Final Report of the Science Advisory Committee

Scientific and Technical Review of the Survey Design and Methods Used by the California Department of Fish and Wildlife to Estimate Red Abalone (*Haliotis rufescens*) Density

CALIFORNIA OST Ocean Science Trust

Connecting Science to Ocean Management

CALIFORNIA OCEAN PROTECTION COUNCIL

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE


Photo: Steve Lonhart

Authored by the
Science Advisory Committee

Coordinated by the
California Ocean Science Trust

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California Department of Fish and Wildlife

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Review Participants

California Ocean Science Trust

Ocean Science Trust (OST) is a nonprofit 501(c)(3) public benefit corporation established pursuant to the California Ocean Resources Stewardship Act (CORSA) of 2000. OST's mission is to advance a constructive role for science in decision-making by promoting collaboration and mutual understanding among scientists, citizens, managers, and policymakers working toward sustained, healthy, and productive coastal and ocean ecosystems.

OST served as the independent appointing agency in alignment with the Procedural Guidelines for CDFW Ad Hoc Independent Scientific Advisory Committees[1]. OST convened the Science Advisory Committee (SAC), and designed and implemented a scientific review process (see Appendix C) that promoted objectivity, transparency, and scientific rigor.

Science Advisory Committee (SAC)

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Dr. Mark Carr is a populations and community ecologist and has extensive experience conducting scuba-based research on the ecology of coastal marine fishes, invertebrates, and kelp forest ecosystems in southern and central California.

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Dr. Karina Nielsen is a marine ecologist with over two decades of hands-on experience designing and conducting field experiments and surveys of invertebrates and other marine organisms on rocky shores, sandy beaches and salt marshes.

Jeremy Prince

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Dr. Jeremy Prince is a resource assessment modeler working at the interface between government and the fishing industry. He has worked widely developing survey and assessment methodology for species as divergent as deepwater fish, sharks, dugong, sea urchins, rock lobster and abalone.

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Dr. Raimondi is interested in understanding factors that are important in the development and maintenance of biological communities. He uses experimentation and field observations of populations and community structure and distributions to motivate specific and testable hypotheses concerning mechanisms affecting their development

[1] Available at: https://nrm.dfg.ca.gov/documents/ContextDocs.aspx%3Fcat%3DScienceInstitute

Stephen C. Schroeter

Research Ecologist, Marine Science Institute, University of California, Santa Barbara, Adjunct Professor, Department of Biology, San Diego State University

Dr. Schroeter is a population and community ecologist working in a variety of habitats including rocky intertidal and subtidal reefs, tidal wetlands, and coastal sage scrub and coastal chaparral communities. This work has involved designing and implementing robust sampling designs aimed at assessing the performance of kelp forest algae, invertebrates, and fish on a large artificial reef and natural reference reefs in San Diego county.

Brian Tissot

Director/Professor, Marine Laboratory, Department of Biology, Humboldt State University

Dr. Tissot is a marine ecologist with over three decades of experience conducting research on invertebrates and fishes in intertidal zone, kelp forest, coral reef, and deep-sea ecosystems. As part of his PhD dissertation he tagged over 5,000 black abalone on Santa Cruz Island and Año Nuevo Island, California and followed them for over 15 years.

California Department of Fish and Wildlife Science Team

California Department of Fish and Wildlife scientists most familiar with the design, methodology and application of red abalone density surveys were engaged in the process and provided input and feedback as necessary throughout the review process. CDFW Marine Region Program Manager, Tom Barnes, was the primary management contact for this review process.

Laura Rogers-Bennett, Senior Environmental Scientist, California Department of Fish and Wildlife, Research Associate, University of California, Davis

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Table of Contents

List of Tables

List of Figures

Executive Summary

This Final Report of the Science Advisory Committee was prepared in response to a scientific and technical review request by the California Department of Fish and Wildlife (CDFW). CDFW's goal in asking for this review was to determine the most robust and tractable methods for estimating red abalone density, which informs management of the northern California recreational fishery. Ocean Science Trust, an independent non-profit dedicated to advancing a constructive role for science in decision-making, designed and facilitated all aspects of the review in alignment with the CDFW Science Institute Procedural Guidelines for Ad Hoc Independent Scientific Advisory Committees.

Maintaining Credibility and Transparency in the Review Process

Upon garnering recommendations from CDFW, the scientific community, and key abalone stakeholder groups, Ocean Science Trust worked with the Ocean Protection Council Science Advisory Team to identify and convene a Science Advisory Committee (SAC) composed of six external experts from appropriate disciplines. The review process took place between July 2013 and June 2014 and was comprised of several public webinars as well as a one-day technical workshop involving the SAC and CDFW scientists. The conversations that occurred between the SAC, CDFW biologists, and stakeholders at each of these key process points, as well as additional analyses conducted by the SAC on CDFW abalone density data formed the basis for this report.

Key Recommendations to Strengthen Current Analytical Methods

The SAC's main evaluation and recommendations aim to strengthen the current sampling and analytical methods under the existing guidelines of the ARMP, and are not intended as an endorsement of the methods that are effectively set by the ARMP. The SAC's recommended analyses center on addressing the primary management question: Given the survey data, what is the likelihood that the actual population has crossed the triggers specified in the ARMP?

Recommendation: Calculate and Plot Estimates of the Population Mean and their associated Confidence Intervals through Time

The sub-samples of abalone captured by the dive surveys are used to estimate the true abalone population density at a given site. What is uncertain is the accuracy of the estimated density, and thus whether or not abalone populations have declined or increased to the point necessitating management action. The density survey data are highly variable due to unavoidable differences in transect location and quality of abalone habitat, as well as year to year and site to site differences in the number of abalone. An important first step to assessing population density estimates relative to management triggers is to consider this variability in abalone density estimates among transects. A very useful analysis for exploring trends over time relative to management triggers, and the uncertainty of those estimates, is to calculate and plot the mean abalone density for each spatial and temporal sampling unit (i.e., a site or the four index sites within a county for a particular sampling period), and their associated confidence intervals (CI). This approach will allow CDFW, the FGC, and others to see how density is changing over time, revealing population trajectories.

To use CIs, the FGC should make an a priori decision about what level of confidence they require of these density estimates to decide that no management action is necessary. For instance, if the FGC decides that they require 95% confidence that they have not crossed a trigger value, then they should examine figures with that confidence interval plotted, along with the relevant management trigger. In the event that the FGC specified confidence interval encompasses the trigger value, regardless of the mean value, then the possibility that the management trigger has been met or surpassed cannot be excluded and there is risk associated with the failure to act.

Recommendation: Generate Cumulative Probability Functions

As a next step, the SAC recommends generating Cumulative Probability Functions (CPF) as the analytical method allowing managers and interested stakeholders to transparently discuss the likelihood or risk that populations have crossed specified management triggers, given the population density estimate and its uncertainty. While CIs help provide an assessment of whether population densities have changed over time, and whether or not they are clearly above or below a trigger level, CPFs provide a means to explicitly evaluate the likelihood that the actual population density has met or surpassed a trigger level.

The CPF is set by the mean, the target value of interest (such as the management trigger), and the standard error of the mean, a measure of variability of the data used to estimate the mean, that takes into account the number of samples that estimate is based on. Considering management options at the different spatial scales (i.e., site, county, fishery) requires separate CFP's for each spatial scale of interest. CPFs can be calculated for any management trigger, such as the depth refuge trigger.

CPFs provide a powerful tool in that they should be compared against target confidence levels set by the FGC a priori. In other words, CPFs can help the FGC think about the tradeoff between the risk of saying the population has not crossed the threshold when it really has, verses the risk of saying the population has crossed the threshold when it has not. Risk being defined as the risk to population and fishery viability, as well as to curtailing a recreational and fishery opportunity for the general public.

Additionally, CPF provides a relatively simple way to assess the adequacy of a sampling design for given management goals. CPF modeling exercises can help to explore tradeoffs between the number of sites and number of samples (i.e. transects) at each site. For example, increasing the number of sites surveyed can increase the “steepness” of a CPF curve (i.e. extent to which confidence changes with change in the estimated mean), or one’s confidence that a given measured density value is above or below a trigger.

Ultimately, considering the raw data, the confidence limits, and the probability that the abalone population density has reached the trigger where some management action is required will provide the FGC with the best guidance as they consider management actions.

Additional Considerations to Potentially Improve Survey Methods and Analyses

The SAC also discussed some general limitations and potential improvements to the current survey methods. These items should be considered in future discussions as CDFW and the FGC move towards long-term management of red abalone.

- **The survey design employed by CDFW requires approximately three years to survey every site.** Given the potential for rapid changes in the abundance of these populations, and the shifting patterns of fishing effort, the current frequency of sampling is probably not adequate for management to detect and respond to rapid changes in population status.
- **This sampling method was not designed to represent or estimate the density of the entire abalone population, or to determine stock-wide biomass.** If the goal of management is to track the condition of abalone populations throughout their range (i.e., stock size, size structure, recruitment rates), a different survey design should be considered and additional survey sites should be included.
- **This review did not evaluate the population size structure data used to evaluate the recruitment trigger in the ARMP.** Size structure data could be used to develop a population viability model and risk assessment, which would provide an additional, independent method of assessing the health of the red abalone fishery. This needs to be explored.
- **Magnitude and distribution of statistical error (variability associated with an estimate of mean density) will vary based on whether the data analyzed incorporates all eight sites (fishery level), four sites (county level), or one (site level).** At the site level the existing variance structure of the underlying transect-level data exhibit substantial deviations from the assumptions of normality and homogeneity of variance that are required by standard parametric statistical analyses. Other non-parametric statistical techniques need to be employed (e.g., Monte Carlo resampling) to analyze transect data at the level of the individual site.
- **Analysis of variance (ANOVA) is not the most appropriate method for addressing the fixed management thresholds specified in the ARMP.** The ANOVA approach used by CDFW does not answer the question of whether abalone densities are above or below specific management triggers.
- **Analysis of Variance (ANOVA) that uses transects as replicate estimates of mean density does not provide inference about abalone populations outside of the eight fished index sites.** Assuming that these eight sites are representative of the north coast, treating transects as independent replicates, commits a statistical error known as pseudoreplication because it is expected that transects within a single site will be more similar to each other than to those from other sites. More importantly, the reality is these are not independent samples taken from a region. They are transects are nested within sites, thus it is very likely that they are non-independent. To make inferences about abalone populations across the entire North Coast, CDFW would have to modify both the survey design and data analysis.
- **The power analyses generated by CDFW is only applicable to the populations of abalone within the eight index sites.** This power analysis is subject to all the same

caveats as the ANOVA and overstates the power to detect changes across the entire region.

- **Statistical modeling techniques can help reduce the uncertainty associated with density estimates.** It is worth exploring whether statistical modeling techniques can help reduce the uncertainty associated with the density surveys. For instance, General Linear Models (GLMs) that incorporate data from all surveys years and sites, can provide powerful and practical ways to increase the precision of estimated densities without requiring additional physical surveys.
- **Additional data, such as habitat type, depth, and recruitment data can provide contextual information to help understand changes in density.** CDFW collects a great deal of valuable data in addition to density, including habitat attributes, depth, and recruitment. This information could be used to understand the context – or the "why" – density may or may not be changing.

Advancing Science to Better Inform Future Management

With CDFW's commitment to revise the ARMP and/or create a separate Fisheries Management Plan (FMP) for the recreational red abalone fishery, there is now an opportunity to build on the existing density data set to redesign the best possible sampling protocol for the species. Throughout the course of their discussions, the SAC identified a number of potential improvements to the assessment of abalone populations that go beyond the statistical and sampling questions that were at the center of the review scope. These suggestions may be helpful to consider in the future process to revise the ARMP or build an FMP.

Recommendations Associated with Existing Density Metric

- **Additional, robust collaboration with outside scientific experts will enhance the intellectual resources contributing to sampling and analysis of red abalone populations.** There are ample opportunities for CDFW to take advantage of the substantial intellectual resources within (and outside) the state to improve understanding of abalone populations. The SAC recommends establishing a standing review committee for the ARMP, somewhat analogous to the Statistical Committee of the federal Pacific Fisheries Management Council, to provide recommendations on the sampling design, analyses and interpretations conducted and generated by this program.
- **Make abalone survey data publicly available.** This would allow outside experts to verify and improve upon the analytical methods that are used for management of this important fishery, as well as help increase perceptions of credibility and build capacity without draining CDFW resources.
- **Consider alternatives to the use of eight index sites to manage the entire fishery.** A sampling protocol distributed across the region would provide a better picture of the stock as a whole, rather than solely within the eight index sites.
- **Develop strategies for more rapid tracking of the resource.** In any new survey design, a highly desirable trait would be the ability to gain data at every site on an annual basis.
- **Incorporate an understanding of the variability of the habitat.** Because certain habitat types are more suitable for abalone than others, incorporating understanding of the habitat (e.g., distribution and quality) at a site can help interpret density estimates. The recently generated seafloor maps for the state of California should be considered for this purpose.

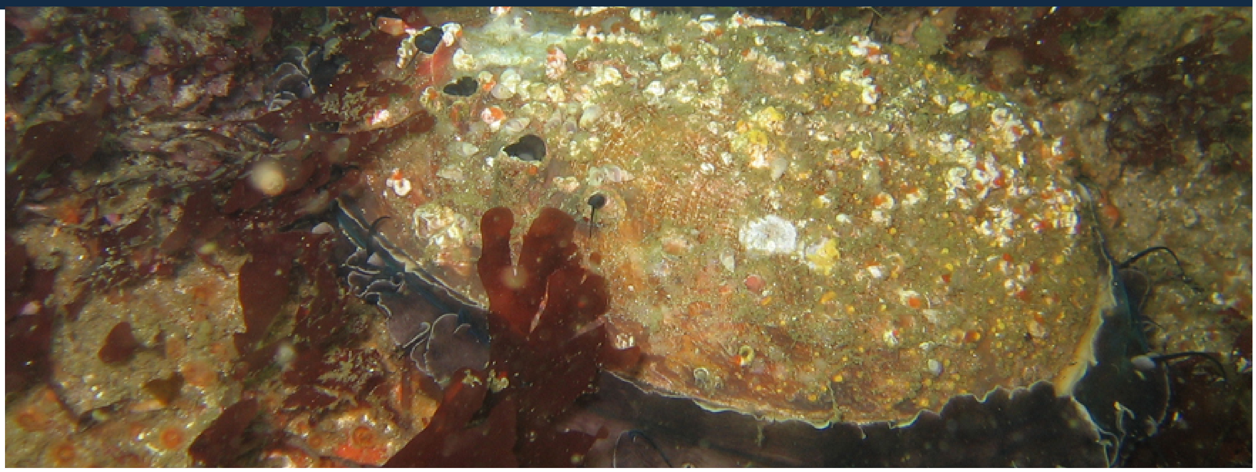
More broadly, CDFW should ensure that their random transect approach accurately captures the distribution of habitat types at the sites.

- **Codify appropriate analysis in the ARMP.** While the ARMP sets very specific guidelines for surveying density and triggers for management action, it is silent on the appropriate level of confidence required in the density estimates to require management action.
- **Revisit sustainable fishery density: incorporate additional data or establish a baseline with greater biological significance.** Given that there were no differences noted between the baseline surveys and the later survey period in 2003, it would be appropriate to consider new baseline numbers from a time period when every index site was surveyed.
- **Modify the current density survey design for a more powerful and efficient approach, including:**
    - **Consider abandoning the sampling of deep transects.** The deepest depth strata where very few individuals reside will skew (zero-inflating, i.e., many counts of zero individuals) the resulting data in ways that impair statistical analyses. However, there are important implications for the inferences generated from any altered sampling designs, which also need to be considered.
    - **Use of permanent or fixed transects.** This approach has the potential to record changes in specific locations and move to the level of monitoring an index of abalone populations rather than managing around an arbitrary density using random transects. Permanent transects do not confound measures of temporal change in density with differences caused by sampling different locations each sampling event. However, they can also involve greater logistical costs.
- **Further explore the utility of fishery-dependent catch data as a tool for informing management.** Our initial analysis of the total recreational take did not reveal a clear relationship between recreational take and density survey data. However, take data depends on effort and changes in regulations (bag limit, area closures), thus catch-per-unit-effort may be a more informative metric than total take.

Recommendations for Moving Beyond a Density Metric

- **Transition to tracking the state of the abalone population.** CDFW now has a valuable long-term data set that could potentially serve as the foundation for restructuring the monitoring and management triggers around whole population indicators.
- **Exploring alternative scientifically based management reference points.** Assuming there is a stock-recruitment relationship, a better metric in lieu of or in addition to density may be to use a fecundity index like Spawning Potential Ratio (SPR) adjusted by nearest neighbor distances.

Introduction



Background

Red abalone (*Haliotis rufescens*) in northern California (north of San Francisco) supports the only active abalone fishery in the state. In 2005, the California Fish and Game Commission (FGC) adopted an Abalone Recovery and Management Plan (ARMP[1]), which guides the management of the recreational fishery in the north, as well as the recovery of abalone stocks in the remainder of the state. The ARMP sets management guidelines and triggers for Total Allowable Catch (TAC) adjustments based on several criteria including density, recruitment, and catch-per-unit-effort. This report reviews the SCUBA survey design and analytical methods for estimating abalone density.

Abalone are vulnerable to overfishing due to low reproduction rates, disease, natural predation, and legal and illegal fishing pressure. California Department of Fish and Wildlife (CDFW) is the state agency responsible for managing California's abalone stocks. The fishery also has a committed group of engaged stakeholders who have expressed concerns about the accuracy of current density survey methods. In response to recent population declines, CDFW recommended that the FGC implement take reductions and fishery closures.

CDFW is committed to incorporating the best scientific information into management decisions. To this end, CDFW approached the California Ocean Science Trust, an independent organization dedicated to advancing a constructive role for science in decision-making, to coordinate a scientific and technical review of the survey design and methods currently used to estimate red abalone density in northern California. Ocean Science Trust designed and implemented a scientific review process in alignment with the CDFW Science Institute Procedural Guidelines for Ad Hoc Independent Scientific Advisory Committees[2].

[1] CDFW Abalone Recovery and Management Plan (ARMP) available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=29511&inline=true

[2] CDFW Science Institute Procedural Guidelines for Ad Hoc Independent Scientific Advisory Committees available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=47644

Review Scope

CDFW's goal in asking for this review was to determine the most robust and tractable methods for estimating red abalone density, which informs management of the northern California recreational fishery. Specifically, CDFW sought scientific and technical review of the:

1. survey design, including strengths and weaknesses of current methods for estimating red abalone density in northern California;

2. application of existing methods, including analysis of existing data, and interpretation of results; and

3. uncertainty associated with existing methods for estimating red abalone density, and its adequacy for informing catch limits and other management controls of the recreational red abalone fishery in northern California, as outlined by the Abalone Recovery and Management Plan (ARMP, CDFG 2005).

CDFW is committed to assessing all review recommendations, and responding as appropriate. Ocean Science Trust designed and implemented all aspects of the review process. Additional details of the review process are presented in Appendix C.

Guide to this Report

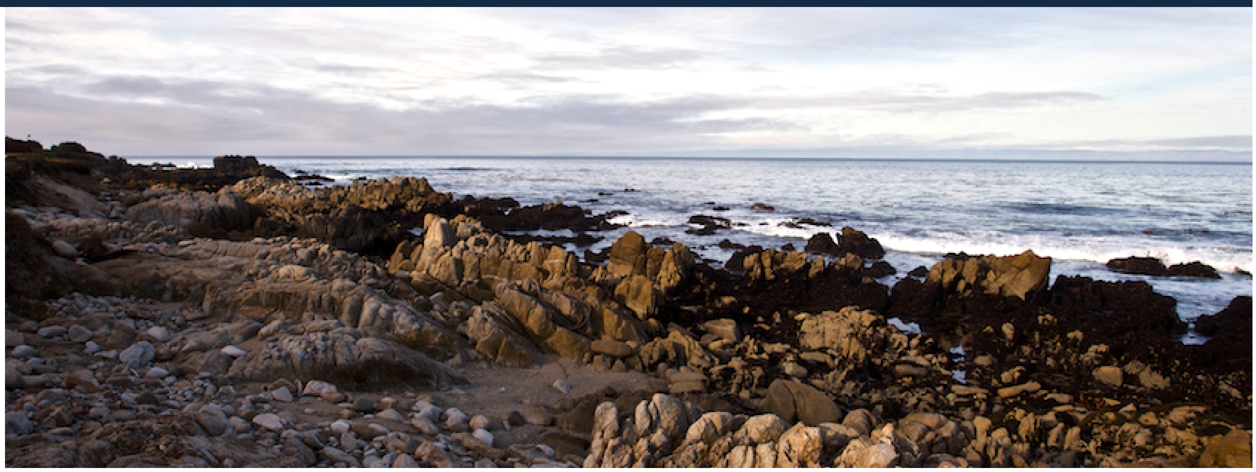
This report was written by the Science Advisory Committee (SAC) with support from Ocean Science Trust staff. It begins with a summary of the ARMP sections that informed this review, including an overview of the management triggers that CDFW's density estimates are meant to inform. Section 2 summarizes our understanding of CDFW's survey and data analysis methods, as presented in the CDFW's prepared background documents and PowerPoint presentations[1] to the SAC. The purpose of these sections is to clarify the assumptions that informed our deliberations. In Section 3, we present our immediate recommendations for the best way to employ the existing methods for estimating red abalone density consistent with the scope of this review. Because so much of the existing survey design is specified by the ARMP, we did not make recommendations in this section that would require changes to these regulations. Finally, in Section 4, we recommend issues to consider in the event of significant changes in the management structure.

We also include several appendices for greater clarity. Appendix A provides greater detail into the SAC's evaluation of CDFW's statistics, including several follow up analyses conducted by SAC members. Because we recommend a different method of analysis rather than improvements to CDFW's existing analyses, this evaluation is not designed to provide guidance for what CDFW should do going forward; rather, this section is included to help explain how the SAC arrived at the suggested analyses and recommendations presented in Sections 3 and 4.

Lastly, Appendix B and C provide PISCO's survey method and an overview of the review process, respectively.

[1] CDFW review materials available at: http://calost.org/science-advising/?page=ongoing-reviews#review-materials

1. Summary of Abalone Management



The red abalone fishery is managed under the ARMP[1] (CDFG 2005). Our understanding is that the ARMP specifies management decisions that may be made at the *entire fishery level* or at the *individual site level*. Although not designated in the ARMP, previous management actions have also been taken at the county level, hence we have considered the adequacy of the survey methods for management at this scale as well.

A set of stock condition criteria guides the management decision-making process. Our charge was to focus solely on the estimation of density obtained using SCUBA surveys. Critical aspects of the survey methods are codified in the ARMP. This includes the number and location of sites for the transect surveys, as well as the essential sampling design. Here, we summarize the sections of the ARMP which the density estimates are designed to inform.

Despite the specificity of the various triggers outlined here, the ARMP offers no guidance on how to analyze survey data, nor the level of precision or confidence required, to determine whether these criteria have been met. Since the survey data are necessarily sub-samples of the larger population (although not random ones), there is uncertainty in the density estimates obtained (as in any such sampling regime) and their domain of applicability is restricted. How to evaluate and resolve these issues in the management decision-making process is not clearly specified in the ARMP.

1.1 Management Triggers

1.1.1. Fishery Level Management

For management at the fishery level (i.e., the entire region of northern California where fishing is permitted), the ARMP specifies density thresholds in two depth ranges. A "sustainable fish-

[1] CDFW Abalone Recovery and Management Plan (ARMP) available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=29511&inline=true

ing density," considered to be the best estimate of a sustainable healthy density to support the ongoing fishery, was established based on the average density measured at three index sites during CDFW surveys conducted in 1999 and 2000 (Fort Ross, Salt Point, and Van Damme). These sustainable fishing densities are: 1) 6,600 abalone per hectare (ab/ha) (0.66 ab/m^2) averaged across all depths sampled, and 2) a separate threshold of 3,300 ab/ha at refuge depths (beyond 8.4 m or 28 feet) (Table 1). The ARMP calls for densities across a total of eight specified index sites (including the three index sites above) to be compared to these "sustainable fishing density" thresholds. If mean density averaged across all eight sites declines below a threshold of 5,000 ab/ha at all depths or less than 2,500 ab/ha at refuge depths, CDFW can recommend a reduction of total allowable catch (TAC) by 25% increments, as specified in the ARMP. These threshold densities represent a 25% reduction below the specified sustainable fishery density. CDFW can recommend a fishery closure when average densities at all eight index sites and at all depths fall below 3,000 ab/ha. If density in refuge depths recovers to more than 3,300 ab/ha and all depths to more than 6,600 ab/ha, the fishery may reopen under the long term management plan. Fisheries will initially be reopened with low TAC levels that can be incrementally increased to former levels over a number of years depending on stock conditions.

Table 1. Total allowable catch (TAC) adjustment decision table using established criteria. Adjustments to the TAC are from the baseline of 400,000 abalone per year or from revised TAC baselines (ARMP Table 7-2, CDFG 2005).

CRITERIA					ACTION
Recruitment		Density (ab/ha) – emergent surveys			
		Refuge (deep)		All depths	
Yes	AND	More than 4,100	AND	More than 8,300	1) **Increase TAC** by 25% (to maximum of 500,000 ab/yr or 125% of revised TAC)
NA		3,300	AND	6,600	2) **Maintain TAC** (400,000 ab/yr or revised TAC)
No	AND	Less than 2,500	OR	Less than 5,000	3) **Reduce TAC** by 25% increments
NA		NA		Less than 3,000 at all surveyed index sites combined	4) **Close fishery** until stocks are recovered according to recovery criteria **AND** enough data are collected to shift to long-term management plan
NA		More than 3,300	AND	More than 6,600	5) If recovery criteria are also met, **reopen closed fishery** under long-term management plan

* The specific density targets in this table are based upon the best available data at the time of adoption and may be changed without full plan amendment pursuant to Section 4.4.1.
Note: A closed fishery will not be opened unless recovery criteria are met.
NA = Not applicable

1.1.2 Site Level Management

The ARMP also specifies management actions that can occur at the level of individual sites

(ARMP Table 7-4, CDFG 2005). If there is a significant decline in catch per unit effort (CPUE) at an index site, as indicated by catch records, CDFW may choose to conduct additional density surveys to determine if a closure is warranted. The CPUE data is used as a trigger for conducting density surveys, rather than as a specific criterion for a site closure. If these surveys indicate density has dropped below 2,500 ab/ha at all depths, CDFW can recommend a closure of the affected site and a reduction in the baseline TAC. A closed site can only be reopened once it has more than 3,300 ab/ha at refuge depths and more than 6,600 ab/ha at all depths, and the entire fishery meets the minimum criteria for an allowable fishery (Table 2).

Table 2. Site closure decision table using established criteria (ARMP Table 7-4, CDFG 2005).

CRITERIA				ACTION
Density (ab/ha) - emergent			**CPUE and Serial Depletion**	
Refuge (deep)		All Depths		
NA		NA	Significant decrease in CPUE, or increase in distance traveled	Density **surveys** to determine if closure is warranted
NA		Less than 2,500	NA	**Close** affected site and reduce baseline TAC
More than 3,300	AND	More than 6,600	NA	**Reopen** closed site

* The specific density targets in this table are based upon the best available data at the time of adoption and may be changed without full plan amendment pursuant to Section 4.4.1.

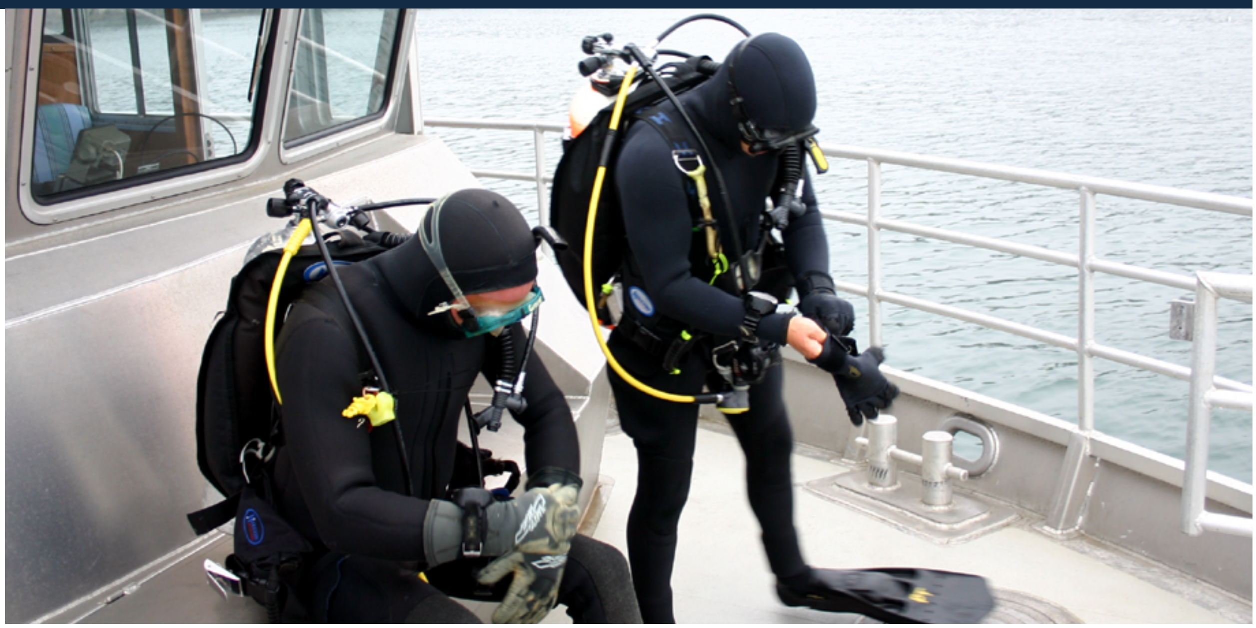
1.1.3 County Level Management

Though not specified in the ARMP, CDFW has recommended to the Fish and Game Commission (FGC) to take actions at the county level to close or reduce fishing pressure based on density data at four index sites from within that county. For example, in response to a harmful algal bloom in 2011, the FGC adopted emergency regulations to close Sonoma County from February 24 through May 24, 2012[2]. In addition, for the 2014 season, fishery regulations were adopted to reduce the yearly limit to no more than 9 (of the allowed 18) abalone to be taken from Sonoma County[3]. CDFW recommended these actions based on data presented by CDFW indicating a decline in average density across all eight sites was largely driven by the four index sites within Sonoma County.

[2] Available at: http://www.fgc.ca.gov/regulations/2012/29_15e2ntc.pdf

[3] Available at: http://www.fgc.ca.gov/regulations/2013/29_15ntc.pdf

2. California Department of Fish and Wildlife Density Estimation Methods and Rationale



In the course of this review, CDFW provided several overviews of their sampling and data analysis methods. These include the document "Estimating Red Abalone Density for Managing California's Recreational Red Abalone Fishery (CDFW 2013[1])," presentations to the SAC during the Review Kickoff public webinar (September 16, 2013[2]), and the Technical Review Workshop on October 23, 2013[3]. CDFW also provided raw transect data so that we could conduct additional analyses. Based on these documents, we summarize our understanding of the methods currently employed by CDFW for estimating abalone density and making recommendations for management under the ARMP.

2.1 Summary of CDFW Methodology, Analysis, and Rationale[4]

A primary component of adaptive management of the recreational red abalone fishery in northern California is the survey of densities conducted by CDFW using SCUBA at index sites. As noted by CDFW and stated in the ARMP, these results are not intended to be scaled up to an overall estimate of population (or stock) density, size, or biomass. Rather, these high- and medium-use fishery sites serve as sensitive indicators of population responses to fishing in the management region. The results of these surveys are meant to be compared to the thresholds outlined in the ARMP.

[1]Available at: http://calost.org/pdf/science-advising/peer-review/Density_Review_Doc_Oct_6_2013-Final.pdf

[2] View the September 15, 2013 meeting webinar here: http://bit.ly/19Xy5ZH

[3] View the October 23, 2013 workshop summary here: http://bit.ly/1k846zj

[4] http://calost.org/pdf/science-advising/peer-review/Density_Review_Doc_Oct_6_2013-Final.pdf

2.1.1 Index Sites

Surveys are conducted at four Sonoma and four Mendocino county sites (Figure 1). These sites were chosen based on their level of use; they represent a large portion of the catch and fishing effort (two high and two medium use sites per county, collectively representing ~48% of the catch in the region). Again, CDFW did not select sites at random to generate total population estimates. Rather, they selected sites in which fishing may have a detectable impact on density to be used as an indicator of the efficacy of the existing management measures at those sites. It takes approximately three to five years to complete surveys at all eight index sites. Non-index sites are also sampled to compare with the fished index sites, although only density data from index (fished) sites are used for management.

Figure 1. Abalone dive survey index sites in northern California (CDFW 2013).

2.1.2 CDFW Survey Design

At each site, 36 transects are surveyed in a stratified sampling design. Nine transects are placed at random in each of the following four depth strata:

a) 0 – 4.5m (1 – 15ft)
b) 4.5 – 8.3m (16 – 30ft)
c) 9 – 13.7m (31 – 45ft) (refuge depth)
d) 13.7 – 18.3m (46 – 60ft) (refuge depth)

The two deeper depth strata c) 9 – 13.7m and d) 13.7 – 18.3m are not optimal habitat for red abalone. Abalone densities at these deeper depths tend to be lower than those in more optimal shallower habitat where kelp is more abundant. Depths beyond 9m are beyond the free diving range of most fishermen, and are considered a refuge from fishing for abalone populations. The ARMP specifies depths below 8.3 m as a deep refuge and considers a healthy population at this depth as essential protection against overfishing.

Within each depth stratum at each site, transects (30 x 2m) are placed at pre-determined, random GPS coordinates. Transect locations are randomly chosen each year, rather than being fixed between survey periods. Transects are deployed by divers along the target depth contour, generally parallel to shore. Transects are located in rocky reef habitats; divers move a transect if they encounter more than 50% sandy substrate. Only emergent abalone are counted. The first 25 individuals for each species of abalone observed along each transect are measured, allowing CDFW to estimate the size frequency distribution of the population. These data are used to assess the population against the recruitment (here, defined as recruitment to the fishery) criteria for management triggers (Table 1; ARMP Table 7-2). Additionally, divers record data on depth, algal cover, and habitat substrate (% type).

2.1.3 CDFW Data Analyses and Results

Comparing Density Against Management Thresholds

As previously noted, the ARMP does not provide guidance on how to conduct data analyses; rather, it includes trigger limits and asks whether the population densities are above or below these limits. CDFW estimates the population density as the mean from all transects in the region of interest. This mean value is then compared to the triggers specified by the ARMP, and if average density falls above or below a trigger, management changes defined in the ARMP may be recommended to the FGC.

CDFW presented mean densities (averaged from all depth strata per site) across all eight index sites and at the individual site level (Table 3). The data from all eight index sites are considered in a single time period “bin” that spans approximately three to five years (the time required to revisit all sites) (see figure 4).

These data (presented in abalone per m^2) indicate that the average density across the eight index sites in the 2009-2012 time period dropped to 0.472 ab/m^2, below the 0.5 ab/m^2 management threshold (sustainable fishery density); in response to these results, CDFW recommended a reduction in take in the fishery.

Table 3. Average densities (abalone/m²), 95% confidence intervals, and number of transects (n) for each index site during three time periods – Earliest (2003-2007), Mid (2007-2010), and Most Recent (2009-2012). Note that units of ab/m2 is consistent with other CDFW documents.

	2003-2007		2007-2010		2009-2012	
Site	Average ± 95%c.i.	*n*	Average ± 95%c.i.	*N*	Average ± 95%c.i.	*n*
Fort Ross	**0.572** ± 0.180	37	0.411 ± 0.107	35	**0.248** ± 0.088	37
Timber Cove	**0.811** ± 0.160	37	0.430 ± 0.137	35	**0.368** ± 0.151	36
Ocean Cove	**0.863** ± 0.240	36	0.622 ± 0.202	36	**0.327** ± 0.113	32
Salt Point	**0.907** ± 0.326	36	0.374 ± 0.127	43	**0.314** ± 0.117	41
Point Arena	**0.571** ± 0.157	38	0.663 ± 0.225	36	**0.812** ± 0.219	40
Van Damme	**1.074** ± 0.286	34	0.623 ± 0.268	38	**0.797** ± 0.314	36
Caspar Cove	**0.576** ± 0.295	35	0.435 ± 0.163	49	**0.393** ± 0.125	55
Todd's Point	**0.428** ± 0.182	34	--	--	**0.514** ± 0.205	31
ALL	**0.725** ± 0.154	287	--	--	**0.472** ± 0.153	308

Analysis of Variance (ANOVA)

In the absence of specific guidance from the ARMP, CDFW has used analysis of variance (ANOVA) to determine whether observed density changes are significantly different from the earlier time points, taking into account the random noise inherent in such sampling programs. The results of the ANOVA were described as evidence that there was a significant reduction in densities at some or all of the index sites over time. These analyses were used to understand declines in density at the level of individual site, four sites within a county, or all eight index sites to further support management decisions. These data were presented to the FGC in support of initial management actions for the county. Such area management options are outlined in the ARMP for future long-term management, but data needs and thresholds have not been specified.

CDFW presented several ANOVA results to the SAC at the public webinar, the technical workshop, and in the background documents. Specific comparisons included:

- 1999-2000 surveys with 2003-2007 surveys
- 2003-2007 surveys with 2009-2012 surveys

For these analyses, ‘Time period,’ ‘County,’ and ‘Site’ were factors, with ‘Site’ nested within ‘County’, and each transect treated as an individual unit of replication.

As an example of such an analyses, CDFW presented results of an ANOVA comparing the 2009-2012 to the 2003-2007 period (Table 4).

Table 4. Nested ANOVA results for the 2009-2012 compared to the 2003-2007 period.

Source	Sum Squares	df	Mean Squares	F	Prob > F
Time	2.93	1	2.93	24.47	0.0000
County	0.28	1	0.28	2.31	0.1295
Site (County)	3.48	6	0.58	4.84	0.0001
Time*County	2.31	1	2.31	19.29	0.0000
Time*Site (County)	1.06	6	0.18	1.47	0.1848
Error	69.41	579	0.12		
Total	79.57	594			

Results of CDFW's ANOVA indicated there was a statistically significant difference in abalone density across all eight index sites, indicated by the significance ($p<0.05$) of the 'Time' component. These results also indicated a significant interaction of 'Time*County'; CDFW presented that the overall fishery decline was driven largely by a 60% decline in Sonoma County sites (data not presented here); however, the analyses presented in Table 4 alone do not provide an estimate of effect sizes, nor do they specifically address whether or not the ARMP-specified management threshold densities have been met or surpassed at any level.

Power Analyses

CDFW conducted power analyses to determine if their sampling design and analyses were sufficient to detect changes in density of a specific effect size (25% reduction in density between time periods) at the fishery (eight index sites), county (four index sites), and site levels (Table 5a-c).

A statistical power analysis is a formal assessment of the probability that a statistical test will correctly reject the null hypothesis when it is, indeed, false (i.e., 1-beta, or Type II error). It provides a mechanism to test the suitability of sampling protocols for detecting effects (differences between means) of a given size. The parameters of a power analysis include sample size, effects size of relevance, and the significance level (i.e., alpha, the Type I error or probability of inappropriately rejecting the null hypothesis). CDFW assessed the adequacy of their sampling design to detect a 25% change in abalone population density. They assumed that sigma (the variance of the data) would decline 25% along with the density, and that a value of (1-beta)>0.8 indicated sufficient power to detect a 25% effect at the 0.05 level. These analyses were conducted using individual transects as independent units of replication.

Table 5. CDFW Power analyses results at various levels that the fishery is managed.
a. CDFW Power Analyses at the Fishery Level across all 8 Sites for the 2003-2007 and 2009-2012 periods.

Time Period	Power (1-β)	Sample Size (n)	Alpha	Beta	Mean 1	Mean 2	Sigma 1	Sigma 2
2003-2007	0.955	287	0.05	0.04485	0.72	0.54	0.73	0.55
2009-2012	0.860	287	0.05	0.13989	0.47	0.35	0.58	0.44

Mean 1: Mean of density from transect surveys
Mean 2 = Set as a 25% decrease in density from Mean 1 to correspond with the level of change needed to be detected.
Sigma: Standard deviation, from the survey data for Sigma 1 and decreased by 25% for Sigma 2

b. CDFW Power Analyses at the Sonoma (4 sites) and Mendocino (4 sites) county level.

County	Time Period	Power	Sample Size (n)	Alpha	Beta	Mean 1	Mean 2	Sigma 1	Sigma 2
Sonoma	2005-2007	0.85089	146	0.05	0.14911	0.79	0.59	0.72	0.54
	2012	0.6926	146	0.05	0.3074	0.31	0.23	0.36	0.27
Mendocino	2003-2006	0.71488	144	0.05	0.28512	0.66	0.49	0.74	0.55
	2009-2011	0.70439	162	0.05	0.29561	0.61	0.46	0.70	0.53

Mean 1: Mean of density from transect surveys
Mean 2 = Set as a 25% decrease in density from Mean 1 to correspond with the level of change needed to be detected.
Sigma: Standard deviation, from the survey data for Sigma 1 and decreased by 25% for Sigma 2

c. CDFW Power Analyses at the Site level across two sites*.

Site	Time Period	Power	Sample Size (n)	Alpha	Beta	Mean 1	Mean 2	Sigma 1	Sigma 2
Van Damme	2010	0.26335	36	0.05000	0.73665	0.80	0.60	0.95	0.71
Fort Ross	2012	0.30383	37	0.05000	0.69617	0.25	0.19	0.27	0.20

Mean 1: Mean of density from transect surveys
Mean 2 = Set as a 25% decrease in density from Mean 1 to correspond with the level of change needed to be detected.
Sigma: Standard deviation, from the survey data for Sigma 1 and decreased by 25% for Sigma 2
*CDFW presented results of their power analyses at the site level using Van Damme (2010) and Fort Ross (2012) as a test cases. Given the results of these analyses (low power), it is assumed that there will not be enough power to detect changes at the site level for any of the index sites.

Given the assumptions of alpha, beta, and using transect as independent replicates, CDFW indicates that they have the power to detect the following changes in abalone density.

- All eight index sites (fishery level): CDFW has the power to detect changes (effect sizes) in density greater or equal to 25% across all 8 index sites for both the 2003-2007 and 2009-2012 time periods.
- Four index sites within a county: CDFW has the power to detect changes (effect sizes) in density greater or equal to 25% at the four index sites within Sonoma County, but not for the four Mendocino County sites.
- Site level: CDFW does not have the power to detect changes (effect sizes) in density of 25% at any of the index sites.

3. Evaluations and Recommendations

The recommendations in this section represent our best assessment of how CDFW and the FGC should consider the abalone density survey data in the context of the current requirements of the ARMP. Given the constraints that the ARMP places on data collection, combined with the document's lack of guidance on appropriate analyses, our emphasis is on addressing the primary management question of whether abalone population densities are above or below specified triggers.

In Section 3.1, we recommend analyses that can be easily implemented, and will allow the FGC to make transparent decisions as to the level of risk or confidence required for management decisions. Then, in Section 3.2, we discuss limitations of CDFW's current sampling methods and data analyses as they were presented to us.

We do not intend this section as an endorsement of the methods that are effectively set by the ARMP. Rather, the recommendations in Section 3 aim to strengthen the current sampling and analytical methods under the existing guidelines of the ARMP. In highlighting the limitations of the current sampling design we hope that this may inform future discussions as CDFW and the FGC move towards long-term management of red abalone. More specific recommendations towards this end are contained in Section 4.

3.1 SAC Recommended Analyses

As outlined in Section 1, the FGC requires clear guidance whether the overall densities of abalone at the index sites are above or below the trigger levels. It is worth noting the important distinction between the densities of the sub-samples captured by the dive surveys and the actual population of abalone in the field. The sub-samples of abalone captured by the dive surveys are used to estimate the true abalone population density at a given site. What is uncertain is the accuracy of the estimated density, and thus whether or not abalone populations have declined or increased to the point necessitating management action. The analyses recommended (indeed, any statistical analysis) serve to highlight this distinction and answer the question: Given the survey data, what is the likelihood that the actual population have crossed the trigger specified in the ARMP?

We recommend Cumulative Probability Functions (CPF) as the analytical method to determine, with transparent probability, the likelihood that populations meet particular management triggers. Additionally, CPFs provide a relatively simple way to assess the adequacy of a sampling design for given management goals. Ultimately, considering the raw data, the confidence limits, and the probability that the abalone population density has reached the trigger where some management action is required will provide the FGC with the best guidance as they consider management actions.

3.1.1 Estimates of the Population Mean and their Confidence Intervals through Time

The survey data to estimate abalone density are highly variable due to unavoidable differences in transect location and quality of abalone habitat, as well as year-to-year and site-to-site differences in the number of abalone. An important first step to assessing populations density estimates relative to management triggers is to consider this variability in abalone estimates among transects.

Confidence intervals...provide the most direct connection between the underlying variability and the level of certainty that managers need to take action.

Variability is typically presented as the variance, standard deviation, standard error, or confidence intervals, all of which are different measures (all mathematically related) of the level of uncertainty associated with the estimated mean density. In various documents connected with this review, CDFW uses all of these measures. In this discussion, we focus on the confidence intervals, since they provide the most direct connection between the underlying variability and the level of certainty that managers need to take action. To use confidence intervals, the FGC should make an a priori decision about what level of confidence they require to decide that no management action is necessary. For instance, if it is decided that they require 95% confidence that they have not crossed a trigger value, then they should examine figures with that confidence interval plotted along with the relevant management trigger (Figure 2A). In the event that the FGC specified confidence interval encompasses the trigger, regardless of the mean value, this indicates caution is required because the possibility that the management trigger has been met or surpassed cannot be excluded. The next step should be to generate a CPF to explicitly explore the likelihood that a trigger density has been met.

Exploring visual representations of means along with associated confidence intervals allows CDFW and the FGC to spot trends and look for shifts at smaller management units (e.g., site or county). A temporal trend of declining density may indicate that a more precautionary management approach is warranted than would be the case for a stable population close to a management trigger.

[Confidence intervals are] a very useful analysis for exploring trends over time relative to management triggers.

A very useful analysis for exploring trends over time relative to management triggers is calculating the mean abalone density for each spatial and temporal sampling unit (i.e., a site or the four index sites within a county for a particular sampling period), and the associated Confidence Intervals (CI). This approach will allow CDFW, the FGC, and others to see how density is changing over time and reveal declining population trajectories (Figure 2).

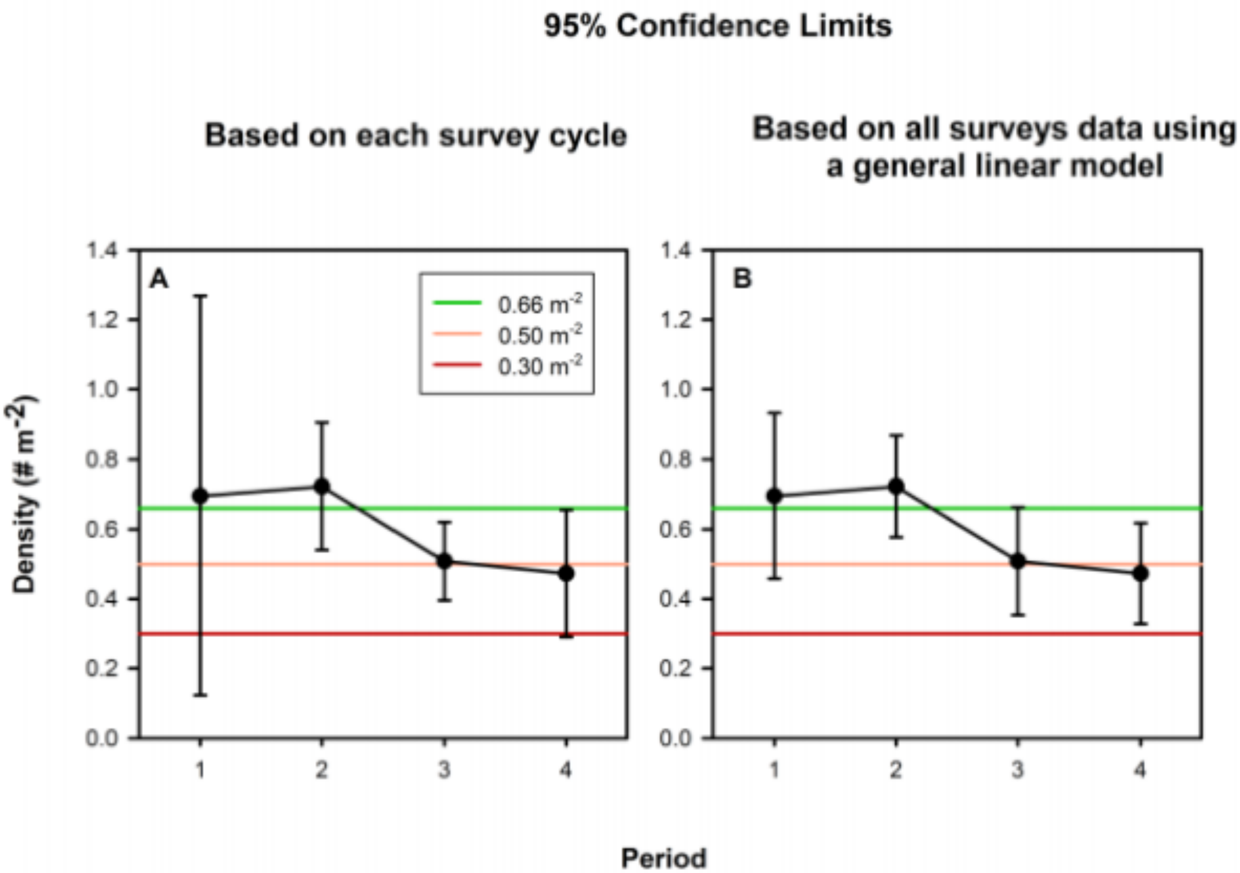


Figure 2. Estimated density of abalone, at the fishery level using site level averages, for each time period with 95% confidence intervals. (A) Means and confidence interval calculated for each period separately. (B) Least square means and their confidence intervals from a general linear model using data from all four time periods. Period 1: 1999-2000; Period 2: 2003, 2005-2007; Period 3: 2007-2010; Period 4: 2009 – 2012. The ARMP-specified management thresholds for all depths are indicated as colored reference lines: 6,600 ab/ha (green) indicates a sustainably fished population density; 5,000 ab/ha (orange) is the density threshold at which reductions in TAC are recommended; 3,000 ab/ha (red) is the density threshold at which a fishery closure is recommended.

3.1.2 Cumulative Probability Functions

Cumulative probability functions can provide managers with a more transparent picture of the likelihood that actual abalone density (at the index sites) has crossed a management trigger, given the population density estimate and its uncertainty. While CIs help provide an assessment of whether population densities have changed over time, and whether or not they are clearly

Cumulative probability functions can provide managers with a more transparent picture of the liklihood that actual abalone density (at the index sites) has crossed a management trigger.

above or below a trigger level, CPFs provide a means to explicitly evaluate the likelihood that the actual population density has met or surpassed a trigger level.

Figure 3 illustrates a CPF calculated for the eight index sites during one year (2009) relative to two management triggers. A similar figure can be calculated for any abalone density estimate and corresponding management trigger. The lower the estimated abalone density, the higher the probability the actual value is below the trigger. Conversely, the higher the estimated density, the lower the probability that the actual density is below the management trigger. For instance, in Figure 3A, considering the management trigger of 5000 ab/ha across all depths in the case where dive surveys estimate the mean density as 5000 ab/ha, there is 50% likelihood (0.5 probability) that the actual abalone density lies above or below that trigger. In the case where the density estimate across all eight index sites at all depths was 4000 ab/ha, there would be a 90% likelihood (0.9 probability) that the actual density is also below 5000 ab/ha.

Using [cumulative probability functions], the Fish and Game Commission can make transparent and explicit decisions about the level of risk they are assuming in taking, or not taking, management action.

Using such a figure, the FGC can make transparent and explicit decisions about the level of risk they are assuming in taking, or not taking, management action when it is possible that density values have met or exceeded, or are close to, management thresholds.

Sampling Design and Precision of Estimates

The CPF is set by the mean, the target value of interest (such as the management trigger), and the standard error of the mean, a measure of variability of the data used to estimate the mean that takes into account the number of samples that estimate is based on. This measure of variability sets the steepness of the curve, and anything that decreases the standard error will increase the confidence that a given estimated density value represents a population that actually is above or below the trigger. Increasing the number of sites sampled would increase the steepness of the curve (i.e. extent to which confidence changes with change in the estimated mean) (dashed lines in Figure 3A, B). For instance, a value of 4000 ab/ha estimated from eight sites would have a 90% chance of being below the 5000 ab/ha trigger limit. That same value estimated based on 16 sites would provide 98% confidence of being below the trigger. By providing guidance about the confidence required for management action, the FGC can use CPFs to aid future survey design. Similar modeling exercises can help to explore tradeoffs between the number of sites and number of samples (i.e. transects) at each site.

Applying CPFs at Different Spatial Scales

Considering management options at the different spatial scales (i.e., site, county, fishery) requires separate CPFs for each spatial scale of interest. CPFs can be calculated for any management trigger, such as the depth refuge trigger of 2500 ab/ha (Figure 3B). The CPFs in Figure 3 were calculated using site as the unit of replication. We recommend this approach for several reasons: as discussed in section 3.2.3, aggregating transects within sites provides scope to consider the survey results as representative of areas more broad than just the index sites themselves. Additionally, the process of averaging normalizes the variance of the underlying data.

Although the methods are the same, caution is required when generating such curves at any spatial scale using transect as the unit of replication. Given the observed underlying distribution of the data (which should be normally distributed to meet the assumptions of these statistical tests), it is not acceptable to use the standard error of these data (which are characterized in statistical terms as “skewed”) for generating CPFs. Standard statistical techniques such as resampling can address this issue and permit generation of CPFs using transect as the unit of replication.

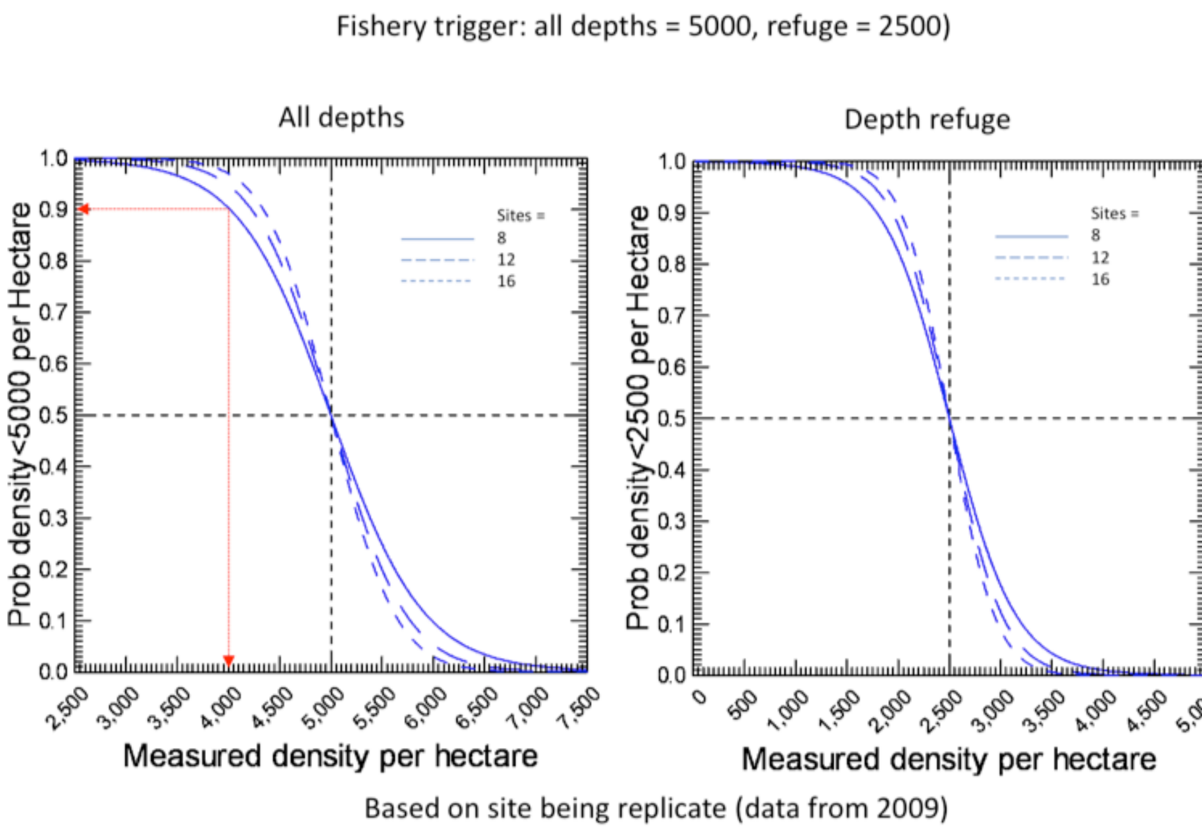


Figure 3: Cumulative probability functions (CPFs) generated from CDFW abalone density data collected in 2009. The CPFs indicate the probability (vertical axis) that the actual abalone density lies below the management trigger for a given estimated abalone density (horizontal axis). (A) Three CPF’s based on a management trigger of 5000 ab/ha across all sampled depths. Arrows (red and blue) are examples discussed in the text. (B) Three CPFs based on a management trigger of 2500 ab/ha within the refuge depths. The three different curves in each figure are calculated for 8, 12 and 16 index sites.

Conclusion

CPFs provide a powerful tool, allowing managers and interested stakeholders to transparently discuss the likelihood or risk that populations have crossed specified management triggers. In practical use, they should be compared against target confidence levels set a priori. For example, if the management goal is that management changes may be triggered with 50% confidence, then a simple demonstration that the measured value is above or below a threshold is

Cumulative probability functions provide a powerful tool, allowing managers and interested stakeholders to transparently discuss the likelihood or risk that populations have crossed specified management triggers.

sufficient. By contrast, a management goal may be to have 90% confidence that a threshold has not been crossed (i.e., density is truly above) 5000 ab/ha. In this case, using current data and current sampling design, this would require a measured density of 6000 ab/ha. Modifications to the sampling design, such as increased sampling effort could reduce uncertainty while maintaining a given level of confidence.

3.2 Assessment of Current CDFW Survey Methods and Analyses

The CPFs represent our best guidance for future analysis of the density survey data in the context of the ARMP. We also delved into the underlying survey design and previous analyses employed by CDFW. Below, we summarize some major considerations regarding the current sampling and analytical methods that arose from our discussions. A more detailed exploration of the technical issues is included in Appendix A.

3.2.1 Sampling Methods

CDFW dive surveys form a valuable long-term data set. [These data] provide general understanding of the ecology of abalone in this region and can continue to provide useful insights about abalone populations.

The fourteen years of CDFW dive surveys form a valuable long-term data set. In addition to its role in management, these data provide general understanding of the ecology of abalone in this region and can continue to provide useful insights about abalone populations going forward. The methods have been applied consistently over time, and were used to set the benchmark fishery densities for the ARMP. While there is legitimate scientific debate as to whether other methods might be "better," it was a reasonable design at the time it was implemented. There is also intrinsic value to this long-term data set. Given the existing language of the ARMP, it appears difficult to change the details of the in-water survey methods, and any such change would need to take the long-term data context into account. Any new sampling design should reflect specific management objectives or criteria and be optimized with respect to efficiency, accuracy and precision; there are many designs that are worth consideration. Below, we discuss some general limitations and potential improvements to the current survey methods.

- **The survey design employed by CDFW requires approximately three years to survey every site.**

  Abalone populations can be dynamic over time scales shorter than three years, driven by fishery and environmental factors. Waiting to survey every index site results in long lag times before the population can be assessed, and management decisions made within the structure of the ARMP. These lag times are reflected in aggregations of the density estimates based on the survey cycle (e.g., 2009-2012). Given the potential for rapid changes in the abundance of these populations, and the shifting patterns of fishing effort, the current frequency of sampling is probably not adequate for management to detect and respond to rapid changes in population status. Ad hoc changes in the survey design, such as shifting all sampling effort to a single county in response to a harmful algal bloom in 2011 recognize, and attempt to address, these challenges but also have the potential to skew the picture by focusing on particular sites. Figures 4 and 5 highlight the difference between the data aggregated across all sites and the underlying surveys as they were collected, respectively. Monitoring the survey data on an annual, un-aggregated basis, can make trends (such as the decline in density that began in Sonoma County in 2008) more apparent.

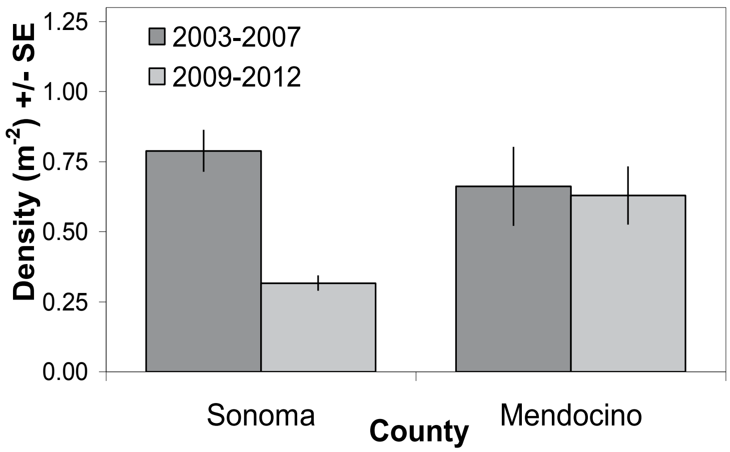


Figure 4: Abalone density measured by dive surveys at 8 index sites, combined by county (Sonoma and Mendocino) compared between two time periods (2003-2007 and 2009-2012).

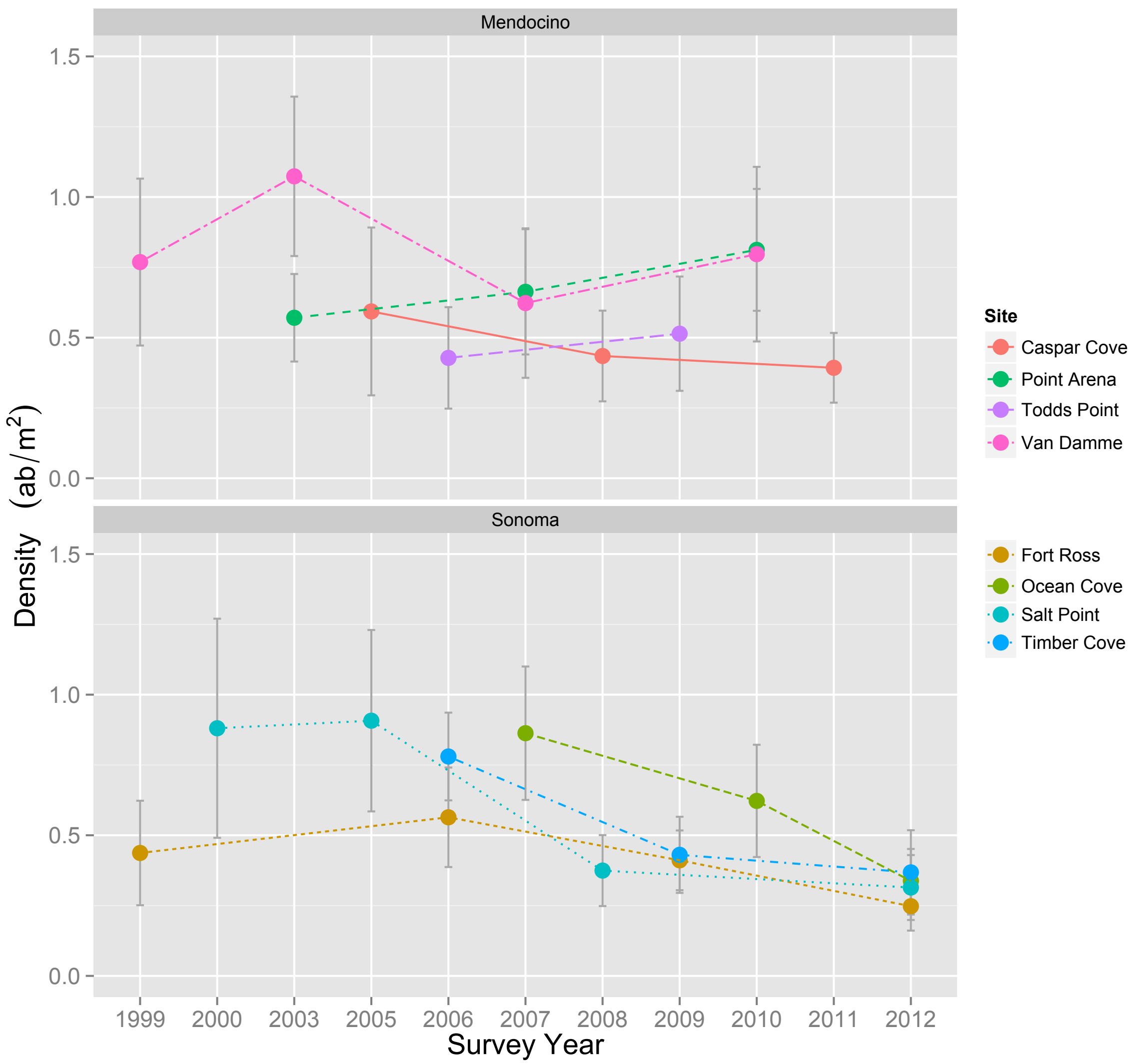


Figure 5. Abalone density survey data (mean +/- 95% confidence interval) by site, year, and county from 1999 through 2012.

- **This sampling method was not designed to represent or estimate the density of the entire abalone population, or to determine stock-wide biomass.**

  The current sampling method is designed to provide estimates of abalone density over time at eight fished index sites. These methods do not (nor are they meant to) provide CDFW with an overall estimate of the total size of the abalone population or biomass in the northern California region. The decision to use these specific index sites (representing moderately-to-heavily fished areas) was made to provide the State with a snapshot of potential changes in density specifically due to fishing pressure. If that is the primary goal of management, this survey design may be adequate. If the goal of management is to track the condition of abalone populations throughout their range (i.e., stock size, size structure, recruitment rates), a different survey design should to be considered and additional survey sites should be included.

- **This review did not evaluate the population size structure data used to evaluate the recruitment trigger in the ARMP.**

  CDFW collects these data during their density surveys, and these are used to evaluate the recruitment threshold of the ARMP. Size structure is often used in fisheries management to assess the state and trajectory of fished stocks and these data should be used to their full extent. In particular, size structure data could be used to develop a population viability model and risk assessment, which would provide an additional, independent method of assessing the health of the red abalone fishery. This needs to be explored. Though we did not investigate, it is likely that the comparison of these data relative to the thresholds outlined in the ARMP will be subject to similar caveats regarding the confidence of the estimates.

3.2.2 Density Estimates at the Fishery, County, and Site Levels

- **Magnitude and distribution of statistical error (variability associated with an estimate of mean density) will vary based on whether the data analyzed incorporates all eight sites (fishery level), four sites (county level), or one (site level).**

  The dive survey sampling design spans at least three spatial levels of interest: fishery, county, and site, each of which has its own variance structure. Confidence intervals at each of these management levels will differ based both on the reduction in the number of sites (and therefore data points) and the difference in variability of the data at each of these levels. The underlying transect-level data exhibit substantial deviations from the assumptions of normality and homogeneity of variance that are required by standard parametric statistical analyses. When individual transect-level data are averaged up to the county or fishery level, the averaging process ameliorates this problem. At the site level, however, the existing variance structure violates statistical assumptions and this is not correctable by standard transformations (e.g., log). Other non-parametric statistical techniques exist (e.g., Monte Carlo resampling) and need to be employed to analyze transect data at the level of the individual site.

3.2.3 Data Analyses Presented by CDFW

- **Analysis of variance (ANOVA) is not the most appropriate method for addressing the fixed management thresholds specified in the ARMP.**

  As noted in the summary of CDFW methods[1] (see Section 2.1 above), their first analytical step is to compare the means estimated from the density surveys against the triggers specified in the ARMP. As they presented their methods to us, however, CDFW then used ANOVA to support management decisions, especially those that occurred in only one county where the ARMP does not have explicit triggers. In general, ANOVA, as used by CDFW, determines if the observed differences in mean densities are statistically significant differences in abalone density between sampling periods, sites or counties. While the ARMP density triggers were initially based on a 25% reduction from the initial baseline dive surveys (across three original index sites), the management question at the site and fishery level has been codified to reference specific trigger densities, not a statistically significant change or decline in density. The question, therefore, is whether abalone densities are above or below specific management triggers. The ANOVA approach used by CDFW does not answer this question.

  Additionally, the take home message from ANOVA is often misinterpreted. A comparison of densities between two survey samples (from different counties or times, for example) that is statistically significant means that there is strong evidence the two samples were taken from counties or times with different mean densities. It does not, by itself, directly indicate the actual magnitude of the difference. If the estimated mean of one group is 25% less (or more) than the other(s) with a probability value of 0.01, it is highly likely that their actual means differ. However, this does not indicate what the actual means might be. This is why ANOVA is not the appropriate tool to assess if fixed management triggers have been surpassed.

- **Analysis of Variance (ANOVA) that uses transects as replicate estimates of mean density does not provide inference about abalone populations outside of the eight fished index sites.**

  As currently conducted, the ANOVA treats each transect as an independent replicate (i.e., estimate) of abalone density across the fishery or county. The implication of this choice is that the entire universe of abalone under consideration is contained within those eight sites, and no inferences are intended beyond these specific sites. While this may be consistent with the language of the ARMP (that management is conducted based entirely on the eight index sites), it limits the ability to use these dive survey data to enhance understanding of abalone populations elsewhere along the coast. If it is assumed that these eight sites are representative of the north coast, then treating transects as independent replicates commits a statistical error known as pseudoreplication because it is expected that transects within a single site will be more similar to each other than to those from other sites.

  To make inferences about abalone populations across the entire North Coast, CDFW would have to modify both the survey design and data analysis. Because the eight sites were not established randomly across the stock, they are unlikely to be representative samples of the entire region. CDFW would need to augment with random (stratified) sites and/or determine how well the eight index sites represent all possible abalone habitat. The analysis of the data at the fishery (or county level) would treat the sites as the units of replication,

[1] http://calost.org/pdf/science-advising/peer-review/Density_Review_Doc_Oct_6_2013-Final.pdf

nesting transects within site. This would reduce the sample size to the number of sites, possibly (though not necessarily) diminishing the power to detect differences among years or counties. Nevertheless, such an approach could provide a much better picture of the abalone population in the region. Without such a change in sample design, users of these data should be cautious in interpreting the results from the index sites as telling the story of the broader population. Additional statistical details are presented in Appendix A.

- **The power analyses generated by CDFW are only applicable to the populations of abalone within the eight index sites.**

  The current survey methods presented by CDFW treats each of the ~288 transects across all 8 sites as independent replicates of abalone density. This is the basis for assuming high statistical power in the ANOVA. This power analysis is subject to all the same caveats as the ANOVA itself (see paragraph above) and overstates the power to detect changes across the entire region. The analysis presented by CDFW nested transects within sites; in this case, the power analysis should also treat site as the unit of replication. Additional details regarding CDFW's statistical presentation are given in Appendix A.

3.2.4. Additional statistical considerations

- **Statistical modeling techniques can help reduce the uncertainty associated with density estimates.**

  It is worth exploring whether statistical modeling techniques can help reduce the uncertainty associated with the density surveys. For instance, General Linear Models (GLMs) can provide powerful and practical ways to increase the precision of estimated densities without requiring additional physical surveys. Figure 2B shows the same data as Figure 2A, but with confidence intervals estimated using GLM. Like all statistical tools, this approach must be used with caution to ensure that the data do not violate underlying assumptions. The data presented in Figure 2 were calculated by averaging the transect-level density data for each site, and using the site-level means to estimate abalone density of the fishery; the site-level means are normally distributed (as expected due to the central limit theorem). However, because the transect-level data are highly skewed in a way that, for this data set, cannot be mitigated with standard data transformations, parametric approaches are not appropriate for estimating confidence intervals (or CPFs) for any of the sites. In cases where the data are not distributed normally, a bootstrapping approach is recommended for generating CIs and CPFs.

- **Additional data, such as habitat type, depth, and recruitment data can provide contextual information to help understand changes in density.**

  CDFW collects a great deal of valuable data during dive surveys in addition to density, including habitat attributes, depth, and recruitment. This information could be used to understand the context – or the "why" – density may or may not be changing. Analytically, there is not a way to incorporate habitat type data in tracking populations over time with associated CIs. However, it can be used to "calibrate" a sample in the area of reference to get a more accurate assessment of why density may be changing. For example, if transects one year encompass a greater amount of sandy bottom habitat than the previous sampling period, declines in density estimates may not be due to fishing pressure but rather as a result of transects placed in a greater proportion of habitat that is less suitable for abalone. Similarly, changes in ocean conditions that lead to increases or decreases in bull kelp, the primary source of food for abalone on the north coast, might explain changes in abalone density. Although CDFW expends effort to collect these data, it does not appear that they have been analyzed to explain variation in their estimates among sites and years. This will be a very useful exercise. Additionally, alternative sources of environmental data are available to enhance their understanding of environmental drivers of population change and these should be explored.

4. Considerations for Informing Future Management

In the course of this review process, we identified a number of potential improvements to the assessment of abalone populations that go beyond the statistical and sampling questions that the review was focused on. In some cases, these recommendations could not be implemented without changing the current language of the ARMP, since that document specifies many details of the sampling. Other suggestions may provide guidance for processes of re-shaping the ARMP or creating a separate Fisheries Management Plan (FMP) for managing the fishery going forward. Because many of these suggestions were outside of the scope of this review, we have not carefully tested or scoped each of them. Future abalone management can build on the existing density data set to design the best possible sampling protocol for the species.

4.1 General Recommendations

- **Additional, robust collaboration with outside scientific experts will enhance the intellectual resources contributing to sampling and analysis of red abalone populations.**

  There are ample opportunities for CDFW to take advantage of the substantial intellectual resources within (and outside) the state to improve understanding of abalone populations. The statistical analyses we have outlined in this report require varying degrees of statistical aptitude to carry out. We are willing, either individually, or as a committee to engage with CDFW to aid in their implementation. Beyond these identified suggestions, CDFW should rely on outside expertise, not just in a review capacity, but to help generate new ideas for best practices in the course of revisiting the ARMP. The process of creating a sampling regime and ensuing statistical tests for any monitoring program is one that can benefit from many perspectives and collective experience. Formal and informal collaborations such as these should be business as usual for the management of California's red abalone fishery.

We recommend establishing a standing review committee for the ARMP, somewhat analogous to the Statistical Committee of the federal Pacific Fisheries Management Council, to provide recommendations on the sampling design and analysis of this program. Such a committee, including members external of CDFW, could evaluate, advise, and otherwise provide external support for CDFW scientists and managers to facilitate achieving their objectives.

- **Make abalone dive survey data publicly available.**

  We believe the raw data from fisheries surveys should be distributed broadly and as soon as possible after collection. This would allow outside experts to verify and improve upon the analytical methods that are used for management of this important fishery. Broad dissemination of these state-collected data will also have ancillary benefits to understanding of the ecological context in which abalone live, as well as help increase perceptions of credibility and build capacity without draining CDFW resources.

- **Consider alternatives to the use of eight index sites to manage the entire fishery.**

  In their background materials, CDFW outlined the motivation behind their index site design: these sites, accounting for almost half the catch in the fishery, serve as an early warning system for declines in the fishery overall. This is a rational strategy for assessing whether fishing regulations are maintaining abalone density. At the same time, we acknowledge that management efforts tuned entirely to a small number of sites seem incongruous with the broad stretch of coast the fishery incorporates. Recognizing the logistical constraints involved, a sampling protocol distributed across the region would provide a better picture of the stock as a whole, rather than solely within the eight index sites.

4.2 Recommendations Associated with Existing Density Metric

- **Develop strategies for more rapid tracking of the resource.**

  As noted above, one of our major concerns is the amount of time required to sample all eight sites and assess changes in abalone density across the fishery. Unless the recreational catch trigger or other unknown events prompt a more rapid return, a significant decline in density at a site could occur in the three years it takes to return to a site. We appreciate the logistical challenges and resource limitations that motivate this extended cycle, but also recognize the possibility of employing new strategies to accelerate the acquisition of information. In any new survey design, a highly desirable trait would be the ability to gain data at every site on an annual basis. Failing that, it is worth exploring ways to use the most recent available data in any given year without needing to aggregate across years to encompass all eight sites. Survey changes, such as devoting less attention to the deep refuge transects, might free up some resources. Other options, such as performing yearly analysis based on the most current data might provide the FGC with more rapid decision options.

- **Incorporate an understanding of the variability of the habitat.**

The random, stratified sampling design may not accurately represent the habitat at each site and may produce unnecessarily variable data. Because certain habitat types are more suitable for abalone than others, incorporating understanding of the habitat (e.g., distribution and quality) at a site can help interpret density estimates. For example, this is the rationale behind the current survey protocol of abandoning any transect that falls on greater than 50% sand. The habitat data, which are not currently analyzed, should be considered to provide context for understanding the reasons behind any changes in measured densities. The recently generated seafloor maps for the state of California should be considered for this purpose.

More broadly, however, CDFW should ensure that their random transect approach accurately captures the distribution of habitat types at the sites. Abalone are associated with particular habitat types and some fraction of the variability in the density estimates among sites and years is likely associated with sampling different parts of the habitat. Since transect locations that encompass more than 50% sand are not surveyed, the implicit assumption is that the data appropriately represent hard-bottomed habitat at each site. This has not been formally assessed. Going forward, it might be more effective to map historic survey densities onto habitat maps for each area (such as generated by the Seafloor Mapping Lab at California State University Monterey Bay) and create maps for each location of where abalone have been most likely to be sampled. These maps should be used to select transect locations that appropriately represent the habitat and abalone population at each site. Prior years' data could be made comparable with such a new survey design by weighting the previous samples by the type of habitat. Using abalone habitat data would help protect against changes in measured population densities that result from varied proportions of sand in the transects among surveys, or the possibility of shifting sand actually changing the amount of suitable abalone habitat among years.

- **Codify appropriate analysis in the ARMP.**

  While the ARMP sets very specific guidelines for surveying density and triggers for management action, it is silent on the appropriate level of confidence required in the density estimates to require management action. Although we have arrived at conclusions for the most appropriate analytical techniques that differ from those employed by CDFW in the past, we appreciate the challenges they have faced in making recommendations in the absence of guidance from the ARMP.

- **Revisit sustainable fishery density: incorporate additional data or establish a baseline with greater biological significance.**

  The sustainable fishing density trigger density of 6600 ab/ha was generated using data from only three sites in 1999 and 2000. Given that there were no differences noted between the baseline surveys and the later survey period in 2003, it would be appropriate to consider new baseline numbers from a time period when every index site was surveyed.

  Only the site-level closure trigger and fishery-level closure trigger are informed by biological information indicating the critical importance of broadcast spawners being aggregated above a minimum spawning density (see ARMP[1] Fig. 5.1 and section 6.2.2.1). In a future management plan, CDFW should revisit the basis for each management trigger; it may be appropriate to consider additional metrics such as spawning potential (see

[1] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=29511&inline=true

Recommendations for Moving Beyond a Density Metric, below).

- **Modify the current density survey design for a more powerful and efficient approach. This could include:**

  1. **Consider abandoning the sampling of deep transects.**

     The deepest depth strata where very few individuals reside, located at the edge of the species depth distribution, provide little insight into the population while also skewing (zero-inflating, i.e., many counts of zero individuals) the resulting data in ways that impair statistical analyses. Since this depth stratification is set in the ARMP, we did not consider the consequences of excluding it, but such changes in the underlying survey methods could reduce year-to-year measurement variability in ways that increase confidence in the understanding of the underlying population. Moreover, it may allow divers to sample more, shallower transects on a sampling day. However, there are important implications for the inferences generated from any altered sampling designs, which also need to be considered.

  2. **Using permanent or fixed transects.**

     A more powerful tool may be a fixed transect approach. This approach has the potential to record changes in specific locations and move to the level of monitoring an index of abalone populations rather than managing around an arbitrary density using random transects. This will likely decrease the variance observed in the current analysis. However, we recognize that with changing a sampling approach and design, CDFW will lose the ability to compare with historic data sets in the future. If existing resources allow, we suggest overlapping current methods with a new approach (a transition phase). Any such survey design should be carefully implemented to ensure that shifting habitat conditions (e.g., sand) do not confound understanding of abalone population densities. We recognize additional concerns with fixed transects, including the challenge (noted by CDFW) of reacquiring transects, and the fact that fishing behavior around the transect sites might cause them to not be representative of the surrounding populations.

- **Further explore the utility of fishery-dependent catch data as a tool for informing management.**

  Our initial analysis of the total recreational take did not reveal a clear relationship between recreational take and density survey data. However, take data depends on effort and changes in regulations (bag limit, area closures), thus catch-per-unit-effort may be a more informative metric than total take. It should be noted that CDFW sampling might not occur at the same sites where recreational catch is occurring, thus caution should be used when exploring this approach.

4.3 Recommendations for Moving Beyond a Density Metric

- **Transition to tracking the state of the abalone population.**

  Both CDFW and the our committee have recognized the value and need to explore shifting monitoring goals from tracking changes in fished index sites to better understanding and tracking the health of the population as a whole (e.g., modeling dynamics of the stock or predict the stock's response to management). We recognize that the ARMP was created in a data-poor environment, and that the monitoring plan was specifically designed NOT to track the population as a whole, but rather to understand fishing related declines in density at eight index sites. However, CDFW now has a valuable long-term data set that could potentially serve as the foundation for restructuring the monitoring and management triggers around whole population indicators. In addition, this strategy may lead to a better ability to manage the stock before a population decline occurs, or react in a timely manner to declines observed in the field.

- **Exploring alternative scientifically based management reference points.**

  The red abalone population might be well served by looking beyond density reference points, and the fishery may support alternative scientifically-based management reference points. Abalone populations are susceptible to the Allee effect where fertilization rates drop as the population decreases (e.g., if mature individuals have difficulty finding mates). Assuming there is a stock-recruitment relationship, a better metric in lieu of or in addition to density may be to use a fecundity index like Spawning Potential Ratio (SPR) adjusted by nearest neighbor distances. This potential biologically-based reference point attempts to model the reproductive capacity of the population. SPR indexes the spawning ability of a stock in the fished condition to the stock's spawning ability in the unfished condition. The utility of specifying management targets in SPR is that it can be estimated from the adult size distribution of the stock, and these data might be obtained through recreational tag returns. A community-based methodology such as this could be used to provide alternative scientifically based management reference points from across all the different fished areas, cost-effectively adding to the detailed survey information from the fewer survey sites. Initial studies could be used to establish the implicit equivalence between the current ARMP standard and the equivalent level of SPR.

  In this way the FGC might hope to be able to monitor and respond to stock trends in all the abalone beds of Northern California.

5. References

1. California Department of Fish and Game. 2005. Abalone recovery and Management Plan.
2. California Department of Fish and Game. 2010. Abalone Recovery and Management Plan Status Report – Northern California Red Abalone Fishery, Marine Region Invertebrate Management Project.
3. California Department of Fish and Wildlife. 2013. Estimating Red Abalone Density for Managing California's Recreational Red Abalone Fishery.

Appendix A: Evaluation of CDFW Analyses Techniques and Suitability for Management

This review process included extensive discussion of the existing analyses performed by CDFW. Ultimately, our recommendation is that a different statistical technique offers the best process for CDFW and the FGC to assess the density of abalone populations as outlined in the ARMP (see Section 3). Thus, this appendix is not intended as the SAC's endorsement of the analyses that were presented. Rather, we present these details of to help clarify some of the information that emerged from our discussions and that led us to our final conclusions. Ultimately, understanding how abalone populations are affected by factors such as depth and habitat type will enhance interpretation of shifts in density and may provide context to explain management decisions identified through CPFs recommended is Section 3.

A1 Reduce variation in statistical analysis

Statistical analyses such as ANOVA attempt to separate changes in populations (e.g., of density measurements) that are attributable to the hypothesis under test from variation due to other directed or random factors. Incorporating additional factors that help to explain population differences into statistical models can enhance the power to attribute observed changes to the hypothesis under test. To reduce unexplained variability in abalone density estimates, CDFW may use ancillary data already collected during surveys (habitat type and depth).

A1.1 Use of depth data

Red abalone are known to be more common at shallow depths and are rare in deeper water. Thus, depth is an obvious choice as covariate which might explain some of the variance in populations between transects. Current CDFW surveys collect transect depth, but do not include this information in statistical analysis. Following methods presented by CDFW, we tested abalone density data between two time frames (2003-2007 vs. 2009-2012) and eight sites, with and without depth as a covariate (Table 6).

The results confirm the significant difference in abalone density between time periods and sites. Including additional factors in the analysis increased both the explanatory power of the model, and the F-value of the test. In particular, including depth improved the ability of the model to explain the variation.

Table 6. The improvement of analyses of variance (ANOVAs) that include depth factors.

MODEL (ANOVA) testing density	F-statistic	R-squared (Adjusted)	Improvement in model
time vs. site (as analyzed by CDFW)	3.84	7.30%	--
time vs. site; depth (fixed factor)	5.74	30.5%	23%
time vs. site; depth (covariate)	4.78	29.7%	22%
time vs. site; depth and nested transect	5.87	30.4%	23%

This model resulted in highly significant 'County x Depth x Period' interaction (Table 7). This underscores the importance of including depth in statistical analyses of the abalone densities.

We also experimented using linear mixed model analysis that included depth categories (matching the sampling design) as a covariate to see if it would yield more explanatory power. The data were ln(y+1) transformed prior to analysis. The model was fit using restricted maximum likelihood (REML) and Kenwood-Rogers method for degrees of freedom.

Table 7. Linear mixed model analysis of abalone survey data at the transect level.

Fixed effects	Df (num)	Df (den)	F	P-value
County (Sonoma and Mendocino)	1	18.1	0.04	0.8453
Time Period (1-4)*	3	934	15.73	**<0.001**
Depth (1-4)#	1	932	309.26	**<0.001**
County x Time	3	934	7.94	**<0.001**
County x Depth	1	932	0.04	0.8370
Depth x Time	3	932	8.82	**<0.001**
County x Depth x Time	3	932	3.55	**0.0141**
Random effects	Estimate	SE		
Site	0.005036	0.003335		
Residual	0.08116	0.003762		

* Period 1: 1999-2000; Period 2: 2003, 2005-2007; Period 3: 2007-2010; Period 4: 2009 – 2012 (Note that years overlap among periods).

Depth categories correspond to the sampling design whereby transects were randomly allocated within depth strata: 1 = 1-1

A1.2 Use of habitat data

Although CDFW collects habitat information during their dive surveys, these data are not coded into their database and were unavailable for our review. To test the impact of incorporating such data in a statistical model, we relied on data collected by PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans) as part of the state-funded North Central Coast Marine Protected Area Baseline Monitoring Project (see Appendix B). These data were collected at comparable locations using similar survey techniques and should provide a reasonable proxy for whether similar analyses can inform CDFW data analyses. The results suggest that habitat type can contribute to some of the variation in the survey data (Figure 6, Table 8, p<0.0001). Aspects of habitat type (particularly slight relief, cobble and canopy) account for some of the variation observed in similar abalone density surveys. Since CDFW already collects habitat and depth information, it would be relatively simple to incorporate this information into the analysis of density estimates to increase the ability to detect changes through time.

Figure 6. Habitat variables and how much of the variation in abalone density estimates was accounted for by each habitat type using the North Central Coast Baseline Marine Protected Area monitoring data. (Collected for PISCO).

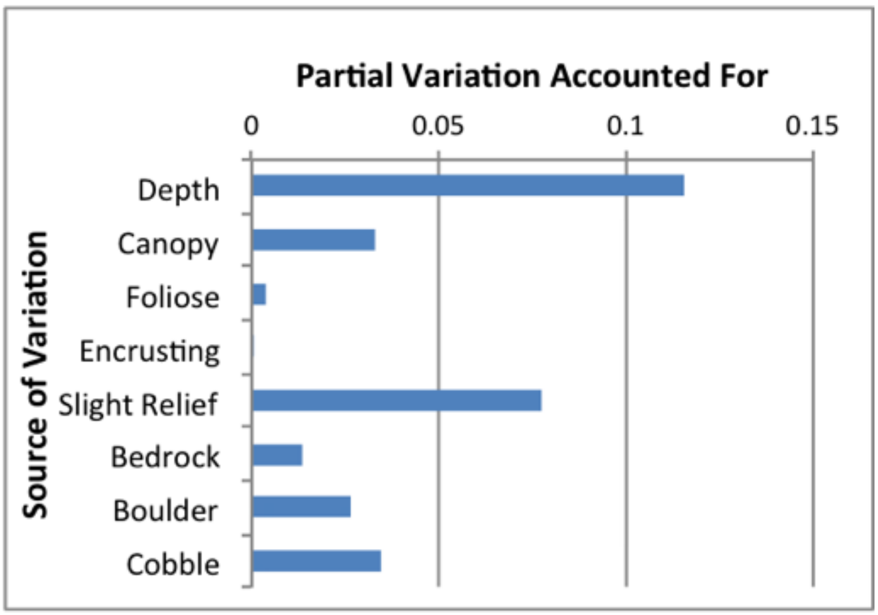


Table 6. A model examining the amount of variance in abalone density data that could be explained by habitat type. Data used in this analysis was collected for monitoring the North Central Coast Baseline Marine Protected Area.

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	775.224632	96.903079	18.94	< 0.0001
Error	265	1356.179946	5.11766		
Corrected Total	273	2131.404578			

R-Square = 0.363715
Coefficient of Variance = 62.53604
Root MSE = 2.262225
Halruf Mean = 3.617474

A2 High variance observed in current survey data

The transect-level data, representing the raw data used in CDFW's analyses, exhibited substantial heterogeneity of variance, even after log transformation (Figure 7). This structured variance has potential to violate the assumptions of various statistical tests. Pooling the transect data and using site as the unit of replication ameliorates this problem.

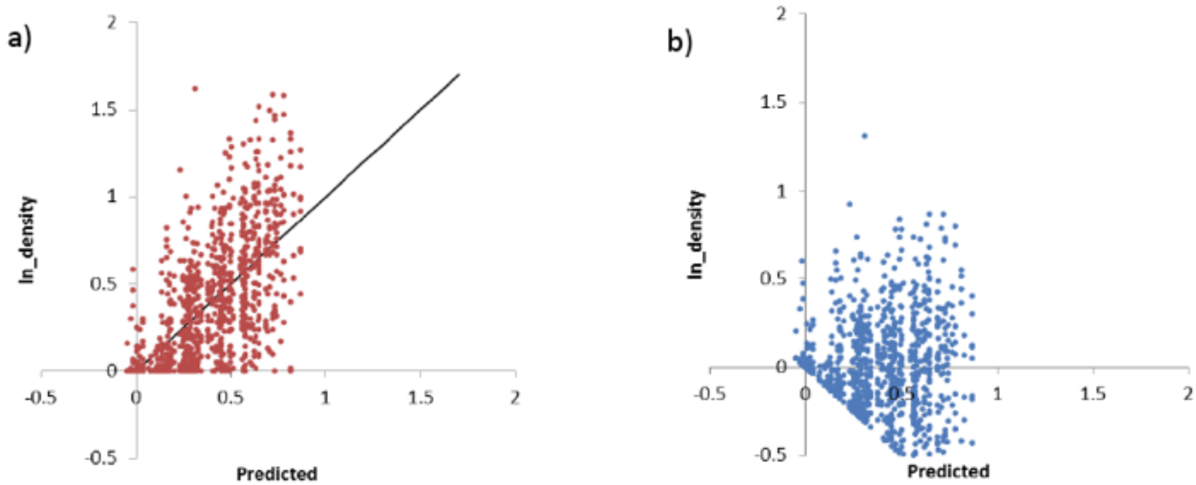


Figure 7. Model fit (a) and residual plot (b) for the statistical model in Table 7. Residuals are ~ normal in distribution but substantial heterogeneity of variance remained even after transformation to the log scale.

Appendix B: PISCO North Central Coast Marine Protected Area (MPA) Monitoring Survey Method

Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) swath surveys for kelp forest community surveys consist of recording the number of all mobile or solitary/conspicuous invertebrates and stipitate kelp species on 'transects.' Dimensions for all transects are 2m x 30m. Subtidal community structure surveys are conducted annually at all sites during the summer or early fall, and quantify substrate type and relief, benthic cover, abundance of major groups of macroalgae and invertebrates, and abundance and size of fishes. Spatial allocation of sampling is designed to measure year-to-year site-wide variability in community structure and the spatial scales at which such variation occurs. A site is defined as a fixed stretch of coastline, occupying approximately 500m. Each site is comprised of 6 benthic transects stratified across the four zones described below.

Kelp forest surveys for the North Central Coast MPA Baseline Program were conducted at discrete sites in California ranging from Point Arena in the north to Salt Point in the south during 2010-2011:

- North Bounding Coordinate: 38.96, -123.36
- East Bounding Coordinate: 38.96, -123.36
- South Bounding Coordinate: 38.48, -123.52
- West Bounding Coordinate: 38.48, -123.52

Each sample area is divided into three 'zones' (by depth - 20m, 12.5m, 5m - or from offshore to inshore at sites with little depth variation) to assure that samples are distributed across the face of a reef from inshore to offshore. Mobile or solitary/conspicuous invertebrates and stipitate kelp species are counted on six transects per site (two transects in each of the three depth zones). Each 'transect' includes an area 2m wide by 30m long. Download the data packages at http://oceanspaces.org/data/north-central-coast-pisco-swath-surveys-shallow-rocky-reefs-and-kelp-forest-habitats-2010-2011.

Appendix C: California Ocean Science Trust Review Process

Overview

The California Department of Fish and Wildlife (DFW) has requested the California Ocean Science Trust (OST) convene a Scientific Advisory Committee (SAC) to conduct a scientific and technical review of the survey design and methods currently used to estimate densities of red abalone (Haliotis rufescens) in northern California. This review will address:

1. survey design, including strengths and weaknesses of current methods for estimating red abalone density in northern California;
2. the application of existing methods, including analysis of existing data, and interpretation of results; and
3. uncertainty associated with existing methods for estimating red abalone density, and its adequacy for informing catch limits and other management controls of the recreational red abalone fishery in northern California, as outlined by the Abalone Recovery and Management Plan (ARMP).

OST will work with the SAC to produce a summary of review outcomes, including 1) assessment of the current practice used to estimate red abalone density, 2) whether current methods could be improved, and 3) if so, a list of ways the methods could be improved. This summary will be made publicly available on OST's website. OST's dedicated webpage for this review is: http://calost.org/science-advising/?page=ongoing-reviews#red-abalone-density-estimates

OST will compile appropriate background materials, draft instructions to guide the SAC throughout the process, and develop and disseminate review outcomes. Throughout the review process, DFW Marine Region Program Manager, Tom Barnes, will serve as the primary management contact. OST will also work with DFW scientists to ensure the SAC understands how density estimate surveys for red abalone are being conducted and interpreted, and facilitate constructive interactions between DFW scientists and the SAC as needed. OST will host two remote meetings via Webex, as well as a one-day in-person technical workshop to meet the goals of the review. Additional details are provided below, but all associated meeting materials, such as meeting agendas and summaries will be made publically available on OST's website.

OST Peer Review Policies

OST has developed the following set of policies that balance objectivity, scientific rigor, candor and transparency to guide the process of this scientific review.

Transparency

SAC members must be willing to serve openly, and allow their names to be associated with this process and review outcomes. OST will make available on the OST website:

- The names and abbreviated CV's of each of the SAC members;
- all meeting materials (e.g. agendas and meeting summaries) and reports associated with the review process; and
- the final summary of review outcomes.

Conflicts of Interest

SAC members will be screened for potential conflicts of interest to determine if they or any of the parties below stand to financially gain from the outcome of the process (i.e. employment and funding). Potential conflicts will be considered and may exclude a potential reviewer's participation.

- The reviewer, the reviewer's spouse, minor child, or business partner;
- The organization where the reviewer is employed, has an arrangement for future employment or is negotiating for employment or grants; or
- The organization where the reviewer is an officer, director, trustee, or partner.

Selection of the Scientific Advisory Committee (SAC)

The SAC will be composed of 3 to 6 external scientific and technical experts from appropriate disciplines. Experts must meet a set of minimum qualifications for scientific expertise, including:

- Demonstrated expertise in scientifically recognized and accepted methods of survey design and sampling methodology, including use of these methods to generate estimates of density.
- An understanding of random stratified sampling in subtidal marine environments.
- A Ph.D. from an accredited university in the life sciences, oceanography, or a related field.
- Senior-authored publications on marine natural resource surveys or assessments in peer-reviewed, scientifically recognized literature.
- Experience conducting field work to survey marine benthic invertebrates is preferred.
- Demonstrated success working collaboratively.

To select members of the SAC, OST will accept recommendations from DFW, the Ocean Protection Council Science Advisory Team (OPC-SAT), and key constituent groups. One member of the SAC will serve as chair to 1) provide leadership among the SAC, 2) help ensure that all members act in accordance with review policies, and 3) promote a set of review outcomes that adequately fulfill the review scope and accurately reflect the views of all SAC members. OST will collect background information in the form of two-page CVs from all nominees willing to serve on the SAC, and work with the OPC-SAT to further vet the nominees. Final selections for the SAC will be made by the OPC Science Advisor (OST Executive Director) in consultation with the OPC-SAT executive committee. All members of the SAC, including links to background information, will be made publically available on OST's website.

Review Process Framework

Webex Kickoff Meeting: Initiation of Review

Once SAC members are confirmed, and all background materials and instructions have been distributed, OST will host a meeting via Webex that includes the SAC, DFW scientists, and any members of the public that wish to join. In this meeting, OST will provide an overview of the scope and process of the review, and DFW scientists will present on the current survey design, methods, and analysis used to estimate red abalone density in northern California. The SAC will then be provided the opportunity to ask questions of the DFW scientists. Members of the public will also be able to submit additional questions. Following this meeting, OST will work with DFW and the SAC to technically evaluate current survey design, methods, and analysis. This meeting will likely occur in mid-September. Once the date is finalized, the meeting will be announced, and all associated meeting materials (e.g. agenda and meeting summary) will be made available online.

One-Day Technical Workshop

OST will convene a one-day technical workshop involving the SAC and DFW scientists to: 1) address any review questions or concerns, 2) explore the sensitivity of the survey results to assumptions and uncertainty, and 3) potentially conduct a comparative data analysis between DFW's data set from density surveys to alternative density survey approaches and/or data sets from other sources. Comparing the data sets may allow the SAC to more thoroughly evaluate DFW's survey design and methodology by comparing it against other standards. This meeting will likely occur in mid- to late-October. While this meeting will not be open to the public, once the date is finalized, the meeting will be announced, and all associated meeting materials (e.g. agenda and meeting summary) will be made available online.

Draft Final Summary Outcomes

OST will engage the SAC in drafting a final summary outcomes document that includes a description of the scientific and technical review process and associated conclusions, and if necessary, recommendations to evaluate methods presently employed to estimate red abalone density in northern California.

- Webex Briefing: Sharing Results – OST will host a Webex briefing where the SAC, led by the chair, will share the draft findings of the review process. The briefing will be open to the public, and include a Q&A so the SAC (and DFW scientists) can answer questions, and receive feedback.
- Finalize Summary Outcomes – Following the Webex briefing, OST will work with the SAC to finalize the summary outcomes. The final summary outcomes will be delivered to DFW and made publicly available on OST's website.

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