

**A New Beginning for Abalone
Management in California:**

**Critique and Comment on the
Abalone Advisory Group's
Discussions**

Jeremy Prince

&

Sarah Valencia

October 2009

Table of Contents

I. Executive Summary.....	3
A. The Allee Effect.....	4
B. Uncertain Assessments and Surveys	5
C. Managing Risk and Uncertainty.....	6
D. Recommended Process for Managing SMI Abalone	7
II. Introduction	8
A. Risk Management	9
III. Sources of Risk.....	10
A. Withering Foot.....	10
B. Otter Range Expansion	11
C. Allee Effect or Minimum Viable Population (MVP).....	11
1. Broader Academic Context	11
2. Allee Effect in California Management.....	13
3. Abalone Ecology	14
4. Distributional Analysis of 2006 SMI Survey Data.....	17
5. Addressing the Risk of Allee's Effect.....	20
D. Declining Population Modeled by AAG Stock Assessment	22
1. Non-Compliance with Accepted Modeling Procedure.....	23
2. Bias through Changing Survey Protocols.....	24
3. Summary on Implausible Model Outputs	29
E. Survey Uncertainty.....	30
F. Uncertainty Regarding Productivity (M) and Sustainable Rates of Harvest	33
IV. Risk Management and a Way Forward.....	35
A. Establish Assessment Framework and TAC Decision Rules.....	37
V. The Future Management System	37
A. Recommended Process for SMI Abalone.....	38
1. Set a TAC with the Decision Table	38
2. MOU with Harvesting Cooperative.	38
3. Annual Surveys and Disease Testing	38
4. Application of a Decision Tree and Meta Rules to Annual Set TACs	39
5. Structured and Controlled Annual Harvest.....	39
6. Increased Size Limit.....	40
7. Ocean Protection Council (OPC) Grant	40
References	41

I. Executive Summary

Under the Abalone Recovery and Management Plan (ARMP) the San Miguel Island Abalone Advisory Group (AAG) was charged with providing recommendations to the California Department of Fish and Game (CDFG) and the California Fish and Game Commission (Commission) regarding the following areas:

- A Total Allowable Catch (TAC) for San Miguel Island red abalone
- Alternatives for allocation between recreational and commercial take
- Alternative regulations to achieve the TAC and allocation
- Potential management, enforcement, and monitoring techniques

Unfortunately it appears that the AAG has become sidetracked by a discussion of ill-defined risks rather than finding ways to address or mitigate these risks. In the Review Committee it convened to aid this process, the AAG had at its disposal a group of scientists with a wealth of expertise in international abalone and fisheries research, assessment and management, and yet the recommendations made by this body (Butterworth et al. 2009) have been largely left out of the discussions of the AAG as it prepares to make recommendations to the Commission.

This paper seeks to provide CDFG and the Commission with options to consider by building on the way forward recommended by Butterworth et al. (2009). It begins by defining and describing the risks associated with a limited trial fishery at SMI and reviews the science underpinning the core issues discussed by the AAG, as well as the scale at which they must be managed. The suggestions made by Butterworth et al. (2009) are then re-tabled and more fully fleshed out in order to illustrate how such suggestions could be put into practice in the California context.

The AAG's discussions have focused on the following risks:

- Withering foot syndrome disease events
- Predation due to otter encroachment
- Uncertain productivity levels
- Reduced recruitment via the Allee effect
- Uncertain assessments and surveys

The first three of these are actual risks. The first two apply across the entire range of California abalone and must be managed at that scale. However, only the additional risk posed by a trial fishery at SMI is relevant for consideration here. This additional risk, along with that posed by uncertain productivity levels, can be managed with the conservative, modern, internationally recognized fisheries management techniques proposed by Butterworth et al. (2009) and elaborated on below. When we examine the science behind

the final two risks (as we do below) it becomes clear that much of the perceived risk is the result of some fairly pervasive misconceptions and misunderstandings.

A. The Allee Effect

The dominant Californian conception of the impact of the Allee effect on abalone is counter to the available abalone science. It is illogical on evolutionary grounds. After all, how can a species ever build up into self-sustaining populations or persist across geological time scales if it has no ability to recover from low stock abundances? A large body of abalone science shows that all species can be highly mobile at scales of 1-100s of meters, and over days, weeks and months. Besides seeking food if necessary, they actively aggregate to spawn, presumably to circumvent the Allee effect. Consequently the Allee effect is only relevant to the consideration of managers if heavy harvesting is permitted immediately prior to or through the spawning season. The disruption of spawning aggregations in the weeks prior and during spawning seasons must be taken into account for management purposes, as it may well prevent the formation of aggregations necessary to achieve the optimal mixing densities of eggs and sperm. Shepherd and Partington (1995), one of the main sources for the Allee concept in abalone, showed that the Allee effect results in a classic Ricker-shaped stock recruitment curve, which relates adult biomass to subsequent recruitment and is commonly incorporated in stock assessments for a wide range of species. The relationship they described between adult biomass and future recruitment for the Australian greenlip became less productive in absolute terms at low abundance so recruitment declined quickly when adult biomass became very low, but nevertheless, it remained productive even at very low abundances.

Analysis of the data collected during the CDFG and National Park Service (NPS) surveys and presented here show that the biology of abalone revealed in the international literature is also at play in the SMI red abalone population. The population at SMI has grown at 9-10% per annum compounding since the Moratorium on fishing was put in place in 1987. The analyses demonstrate that the concept of Minimum Viable Population (MVP) as cited by the ARMP (2,000 abalone/ha) and applied by the AAG to SMI is a gratuitous extrapolation of its original context and thus has little meaning for the rebuilding of California's abalone resource.

As applied by the AAG, which has followed the protocols developed for the CDFG surveys, the area of abalone habitat at SMI is defined as the area covered by the kelp canopy (1,048 ha) and the surveyed population abundance is divided by this area to produce estimated densities of 1,100 – 1,800 abalone/ha. These densities are clearly below the level defined in the ARMP, a level implied and assumed by the AAG to be driving a continuing decline in recruitment and adult population even without fishing. But those estimated densities are entirely the result of the assumption that abalone area is the same as the aerially surveyed area of kelp canopy. In fact, of the 4,796 survey segments searched during the 2006 survey 70.3% of the area under the kelp canopy held no abalone, a similar distribution to that derived by Prince et al. (1998) for a range of Australian species. According to substrate data collected during that survey of the 70.3% of the kelp canopy without abalone, 12.0%

of segments surveyed were sand and 6.8% were cobble (small rocks that can move in heavy surge), both of which are habitat types abalone are not expected to occupy. The remaining 51.5% were apparently suitable habitat but for reasons known only to abalone no abalone were found.

The absolute level of 2,000/ha has little quantitative basis for the Australian greenlip abalone (*H. laevigata*) with which it was developed, and no quantitative basis at all when applied to red abalone. Red abalone are 2-3 times heavier, and so presumably produce 2-3 times more eggs and sperm and thus should be capable of successful spawning if aggregated less densely. Instead, accepting that 2000/ha provides some arbitrary benchmark of the nearest neighbor distances which will impact fertilization success, the 2006 survey show that only 8% of abalone at SMI occurred at densities <2,000/ha. As with abalone all around the world, the red abalone at SMI aggregate and live at densities well above the theoretical MVP. In fact the average abalone surveyed in 2006 was found to be living at 8,185 abalone/ha and >73% of the abalone sampled live at densities > 3,000 abalone/ha.

Thus, as originally conceived by Shepherd and Partington (1995), the Allee effect is nested within the standard fisheries dynamics assumptions about how adult biomass determines the abundance of future recruitment. Left with sufficient time after fishing or predation abalone reform their aggregation structure. It must be assumed that this behavior is to minimize the potential for the Allee effect occurring and in the Australian greenlip it has been shown that proximity to other adults is a necessary stimulant for breeding. However, within the context of abalone assessment and management the Allee effect will have little consequence, unless heavy fishing is permitted immediately prior to or during the spawning season, when the effect of fishing will disrupt breeding aggregations and prevent the abalone achieving optimal fertilization conditions. Without the physical effect of heavy fishing through the spawning season the Allee effect is incorporated into standard fisheries assumptions about the relationship between adult stocks and future recruitment which are that stocks remain productive, but at lower absolute levels, even when relatively depleted.

B. Uncertain Assessments and Surveys

The outputs of the AAG modeling process, which purport to show that recruitment and biomass at SMI is continuing to decline without a fishery or some other exogenous cause of mortality, are entirely baseless. As illustrated with quotations by a trinity of the world's most experienced fisheries assessment modelers (Hilborn, Walters and Punt) a standard practice in fisheries assessment is the error checking of models by testing whether they decline in the absence of fishing. This basic test has not been performed for the AAG, and in fact this scenario has been accepted as the AAG's base case. As argued above, with regard to the Californian conception of the Allee effect, the notion that a population will continue monotonically declining without some source of external mortality (fishing, heavy predation or disease) is so inherently unlikely from an evolutionary perspective it should

never have been accepted by the AAG without strong and compelling evidence that it is in fact the case.

As concluded by Butterworth et al. (2009) this modeled result has most likely been driven by the unfounded assumption that the selectivity of the survey protocol with regard to the cryptic juvenile size classes has remained constant through the many surveys the CDFG have conducted since the 1970s. This is clearly not the case. Prior to the 2006 surveys the protocols included turning boulders and searching the cryptic habitat preferred by the smaller abalone. The most recent survey protocol does not include searching for juveniles in this way. The model assumption of constant survey selectivity will have created the result which makes it appear that recruitment rates have declined over the last decade, which in turn will drive the result that adult biomass is declining.

The reliable data in the situation are:

- the time series of adult size structure from the CDFG surveys
- the recent CDFG survey data since 2006 and
- the National Parks surveys conducted by CINP at Wycoff Ledge at SMI since 1983 using a standard protocol.

All these solid lines of evidence show the population at SMI has been increasing since the moratorium. Based on the Wycoff Ledge data we estimate a compounding rate of 9.5% since the close of the fishery. This is in keeping with the international understanding of abalone fisheries dynamics, while a modeling process that describes decline in the absence of fishing is not.

C. Managing Risk and Uncertainty

Butterworth et al. (2009) suggested that these various sources of risk and uncertainty, real and perceived, should be managed and quantitatively evaluated with a trial fishery in the southwest zone of SMI. To that end they recommended applying a world's best-practice approach with a conservative bias to set up a closely monitored, limited trial fishery in the southwest zone of SMI. The approach they recommended would constrain the harvest to a sub-section of the SMI resource allowing both the impact of fishing and future environmental variability to be determined through future surveying inside and outside the trial fishery. Butterworth et al. (2009) also suggested that areas outside the trial harvest area could become the source for brood-stock transplantation as per the option for a non-consumptive TAC.

Butterworth et al. (2009) recommend that the uncertainty in survey estimates and the productivity of abalone be managed by setting a conservative TAC for the trial fishery based on the 95% lower confidence level of population estimates derived from survey data, and a harvest rate of 10% on the abalone above 8 inches (203 mm). This approach will ensure there is only a 5% chance of the actual population being smaller than the survey estimate, and that the harvest rate is equivalent to the lowest end of estimates of natural

mortality of abalone. In the opinion of Butterworth et al. (2009) “[g]iven such a relatively high age at first capture, this 10% proportional take is well below standard fishing mortality reference points.”

Pursuant to these suggestions and applying a quantitatively proven approach used in both the South Australian and Victorian abalone fisheries (McGarvey et al. 2008, Mayfield et al. in prep), we employ a bootstrap analysis of the 2008 survey data to populate a decision table which managers can use to balance acceptable and explicit levels of uncertainty and risk with TAC levels for the southwest zone of SMI. Following the recommendations of Butterworth et al. (2009) the 95% lower confidence interval estimate and a 10% harvest rate on abalone larger than 8 inches suggests a TAC of 10,728 abalone.

D. Recommended Process for Managing SMI Abalone

Finally this document outlines a short- to medium-term process by which the trial fishery at SMI should be managed. The proposal for this process has been developed over several years in consultation with the Californian Abalone Association (CAA), CDFG staff and a range of external technical expertise.

The CAA would establish a harvesting cooperative to receive a TAC allocation, which would require annual CDFG approval contingent on adherence to previously agreed upon conditions and standards. Within that context the CDFG and the harvesting cooperative would develop a Memorandum of Understanding (MOU) documenting the standards and conditions required, and this MOU would be presented to the Commission for approval. It is suggested that these standards and conditions would initially involve setting the TAC for the southwest zone of SMI using a Decision Table similar to that presented here (Table 1). So as to minimize any additional risk from disease or otter predation it is proposed that meta-rules would set future TACs to zero in the event of a disease outbreak or encroachment by otters. This would necessitate continuing annual surveys to monitor abundance, aggregation structure and size composition as well as disease status and otter predation. Under the MOU the harvesting cooperative would also plan and coordinate with the CDFG short periods of structured harvesting with the aim of increasing the transparency of the harvest process and creating cost efficiencies in the catch monitoring and enforcement processes. The MOU would also require the harvest cooperative to gather detailed logbook and electronic data recording details of that catch (weight, number and size) and effort (time spent harvesting, GPS tracks of divers).

In the medium- to longer-term a Decision Tree approach should be developed so that spawning biomass targets can be explicitly incorporated into the TAC setting process. To this end the initial TAC should also include provisions to obtain length based samples of red abalone for biological studies so that locally accurate models of Spawning Potential Ratio, (or SPR), also referred to as Full Life-time Egg Production (FLEP), can be developed. This would then allow the local biology of red abalone to be incorporated into the TAC setting process with the aim of explicitly managing to conserve levels of spawning biomass proven by international experience to support continued population growth.

II. Introduction

After the adoption of the Abalone Recovery and Management Plan (ARMP) in December 2005, the Department of Fish and Game (CDFG) moved forward with the consideration of a limited abalone fishery at San Miguel Island (SMI) prior to full recovery. In order to maximize the CDFG's ability to properly design this fishery a cooperative planning approach was created to directly involve stakeholders in development of potential fishery alternatives. Charged with leading this cooperative approach, the San Miguel Island Abalone Advisory Group (AAG) was empanelled to provide recommendations to the CDFG. The AAG was not established as a decision making body; instead it was to provide recommendations to be considered by resource managers of the CDFG and the Fish and Game Commission (Commission). The AAG was not expected to reach consensus, rather it was expected to develop a reasonable range of alternatives that achieve the goals of the ARMP.

The AAG was charged with providing recommendations regarding the following areas:

- A Total Allowable Catch (TAC) for San Miguel Island red abalone
- Alternatives for allocation between recreational and commercial take
- Alternative regulations to achieve the TAC and allocation
- Potential management, enforcement, and monitoring techniques

We have been privileged to attend several AAG meetings in person and by phone and have followed much of the documentation that has been generated by the group. Unfortunately it appears that the AAG has become sidetracked by a discussion of ill-defined risks rather than looking for solutions to address or mitigate these risks. An international panel of experts, invited to review the AAG's assessment of SMI (Butterworth et al. 2009) politely pointed this out and attempted to return the AAG's discussion to its central tasks. However that panel's work also seems to have been lost without comment in the AAG's processes, and the AAG has been bogged down for many months without making progress on providing recommendations for TACs, alternatives for allocation and regulating TACs and potential management, enforcement and monitoring techniques.

This paper seeks to fill in the gaps surrounding the sources of uncertainty that have consumed the AAG's discussions and build on the way forward recommended by Butterworth et al. (2009). We define and describe the perceived risks that the AAG has associated with limited trial fishery at SMI, and review the science underpinning the main issues as well as the scale at which they operate and must be managed. With the aim of giving the CDFG and the Commission options to consider, it re-tables the suggestions of Butterworth et al. (2009) for a way forward and fills in some of the detail that will be required to implement that initiative.

This paper supports the suggestion of Butterworth et al. (2009) for a limited, closely-studied trial fishery within a restricted area on the southwest corner of SMI and illustrates that this is the only method of those currently under consideration that would allow both continued monitoring as well as direct testing of the concerns raised by the AAG process. Finally, in response to the recommendations of Butterworth et al. (2009) this paper provides a detailed integrated risk management framework and outlines a quantitative harvest policy that could be developed further within the framework of the ARMP.

A. Risk Management

To incorporate risk into management one must go beyond the probability of the occurrence of the event and consider the scale, magnitude and longevity of the impact of that event if it were to occur. In this way a rare but manageable event with grave irreversible broad-scale impacts will be managed as a higher risk than one with a significant impact that is common but short term and local (Berkes et al. 2001). Resources such as California's red abalone (*Haliotis rufescens*) stock face a suite of risks across scales extending from individual reefs to the entire species range and spanning weekly to decadal time frames. Appropriate management measures must address these different scales through a range of socio-political devices. The AAG was established by the Commission to develop a range of alternatives for managing a limited fishery for red abalone at SMI. To fulfill this task, the AAG must address the management of the *additional* risks posed to the red abalone population by this proposal and should focus its discussion on managing those local and additional risks rather than the broad scale risks to abalone across the entire state of California.

The focus of this paper will be on this narrower subset of additional local risks posed by the SMI proposals rather than the long term broad-scale risks of disease, predator expansion and climate change, which must necessarily be dealt with by statewide political mechanisms. Despite this focus, the tenor of the AAG's recent discussions makes it necessary to place these limited additional local risks within the broader context of perceived risks.

The main perceived risks that the AAG's discussions seem to have focused on include:

- Withering foot syndrome disease events
- Predation due to otter encroachment
- Reduced recruitment via the Allee effect
- Uncertain productivity levels
- Uncertain assessments and surveys

III. Sources of Risk

A. *Withering Foot*

The withering foot syndrome (WFS) seems to be less pathological to *H. rufescens* in cooler waters. Being on the oceanographic boundary and receiving abundant cold water influences, the SMI population has apparently remained relatively unimpacted by WFS to date. This situation might be expected to change some time in the future, particularly with global warming. On the other hand it might be hoped that, as time passes since the first exposure, some level of resistance to WFS is also accumulating. Since the strong La Niña event in the early 2000s commercial, recreational and research divers throughout southern California have reported growing numbers of small aggregations of several abalone species in former beds. Recovering populations as far north as the Farallon Islands could be reduced again by a resurgence of WFS which might accompany a period of strong El Niño conditions and warm surface waters unless some level of resistance has been developing over the last three decades.

It should be noted that the status of recovering abalone populations are currently not being monitored outside of the SMI initiative. It should also be noted that the risk of WFS cannot really be managed in any significant sense of the word. Any disease event in southern California cannot be prevented from occurring, or ameliorated once it has occurred. Management can only rebuild and maintain populations at robust levels in a number of locations in the hope of greater survivorship after a disease event. The risk of such an outbreak is independent of whether or not a trial fishery occurs on a part of SMI. The only additional risk in the co-occurrence of a trial fishery and a disease event would be a slightly higher level of depletion in the area of the trial fishery. If the fishery is restricted to a specific area the additional risk will also be localized and can be reduced to almost zero by:

1. Allowing only a light abalone harvest in the fished area so that fished and unfished populations remain at similar high levels in case of disease event.
2. Making the TAC conditional on population monitoring demonstrating that the population remains un-impacted by disease.
3. Ceasing fishing at the onset of a WFS outbreak to prevent further depletion of disease-depleted stocks.

Thus risk from a WFS outbreak can be managed by conducting disease monitoring programs in conjunction with annual surveys and agreeing to a meta-rule that the annual TAC should be set to zero in the event that a disease outbreak is detected, and until the population rebuilds to the previously fished level.

B. Otter Range Expansion

If the range of sea otters expands any further into Southern California the abalone population at SMI is likely to be depleted by >90% and will obviously not be able to sustain a fishery. This issue is similar to the risk posed by WFS: it will not be managed or monitored in southern California outside of SMI, it cannot be effectively prevented, and its impact will be far greater than a light human harvest. The only amelioration possible if it occurs is to avoid adding fishing pressure on top of otter depletion.

Likewise the risk to the SMI abalone populations from future depletion by sea otters is independent of whether or not a trial abalone fishery is attempted before that happens. The only additional risk posed by a trial fishery will be limited to the fished area and that can be avoided by agreeing to incorporate another meta-rule into the harvest strategies decision rules so that the annual TAC is set to zero in the event that sea otters encroach upon abalone grounds at SMI.

C. Allee Effect or Minimum Viable Population (MVP)

1. Broader Academic Context

The Allee effect refers to a reduction in reproductive success at low population numbers. In the case of abalone, gametes released into the water columns are unable to find each other, and this fertilization cannot occur. In the abalone literature the idea originally derives from work done on the Australian greenlip abalone (*H. laevisgata*) that demonstrated and modeled the phenomena using the results of laboratory and field studies.

Shepherd and Brown (1993) introduced the terms "Minimum Viable Population" (MVP) and the "Allee effect" into discussions of abalone ecology. They observed trends from 1968 to 1990 in a population of *H. laevisgata* living inside and outside of a marine reserve at West Island in South Australia. The study site was a contiguous reef complex over an area of approximately 4,120m², of which almost 20% was protected by a small (800m²) marine reserve. Greenlip abalone populations are known to be highly mobile (Shepherd and Partington 1995) and the majority of the reef area remained fished during the period of the study. A low level of illegal harvest in the marine reserve may also have occurred.

Shepherd and Brown (1993) observed a starting mean density of 3,700 abalone per hectare (ab/ha) in 1970, which had declined by 23% in 1983, and by 68% in 1990. The proportion of aggregated adults in the area open to fishing (Dinora Reef) declined from 68% down to 14% in 1990 as densities declined from 2,120 to 1,070 ab/ha. A shift in size structure also occurred but differed between areas. On Dinora Reef, outside the reserve, the proportion of abalone >130 mm (the legal minimum size) declined from 40% of adults in 1983 to 28% in 1990 whereas within the reserve the same size class increased from 20% to 28% during the same period. Shepherd and Brown concluded that fishing over the majority of the reef and possibly some illegal take from the marine reserve caused the population to decline from around 1,500 mature animals in 1970s, down to <500 in 1990.

Recruitment in the marine reserve, monitored as the number of 2-3 year old abalone emerging, was first observed to be relatively low during the period 1975-79. Although it returned to higher levels for a period, Shepherd and Brown believe that the period of lower recruitment, combined with continued relatively uncontrolled fishing, started an ongoing decline in adult numbers which drove densities down to levels where aggregations were disrupted and Allee's effect became a problem, and as a result recruitment failed after 1984: "It is clear, in retrospect, that a population size of less than about 800 individuals [1,940 ab/ha] was critically low and must have increased the probability of further decline." Shepherd and Brown emphasized the additional impact on reproductive potential due to rarity. Noting that the proportion of the population found in aggregations declined from 76% to 16% while density declined from 1.8 to 0.7/m², Shepherd and Brown concluded that "the loss of reproductive potential due to fishing is multiplied by a factor related to the ability of abalone to aggregate. Thus the effective population size declines more rapidly than the true population size as density declines." (p. 2005, Shepherd and Brown 1993).

In parallel to the above study Shepherd and Partington (1995) published a paper on the population dynamics of greenlip abalone in Waterloo Bay and used that as a means to discuss similar issues. The Waterloo Bay stock is a genetically and reproductively isolated stock that Shepherd surveyed from 1978-90. The stock is clearly defined by its isolated geography and through the movement of sub-adults and adults remains relatively homogenous despite occupying several distinct habitat types. Waterloo Bay was fished heavily from the early 1970s until closure to fishing in 1982, and then re-opened to fishing in 1986 with a size limit increase. Shepherd and Partington (1995) found that, while influenced by many factors, recruitment (measured as abundance with a two year lag) was 2.7 times higher in the six years following the closure than in the preceding seven years under intense fishing. Under intense fishing with low size limits aggregations were fewer and smaller. When fishing ceased the size of the abalone and the clusters they formed increased, and they declined again when fishing recommenced, but they noted that during the second period of fishing the size of abalone and their clusters remained larger than when fished initially because the size limit had been increased (Shepherd and Partington 1995).

Shepherd and Partington (1995) used trends in the size of aggregations along with a model developed for sea urchins to relate the intensity of aggregation to fertilization success and adult abundance, and with this model they estimated a stock-recruitment relationship for Waterloo Bay. The shape of the curve they estimated is a classical Ricker type showing a compensation at high stock sizes and indicating that below adult densities of about 1,500 – 2,000 ab/ha the population is increasingly vulnerable to recruitment failure and ultimately to collapse.

"[T]he positive intercept of the curve which is analogous to a compensatory effect (Clark 1974) may have biological significance. It may indicate the strength of the Allee effect. This is supported by the present data on density v. proportion clustered showing zero clustering at low densities under heavy fishing. In this

respect the WB data are in fair agreement with Shepherd and Brown (1993) in which recruitment failed below a mean density of about 3,000 ab/ha. Subsequent history of the WB population has borne this out because it had again collapsed by 1994 with a return to the low densities of 1976-78." (p. 678, Shepherd and Partington 1995)

Babcock and Keesing (1999) measured fertilization rates in the laboratory as a function of sperm dilution and also conducted tests in the field to measure the decline in fertilization rate as a function of distance from where the sperm was experimentally released. They observed that fertilization rates declined abruptly with increasing distance from the point of release but concluded that the decline was not as abrupt as that observed with sea urchins and smaller than that measured for starfish. In their discussion they suggest this may be due to the synchrony of abalone spawning and the selection of low water flows for pulses of spawning. Using reported densities from the earlier studies of Shepherd and Brown (1993) and Shepherd and Partington (1995), which have been discussed above, Babcock and Keesing went on to argue that populations with nearest-neighbor estimates for male-female of 1-2 m were prone to declining, while the stable populations they worked with had estimate male - female distances <1m.

2. Allee Effect in California Management

At the time of the fishery closure in 1997, few references had been made to the Allee effect in California. Tegner et al. (1989) was the first to touch on "reduced fertilization efficiency" as one of a number of possible explanations for the observed decline in landings. Later, Tegner et al. (1996) and Davis et al. (1996) drew directly from the Australia literature (McShane 1995, Shepherd and Brown 1993) to describe the phenomenon of depensation as a factor in the decline of white abalone (*H. sorensii*). Interestingly, Tegner et al. (1996) cited a minimum viable population as being "more than 800 individuals" while Davis et al. puts the number at "several thousand individuals", adequately capturing the general lack of consensus in the literature.

By the early 2000s, however, the Allee effect had come into vogue, with a number of papers citing the phenomenon as a major player in the decline of California's abalone fishery. The term's inception in the California context can be traced to the *Workshop on Rebuilding Abalone Stocks in British Columbia*, in which five of the papers presented alluded to the idea (see Tegner 2000, Davis 2000, Jamieson 2000, Campbell 2000, and Withler 2000; Tegner 2000 also cites Babcock and Keesing 1999). Also presenting at this workshop were biologists from the CDFG who would later play a significant role in drafting the state's ARMP (see Karpov et al. 2000).

By the time the ARMP was adopted in late 2005 the concept of the Allee effect and a corresponding minimum viable population (MVP) for abalone was firmly entrenched in the lexicon of abalone management in California. This is reflected in the ARMP, which sets the MVP for each of the seven species at 2,000 individuals per hectare (ha) and bases this on two sources. The first is Shepherd and Brown (1993); the second source is Tegner et al.

(1989), which describes mean densities at Santa Rosa Island from 1978-82 as being "comparable to the average 0.2 abalone per m² found in the Victorian fishery for *H. rubra*" (Tegner et al. 1989). The ARMP interprets these results to illustrate the densities precipitating the decline of the fishery (Karpov et al. 1998); however, the Tegner paper points to an already declining fishery. The ARMP notes that the "MVP for each species may change as more information on recovering populations is obtained." (p. 75, ARMP)

3. Abalone Ecology

Abalone ecology leaves little doubt that, at extremely low densities, the Allee effect is real. However, in the AAG's discussions and in the general context of Californian abalone management, the concept has been applied in a manner that is conceptually different from its original application and contrary to the scientific data. Shepherd and Brown (1993) found declines at low density in very small, isolated populations of a few thousand individuals, while at SMI even the most conservative interpretations of the last few years of survey data put the population at a few hundred thousand emergent abalone, and likely much higher. In this flawed application of Allee's effect red abalone are implicitly regarded as immobile, fixed to their scars and unable to cross the meters that may separate them to aggregate at densities capable of optimizing fertilization. The Technical Panel's model runs showing a continued decline in recruitment since the moratorium bolster this circular thinking. The implied logic is that, once fishing depleted the population, the abalone left dispersed by fishing never re-aggregated, even after a decade without fishing.

The AAG has attempted to use kelp canopy, quantified with aid of aerial photography, as a proxy for the area of kelp beds, and then arbitrarily defined this as the area of available abalone habitat. As a result, the MVP for SMI as outlined by the ARMP is calculated as:

>2,000 abalone x 1,048 ha (estimated total area of kelp canopy, excluding marine reserves)
or 2,096,000 abalone at SMI

But this does not account for the fact that a high proportion of the sea floor that falls under the kelp canopy is sand (abalone prefer rocky reef substrate). It also does not take into account the fact that typical abalone habitat is some sub-set of the total reef area found within the canopy cover of the kelp beds, and that there are areas where abalone are never observed despite the classification of "potential habitat". Typically 70-80% of an abalone stock will be found living at high densities in just 20-30% of the habitat (Prince et al. 1998) and this pattern of aggregation has probably evolved to improve reproductive success. Finally, it does not explain the fact that, by a number of accounts from commercial, recreational, and research divers, abalone sightings have increased in frequency since the moratorium despite the fact that populations have been determined through survey efforts to be below this rather arbitrary magic number.

If this logic is correct, how can abalone populations ever recover from low levels, and how did abalone populations build up in the first place following the depletion of otters in the 1800s? This is a view that assumes they have no natural resilience and can never recover from an event that badly depletes them.

This conception is flawed because abalone have evolved patterns of movement which minimize the potential for Allee's effect occurring, and so confer on the species the resilience they have needed to survive for millions of years. Abalone do not remain immobile, as casual observers of the scar beneath an abalone might be tempted to think. Instead, a broad range of studies show that abalone within populations are extremely mobile, moving in and out of feeding aggregations and aggregating more intensively to breed (Ault and DeMartini 1987, Prince 1989, 1992, Shepherd 1986a and b, Shepherd and Partington 1995).

Ault and DeMartini (1987) released 3,877 tagged red abalone at Point Cabrillo and re-sighted 58% at least once over the next five years. They measured a median distance moved of 87m and a range of movement rates from 1 to 150m per month:

"The red abalone population at Point Cabrillo was in a constant state of flux due to movement and dispersal, with the new members entering the area as well as leaving the area. However, some abalone remained in the general vicinity for relatively long periods. We probably have underestimated the extent of movement as it is likely that some abalone left the zone in which they were released, only to have returned to the same general vicinity before the next observation." (p. 209, Ault and DeMartini 1987)

They also noted that some abalone were likely to have moved out of the research site. They observed 29 instances of movement >350m over 3 to 61 months between sightings. One tagged abalone released in the Inner Surge Channel of their site was "recovered alive approximately 9 years later by a sport diver near Caspar State Beach, a distance 2.4km north of the study site in least-linear transect from the point of release." (p. 208, Ault and DeMartini 1987). They surmised that food availability influenced movement rates as they had gained the qualitative impression that movement was less and scars were more deeply formed where food was abundant.

Frequent movement has also been documented within populations of Australian greenlip abalone. Shepherd and Partington (p. 678, 1995) noted that within Waterloo Bay "on reefs of low relief, where crevices are often in limited supply, abalone keep moving in the direction of approaching swell until they find a crevice. In this habitat up to 90% of the population may be mobile." Shepherd (1986) documented a seasonal signal in the degree to which greenlip abalone aggregate at the seaward edges along the sand-lines of the reef. A larger proportion of the population was found in aggregations immediately prior to and during the spawning season. More recent research has shown the sand-line habitat to be the favored settlement habitat for larval greenlip (Shepherd and Partington 1995). Shepherd and Partington (1995) and Babcock and Keesing (1999) both emphasize the importance of greenlip abalone physically moving into aggregation as a stimulus for initiating spawning activity.

Prince (1989, 1992) provides a similarly mobile picture for the Australian blacklip abalone (*H. rubra*). During a four-year study some 7,500 abalone were tagged in an isolated 1km² reef in southern Tasmania, Australia, which local divers had closed to fishing. A total of 1,219 movements were observed between points of a permanent transect during a multiple-recapture study, and a single-point-of-release-and-recapture study was also conducted during which the movement of a further 2,503 abalone were recorded. Together with mapped abundance and feeding studies, Prince (1989, 1992) used these data to model the movement and distribution patterns of abalone on the reef. Movement was modeled simply as a slight tendency to move to shallower areas to aggregate for breeding countered by an increased probability and rate of movement if food availability was reduced by high abalone densities. These two simple counter-acting movements explained the clustered distribution pattern mapped for the study site.

Observations of *H. midae* recorded by Tarr (1995) support Prince's conclusions regarding the influence of the opposing forces of competition for food and reproductive success on abalone distribution. Tarr followed a small group (n=58) of *H. midae* on two rocks in a marine reserve in South Africa for three years and found that 46.6% of these individuals were still on the rock at the end of this time, with 81.5% of these stationary abalone occupied their original scar for the entire time. According to Tarr, "[t]he mean size of the abalone tagged was large, and all the smaller abalone eventually moved from the site." (p. 586, Tarr et al. 1995) He attributes this sedentary behavior in mature adults to site preference, noting that, "once a favourable site has been occupied, an adult will defend it against other abalone, with violent rotation of the shell, thereby ensuring an even spacing of adults over prime reef areas." (p. 586-7, Tarr et al. 1995). In this way, abalone are able to structure their distribution to achieve their preferred densities. Tarr also notes that movement is a normal part of the ecology of *H. midae*: "[A] gradual offshore movement of abalone must occur as individuals disperse to favorable reef areas, and aggregations of adults develop in these areas." (p. 588, Tarr et al. 1995)

A few papers have examined abalone movement in the context of fisheries management. Officer et al. (2001) studied the propensity for blacklip abalone to re-aggregate after fishing. They surveyed abalone in four (two fished and two control) plots of 576m² at two sites before a controlled removal of 35% of the abalone present, three to four weeks after a fish down, and again ten weeks later to assess recovery. Officer et al. observed "a decrease in the abundance of less than 20%" in fished sites, indicating that abalone had indeed moved into the plots from outside areas (p. 773, Officer et al. 2001). Officer et al studied not only movement but aggregative behavior, noting that "[i]n both sites approximately 80% of abalone were located within 30cm of their nearest neighbor" before fishing, and that, by the second post-fishing survey, nearest neighbor distributions had returned to the distribution found prior to fishing. While this tendency to move after fishing can strongly impact estimates of abundance and natural mortality and should be taken into account in managing a fishery, it also illustrates the ability of abalone to re-aggregate to their preferred density in the face of fairly heavy fishing. Dixon et al. (1998) used a similar

experimental design and estimated similar abalone dispersal and re-aggregation rates in response to fishing

The observations of the spawning of *H. kamtschatkana* by Breen and Adkin (1980) and Stekoll and Shirley (1993) reveal an even more highly mobile view of behavior during the act of spawning with abalone climbing to the highest points of the reef, piling on top of each other five to six abalone deep, and climbing together up onto the stipes, stalks and blades of the kelps around them. Abalone eggs are heavy and the climbing behavior during mass spawning is thought to optimize fertilization success by allowing females to drop their eggs down through the cloud of sperm created by males under the conditions of low water movements selected by the abalone for spawning. Similar behavior has been reported by Australian commercial divers who have observed natural mass spawnings of *H. rubra* (Prince personal observation).

As demonstrated in this review, the overwhelming body of science shows that on scales of tens and even hundreds of meters and over time scales of nights, weeks and months abalone are remarkably mobile, and aggregate even more actively during their breeding seasons. It is also known that manufacturing the slime trail over which they glide is an energy intensive process (Culley and Sherman 1985), so the observed aggregative mobility associated with breeding is unlikely to have evolved without strong evolutionary reason. It follows that this evolutionary reason is to improve the resilience of the species by minimizing the potential for Allee's effect occurring. It can be assumed these movement patterns exist so that whatever abundance of abalone exists in an area at the time of spawning, they will form aggregations at densities likely to optimize their fertilization rates.

Accepting this logic, Allee's effect is only likely to occur when fishing continues through the spawning season at rates that deplete aggregations faster than they can reform, as was the situation observed by Shepherd and Brown (1993) and Shepherd and Partington (1995). But the obverse of this logic is that in unfished populations, or where fishing is light and or occurs months or weeks before the spawning season, the Allee effect poses little if any risk.

4. Distributional Analysis of 2006 SMI Survey Data

A simple analysis of the distributional data gathered during the 2006 SMI surveys illustrates the propensity of abalone to form aggregations and live at high densities. The CDFG survey protocol considers the entire area under the kelp canopy of SMI to be abalone habitat and involves counting abalone within 5m segments along transects placed randomly under the kelp canopy. The boundary of the kelp beds, and so by definition the area of the survey, is determined using aerial photographs of kelp canopy. For this analysis the 2006 SMI survey counts of abalone within each 5m segment of the transect are each used as an estimate of the density at which the sampled abalone were living.

Analyzing the data this way shows that, of the 4,796 segments surveyed, 70.3% of the area under the kelp canopy held no abalone. According to substrate data collected during the survey of this 70.3% of the kelp canopy without abalone, 12.0% was sand, and 6.8% was

cobble (small rocks that can move in heavy surge), both habitat types abalone are not expected to occupy. However, based on the substrate data the remaining 51.5% was apparently potentially suitable abalone habitat although it did not contain abalone.

Figures 1 and 2 provide two views of the observed density profile formed by SMI abalone within the remaining 30% of the habitat. Figure 1 plots the percent of abalone sampled against the density at which they were observed within each 5m segment of transect. It shows that almost 10% of the sample was recorded at densities of around 2,000 abalone/ha and that only 8% of the sample was found occurring at densities below this level. Figure 2 shows a similar view to figure 1 but plotted as the cumulative percent of the abalone sampled. From figure 2 it can be seen that >73% of the sample occurred at densities of 3,000 abalone/ha or greater and at those densities they cover approximately 10% of the broader survey area. This concentration profile is a common feature of abalone populations with 70-80% of the population normally occurring in 10-20% of the potential area (Prince et al. 1998).

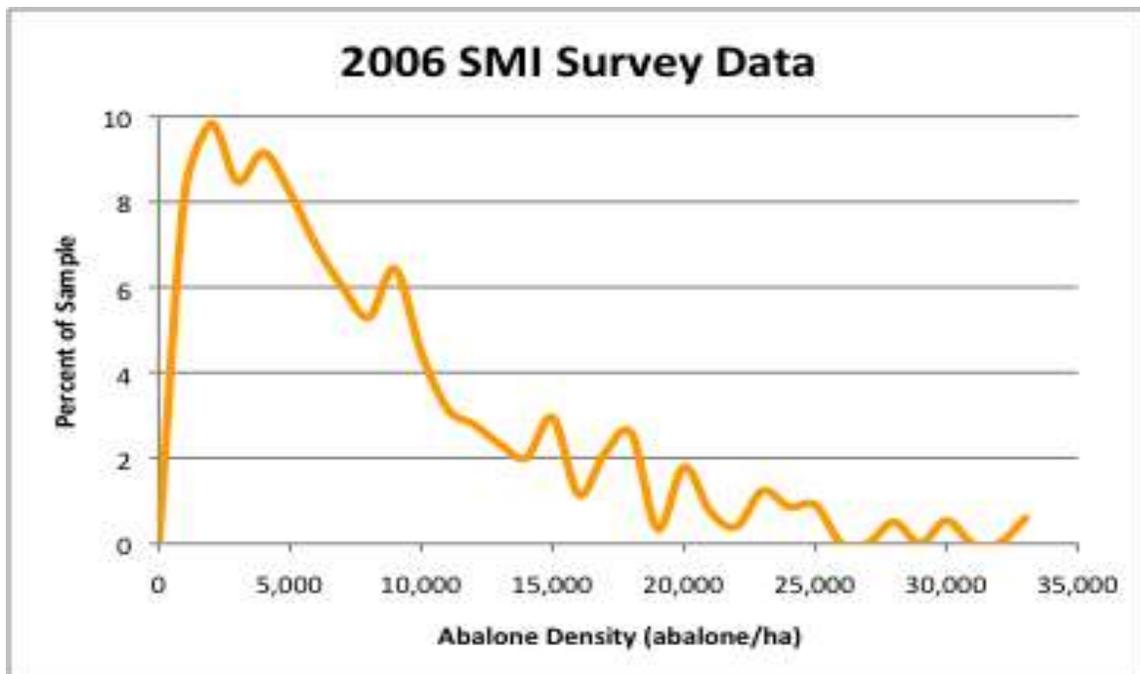


Figure 1. Percent of abalone sampled during the 2006 surveys plotted against the density at which they were observed within each 5m transect segment.

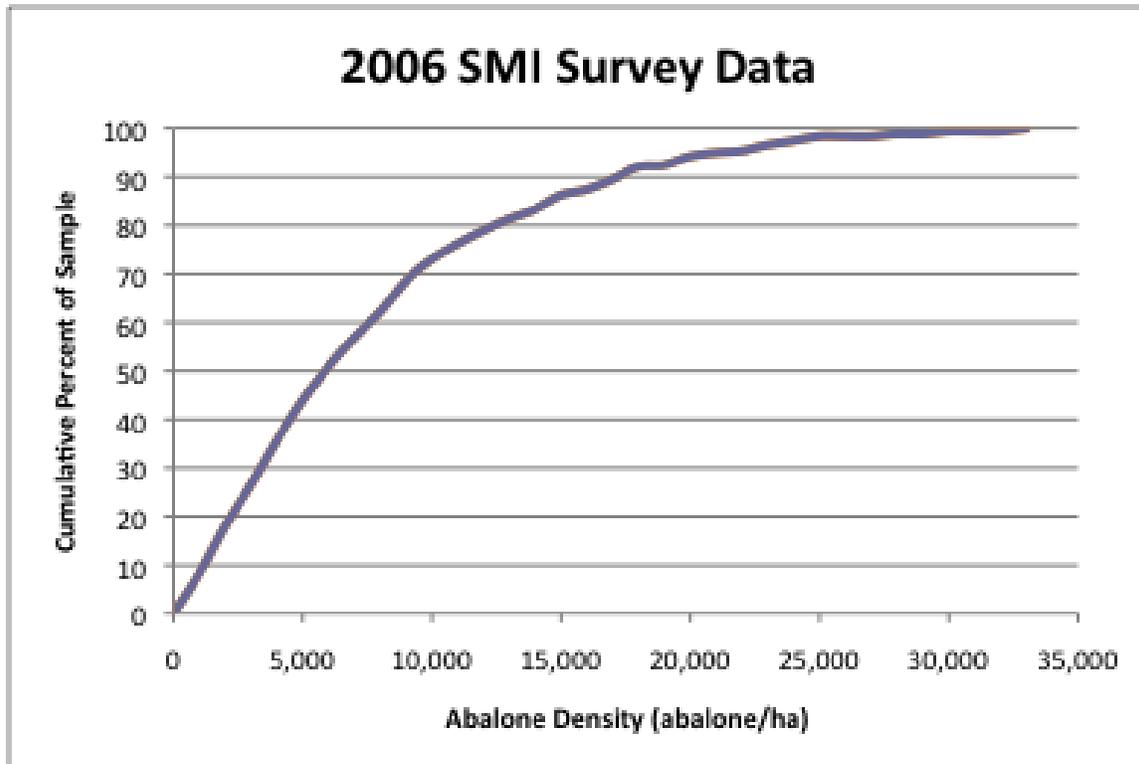


Figure 2. Cumulative percent of abalone sampled during the 2006 surveys plotted against the density at which they were observed within each 5m transect segment.

From these data it can also be estimated that, while abalone were only observed within 30% of the habitat covered by kelp canopy, their average density in the areas they occupied is actually 8,185 abalone/ha, well above the MVP specified in the ARMP. It is at this localized density that fertilization and larval dispersal is occurring. Given the difference between the size of the area deemed by survey protocol to be abalone habitat and the area the abalone have actually selected to aggregate within, it is not surprising that the latest density estimate derived from the survey and used by the AAG (1,539 abalone/ha in 2008) is so much lower than the actual effective density (8,185 abalone/ha) at which the average abalone at SMI is spawning. Clearly the estimated survey density and the AAG's application of the concept of MVP is an anthropomorphic construction which has little relevance to the density at which the average abalone SMI actually experiences. The abalone demonstrate by their actual distribution that the human definition of abalone habitat is incorrect, illustrating the arbitrary nature of the MVP contained in the ARMP and the way it has been applied during the AAG's discussions.

This point is further emphasized when it is realized that an MVP of 2,000 ab/ha is entirely based on the Australian greenlip *H. laevigata* which, at maturity, are only 30 to 50% of the weight of a mature red abalone. The amount of eggs and sperm an animal produces is generally assumed to be proportional to weight, so it can be assumed that adult red abalone produce double or triple the amount of eggs and sperm. At the same population densities these individuals will produce clouds of eggs and sperm several times more dense than the species on which this number is based. So, as noted by Butterworth et al. (2009), we should be dealing in biomass estimates rather than number of abalone per hectare, in which case an MVP of 2,000 greenlip abalone/ha is equivalent to around 700-1,000 red abalone/ha.

Regardless of the arbitrary nature of the limit set for Minimum Viable Population density in the ARMP, the indisputable fact is that the average SMI abalone is spawning at densities four times greater.

5. Addressing the Risk of Allee's Effect

It is within this context that the timing and rate of harvesting has the potential to interact with the natural ability of abalone to maintain themselves in aggregations of sufficient density. This explains the constant theme of over-fishing which Shepherd and Brown (1993), Shepherd and Partington (1995) and Babcock and Keesing (1999) link with their discussion of Allee's effect. In this context Shepherd and Partington (1995) fit Allee's effect into the lower left-hand side of a classical Ricker-type stock recruitment curve to describe a relationship that has compensation at high stock sizes (1.0 – 2.0 ab/m²), where recruitment becomes limited by competition for resources, as well as depensation (Clark 1974) at low adult densities (0.15 – 0.2 abalone/m²) whereby recruitment can fail entirely at low levels of spawning biomass. Note that Shepherd and Brown (1993) supported managing for the breeding biomass target of 50% of Full Lifetime Egg Production (FLEP) with the implicit assumption that at higher levels of spawning biomass Allee's effect no longer poses a risk for a population. This original conception of Allee's effect as occurring in a heavily fished population on the left hand limb of a stock recruitment curve is consistent with the movement modeling of Prince (1989, 1992) which showed that at light to moderate fishing pressure the catch rates of the divers were elevated by the re-aggregation of the abalone and the divers' knowledge of aggregation sites. However, at high rates of fishing pressure, abalone are repeatedly fished before they can re-aggregate and catch rates fall. It is in the context of continued overfishing, when population's are held at low densities and prevented from re-aggregating, that the risk of Allee's effect may become real.

Thus the Allee effect is both a product and a symptom of overfishing, and consequently the risk posed by Allee's effect at SMI can be managed by avoiding overfishing and timing harvest to allow spawning to occur in undisturbed aggregations. If heavy fishing, or even lighter pulses of fishing immediately prior to, or during, breeding events, were to be allowed the effectiveness of spawning could be reduced.

It should be noted that Butterworth et al. (2009) suggest that the initiation of an experimental fishery with a 10% take of the surveyed population above 203 mm in the Southwest Zone is a risk-averse strategy, and likely to be well within the level the resource can sustain. This basic outline of a management proposal addresses all local risks voiced by the AAG, and includes monitoring to detect the impact of risks from larger scale effects that cannot be directly managed for. By isolating the fishing trial into just one small region of SMI it is possible to employ mandatory ongoing monitoring to test the range of concerns raised in opening this fishery and end the trial if serious impacts are detected. It is also important to note in their proposal for an experimental fishery the fact that a TAC of 10% of abalone over 203mm in the Southwest Zone removes only 1% of the estimated population at SMI. Three-fourths of the available abalone habitat at SMI will remain outside the fished area and thus outside the local risks posed by the proposed fishery, acting as a de-facto reserve. This will keep FLEP over 80% (Leaf et al. 2008) in the fished area, well above the 50% proposed by Shepherd and Brown (1993).

Thus with the small TAC, limited area of fishing and conservative size limits proposed by Butterworth et al. (2009) the threat of Allee's effect can be effectively managed so that the residual risk is vanishingly small and extremely localized. Meanwhile the required ongoing monitoring and research will document the resource's response and allow for the perceptions of risk to be updated by quantitative data, and also allow for a proactive management response if monitoring reveals a population decline. In this way the residual risk associated with Allee's effect can be managed to zero over a time scale of several years.

To demonstrate this point we explored the size composition data from the 2006 CDFG survey. We created a model to mimic removal through fishing and tested the effect on the distribution of large abalone. We created a bootstrap algorithm to randomly select a legal sized abalone from the SMI 2006 survey data for removal. In order to mimic fishing behavior, the model then searched for and removed any other abalone found within the same 2m by 5m quadrat, or any of the adjacent quadrats (a 120m² area). In this way we hoped to replicate the way a diver, upon finding an aggregation, will remove all legal sized abalone in that aggregation, and test the effect of such behavior on the density of the remaining population. Once the simulated diver removes all abalone over 203mm in an "aggregation" (as we have defined it here), the diver randomly chooses another legal sized abalone and continues the process until the quota we have set (up to 70% of the total legal sized abalone) is reached. We calculated both the mean and the 95% confidence intervals from 1000 repeated fishing trials. Figure 3 shows the percent of the population at each density before fishing (black line), as well as the percent of the population at each density after removing 70% of the legal sized individuals (green line, grey lines give the 95% confidence intervals). We chose to show the results of a 70% removal because a 10% removal (the percent removal advocated here) is virtually undetectable as a change in the density experienced by each abalone. Even a 70% removal has very little effect. What little effect a 10% removal would have on abalone density could be mitigated by employing a harvest rule stating that no more than 30% of the legal sized individuals in an aggregation could be harvested.

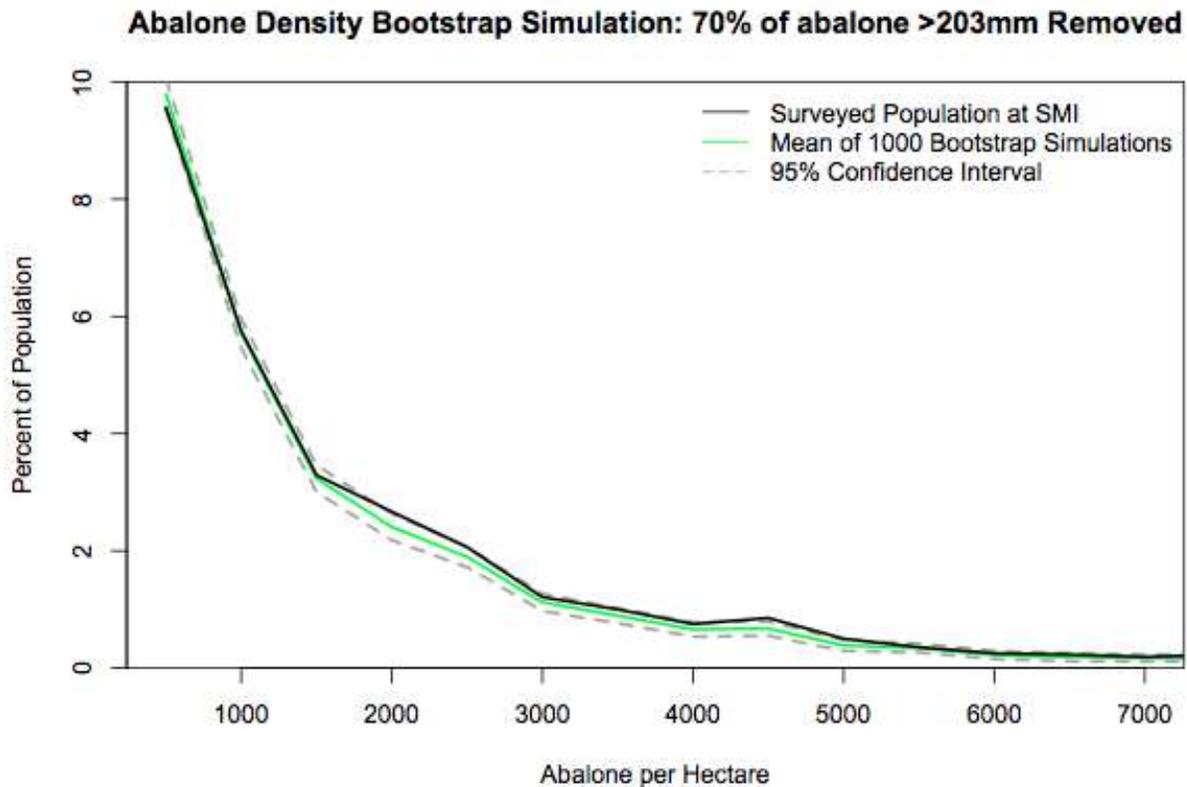


Figure 3. A plot of the percent of the population at each density before fishing (black line), and the change that would occur if 70% of the legal abalone were removed (green line). The grey lines give the 95% confidence interval. The level of 70% removal is used in figure for illustrative purposes, because the 10% proportional harvest scenario cannot be distinguished from the before fishing density structure.

D. Declining Population Modeled by AAG Stock Assessment

The modeling work conducted on behalf of the AAG by Yan Jiao under the guidance of the Technical Panel has added an additional aura of uncertainty and risk to the AAG process. The assessment results purport to indicate that the SMI abalone population has suffered a decline in recruitment over the last couple of decades. However, we argue that this modeled outcome is a result of uncertainty and gaps in the data and changes in data collection protocol over time, and contrary to observed trends over the last 10 years. In addition, the model work was found to be incomplete by Butterworth et al. (2009), a body which included scientists with a great deal of experience with abalone stock assessment models. There is actually no evidence that this modeled result has any basis in reality, as the assessment model has been given no credible data to support a declining trend.

1. Non-Compliance with Accepted Modeling Procedure

Those from outside the field of assessment modeling need to understand that commonly the combination of uninformative data and incorrect prior assumptions will cause the fitting routines to converge on estimates and predictions that make no sense, i.e. negative recruitment or positive mortality rates. In the field of international fisheries assessment modeling it is standard practice to 'tune up' the biological model underlying an assessment by making it sure it doesn't produce such implausible behavior.

One commonly applied method is to test the potential of a stock to rebuild without fishing. It is normal practice to discard model structures that suggest that a stock will continue to decline in the long term without fishing. This normal procedure is exemplified by the following quotations from some of the world's most experienced fisheries assessment modeler's.

"The lowest value for steepness was set to 0.25 because He et al. (2006) demonstrated that values for steepness less than this are highly unlikely." Cope and Punt (2009). (Note: 'Steepness' is defined as the proportion of recruitment produced by 20% of unfished spawning biomass, and is a measure of a stock's ability to replace itself at 20% of virgin biomass.)

"Most fisheries management is built on the assumption that more or less sustainable yields are possible." Hilborn and Walters (1992).

The Technical Panel does not appear to subscribe to these views and has instead adopted as its preferred base case a scenario that is fundamentally implausible. This indicates that the Technical Panel may have been biased by the gratuitous applications of the concept of the Allee effect to the population at SMI. This is the only explanation for moving forward with a model that shows a declining population in the absence of fishing pressure.

Working from first principles and excluding disease epidemics or the onslaught of a 'new' key predator like the sea otter, biological populations persist in time by retaining the capacity to increase. In the absence of some 'unnatural' or additional cause of mortality, to propose that an unfished stock continues to decline in the long term is illogical. To illustrate this point one just needs to ask the question: how is that this apparently declining stock came to exist in the first place when it has no capacity to increase from low stock levels? Such a species could never have expanded in the first place to fill the habitat it is currently found in. In the case of the red abalone, after countless millennia of heavy sea otter predation how could such a species build the populations that were first fished in the late 1800s? Logically, without an undetected additional agent of mortality, a stock can only experience a long term decline after it has grown up to and then beyond its climax level and then begins declining back down towards the equilibrium level for that population. Consequently assessment scientists have learned to distrust this dynamic without strong evidence in the data inputs that this is in fact the case.

One could argue that there has been substantial ongoing illegal fishing at SMI since the moratorium, resulting in continued population declines in the absence of a legal fishery, and that the model has detected the effects of this. However, the change in the size distribution of the population since the moratorium (shown below in figure 4) indicates that this is not the case. In 1997 only 1% of the observed population was larger than the size limit, while in 2008 almost half of the emergent population is this size or greater. This shows that abalone have continued to grow at SMI without suffering significant removals of large animals.

As Butterworth et al. (2009) emphasize in their comments, the only reliable information the AAG assessment model contains are the recent survey data, which are of exceptionally high quality. Consequently they recommend relying almost entirely on that data for moving forward, via a decision table assessment of biomass and conservative yields, as developed below. Unfortunately surveys of this quality do not exist throughout the time span this stock has been fished, and in this case the time series data normally required to identify the sorts of trends analyzed by the model are very problematic. So the question becomes: how is the model deriving the result the AAG is using as its base case, and is the basis for it sound? Or alternatively, is it simply an implausible fitting of the model that should have been weeded out early in the process of model development but, due to entrenched beliefs regarding the Allee effect, is in danger of becoming firmly established as 'fact' because now it is the output of a scientific model?

As noted by Butterworth et al. (2009) the modeling conducted has not been reported in a manner that can be easily understood and scrutinized so it is difficult to be certain exactly what has happened:

III. 3. The report tabled did not fully explain some of the details of the assessment model, perhaps because it had to be prepared in a very short time; future reports need to provide the specifications of this model in complete detail. Furthermore, such reports should contain summaries that present their conclusions in a form more readily understood by non-specialists.

2. Bias through Changing Survey Protocols

Despite the obscurity of the modeling it seems almost certain that the outputs suggesting declining recruitment and biomass trends are an artifact of the modeling process driven by assumptions (implicit or explicit) about the selectivity curve which have been used to model the availability of small abalone to the research surveys.

Juvenile abalone are cryptic and hide wedged into crevices and under boulders (Prince et al. 1988). They only begin to emerge into the front of crevices and then out onto reef flats as they mature, where they become available to harvest and are easily sighted in surveys (Prince et al. 1988). Consequently monitoring abundance of juvenile and pre-recruit size classes has always been a difficult issue for abalone science worldwide (e.g. Dixon et al.

2006). If this model was provided with the assumption, either implicitly or explicitly, that a fixed proportion of the smaller cryptic size classes have been found during each survey (i.e. the selectivity curve has remained constant across all the surveys) it will inevitably infer that any changes in the proportion of the juvenile size classes has resulted from a change over time in recruitment rates. It seems certain that the AAG's model has been structured around the assumption that juvenile abalone have been surveyed with the same selectivity and rigor (selectivity curve in modeling language) during every survey, and changes in the proportion of small abalone over time will be interpreted as due to varying rates of recruitment. If recruitment declines for long enough, or far enough, it will also cause the model to estimate a declining trend for adult biomass as well. This logic is hardwired into the Technical Panel's model if it implicitly or explicitly has analyzed the survey data assuming constant selectivity over the surveys.

However, survey protocols with regard to searching for small abalone have changed radically through the years. The original survey protocol in the early 1970s (1974) was simple: swim and count emergent abs. This protocol changed in the 1990s (1993-97). The Cruise report 93-M-6 shows the procedures during timed swims then started including some invasive searching of cryptic habitat targeting juveniles, in addition to counting emergent abalone along survey transects: "When possible, boulders were turned to search for juvenile abalone." Reports 97-M-1 and 97-M-5 also describe the use of these invasive techniques. In 1997 surveys were part of a collaboration with commercial fishermen who were asked to direct CDFG researchers to where juvenile abalone might be easily found and CDFG researchers specifically targeted these areas with the aim of constructing length frequency histograms for the cryptic juvenile size classes (Karpov et al. 1998). In 1999 the protocol changed to counting aggregations, reflecting a growing interest in the Allee effect, and this protocol continued through 2000 and 2001 using the timed swim method, with some searching of cryptic habitats for juveniles, some aggregation counting and only a little transect work. So in these earlier surveys researchers mainly conducted timed swims during which they counted and measured emergent abalone, and then turned boulders looking for juveniles, and there was much less emphasis on swimming along randomly placed transect lines.

By point of reference, since 2006 the survey protocol has been based on randomly placing 60m transects within the boundary of the kelp canopy mapped by aerial photography over several years. Within a 2m wide strip along either side of the 60m transect line, emergent abalone have been counted within 5m segments. There has been no searching of cryptic habitats for juveniles.

Clearly this evolution of survey protocols will have produced marked changes in the actual selectivity curve of the surveys. Without modeling this as a different selectivity curve for each survey protocol, the model will have been constrained to attribute the changes in the proportion of small abalone measured to changes in abalone recruitment, when they were actually produced by changing survey protocols. In this case the length-frequency data from early 1990s, when survey divers searched cryptic habitats for small abalone, and

particularly in 1997 where commercial divers told research divers where juveniles would be most easily found, will have been interpreted by the model as indicating a higher previous level of recruitment. The 1997 protocol seems to have been interpreted by the model as a pulse of previous recruitment on top of normal, while the current survey protocol is being interpreted as continuing current lack of recruitment. According to the logic built into the population model this must over time start decrease estimated adult biomass.

In this way the assumption of the same selectivity curve for all the surveys will have resulted in erroneous estimates of recruitment trends and consequently adult biomass trends as well. The summary points from Butterworth et al. (2009) suggest that they came to a similar diagnosis:

III. 2. A flexible functional form should be used to model selectivity-at-length for abalone sampled in the 2006+ surveys, and used in providing model predicted values for proportions at length and abundance corresponding to these surveys.

III. 4. "A baseline assessment should be considered based on input from the most reliable data only – likely past catches and the proportions-at-length and abundance estimates from the 2006+ surveys. The effects of adding further relative abundance information should be explored through sensitivity tests."

III. 5. More model fit diagnostics should be reported so that the quality of fits can be judged better, and with a view to clarifying which elements of the inputs have the greatest influence on key features of the outputs (such as recent resource trends): for example, both data and model predictions should be compared for each data series input, together with the value of the associated residual standard deviation, for maximum penalized likelihood estimation.

From the summary points above, regarding:

- flexible functional forms for selectivity curves,
- base-line assessment cases based on 'input from the most reliable data', and
- reporting model fit diagnostics so that the quality of fits can be better judged with a view to clarifying which inputs have greatest influence

Butterworth et al. (2009) found the model runs suggesting declining recruitment and biomass lacked credibility. In Section IV Point 6 they make it very clear that their judgment was that the SMI has, at the very least been stable for the last two decades:

IV. 6. The adequacy of the Abalone Recovery management Plan (California Department of Fish and Game 2005) generic minimum-viable-population threshold value of 2,000 abalone per hectare for SMI should be evaluated in the context of 20 years of apparent population stability.

It should also be noted that the historic time series of length frequency data is more reliable where it pertains to the size range of the larger, fully-emerged and -recruited size classes, because that part of the size structure has not varied with changing survey protocols. In this respect the time series shows that there has been a considerable increase in the proportion of the population larger than the old legal size limit. The percentage of the population larger than 197mm has increased from less than 1% in 1997 (the year the moratorium was enacted) to 47.8% in 2008 (Figure 4). In light of the high fecundity of these large individuals (Rogers-Bennett et al. 2006) one can assume that gamete production has similarly increased in magnitude and that the area their aggregations now cover has grown as well i.e. biomass is growing. This is what commercial, recreational, and research divers alike are uniformly reporting as well.

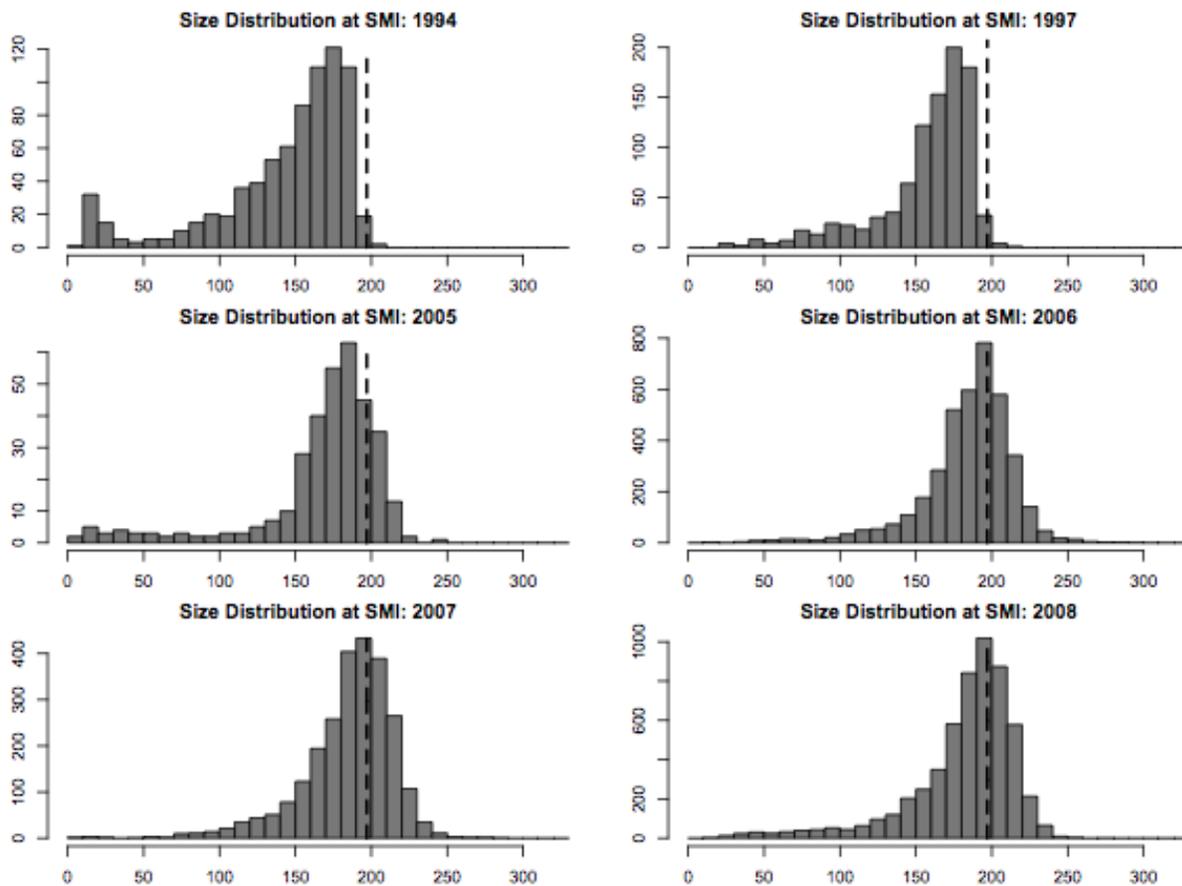


Figure 4. Length frequency histograms (maximum length in mm and number counted) for the abalone surveyed during CDFG surveys 1994-2008.

Discounting the model's estimate of declining recruitment as baseless, and assuming that on average recruitment has stayed stable since the moratorium, as Butterworth et al. (2009) evidently do, these size data suggest that there has actually been considerable growth in SMI breeding biomass since the moratorium stopped fishing (Figure 5).

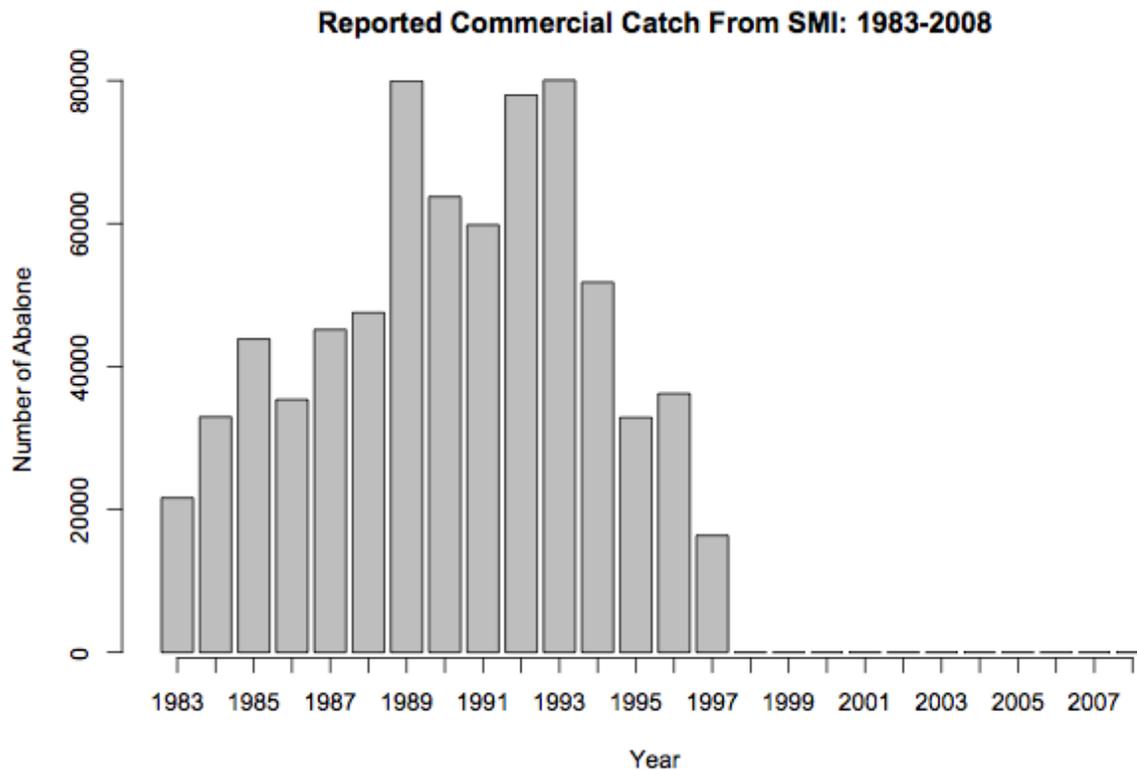


Figure 5. Time series of reported commercial catches (number of abalone) from SMI 1983-1997. *1997 was a curtailed harvest season: 30% of normal years.

This view is supported by an analysis of the CINP data from Wycoff Ledge at SMI (Figure 6), which, despite the inherent variation in the time series, clearly shows that the population has increased at about 10% per year since the fishery closure in 1997, despite starting out at one-tenth the density of the supposed "MVP" of 2,000 ab/ha. A simple exponential growth model was fitted to the Wycoff abundance data before and after the close of the fishery and it estimates the population has grown at an instantaneous rate of 0.1 which, expressed as an annual proportion, is an 9.5% rate of growth since the closure of the fishery in 1997.

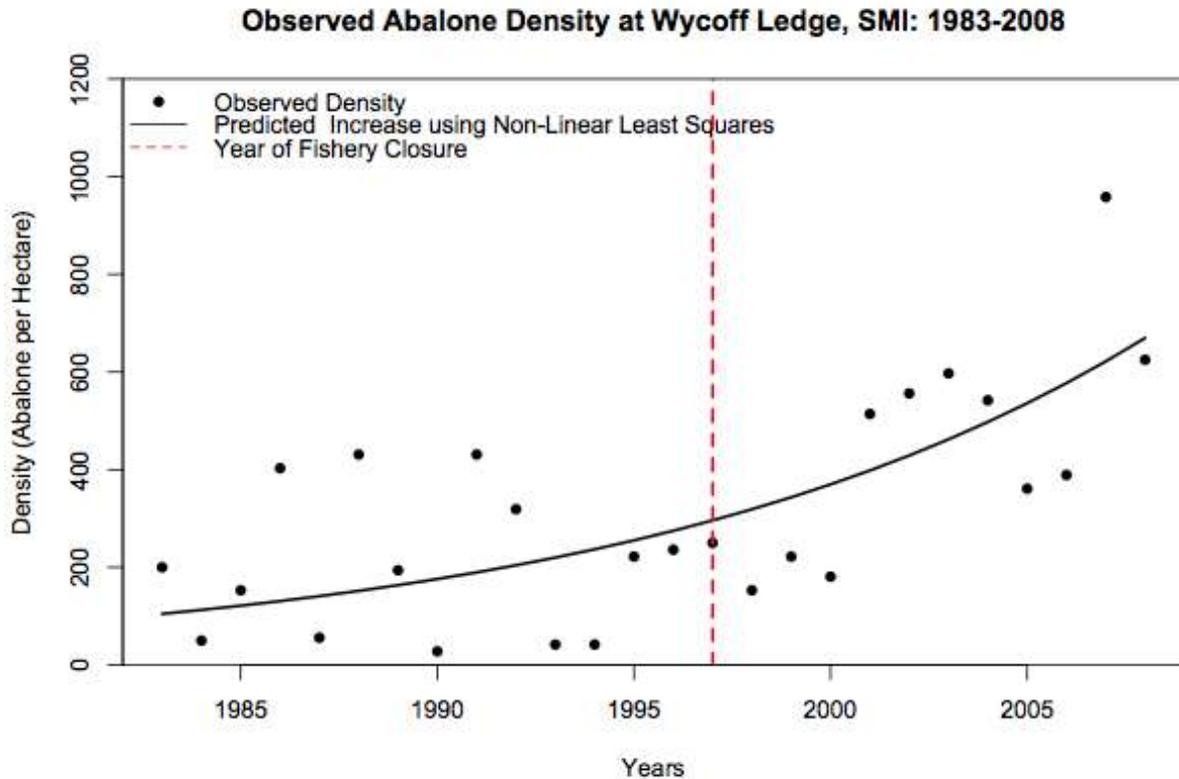


Figure 6. CINF transect counts at Wycoff Ledge at SMI fitted to a simple logistic growth model since the moratorium in 1997 suggests the population has grown at an instantaneous rate of 0.1 since that time.

In figure 6, based on a standardized transect survey protocol which has not changed over time, we get confirmation that the SMI abalone population is behaving consistently with what is expected of the stock on the basis of international fisheries science.

3. Summary on Implausible AAG Model Outputs

In summary, model runs predicting the decline of an unfished stock are inherently implausible and not normally permitted to enter an assessment process without impeccable data showing this to be the case, and only then with significant further testing and clarification as to the drivers of this behavior. The Technical Panel has given no explanation of the drivers behind the purported decline at SMI. In contrast, we have demonstrated that the decline detected by the model is an artifact of using a uniform selectivity across all surveys. This is supported by the National Park data from Wycoff Ledge, which visibly shows a population that has increased from local densities well below the theoretical MVP at a rate of 9.5% per annum since the moratorium, and adds weight to

the opinion that this assessment model is flawed, an opinion also advanced by Butterworth et al. 2009.

In consequence we support Butterworth et al. (2009) in placing no credibility on the Technical Panel's modeled outputs, especially not in the suggestions that the SMI has continued declining over the last two decades. Like Butterworth et al. (2009) our interpretation is that the population of SMI has in fact been growing since the moratorium was imposed, so we do not accept the modeler's claim that there is in fact a real risk of decline even without fishing. Any risk posed to the population under harvest can be managed through the limited trial fishery proposed by Butterworth et al. (2009) and by establishing a TAC setting process which will stop harvest if surveying with a standard protocol indicates the purported decline in recruitment and biomass is real and ongoing.

Our goal is a well-managed, long-term sustainable fishery at SMI as well as a healthy red abalone population that continues to rebuild. This can be achieved through the monitoring and management system outlined below, which supports the small-scale trial fishery proposed by Butterworth et al. (2009). This plan requires continued collection of high-quality survey information which will measure trends in recruitment and spawning biomass. If recruitment (or spawning biomass) is found to be declining it will become impossible to sustain any level of catch and maintain the population's current abundance, so the TAC-setting system proposed below will close the fishery. Thus, whatever the actual level of risk associated with this issue, it can be managed within the TAC-setting process by ensuring that a management system is put in place that reduces or stops harvest if those risks are realized.

E. Survey Uncertainty

The ideas outlined above argue that the local risks associated with the proposed trial fishery can be minimized under a level of fishing that maintains current population levels or allows it to continue growing. However, our ability to set sustainable catch levels will be determined by the accuracy of our estimates of the current population and our ability to detect changes in the future. Within the AAG it has been posited that there is a risk that overfishing might inadvertently occur because both our estimates of abundance and the productivity of the SMI stock is imprecisely known. In this section we consider the risk posed by imprecision in the estimate of biomass that have been derived from the surveys, and on which any TAC must be based.

In re-opening a fishery of a resource that is rebuilding, a number of unique challenges are faced. The most commonly published stock assessment techniques are developed to set TACs based on both fishery-independent (observed abundance) and fishery-dependent (catch effort, total catches, and size distribution of landings) data and then analyzing trends in both types of data in the context of what is known about that stock's biology. In the case of a fishery that has never been fished or is to be re-fished after a period of closure, the biology of the species must be used with single (fishery independent) estimate of the population. In the case of SMI the three recent surveys have produced similar estimates, so

they can be thought of as replicates of each other. For convenience this paper has worked with the most recent (2008) survey data. This problem has been faced in other abalone fisheries around the world and in Australia the standard approach is construct a decision table so that the uncertainty in expected productivity can be explicitly laid out in tabular form varying with both survey precision and estimates of natural mortality. Over the last few years this approach has been used in South Australia where a large previously unfished area of stock has been added to an Individually Transferable Quota managed fishery (McGarvey et al. 2008). In Victoria, where industry associations closed reefs for three years after a viral epidemic, and are now re-opening them cautiously to re-fishing (Mayfield et al. 2008). While in Western Australia the technique has been used to estimate the lost value of abalone beds from which the fishery is being excluded so an MPA can be established (Hesp et al. 1998). In all these instances commercial divers and research staff have participated in the biomass surveys not unlike the CDFG surveys, and the survey data along with what is known of abalone biology have been used to set conservative levels of production.

The basic principle of fisheries assessment is that a conservative TAC (which should maintain stable stock and recruitment levels, and also allow a stock to build back to optimal levels) can be estimated from the natural turnover rate, or productivity, of the stock. In fisheries biology this is the same as the natural mortality rate (M). By this logic a sustainable take is similar to the natural 'unfished' turnover (M) of the stock (Biomass):

$$\text{TAC} = \text{M} \times \text{Biomass}$$

The issue here is that, in reality, you can never be entirely certain about either M or the Biomass. To address this issue a risk analysis approach has been developed in South Australia (McGarvey et al. 2008, Mayfield et al. 2008) to assess the uncertainty surrounding survey estimates of Biomass associated with both natural productivity and confidence in the survey technique. The uncertainty from each of these two sources are shown in a tabulation of the surveyed population estimate, with alternative natural rates of productivity (M) running down the table, and different possible stock sizes (and their probability given the data) running across the table. This classic decision table format allows management decisions to be made while explicitly addressing risks inherent in estimating a TAC based on a single fishery-independent survey (McGarvey et al. 2008, Mayfield et al. 2008).

McGarvey et al. used aerial photography and topographic maps to define an area of hard-bottom that had never been fished due to its location and the small size of the abalone. They systematically-placed transects in a bounded area and counted and measured emergent greenlip abalone within 1m each side of the transect, finding average density of 0.069 ab/m² (690 ab/ha). They used a two-level bootstrap algorithm to estimate the absolute abundance of abalone within the surveyed area, as well as the confidence intervals around that estimate. They tested the ability of this method to detect a change in abundance associated with fishing by conducting a controlled fish-down and re-surveying the area after fishing. The method showed that they were able to accurately estimate the change in abundance from survey: "The number of abalone removed by harvesters

(25,378) fell within a 50% CI, and well within a 95% CI, for the survey-predicted reduction in population of harvestable-sized abalone" (p. 1935, McGarvey et al. 2008). McGarvey et al. and Mayfield et al. (2008) demonstrated the use of this method in quota-setting by developing what they termed a Decision Table, which lists the estimated stock size at various probabilities, as well as the TAC associated with different fishing rates at each level of risk. A variation of this method is also being employed to assess stock recovery and to re-open the fishery after a disease outbreak in the Western Zone of the Victorian fishery (Mayfield et al. in prep).

Butterworth et al. (2009) recommended applying a similar approach to the abalone resource on the southwest of SMI, i.e. using the population estimate at 95% lower confidence interval to mitigate any risk associated with survey uncertainty. The implication of using the lower 95% confidence interval is that we can be 95% certain that the actual number of abalone in that area will be equal to or greater than that estimate. Thus we will be erring on the side of caution with regard to the Biomass inside the trial fishing area when multiplying by our estimate of productivity (M) in setting the TAC.

We have followed this suggestion to derive conservative estimates of the population in the southwest zone of SMI from the 2008 survey data (table 1). We also used the bootstrap approach followed by McGarvey et al. (2008) to estimate the 95 -70% confidence intervals, and used the lower 95% confidence interval in the TAC estimate per Butterworth et al.'s recommendation.

Bootstrapping involves the repeated random re-sampling of the data set of transect counts to derive multiple estimates of mean survey abundance, and then computing the variance within those newly created data sets. We randomly re-sampled the transect counts from the 2008 survey, with replacement, to propagate the variation in the observed transect counts through to the estimate of absolute abundance, regardless of the underlying distribution of the data points. We deviated slightly from the approach used by McGarvey et al. (2008) in that we treated the two reciprocal transects at each randomly chosen survey site as a single 60 x 4m quadrat rather than treating each of the two transects at each site as independent, because we found that paired transect counts are highly correlated. We sampled from these 60 x 4m abalone counts to create 10,000 new data sets, each a dataset that could have potentially been observed at SMI, and used these to calculate 10,000 potential mean density values. We then used this distribution of means to determine the risk probabilities and created a decision table for SMI (Table 1). Looking across the top two rows of Table 1 one can see the population estimates derived from the 95-70% confidence intervals. The top row contains the estimate of the total emergent population and the second row contains the estimates for the population > 203mm (or 8 inches).

Based on the distribution of transect observations, there is a 95% probability that the absolute abundance of emergent abalone in the southwest zone is equal to or greater than 320,220, and that 107,278 of those were >203mm in 2008.

F. Uncertainty Regarding Productivity (M) and Sustainable Rates of Harvest

The logic outlined above is that through management decisions the local risks created by the proposed trial fishery can be explicitly reduced. The uncertainty in the statistically estimated stock size has been estimated in Table 1. This raises the issue of what level of productivity (M) should be assumed. The AAG's meeting documents record their concern that overfishing will inadvertently occur because estimates of the productivity of the SMI abalone are imprecisely known. However there is a broad body of science about the natural mortality rate of abalone.

The influence of the assumption about M is displayed in Table 1 running down the rows 0.05 to 0.35, which may also be referred to in this document as a percentage (i.e. 5-35%). M is synonymous with the terms productivity, turnover rate, harvest fraction, and (by Butterworth et al. 2009) proportional-take. Running down a column in Table 1 shows the implication for the TAC calculation of what you assume about proportional-take.

Shepherd and Breen (1992) provide what is still the most thorough review of the international literature on the estimation of mortality rates for abalone, particularly with regards to studies of wild populations. They emphasize the variability in mortality rates observed between species, age, habitat, density and other environmental differences. Natural mortality rates decline with increased age/size before stabilizing at low levels in the emergent adult population. Shepherd and Breen (1992) attributed the variability between species to both latitudinal differences, with colder water having lower mortality rates, and differing assemblages of predatory species. They hypothesized that colder water species such as *H. kamtschatkana* and *H. iris* have lower adult mortality rates (0.1-0.2) while warmer water species such as *H. marae*, *H. corrugata*, *H. fulgens* and *H. laevigata* have higher adult mortality rates 0.25-0.35, with *H. rubra* being between those groups. Inconveniently they leave the red abalone *H. rufescens* from their list but one presumes from the various Californian studies that its mortality rate lies somewhere between these extremes.

Butterworth et al. (2009) were clear on their opinion about this topic: "Given such a relatively high age at first capture, this 10% proportional take is well below standard fishing mortality reference points." What they are referring to is equating the proportional take of 10% with an estimate of natural mortality (M) considered by science to be the lowest end (M=0.1) of the range of estimates in the literature (0.1-0.35) even though the red abalone is thought to be more productive than that. Of course local management strategies can be made even more precautionary by choosing a lower rate of harvest with which to set the TAC, and so explicitly assume even lower rates of natural turnover in the stock.

In this context it should again be remembered that under this proposal, supported by Butterworth et al. (2009), the TAC is for one year and harvest will only occur in the southwest zone of the SMI. The rest of the island would not be harvested. But stocks around SMI would continue to be monitored with surveys so changes in surveyed biomass

would change the following TAC. In this broader low-risk context it can be argued that very little additional adjustment for risk is needed in establishing the agreed upon harvest rate. This is undoubtedly the same logic Butterworth et al. (2009) used in coming to their recommendation that a 10% harvest rate would be conservative for the SMI population.

Applying Butterworth et al.'s (2009) suggestion of a 10% harvest rate of the lower 95% confidence estimate of the population in the southwest zone greater than 203mm, we recommend an initial TAC of 10,728 abalone (Table 1). In this manner we can use the uncertainty in the survey estimates to set a precautionary TAC, thus mitigating the risk of overestimating the population in the southwest zone to only 5% and using the lowest observed rate of natural mortality for any abalone species anywhere in the world.

Total Population In SOUTHWEST Zone	320,220	335,562	345,560	353,252	359,640	365,186
Population > 203mm	107,278	112,418	115,767	118,344	120,484	122,342
Harvest Fraction	95%	90%	85%	80%	75%	70%
0.05	5,364	5,621	5,788	5,917	6,024	6,117
0.1	10,728	11,242	11,577	11,834	12,048	12,234
0.15	16,092	16,863	17,365	17,752	18,073	18,351
0.2	21,456	22,484	23,153	23,669	24,097	24,468
0.25	26,819	28,104	28,942	29,586	30,121	30,586
0.3	32,183	33,725	34,730	35,503	36,145	36,703
0.35	37,547	39,346	40,518	41,420	42,169	42,820
0.4	42,911	44,967	46,307	47,338	48,194	48,937

Table 1. A Decision Table based on the 2008 SMI survey data showing how estimates of a sustainable TAC varies with increasing the level of uncertainty in the survey estimate; across the columns we are 95-70% certain that actual abundance is greater or equal to the survey estimate in that cell. The TAC estimate increases as the assumed productivity (M) increases down the rows. The top row contains total emergent population estimates for the southwest zone of SMI. In the second row are the estimates for the population >203mm or 8 inches. All subsequent rows are calculated using the >203 population.

IV. Risk Management and a Way Forward

Having reviewed the various sources of uncertainty and risk that have been raised in the discussions of the AAG with regard to setting a TAC for SMI we can see that several issues, namely disease and otter encroachment, must be principally managed in the broader state wide context with the other Californian stocks, and locally by using monitoring to ensure that fishing does not compound declines that might occur in the future due to disease or otter encroachment.

At the local scale, the risks associated with the trial fishery, i.e. Allee effect, model uncertainty and general lack of knowledge, can all be managed by allowing a closely monitored trial fishery on a small sub-section of SMI and setting a TAC for the trial fishery which ensures a low exploitation rate and high certainty based on the high quality recent survey data.

As Butterworth et al. (2009) concluded in Section IV. Risk Considerations and Computations:

7. [If the MVP value from the ARMP and interpreted by the AAG is used it] would effectively preclude re-opening an abalone fishery at SMI at present. However, initiation of an experimental fishery that (for example) is restricted to the Southwest Zone and taking only 5-10% of the population above 203 mm is a risk-averse alternative, and likely to be well within the level the resource could sustain.

Butterworth et al. (2009) also mapped out the way forward (Section V):

1. A program of experimental fishing should be considered for the Southwest Zone as an initial step in pursuing the options for removals. If specific sustainability criteria are met then this might subsequently be expanded in a stepwise post-moratorium process that is consistent with the Abalone Recovery and management Plan (CDFG 2005). An increased minimum legal size would provide additional resource protection without unduly reducing the available stock. For instance, if set to 203mm as tabled in the SMI survey report, the stock size would be 9-15% less than at the current minimum legal size of 197mm. A conservative risk-averse approach could be based on the 95% lower confidence level of the estimated abundance from the 2007 abundance survey. For instance, an experimental TAC of 8,300 red abalone would provide a viable harvest whilst leaving 90% of the available stock (to which recruitment would be added next year). Given such a relatively high age at first capture, this 10% proportional take is well below standard fishing mortality reference points."

2. The experimental harvest could be timed to occur during a defined period allowing for weather and market considerations. This would ensure that concerns regarding regulatory compliance could be more easily satisfied without undue costs."

3. The Southeast Zone should remain as an unfished control region that enables the detection of changes in abundance caused by environmental effects. This region could also be used as a source for brood-stock transplantation as per the option for a non-consumptive TAC."

4. If an experimental commercial harvest is implemented, then recreational stakeholders should be provided with equitable resource access without compromising the integrity of the experimental strategy"

A. Establish Assessment Framework and TAC Decision Rules

Furthermore Butterworth et al. (2009) laid out what should be the next steps (Section VII. Next Steps):

"If the approach outlined above for a possible way forward is taken further, there are certain prerequisites to implementation and permitting removal of abalone.

- 1. The details of a monitoring program must be specified and agreed to.*
- 2. A power analysis must be conducted to confirm that the monitoring will be able to detect effects of importance, in particular that of reduction in abundance as a result of removals.*
- 3. The statistical catch-at-age assessment methodology should be advanced in line with the advice given above, and used in projection mode to estimate the range of possible consequences for SMI abundance of any level of removals that comes under consideration"*

V. The Future Management System

Anticipating the need for these next steps the Executive Board of the CAA met at UCSB on 8 December 2008 with me (Prince), UCSB academics, and CDFG officials including John Ugoretz to develop a blueprint for a future management system that they could begin developing with help from UCSB.

The CAA had requested Joe Sullivan, who has experience the formation of Fishing Industry Co-operatives in Alaska for the purpose of fisheries management, to advise them on the way forward. The meeting considered a document he had prepared for them. Sullivan had outlined three components of Cooperative development as follows:

- A regulatory limited access program that defines the class of divers eligible to participate, and defines the key characteristics of their limited entry licenses – i.e., duration, transferability, etc.
- A regulatory framework for co-management – i.e., substantive definition of a cooperative's fishery management authority and its related performance standards, cooperative allocation eligibility criteria, and procedures for making an application for an allocation and making annual performance reports.
- A cooperative that has the institutional capacity to perform co-management responsibilities implying both capacity for the organization and technical feasibility in the data gathering, assessment, and management procedures.

The focus of the meeting was fleshing out the technical detail of the third component, and what follows builds on the recommendations developed during that meeting.

A. Recommended Process for SMI Abalone

1. Set a TAC with the Decision Table

Similar to the recommendations of Butterworth et al. (2009) the meeting agreed that the Decision Table approach as applied in South Australia by McGarvey et al. (2008) provided a solid risk averse means of establishing an initial TAC for the trial fishery. This document has followed the suggestions of Butterworth et al. (2009) to minimize the risk of over-fishing, and used the results of the 2008 survey to estimate a TAC of 10,728 red abalone (>203mm) from the southwest zone of SMI.

This Decision Table approach could be set into regulation and based on an annual or bi-annual survey used to annually set the TAC until an enhanced integrated approach to TAC setting based on modeling time series data is proven, accepted and incorporated into regulation.

2. MOU with Harvesting Cooperative.

Through consultation with recognized expertise in the field the CDFG should specify the standards to which the SMI resource is to be managed, and protocols for data collection and analyses, along with how they will be used to determine TACs. A Memorandum of Understanding (MOU) should then be developed with harvesting cooperative/s allowing for CDFG to agree to annual TAC's provided they are satisfied that the standards agreed under the MOU are being met by the harvesting cooperative/s.

3. Annual Surveys and Disease Testing

The meeting referenced above found that, at least initially, density and size data will need to be collected every year. In the long-term there will need to be some thought given to making the data collection process as cost effective as possible. In the medium- to long-term income from harvesting must be able to support the cost of operation including the annual survey event. This is a key issue faced by fisheries managers all over the world; how to efficiently survey catch and population changes over the broad spatial scales that many fisheries take place. The problem is compounded by the patchy nature of abalone, which results in high variances in fishery-independent surveys and makes statistical power to detect change that much harder to achieve.

A power analysis completed on the survey data from 2006 to 2008 shows that, with the current variance in the data, in order to detect a difference in means of 20% from year to year with 80% probability more than three times as many independent observations are needed. Abalone managers around the world have attempted to address this problem, and a number of papers have been written comparing different fishery-independent survey methods (McShane 1994, Tarr et al. 2000, Andrew et al. 1996, Gorfine et al. 1998, McGarvey et al. 2008). There has been much debate regarding fixed vs. systematic vs. random transects, how to choose survey regions, and stratification. A recent Australian research project (Mayfield et al. in prep) has been very successful in reducing the variance associated with abalone surveys using diver knowledge. With this approach divers have

used their knowledge to map the main concentrations of abalone on the fishing grounds, and these maps have been the basis for the first level of survey stratification, with sampling being concentrated within the nominated areas of high density, and a much lower level of sampling dispersed across the areas known to contain little biomass. Australian studies are also examining the use of GPS technology to track the search area of commercial divers and the early indications are that this technology may provide a reliable and cost effective means of tracking abundance as a function of catch per area swept, rather than the discredited index of catch per unit of diving time. These initiatives suggest there is considerable promise in the medium-term future for improving both the precision and cost effectiveness of monitoring abalone abundance in California.

4. Application of a Decision Tree and Meta Rules to Annual Set TACs

In the medium-term a specific "Decision Tree" should be developed for red abalone at SMI based on maintaining the surveyed density of the abalone and their size structure at target levels which will ensure high levels of breeding biomass are maintained. It should explicitly incorporate a conservative management approach of 50-70% of Spawning Potential Ratio (SPR), which is the proportion of spawning conserved in a fished population relative to the level of spawning expected if the population was left unfished.

Worldwide, fisheries biologists and managers are recommending that SPR targets of 30-50% should conserve fish stocks, so a target of 50-70% should build in a precautionary margin for environmental variability, poaching, and other extreme events that might increase rates of natural mortality. *Nota bene*: Shepherd and Brown (1993) who first raised the issue of the Allee's effect for abalone supported a local target SPR of 50%. With this type of target the SMI abalone population should be able to continue re-building even in a worst-case scenario. The Decision Tree would be used to assess the stock relative to the target level of SPR and revise the annual TAC upwards or downwards depending on whether the stock was above or below the spawning biomass target.

Having established an initial TAC for a trial fishery, provision should be made within that TAC to gather size structured samples so that the local relationships between length, width, height, weight and fecundity studies can be described and SPR models developed so that a Decision Tree can be conditioned on data from the southwest zone of SMI.

Special over-riding decision rules involving a cessation of fishing should also be incorporated into to the annual TAC setting process so that, in the event of a disease outbreak, or otter predation, fishing pressure does not exert additional pressure on the abalone stock within the trial fishery.

5. Structured and Controlled Annual Harvest

While regulations regarding harvesting might allow for harvesting to take place all year round, the harvesting cooperative will foster confidence in the fishery and make the processes of data collection and enforcement more cost-effective by developing and coordinating a structured, controlled annual harvest. In this way annual surveys and

harvests could be conducted within a short space of time, or several short harvesting sessions, which CDFG research and enforcement personnel could plan around. This approach will lead to greater transparency and cost efficiencies for the processes of stock and catch monitoring

During harvesting, fishery-dependent data will be collected by the fishermen using the Harvest Log created by the CAA. These logbooks collect the full range of fisheries data including dive positions, time and duration, catch in total number, size and weight. The GPS technology being deployed in the Australian fishery to document dive tracks will also be deployed and the size profile of the catch will be monitored.

6. Increased Size Limit

An increased 8 inch size limit is suggested on the basis that it would conserve higher levels of breeding potential in each aggregation by reducing the number of legal size abalone in each aggregation and so force divers to search a larger area to fill their individual catch targets. Shepherd and Partington (1995) documented how an increased size limit resulted in a larger aggregations being left after harvesting along with a larger average size amongst the remaining abalone.

The other rationale underlying this recommendation is that the recent Australian experience has shown that size of maturity varies markedly between populations, and many of the original scientific studies of size of maturity occurred in relatively sheltered locations and lees, which are characterized by their relatively small size of maturity. In time it may be found that the original legal size limit may not have been conservative for many of the main commercial abalone beds in southern California. In this case it would be precautionary to trial an increased size limit for the trial fishery at SMI. The abundance and size composition data from the surveys show that the suggested TAC will be easily filled with abalone above that size which will avoid excessive handling of abalone just below the measure.

7. Ocean Protection Council (OPC) Grant

The CAA with support from the CDFG should develop an application for OPC funding to support a University of California at Santa Barbara student who can:

- Provide technical support to develop the "Decision Tree" for SMI red abalone
- Develop modeling concepts
- Provide technical support for data gathering (including stereo video)
- Develop system for storing and using data

References

- Ault, J.S. and J.D. DeMartini. (1987). Movement and Dispersion of red abalone *Haliotis rufescens*, in Northern California. *Cal. Fish and Game* 73: 196-213
- Babcock, R., and J. Keesing. (1999). Fertilization biology of the abalone *Haliotis laevis*: laboratory and field studies. *Can. J. Fish. Aquat. Sci.* 56: 1668-1678
- Berkes, F., R. Mahon, P. McConney, R.C. Pollnac and R.S. Pomeroy. (2001). *Managing Small-Scale Fisheries*. International Development Research Centre, Ottawa.
- Breen, P.A. and B.E. Adkin. (1980). Spawning in a British Columbia population of northern abalone, *Haliotis kamtschatkana*. *The Veliger* 23: 177-179
- Butterworth, D., H. Gorfine, S. Schroeter and E Weber. (2009). Evaluation of the Red Abalone Stock Assessment by the Review Committee in the Support of Deliberations of the Abalone Advisory Group. La Jolla, California 17-18, February 2009
- Campbell, A. (2000). Review of northern abalone, *Haliotis kamtschatkana*, stock status in British Columbia. In Workshop on rebuilding abalone stocks in British Columbia. Edited by A. Campbell. *Can. Spec. Publ. Fish. Aquat. Sci.* 130: 41-50
- Cope, J.M. and A.E. Punt. (2009). Length-based reference points for data-limited situations: applications and restrictions. In Proceedings of the Californian Sea Grant Workshop on Managing Data-Poor Fisheries: Case studies, models and solutions. Berkeley 1-4 December 2008. pp. 30.
- Culley, M. and K. Sherman. (1985). The effect of substrate particulate size on the production of mucus in *Haliotis tuberculata* L. and the importance of this in a culture system. *Aquaculture* 47: 327-334
- Davis, G. E. (2000). Refugia-based strategies to restore and sustain abalone *Haliotis* spp. populations in southern California. In Workshop on rebuilding abalone stocks in British Columbia. Edited by A. Campbell. *Can. Spec. Publ. Fish. Aquat. Sci.* 130: 133-138
- Davis, G.D., P.L. Haaker and D.V. Richards. (1996). Status and trends of white abalone at the California Channel Islands. *Trans. Am. Fish. Soc.* 125: 42-48

- Dixon, C.D., H.K. Gorfine, R.A. Officer and M. Sporcic. (1998). Dispersal of tagged blacklip abalone, *Haliotis rubra*: Implications for stock assessment. *J. Shellfish Res.* 17: 881-887
- Dixon, C.D., R.W. Day, S.M.H. Huchette and S.A. Shepherd. (2006). Successful seeding of hatchery-produced juvenile greenlip abalone to restore wild stocks. *Fish. Res.* 78: 179-185
- He, X., M. Mangel and A. MacCall. (2006). A prior for steepness in stock recruitment relationships based on an evolutionary persistence principle. *Fish. Bull.* 104: 48-433
- Hesp, A., N. Lonergan, N. Hall, H. Kobryn, A.M. Hart, F.P. Fabris and J. Prince. (2008). Biomass and commercial catch estimates for abalone stocks in areas proposed as sanctuary zones for the Capes Marine Park. Western Australian Fisheries Department. Fisheries Research Report N. 170. pp 52.
- Hilborn, R., and C.J. Walters. (1992). *Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty*. (Chapman & Hall: New York)
- Jamieson, G.S. (2000). Marine protected areas and their relevance to abalone (*Haliotis kamtschatkana*) conservation in British Columbia. *In Workshop on rebuilding abalone stocks in British Columbia. Edited by A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci.* 130: 139-148
- Karpov, K.A., P. Haaker, D. Albin, I.K. Taniguchi and D. Kushner. (1998). The red abalone, *Haliotis rufescens*, in California: Importance of depth refuge to abalone management. *J. Shellfish Res.* 17: 863-870
- Karpov, K.A., P. Haaker, I. Taniguchi and L. Rogers-Bennett. (2000). Serial depletion and collapses of the California abalone (*Haliotis* spp.) fishery. *In Workshop on rebuilding abalone stocks in British Columbia. Edited by A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci.* 130: 11-24
- McGarvey, R., S. Mayfield, K. Byth, T. Saunders, R. Chick, B. Fourer, J.E. Feenstra, P. Preece and A. Jones. (2008). A diver survey design to estimate density, biomass, and spatial distribution. *Can. J. Fish. Aquat. Sci.* 65: 1931-1944
- Mayfield, S., R. McGarvey, I.J. Carlson and C. Dixon. (2008). Integrating commercial and research surveys to estimate the harvestable biomass, and establish a quota, for an "unexploited" abalone population. *ICES J. Mar. Sci. Avd. Acc.* 26: 1-9

- Mayfield, S., R. McGarvey, H.K. Gorfine, H. Peeters, P. Burch and S. Sharma. (2009). Biomass of blacklip abalone (*Haliotis rubra*) between Pt Fairy and the Craggs. In the Western Zone of the Victorian abalone fishery. SARDI Publication No. F2008/000958-1
- McShane, P.E. (1995). Recruitment variation in abalone: its importance to fishery management, *Mar. Freshwater Res.* 46: 555-570
- Officer, R.A., C.D. Dixon and H.K. Gorfine. (2001). Movement and re-aggregation of the blacklip abalone, *Haliotis rubra* Leach, after fishing. *J. Shellfish Res.* 20: 771-779
- Prince, J.D. (1989). The fisheries biology of the Tasmanian stocks of *Haliotis rubra*. PhD Thesis. University of Tasmania, Australia.
- Prince, J.D. (1992). Exploring the dynamics of abalone fisheries using a spatial model of an exploited stock of *Haliotis rubra*. In *Abalone of the world: biology, fisheries and culture*. Edited by Shepherd S.A., Tegner, M.J., Guzman del Proo, S.A. Blackwells, Oxford. 744 pp.
- Prince, J.D., T.L. Sellers, W.B. Ford, and S.R. Talbot. (1988). Recruitment, growth, mortality and population structure in a southern Australian population of *Haliotis rubra* (genus *Haliotis* ; Mollusca : Gastropoda). *Mar. Biol.* 100: 75-82
- Prince, J.D., C. Walters, R. Ruiz-Avila and P. Sluczanowski. (1998). Territorial user's rights in the Australian abalone fishery. In *Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management*. Edited by G.S. Jamieson and A. Campbell. *Can. Spec. Publ. Fish. Aquat. Sci.* 125: 367-375
- Shepherd, S.A. and P.A. Breen. (1992). Mortality in abalone: its estimation, variability and causes. In *Abalone of the world: biology, fisheries and culture*. Edited by Shepherd S.A., Tegner, M.J., Guzman del Proo, S.A. Blackwells, Oxford. 744 pp.
- Shepherd, S. A. and L. D. Brown. (1993). What is an abalone stock: Implications for the Role of Refugia in Conservation. *Can. J. Fish. Aquat. Sci.* 50: 2001-2009
- Shepherd, S. A. (1986a) Studies on Southern Australian abalone (genus *Haliotis*) VII. Aggregative behaviour of *H. laevigata* in relation to spawning. *Mar. Biol.* 90: 231-236
- Shepherd, S. A. (1986b). Movement of the southern Australian abalone *Haliotis laevigata* in relation to crevice abundance. *Aust. J. Ecol.* 11: 295-302

- Shepherd, S. A. and D. Partington. (1995). Studies on Southern Australian abalone (genus *Haliotis*) XVI. Recruitment, habitat and stock relations. *Mar. Freshwater Res.* 46: 669-80
- Stekoll, M.S. and T.C. Shirley. (1993). *In situ* spawning behavior of an Alaskan population of Pinto abalone, *Haliotis kamtschatkana* Jones, 1845. *The Veliger* 36: 95-97
- Tarr, R.J.Q. (1995). Growth and movement of the South African abalone *Haliotis midae*: A reassessment. *Mar. Freshwater Res.* 46: 583-590
- Tegner, M.J., P.A. Breen and C.E. Lennert. (1989). Population biology of red abalone, *Haliotis rufescens*, in Southern California and management of the red and pink, *H. corrugata*, abalone fisheries. California Department of Fish and Game. *Fish Bull.* 87: 313-339
- Tegner, M.J., L.V. Basch and P.K. Dayton. (1996). Near extinction of an exploited marine invertebrate. *Trends Ecol. Evol.* 11: 278-280
- Tegner, M.J. (2000). Abalone (*Haliotis* spp.) enhancement in California: what we've learned and where we go from here. *In* Workshop on rebuilding abalone stocks in British Columbia, *Edited by* A. Campbell. *Can. Spec. Publ. Fish. Aquat. Sci.* 130:61-71
- Withler, R.E. (2000). Genetic tools for identification and conservation of exploited abalone (*Haliotis* spp.) species. *In* Workshop on rebuilding abalone stocks in British Columbia. *Edited by* A. Campbell. *Can. Spec. Publ. Fish. Aquat. Sci.* 130: 101-110