., from closed to de minimis and from de minimis to open, but no jump from closed to open), but multiple steps can be taken in the negative direction, as necessary. This restriction is codified into the decision trees; no additional steps are necessary to execute this condition.

The proposed management strategy is designed to be applied annually. This condition has implications both in terms of timely reactivity to population changes, but also to observation-error-driven oscillation between management status, cautious but timely transitions between management status, and administrative considerations. Given a decision interval of one year, the management strategy is applied as follows. When an updated management status is to be applied in year *y*, data analysis and decision-making occur in year *y-1*, and data analysis relies on field sampling in years *y-2, y-3, y-4*. The need to utilize field sampling in years *y-2, y-3, y-4* reflected the desirability to have obtained sufficient geographic sampling coverage to most reliably characterize the fishing zone as a whole. This means that recursive annual decision-making relies on a 3-year moving window of field sampling.

Part A: exceptional circumstances

Through discussions with the Project Team, Part A was identified as a necessary precursor that examines the state of the northern California environment and the productivity of red abalone. This step was developed by the Project Team as both an ecological safe-guard and as an opportunity to consider whether exceptional circumstances are occurring in a variety of indicators (e.g., kelp abundance, sea urchin density, ocean temperature, body condition, gonad condition). Where such exceptional circumstances protocols are used in other fisheries, responses to exceptional circumstances tend to either trigger a formal review of the management strategy or trigger an ad hoc management adjustment in the current decision interval (Butterworth 2008, Carruthers and Hordyk 2018). The Project Team aligned identification of exceptional circumstances with the latter, requiring Commission direction and potential temporary adjustments to regulations.

A set of rules for what constitutes exceptional circumstances is not explicitly defined here, nor are justifications for triggering this condition, nor the protocol or advisory process involving Commission decision-making. Part A, as described here, should be regarded as reflective of discussions held by the Project Team regarding the essential nature of such a protocol and the potential utility of such a protocol to incorporate a variety of environmental and red abalone productivity indicators into a more holistic decision-making framework. This protocol may also be useful for responding to conditions under which the decision trees (i.e., harvest control rule) have been identified as not providing robust performance; which may be identified or revealed by management strategy evaluation (MSE). Thus, a useful harvest control rule can be implemented under the principle motivation of establishing consistent decision-making, within the broader context of an FMP that also acknowledges the need for occasional reliance on ad hoc regulatory adjustments (Butterworth 2008, Carruthers and Hordyk 2018).

Development of an exceptional circumstances protocol within the FMP likely requires substantially more detail than has been provided by the Project Team. The previous peer review made a related statement reflecting the need for more clearly articulated procedures for the use of a variety of indicators in decision-making; especially those discussed here in Part A. Thus, a more detailed description of an exceptional circumstances protocol should be added to the FMP. The aggregation of these indicators into an exceptional circumstances protocol, while intuitive, does not negate the need for further refinement of the justification for the types of information and the manner in which these indicators trigger an exceptional circumstance. For some indicators identified as pertinent to Part A, additional research regarding the mechanistic linkages in system dynamics would also likely be beneficial. Several environmental and productivity indicators identified prior to the peer review are:

- Ocean Temperature
- Canopy-Forming Kelp Abundance
- Sea Urchin Density
- Body condition and gonad condition (productivity)

Some additional indicators identified by the Project Team are:

- Sea star presence/density
- Acidification, pH
- Oxygen saturation
- Harmful algal blooms
- Disease
- Pacific Decadal Oscillation

Importantly, the Project Team noted that indicators described above may not necessarily require Commission direction, but in some circumstances indicators may instead trigger the collection of additional or more up-to-date abalone data, including density and length frequency distribution data. Such a protocol would allow more up-to-date information to be used in Part B. Thus, as circumstances dictate, reliance on the 3-year moving window of field sampling can be limited, instead using up-to-date information gathering that is triggered under an exceptional circumstances protocol.

Part B: Traffic light decision trees

Part B relies on the use of two data streams: density and length frequency distributions. Project Team discussions centered around the use of density, length frequency distributions, and productivity indicators (i.e., either gonad index or body condition). The productivity indicator(s) have been shifted to Part A. Part B begins by guiding the selection of the correct decision tree to be applied based on the management status in the previous decision interval. The correct decision tree to follow is determined by the previous management status (i.e., the management status in the previous decision interval).

- If the previous management status is closed, proceed to tree #1 (Fig. 2)

- If the previous management status is de minimis, proceed to tree #2 (Fig. 3)
- If the previous management status is open, proceed to tree #3 (Fig. 4)

In any instance where insufficient density or length frequency distribution data are available to proceed to a decision tree, then an interim decision is to be made at the discretion of the Commission.

When following a path through a decision tree, pay special attention to the text on the left side of the tree. This text will state which indicator to apply at each node. Pay special attention to the text pertaining to the density indicator(s). Do not jump ahead in following a path through the decision tree. It may appear that some pathways are repetitive or redundant, but this is not the case and each decision tree is designed to cover most eventualities.

Indicators used in each decision tree are presented according to their color category. Assignment of a color category to an indicator is determined through the analysis of the various data streams, and comparison of indicator values to pre-agreed quantitative reference points. In the case spawning potential ratio (SPR), categories are assigned relative to a target reference point. In the case of density, a more involved approach is used that requires specification of limit, intermediate, and target reference points. Target reference points define the desirable expectations of the fishery and the stock. The level of concern for fishery sustainability is low. Intermediate reference points are established so that management actions are triggered as concern for sustainability grows. Limit reference points define a state of the resource that is to be avoided.

Calculation of the SPR indicator and reference point selection

Given that analysis and consultation is to occur in year *y*-1, where *y* is the year in which the updated management status is to be applied, data used in calculating SPR is obtained from field sampling in years *y-2, y-3, y-4.* Analysis of field sampling data suggests that 150 – 300 individual length measurement of red abalone in the exploited phase (>178 mm shell length) per site could be a reasonable rule of thumb for a minimum data collection standard (Technical Appendix 1). Within a defined fishing zone, sampling at more than 10 sites appears necessary to characterize variation in SPR at this geographic scale (Technical Appendix 1). Furthermore, this management strategy is constructed on the premise that CDFW will maintain its historical site sampling regiment. Success of this strategy will likely depend additional sampling by RCCA or other organization to meet necessary site coverage. In any instance where a site is visited two or more times within the 3-year moving window, the most recent site visit is to be used in data analysis.

For each year-site combination visited within a defined fishing zone during years *y-2, y-3, y-4*, SPR is calculated according to the length-based SPR method (Hordyk et al. 2015). The maximum likelihood LB-SPR estimation routine requires input parameters of *M/K*, asymptotic length, coefficient of variation of asymptotic length, and a logistic maturity curve (Hordyk et al. 2015). *M/K* was specified as 1.15, obtained from life history information of California red abalone, and consistent with the life history of other abalone species (Leaf et al. 2007, Rogers-Bennett et al. 2007, Prince 2016). The ratio $L50/L\infty = 0.51$ was obtained from life history and histological studies of California red abalone (Giorgi and DeMartini 1977, Rogers-Bennett et al. 2004, 2007). Site-specific *L50* is obtained through examination of the tail of the left-hand portion of the length frequency distribution, noting that histological studies provide similar estimates of this quantity of approximately 130 mm (Giorgi and DeMartini 1977, Rogers-Bennett et al. 2004, Prince 2016). Maturity is specified as a logistic function, with parameters *L50* and *L95* indicating lengths at 50% maturity and 95% maturity, respectively. *L95* was assumed to follow the approximate value of *L95/L50*=1.15, which is consistent with histological studies of red abalone maturity (Rogers-Bennett et al. 2004). Alternative parameterizations are described in Prince (2016).

Having calculated SPR for each year-site combination, the fishing zone is characterized as red, yellow, or green according to a selected SPR reference point. A variety of issues should be addressed in selecting an SPR reference point, but perhaps the most salient is to consider the use of a target SPR that is conservative enough to buffer abundance away from low levels, especially because red abalone are vulnerable to environmental conditions in terms of their survival, growth, and reproductive success (Tegner et al. 2001, Harley and Rogers-Bennett 2004, Rogers-Bennett et al. 2012). Analysis of red abalone and a variety of other species has shown that maintaining higher average biomass levels, in the face of environmentally-induced biomass fluctuations, carry lower probabilities of crossing thresholds representing undesirable conditions (Bellquist n.d., Punt et al. 2012, Harford et al. 2018).

Selecting a target SPR reference point will require refinement via MSE. SPR indicator color is calculated as follows. A target SPR reference point λ_{SPR} is compared to the empirical distribution of SPR estimates of sites within a zone. The percentiles, T_{SPR}, determine color category as follows (Fig. 5):

If $> T_{SPR,red}$ of SPR estimates fall below λ_{SPR}, then RED. (e.g., If $> T_{SPR,red} = 75\%$ of SPR estimates fall below $\lambda_{SPR} = 0.75$, then RED

If $< T_{SPR,green}$ SPR estimates fall below λ_{SPR} , then GREEN. (e.g., If $< T_{SPR,green} = 25\%$ of SPR estimates fall below $\lambda_{SPR} = 0.75$, then GREEN

Otherwise, YELLOW

Calculation of density indicator

Given that analysis and consultation is to occur in year *y*-1, where *y* is the year in which the updated management status is to be applied, data used in calculating density is obtained from field sampling in years *y-2, y-3, y-4.* Since density and length frequency samples are collected during the same survey events, the same advice holds that the functioning of this indicator is constructed on the premise that CDFW will maintain its historical site sampling regiment, and that supplemental sampling by RCCA or other organizations would be necessary to meet site coverage needs. In any instance where a site is visited two or more times within the 3-year moving window, the most recent site visit is to be used in data analysis.

Selecting density reference points will reflect a variety of considerations, with refinement of reference points to be supported by MSE. Project Team and modeling discussions have reflected consideration of a limit reference point in proximity to 0.2 abalone per m^2. Based on a variety of evidence, it is thought that productivity could be compromised below this density level. At Santa Rosa and Santa Cruz Islands, Kelp Forest Monitoring Program (National Parks Service) data show that red abalone populations in 1983 were below 0.2 abalone per m^2, following these densities, populations continued to decline to <0.05 abalone per m^2 (Tegner et al. 1989, Karpov et al. 1998). Red abalone densities before 1983 at these island sites (1978-1982) were <0.3 abalone per m^2 (Tegner et al. 1989). In Washington State, northern abalone *H. kamtschatkana kamtschatkana* densities have declined by 77% with all sites now <0.15 abalone per m^2 (Rothaus et al. 2008). At these low densities, populations continued to decline and there is now apparent recruitment failure (Rothaus et al. 2008, Rogers-Bennett et al. 2011). Northern abalone have also showed reduced productivity along the west coast of Vancouver Island, British Columbia, Canada following declines in density below 0.3 abalone per m^2 (Tomascik and Holmes 2003). In South Australia at West Island, given the assumption that declining parental stock contributed to poor recruitment, Shepherd and Brown (1993) measured densities between 0.25 and 0.015 abalone per m^2 prior to the period of poor recruitment. Additional reference points, termed intermediate and target densities are also required. Selection of these reference points will be guided by past CDFW densities surveys in northern California (Technical Appendix 1).

Whole-site density of emergent red abalone should be calculated according to an appropriate statistical distribution thought to give rise to the data. This consideration is explored in Technical Appendix 1, revealing a right-skewed distribution of counts and sometimes a non-negligible number of zero count transects, which is consistent with log-normal or delta log-normal sampling distributions (Pennington 1983, Lo et al. 1992, Fletcher 2008). Thus, for each year-site combination, summary statistics of density should be calculated according to the following three steps:

1. Separately fit log-normal and delta-lognormal distributions to red abalone transect counts;
2. Use Akaike Information Criteria to determine the ‘best approximating model’ (Burnham and Anderson 2004);
3. Estimate summary statistics (including confidence interval of the mean) according to the best approximating distribution.

Once the CI of the mean of each site-year combination is calculated, the color category is calculated for each of three indicators that are based on whether CIs contain the reference defined limit, intermediate, or target reference points.

<u>Density limit reference point indicator</u>

A limit density reference point λ_{DL} (e.g., $\lambda_{DL} = 0.2$ /m^2) is defined. Percentiles, T_{DL} determine color category as follows:

If $< T_{DL}$ of density CIs are greater than λ_{DL} , then RED. (e.g., If $<$ 100% of density CIs are greater than 0.2 /m^2, then RED)

Otherwise, YELLOW

<u>Density intermediate reference point indicator</u>

An intermediate density reference point λ_{DI} (e.g., $\lambda_{DI} = 0.3$ /m^2) is defined. Percentiles, T_{DI} determine color category as follows:

If $< T_{DI}$ of density CIs are greater than λ_{DI} , then YELLOW. (e.g., If $<$ 100% of density CIs are greater than 0.3 /m^2, then YELLOW)

Otherwise, GREEN

<u>Density target reference point indicator</u>

A target density reference point λ_{DT} (e.g., $\lambda_{DT} = 0.4$ /m^2) is defined. Percentiles, T_{DT} determine color category as follows:

If $< T_{DT}$ of density CIs are greater than λ_{DT} , then YELLOW. (e.g., If < 100% of density CIs are greater than 0.4 /m^2, then YELLOW)

Otherwise, GREEN

Management strategy components explored during MSE

A methodical evaluation the parameters values associated with SPR and density (i.e., λ , *T*, confidence intervals and de minimis TACs) are of highest priority because these parameters are most likely to affect the trade-off between opportunities for fishing and red abalone recovery. While some rationale is already provided regarding reference point specification, these reference points require further consideration in terms of (1) their performance during MSE testing, and (2) the satisfactory nature of this performance to the Project Team. The peer review provided some direction on this issue, suggesting that application of MSE to the question of reference point selection should provide some justification for their use, based on performance outcomes (OST 2018).

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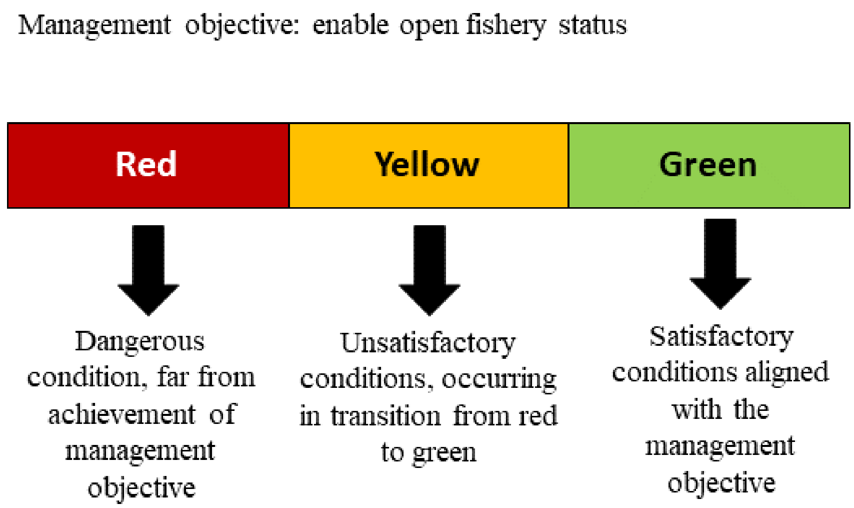

Figure 1. Traffic light method.

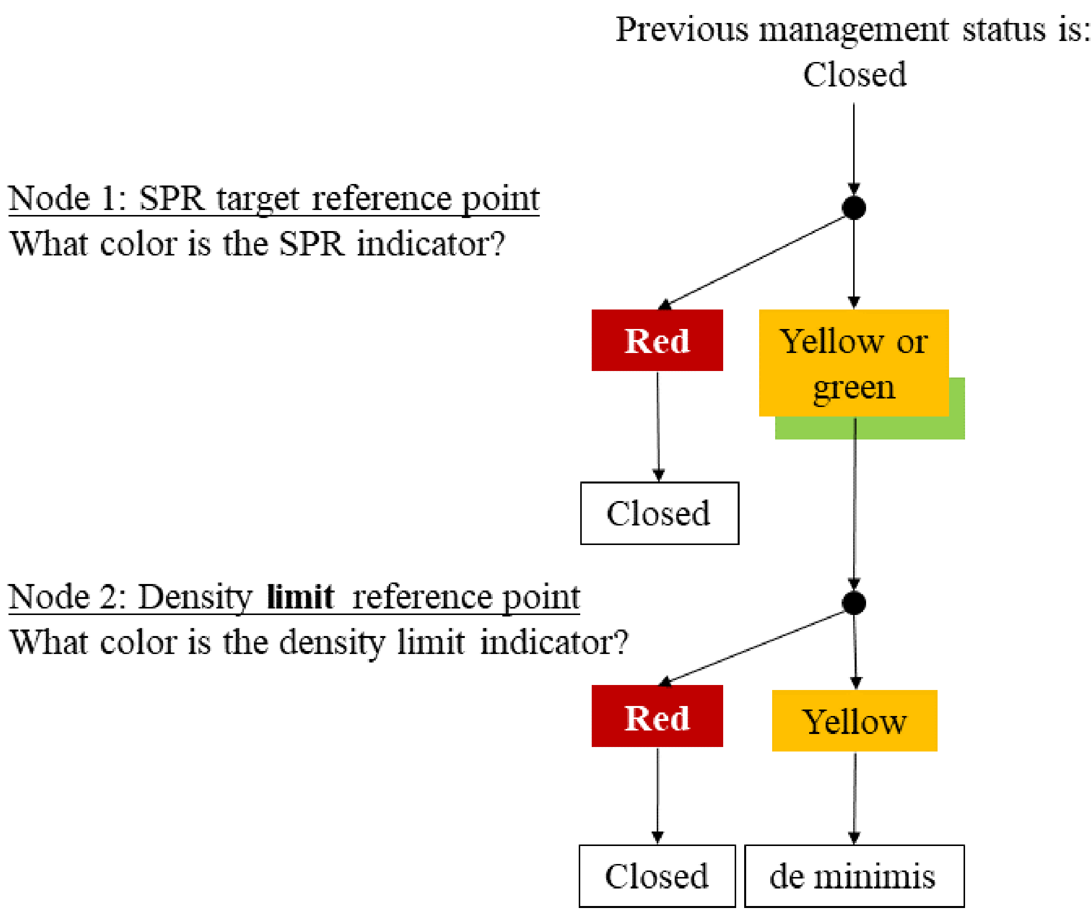

Figure 2. Part B of the management strategy. Decision tree #1. Applied when previous management status is closed.

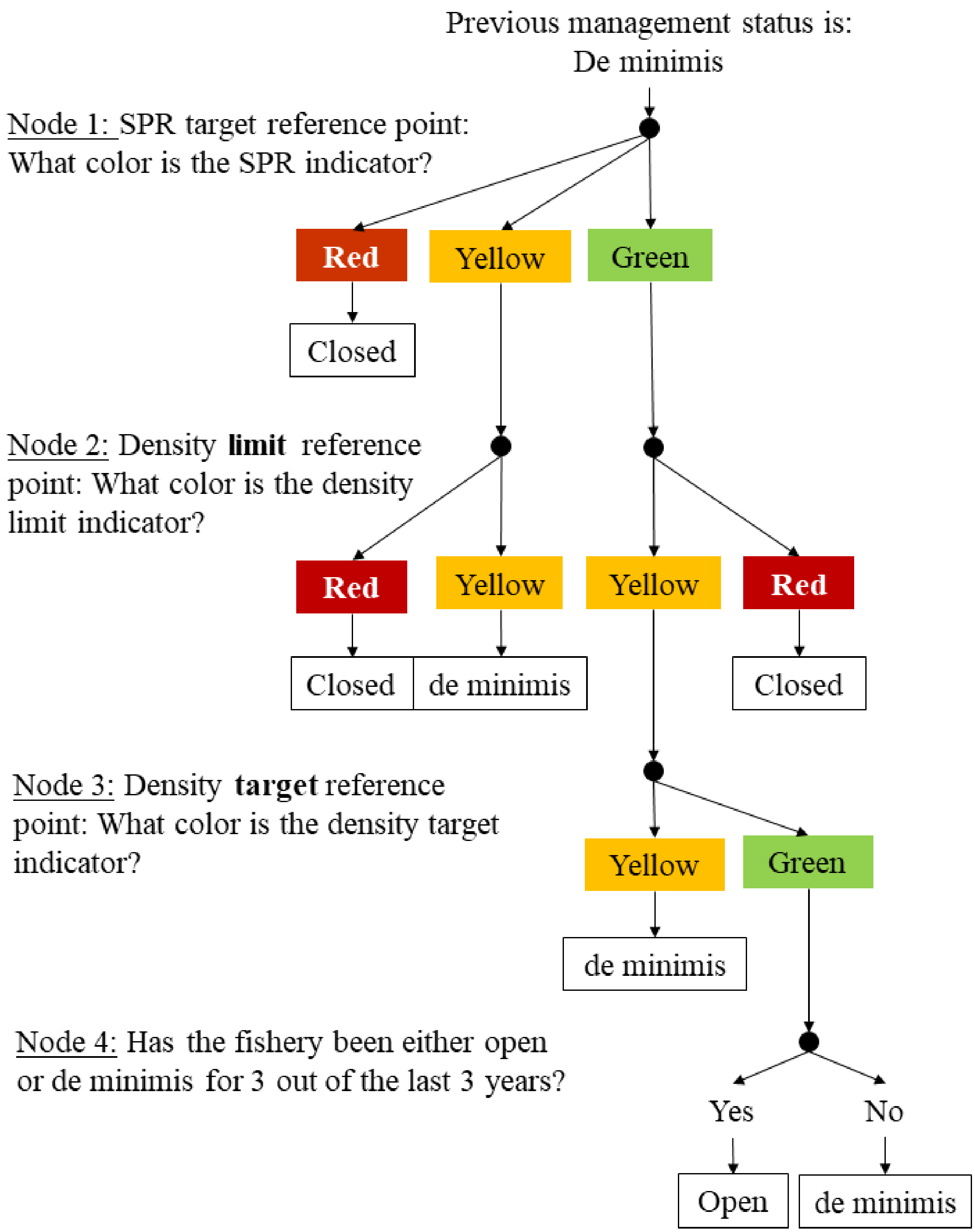

Figure 3. Part B of the management strategy. Decision tree #2. Applied when previous management status is de minimis.

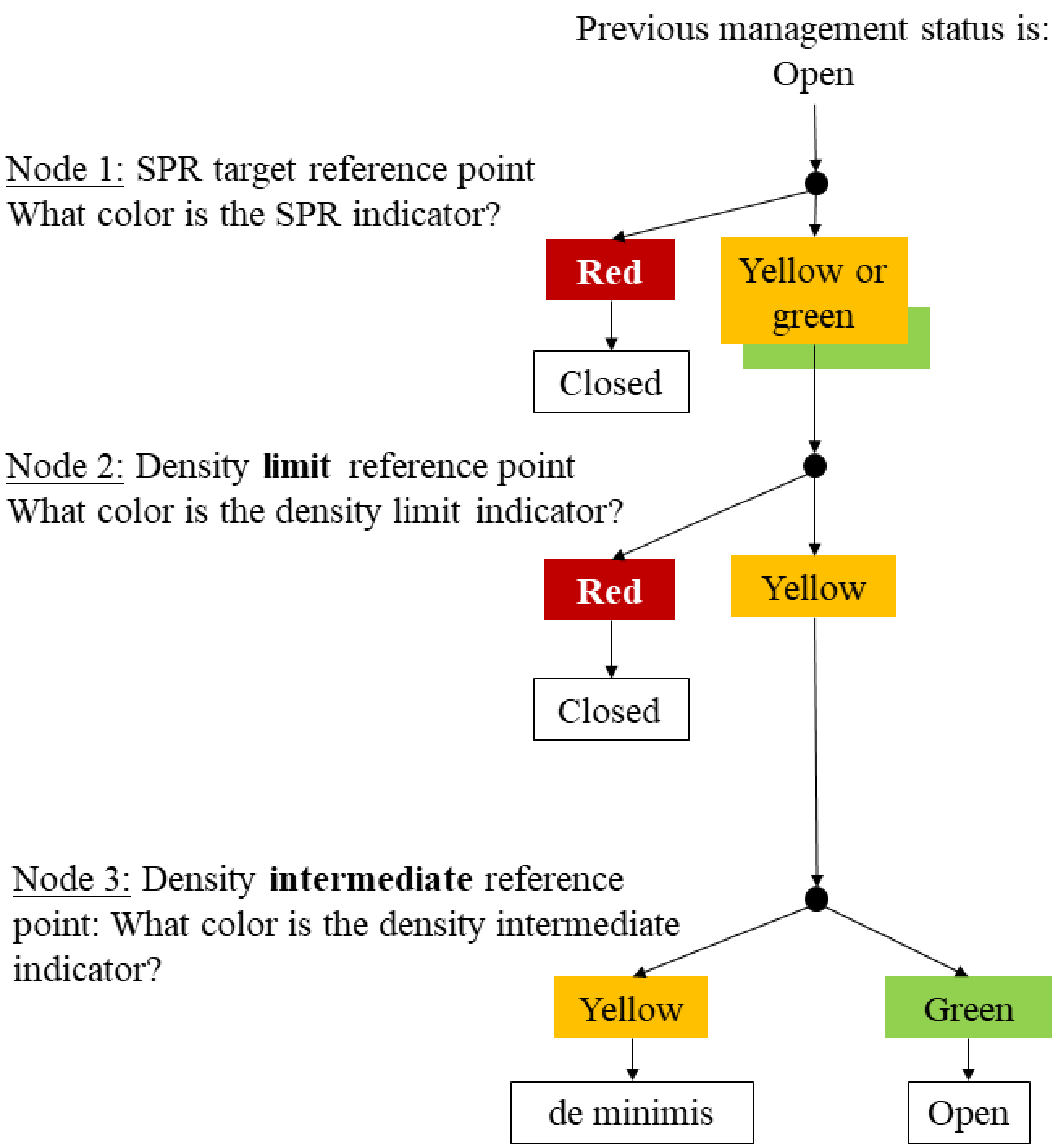

Figure 4. Part B of the management strategy. Decision tree #3. Applied when previous management status is open.

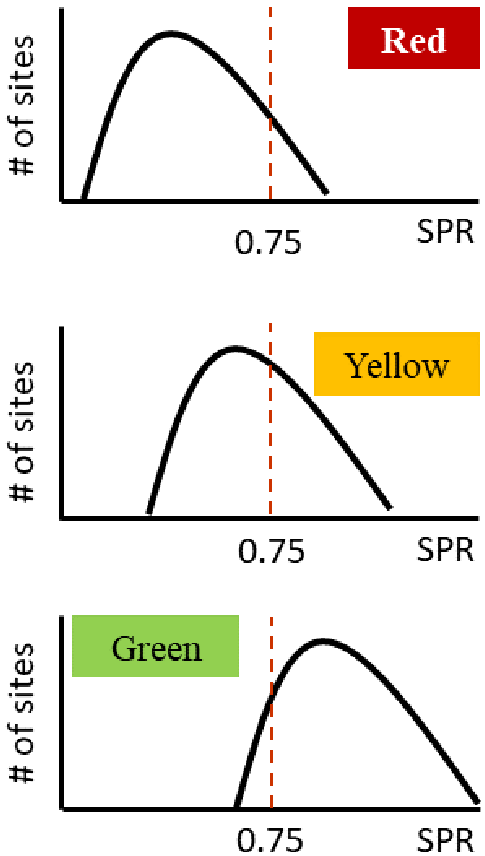

Figure 5. Illustration of the traffic light approach as applied to the SPR indicator.