# Appendix H: Technical Panel's Final Report "*Developing a Total Allowable Catch framework for Red Abalone at San Miguel Island*"

# Developing a Total Allowable Catch Framework for Red Abalone at San Miguel Island

## Final Report of the Technical Panel

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## 1.0 Background and Charge to the Technical Panel:

In 2006, the California Fish and Game Commission (CFGC) directed the Abalone Advisory Group (AAG) to develop an objective assessment of the red abalone (*Haliotis rufescens*) population that inhabits San Miguel Island in the Channel Islands off the southern California coast. Specifically, the charge was to assess the broad impacts to the population associated with a potential fishery and explore potential total allowable catch, (TAC) options. In this context, the AAG, along with California Department of Fish and Game (CDFG) identified a formal Technical Panel (TP) that was charged with coordinating the overall assessment effort, including appointment of a lead analyst. The TP served as a working panel for deliberations concerning sources of data, modeling approaches, future analysis considerations, and finally, critical factors associated with both this species' biology, as well as management concerns. This report presents the findings, methods and results of the analytical work to date and identifies additional factors that must be considered if fishing at any level is deemed appropriate for this population. In the report the TP also responds to the peer review held in Feb. 2009 in La Jolla, California.

## 2.0 Structuring a Total Allowable Catch Framework:

The level of a TAC will be a qualitative decision that will ideally be informed by quantitative models, population surveys, abalone population dynamics, and AAG, TP and Review Committee input. Decisions will need to be made combining quantitative and qualitative information and what is in the best interests of the abalone population and the public. Two decisions that need to be made are 1) when and if to reopen the fishery and 2) how many abalone to take.

The Technical Panel after reviewing the analyses and modeling work that has taken place is recommending a precautionary approach. This is due in part to the fact that this fishery is currently under a moratorium and there are no harvest control rules in place. Furthermore, the life history of the species in the region and this genus worldwide suggests abalone may not be able to withstand intense fishing pressure as many populations have collapsed. The Technical Panel further recommends that a number of issues be worked on prior to the opening of a potential fishery at San Miguel Island. The TP strongly recommends that the AAG and CDFG discuss and reach consensus on biological reference points that can be used to trigger management actions whether they be density estimates from survey data or other BRP. If they are density estimates or changes in density, then power analyses will need to be explored to determine the effect size that can be detected with the existing (or expanded) red abalone surveys conducted at SMI. Preliminary power analyses indicate that, with an increased level of sampling, surveys could detect 30-50% changes in density. This level of power would not allow for management responses until 30-50% of the fished population has declined, suggesting management would not be responsive to smaller changes in density using this approach.

The Technical Panel would like to emphasize the value and use of fishery models for TAC determination, evaluation and analysis of risk. In this light, we see a number of options. Statistical Catch at Age/size (SCA) models may be useful in this regard as a management tool. While SCA methods have drawbacks particularly when trying to estimate abundance from a closed fishery, we view this approach as useful for a Risk Analysis approach. A number of potential revisions of the SCA model have been suggested and need to be implemented (see section 4.0). With this refined SCA model, we can examine the potential impact of proposed TAC levels and size limits on the continued growth of the population. (see section 2.1 for more details)

Another option for the future would be using per recruit models as one way to examine size limits, Marine Protected Areas and F values. Implementing a MPA and increasing the minimum legal size from 178mm both increased the % of egg production maintain relative to base models in a previous deterministic red abalone egg per recruit model (Leaf et al. 2008). In this case, we also recommend exploring the use of a stochastic egg per recruit approach to encompass important year to year variation in vital rates such as reproduction and growth. In previous egg per recruit models of the southern California fishery, maintenance of 48% of the egg production failed to maintain a sustainable fishery (Tegner et al. 1989). This metric can be useful in the development of Biological Reference Points (BRP) using this method for fishery management. One drawback to using this approach alone is the egg per recruit models will not give information on total abundance.

Finally, we would like to emphasize the use of a risk analysis being conducted prior to the opening of a fishery for this species. In this case, proposals for how many abalone can be taken (TAC) can be simulated using different fishing mortality rates (specifically F=0.1, 0.05, 0.02 and 0) to examine short and long term sustainability given different types of stock recruitment relationships in a formal risk analysis framework.

**2.1 Risk Analysis Within the TAC Framework**

Both the TP and the Review Committee recommend a formal risk analysis for examining the tradeoffs associated with different TAC levels and size limits. Formal risk assessment using different fishing rates (or TACs) can be conducted using a Monte Carlo simulation study. In this way the TP, AAG and FG Commission will be able to visualize the various risks associated with the decisions they will be making. The recent San Miguel Island survey data in 2006, 2007 and 2008 can be used as Bayesian priors. In Bayesian probability calculus, the probability of a hypothesis given the data (the *posterior*) is proportional to the product of the likelihood times the prior probability. Age and length data from the surveys will be used to structure the SCA model. A revised

SCA model is needed to estimate the historic levels of stock and recruitment as well as current stock structure and their uncertainties. Multiple stock recruitment relationships can be investigated given the high degree of uncertainty in this relationship for red abalone (Jiao et al. 2009) and its influence on the population projections. The estimated age/size structure determined for the population during the 2008 fishery independent surveys in combination with various stock/recruitment relationships models can be used to start the projections. We recommend examining both short (1-5 year) and long term projections (10+ years) knowing that the uncertainty levels for the long term projections will be greater than those for the short term projections. We recommend certain variables be programmed such that they can be manipulated to look at changes in risk with different parameter values such as the TAC and the size limit. The TP strongly recommends conducting this risk analysis using the TAC and size limits being considered for any fishery prior to the start of removals. Relocation programs while they do involve removals allow for the return of the animals if their removal leads to an undesirable drop in abundance or recruitment.

Levels of acceptable risk are another qualitative decision ideally based on information from multiple sources including modeling results. There has been some progress made in quantifying terms such as critically endangered and vulnerable into probabilities of extinction. Clearly we would like the population at SMI to remain well above the World Conservation Union's Red List Criteria for species which suggests that vulnerable species are those in which there is a >10% chance of extinction in 100 years. These guidelines may be helpful in determining a lower threshold when examining the results of risk analysis projections.

**2.2 Additional TAC Considerations**

The Technical Panel with input from the Review Committee would like to highlight a number of critical issues that will impact the development of a TAC:

- **Minimum Viable Population Size** – Minimum viable population size is a minimum value below which recruitment and populations decline. Information on abalone densities from southern California (Tegner et al. 1989), Washington State (Rothaus et al. 2008) and Australia (Shepherd and Brown 1993) suggest that populations below 500-3,000/Ha are susceptible to population collapse and recruitment failure.
- **Replacement Densities** – Replacement densities, the number of abalone needed to replace those dying from natural mortality >203mm), can be estimated knowing the number of sublegal abalone, growth rates and natural mortality rates. In the SW zone at SMI, the number of abalone needed to replace those dying of natural mortality (68/Ha.) exceeds the number available (34/Ha.) and the population is projected to decline in the absence of fishing.

- **Recruitment Monitoring** – Recruitment monitoring is needed to explore the population dynamics of the stocks and determine the excess individuals available to a fishery. The nature of the relationship between recruitment levels and stock size is needed for fishery models such as catch at age models. Recruitment collapse is one potential BRP that could be used to halt fishing.
- **Experimental Fishery** – Experimental fisheries can be used to explore the sustainability of fishing practices on real populations. Experimental fisheries management can be adaptive using information gained from monitoring programs and fishery models to modify fishing regulations.
- **Monitoring Program and Sampling Power** – Monitoring programs designed to provide feedback for experimental fisheries are limited by their ability to detect specific effect sizes. In this case, 130 transects are need in the SW zone to detect a change in density of 30%. This sampling effort would need to increase to 300 transects to detect a smaller effect size of 20% change in density.
- **Enforcement** – Wildlife protection costs for enforcing fishery regulations (size limits, season closures etc.) as well as preventing illegal commercialization needs to be considered. In addition the remote location and need for enforcement of the MPA will need to be considered in this potential fishery.
- **Population Genetics** – Genetics work for red abalone at SMI and elsewhere in California is currently underway. Preliminary results suggest that SMI is 98% self-recruiting and that it may be a source population for neighboring islands.
- **Disease** – The abalone disease Withering Syndrome is endemic to southern California waters. Disease surveys indicate that 58% of the population (12% heavy infection) on the island tested positive for the bacteria which causes WS when abalone are stressed with warm water. In the lab, 64% of SMI abalone died when exposed to warm water mimicking the 1997-98 El Nino event. Furthermore, egg and sperm production was drastically reduced in the survivors with 80% of the females and 88% of the males lacking gametes.
- **Marine Protected Areas (MPA)** – MPAs may function to protect a portion of the population from fishing. In the SW zone at SMI there is the Judith Rock MPA where no fishing is permitted. This region may act as a refuge for legal size abalone. Abalone in the MPA will be subtracted from the TAC.
- **Allee Effects –** Populations at low density can suffer from Allee Effects where population declines occur faster as populations size get smaller due to reduced reproductive success at low densities. Abalone may need sufficient numbers of males and females in close proximity for successful fertilization of gametes once they are spawned into the water.

- **Spatial Recovery** – One of the key provisions within the ARMP is the recovery of multiple areas of historic occupancy for abalone. Recovery Criteria 2 and 3 state the goal is for recovery in multiple areas with densities above MVP. Key locations were identified for red abalone at SMI, SRI, SCI and in the San Diego Area as well as in central California.
- **Historic Baselines** – Baseline abundances of abalone in southern California exceeded those in northern California (Rogers-Bennett et al. 2002). Today densities in central and southern California are extremely low except on the south side of San Miguel Island (approx 13 miles of coastline).
- **SMI Fishery Revenues** – Projected revenues from the SMI fishery based on a TAC of 6700 range from $40,200 to 67,000 if landing taxes range from $6 to $10 per abalone.

### 3.0 Improving the Stock Assessment of Red Abalone at San Miguel Island

The TP's lead modeler Dr. Yan Jiao worked with the TP to evaluate a number of classical fishery models for their use with a potential red abalone fishery at San Miguel Island. For more detailed information refer to Dr. Jiao's Final Report "Improving the Stock Assessment of California Red Abalone (*Haliotis rufescens*) in San Miguel Island" dated Jan. 2009.

#### 3.1 Methods

Available red abalone data were coalesced from various sources, filtered, summarized into appropriate time series and finally, used in classical stock assessment models to evaluate potential BRPs. BRPs are fishery resource indicators corresponding to a particular biological state (ie. fishery BRPs are: $F_{0.1}$ ; $F_{max}$ ; $F_{MSY}$ ; $F_{x\%}$) that can be used to guide potential fishery management recommendations. In 2006 and 2007 extensive subtidal population surveys at San Miguel Island were conducted by the California Department of Fish and Game (Department), the former commercial abalone industry, partners and volunteers. Site specific data were also collected by the Department to estimate red abalone reproduction and assess disease status of the existing stock. A single laboratory temperature experiment to assess the potential for future disease impacts was also conducted. These data and other data were used in yield per recruitment, egg per recruitment and catch at age/size fishery models.

Potential fishing levels (e.g., a TAC) were evaluated across a suite of typical BRPs used in fisheries in conjunction with population abundance estimates generated from the dive-based surveys. Both yield- (YPR) and eggs-per-recruit (EPR) analysis was conducted to examine potential BRPs that would be considered sustainable (over the long-term); however, given the relatively low productivity of this species (in general), recruitment overfishing concerns (say EPR calculations) were necessarily emphasized over growth overfishing considerations (i.e., YPR considerations). The risk of population decline is assessed based on alternative fishing schemes that are projected forward in time. Also, a surplus production model (age-aggregated state-space approach) was developed earlier in the modeling effort, but was omitted from the suite presented here, given inherent difficulties in estimating critical biological attributes associated with this method, (e.g. starting biomass, intrinsic rate of increase, temporal variation in growth, and maximum sustainable yield (MSY) statistics). That is, model results were very sensitive to even small parameterization changes and thus, general consensus maintained that robustness in the overall analyses was best achieved using the age-structured approaches that follow.

Growth is considered a highly influential parameter in stock assessment models, particularly, in the case of long-lived, sedentary species, such as abalone. Thus, a hierarchical von Bertalanffy growth model, based on an extensive tag recapture study, was employed to examine variability in growth of this species across time. The growth model examinations indicated relatively strong annual (or over a series of years) variation in growth, likely due in part to slower growth exhibited during (warm water) *El Niño* events. Uncertainty in growth was captured via sensitivity analysis conducted in the per-recruit and catch-at-age modeling approaches.

### 3.2 Results:

Two classes of models were examined to explore the feasibility of determining BRPs for management: 1) per recruit and 2) catch at age. Using the yield per recruit model, expected yields are calculated given various fishing scenarios over the life span of the abalone. Results from the yield per recruit model had a mean of 1.53 with relatively little variation around the mean (CI 90%) using a range of natural mortality estimates (M=0.11-0.23) and a fishing mortality rate of F=0.1. This result is due primarily to the low maximum length ($L_\infty$) value from the growth model. The other potential BRP, maximum fishing mortality ($F_{max}$), has similar yield per recruit and variation but is considerably larger than F=0.1 and so is not recommended. F=0.1 is much higher than the estimated historic fishing mortality rate, but see Review Committee's recommendations. In general these results suggested BRPs derived from the yield per recruit models were more stable and precise compared with BRPs from egg per recruit models. A range of TAC options are presented.

**TAC Option 1:** The BRP derived from the yield per recruit model F=0.1 is combined with the 2007 population survey results. For the model, a size at entry to the fishery of 197mm (former commercial legal size), the probability of fishing mortality $F>F_{BRP}$=30% and the population survey results (308,000 red abalone >197mm) to get a TAC of 174,510 red abalone per year. However, we find a 100% chance that the population will decline in the next year given this TAC. Furthermore, per recruitment models assume constant recruitment, which is not true for abalone, which have highly variable recruitment success.

**TAC Options 2-4:** Results from the statistical catch at age model yield a TAC of 22,990 given the BRP used is fishing mortality at maximum sustainable yield and a size at entry to the fishery of 197mm. In this model, a proxy for fishing mortality, $F_{msy}$, of 0.15 is used rather than the wide range of estimates derived by combining the yield per recruit and the stock recruit models (Shepherd 1982). Since spawning stock size is difficult to estimate and there is a weak relationship between stock size (number of adults) and recruitment (number of juveniles), BRPs derived from this method are not recommended for management.

In cases such as this, Patterson (1992) recommends using empirical reference points, such as the natural mortality rate as a proxy for $F_{msy}$, which in this case yields a third TAC estimate of 11,120 abalone per year. Similarly, this model shows a 100% chance that the population will decline in the next year given this TAC option. If we lower the TAC to zero as an alternative TAC option, we still find a 100% chance that the model population will decline in the next year given no fishing.

### 3.3 Discussion:

Regardless of the TAC option selected, including the no fishing option, there is a high probability of the model population declining in the next year. This result comes from the catch at age/size model in which the number of abalone at one year (and one age) is estimated from the previous year adding recruitment, and subtracting mortality (natural and fishing). Abalone abundance fluctuates widely between years in the catch at age model due to a few strong recruitment events. Irregular recruitment is a feature of the biology of this species. Recruitment to the population was estimated directly each year in this model since there is a weak relationship between the number of new recruits and the stock size.

Uncertainty in the abundance data from the catch at age model results were tested using sensitivity analyses. Four different weighting scenarios were examined weighting the 4 sources of input data differently. Those weightings which enhanced the contribution of the more reliable catch and length frequency data in the model had more robust abundance results compared with other weighting scenarios emphasizing relative abundance indexes. The results from this model show that the population is declining due to fewer new recruits entering the population than the number of abalone leaving the population through natural mortality. This indicates there are no excess individuals in the model population available to a fishery. Current red abalone stock size at San Miguel Island is now low compared with historic levels (see catch data).

## 4.0 TP Response to the Review Committee's Report:

The Review Committee met in Feb. 2009 and made suggestions as to future modeling directions, when to open a fishery, and how many abalone could be safely fished. These were qualitative decisions made after viewing quantitative information. The Review Committee suggested that the fishery could be opened in parallel to a number of other issues being sorted out. By contrast, the TP's recommendation is to conduct additional work such as the risk analysis exploring how many abalone to take as well as think through additional TAC considerations prior to opening of the fishery. The Review Committee had more confidence in the 2006-2008 SMI surveys than the other fishery independent surveys a view also shared by the TP. The Review Committee went one step further and advocated dropping the use of all other survey data in future modeling work. The Review Committee also advocated taking an experimental fishery approach. They offer as a suggestion a fishing mortality rate of 10% in the SW zone only working with the lower 95% confidence interval of the population estimate. Using the revised population estimate this would go from 8300 red abalone in the Review Committee's document to 6700 abalone. The TP favors a risk assessment approach in evaluating a range of fishing options including the 10% recommendation by the Review Committee as well as a range of more conservative fishing mortality rates (5,2,1 and 0%). The TP would like to see a quantitative rationale for the level of fishing (10%) and size limits (203mm) proposed by the Review Committee prior to the opening of the fishery. Quantitative approaches for assessing fishing levels and size limits for red abalone have been demonstrated previously (Rogers-Bennett and Leaf 2006, Leaf et al 2008).

The TP suggests more conservative fishing strategies at the start of the fishery are warranted due to the following 1) fishery coming out of a moratorium, 2) new work examining the potential productivity of the population through estimates of replacement densities, which suggests there is little if any surplus resource available for fishing at SMI.

The reviewers also bring up a number of issues with respect to analyses that have been conducted, red abalone management and a potential fishery at San Miguel Island (see report from Review Committee Feb. 2009 for full text). The reviewers suggest moving ahead with a Risk Analysis using the SCA and provide the following suggestions.

Suggested Revisions to the SCA Model

- Double check historic catch data to examine downward trend in landings prior to fishery closure in 1997
- Explore the use of a flexible functional form to model selectivity
- Focus on 2006-2008 survey data rather than additional fishery independent survey information
- Explore use of a multinomial with the observed number of abalone as a way to scale the likelihood for proportions at length as these data are not independent due to the long life of red abalone
- Explore options such as shrinkage to the mean of estimates of more recent year class success as this is being fit as a stock-recruitment relationship within the SCA model.

Suggestions for Future Risk Assessment Modeling

- Evaluate risk over short and long time (>20 years) frames.
- Use fixed fishing levels and then in the future it is possible to explore fishing with feedback controls
- Year class strength projections can be explored sampling from lognormal distributions with mean, variance and first order

autocorrelations determined from the previous 20 years or from other abalone resources
- BRPs can be explored using this risk framework by projecting the SCA model forward until the age/size structure stabilizes

We wish to thank the reviewers for their review, expertise and time.

**5.0 Discussion of TAC Considerations:**

Here we address some of the major issues discussed within the TP and the Review Committee in more detail.

**5.1 Minimum Viable Population Size (MVP):**

There have been a number of deliberations both within this process, within the Abalone Recovery and Management Plan as well as outside of California on the topic of MVP size for abalone. While there is no definitive number for MVP we argue that there are clear thresholds that, when crossed, have lead to stock collapse in a number of abalone fisheries worldwide. These threshold (non-linear) responses to population declines can come about due to a lack of fertilization success at low population densities. This is one type of Allee Effect in which animals at low population densities have poorer reproductive success than their population numbers otherwise indicate. Allee effects have been formally incorporated into population models in which increases in mortality due to fishing can drive populations to extinction when interacting with critical Allee thresholds (Gascoigne and Lipcius 2004).

In free spawning marine invertebrates Allee Effects can come about when adults are too far apart such that eggs are not fertilized during spawning. Fieldwork with abalone indicates that males and females need to be less than 2.5 m apart for successful fertilization (Babcock and Keesing 1999). Spacing between individuals increases as population density decreases (see figure 1 below for our work on aggregation size and nearest neighbor distances for red abalone at sites with varying densities including SMI) potentially negatively impacting fertilization success.

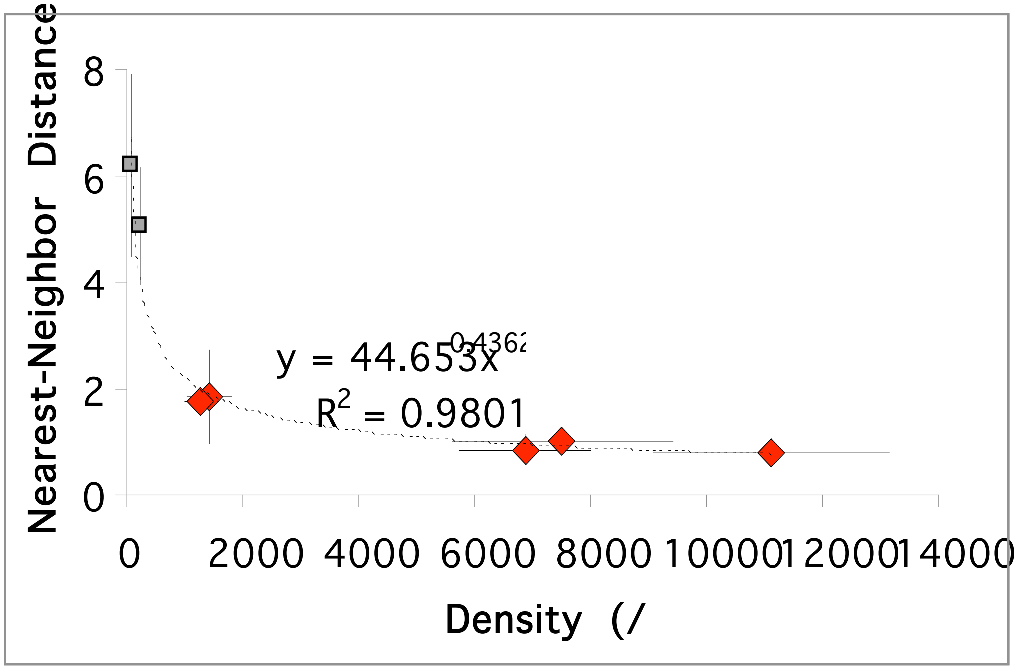


Figure 1. Density of abalone as measured along transects compared with the distance between a randomly selected abalone and its nearest neighbor. Red diamonds are data from red abalone populations and grey squares are for pink abalone population near San Diego. San Miguel Island and Hopkins near Monterey have comparable nearest neighbor distances, just under 2 m. (Button and Rogers-Bennett in prep)

In southern California, Tegner et al. (1989) found that densities at Johnson's Lee showed no declines from 1978-1982 and averaged 632/ Ha. By 1993 however, densities at this location had decreased 10 fold and were down to 60/Ha (Haaker and Karpov unpubl data). Fishing continued at this island until the close of the fishery in 1997. At Santa Cruz Island, densities declined from 440/Ha. to nearly zero from 1983 to1996 while fishery landings were low from 1987 to the present.

Shepherd and Brown (1993) found that recruitment started to decline when densities fell below 3,000 ab/Ha and that populations of adults collapsed when adult densities fell below 1,000 ab/Ha. In Washington State, densities of northern abalone in 1992 at 10 sites ranged from 500 to 3200/Ha. and have declined steadily since then such that in 2006 all sites are now below 1,000/Ha. (Rothaus et al. 2008). Furthermore, the absence of juvenile abalone at these sites suggests recruitment failure (a non-viable population). Northern abalone were surveyed at Point Arena in northern California in 1971-2 and were found to be at 324/Ha.. Modern surveys show northern abalone have declined in the region to very low densities ranging from 0-95/Ha. at 8 sites in 2005-7.

One exception to this MVP size estimate of 2000/Ha. appears to be found in central California. Red abalone densities were determined inside a marine reserve where abalone populations are restricted to deep crevice habitat by sea otter predation. These abalone appear to have persisted for 30 years at densities averaging 1800/ Ha. (Micheli et al. 2008). In this unique habitat abalone are restricted to deep crevice habitat where they are in close proximity to one another. This short nearest neighbor distance may facilitate fertilization success even at low overall densities.

We suggest that while there may be some unique cases where abalone at less than 2,000/Ha. are viable and reproducing (e.g. in close aggregations in Monterey) there are more examples where once abalone drop below this threshold populations are at risk of recruitment failure and may not be able to support a fishery. Abalone in the SW zone at San Miguel Island in 2006 and 2007 were estimated to be at 1600/Ha. and 1,400/Ha. respectively while overall densities at the island were lower.

**5.2 Revised Population Estimates:**

The Review Committee endorsed the recommendation of AAG/TP member John Butler that the department of Fish and Game divide habitat into suitable and unsuitable (sandy) areas to further stratify sampling to improve the current population estimates prior to the opening of a potential fishery. Given that a portion of the habitat will be taken away from the estimates (unsuitable portion), this will lead to smaller area and smaller but more accurate population estimates.

The 2007 survey incorporated collection of more explicit habitat information for each abalone encountered along the transect. No formal habitat survey (independent of the abalone survey) was conducted, however a more refined estimate of substrate type can be gleaned from these transect data. Substrate type and relief was recorded for each abalone observed on the transects. Results show that all abalone were either on reef or boulder substrate (Table 11 SMI red abalone survey report 2007). Thus, the overall percentage of reef and boulder substrates can be combined for each zone and used to determine the proportion of the overall kelp coverage area that is appropriate abalone habitat. The population estimates could then be calculated based on this more refined area estimate. This is appropriate as the surveys were focused on abalone habitat. The 2007 survey revised population estimates are shown in Tables 1 and 2 using the refined habitat description.

Table 1. Abalone population estimates using reef/boulder portion of maximum kelp area and mean density.

| Zone | Percentage of Reef/Boulder | Abalone Habitat {Max. Kelp ($m^2$) X Reef/Bould. %} | Mean Estimate | Abalone ≥ 178 mm (7 in.) | Abalone ≥ 197 mm (7.75 in.) | Abalone ≥ 203 mm (8 in.) |
|---|---|---|---|---|---|---|
| Northwest | 81% | 4,381,485 | 44,000 | 12,000 | 4,000 | 2,000 |
| Southeast | 83% | 2,299,321 | 299,000 | 201,000 | 104,000 | 71,000 |
| Southwest (excludes Judith Rock SMR) | 79% | 1,810,010 | 272,000 | 196,000 | 121,000 | 91,000 |
| Grand Total | | 8,490,816 | 615,000 | 319,000 | 229,000 | 164,000 |

Table 2. Abalone population estimates using a calculated proportion of maximum kelp area and 95% lower confidence limits density.

| Zone | Percentage of Reef/Boulder | Abalone Habitat {Max. Kelp ($m^2$) X Reef/Bould. %} | 95% Lower Limit Estimate | Abalone ≥ 178 mm (7 in.) | Abalone ≥ 197 mm (7.75 in.) | Abalone ≥ 203 mm (8 in.) |
|---|---|---|---|---|---|---|
| Northwest | 81% | 4,381,485 | 22,000 | 6,000 | 2,000 | 1,000 |
| Southeast | 83% | 2,299,321 | 176,000 | 118,000 | 61,000 | 42,000 |
| Southwest (excludes Judith Rock SMR) | 79% | 1,810,010 | 200,000 | 144,000 | 89,000 | 67,000 |
| Grand Total | | 8,490,816 | 398,000 | 268,000 | 152,000 | 110,000 |

The revised population estimates are more accurate than the estimates presented in the San Miguel Island red abalone survey report from 2007 in Tables 5 and 6.

Future population estimates could include habitat survey information. Habitat estimates can be derived from surveys of random points located within the kelp beds inside each of the zones at San Miguel Island. Once data from these random points are collected, the proportion that is rocky reef and boulder can be determined and the number of abalone on boulder and reef habitat can be used to generate improved population estimates. These habitat estimates could be used with the data already collected in 2006-2008. Unfortunately, habitat surveys conducted using side-scan sonar are generally not conducted in shallow kelp areas so data from this technology may not exist for shallow kelp beds around SMI.

Another strategy to improve the population estimates in the future, if habitat surveys are not feasible, would be to modify the transect protocols to survey within all the habitat types under the kelp beds. This would entail conducting all survey transects along the predetermined randomly selected compass heading rather than divers adjusting headings on site to stay on rocky habitat. This method would include surveying substrates that are known not to support abalone. This option would be less desirable than accurate estimates of habitat types in the kelp beds but would be required if habitat estimates are not available.

**5.3 Selectivity:**

The issue of selectivity has come up in both the TP and Review Committee deliberations. Initially, the TP tackled this issue using a step function with 100mm as the cut off for selectivity in the SCA model. Researchers with extensive field experience felt confident that abalone, once they turn 100mm in size, are equally as likely to be picked up in surveys as all other sizes greater than 100mm while below this size abalone may be more cryptic, especially in the 10-50mm size classes. Prior to the review Dr. Jiao prepared a logistic function centered around 100mm rather than a step function to evaluate selectivity. The use of this more flexible function did not substantially change the results of the SCA model. The Review Committee pointed out the importance of this parameter in model results and suggested a number of different selectivity functions be explored in a sensitivity analysis. This approach, exploring a number of potential options for selectivity, is recommended.

**5.4 Growth and Mortality Estimates:**

Growth estimates for the stock assessment and other analyses have been completed using the best available growth data. These are data from 1978-1983 study at Johnson's Lee on the south side of Santa Rosa Island. These tag recapture data are quite extensive, including more than 1,000 recoveries and abalone ranging in size from approximately 50 to 220mm. These data also span good and poor growth years encompassing an El Niño event.

Reviewers bring up the point that this site was fished during the years of the tag recapture study. To our knowledge there were no unfished sites in the region for tag recapture work to have been conducted and no other tag recapture data to use. Therefore, these data will need to be examined in light of the probability that larger individuals greater than the former minimum legal commercial size (197mm) may be less abundant in the data set than there would have been if no fishing were occurring. In fact, there are few recoveries of red abalone from this data set greater than 203mm. The impact of fewer large red abalone is that the von Bertalanffy growth estimate k derived from this data set would be greater than that from a data set with more large slow growing adults. This suggests a potential bias in the growth rates (faster than usual growth). Few large adults would impact the estimated size of L inf, making it smaller than if there had been more large adults. Abalone in this recapture study would grow faster and hit a smaller maximum size sooner than if there were more large adults in the study. These results on K and L inf can be seen with artificial data sets in which the numbers of large adults are removed mimicking fishing. Faster growth rate estimates could lead to bias toward more liberal fishing recommendations but would not lead to more conservative recommendations.

There are a number of methods that can be used to address limited sample sizes of particular size classes for growth data. (1) These types of problems are encountered frequently for rare species and semi-empirical methods have been developed to better estimate growth in regions of the growth curve where data are sparse; for example white abalone (Rogers-Bennett and Rogers 2006). (2) Growth rates from red abalone in other regions may also be examined for their usefulness. Estimates of growth rates exist from a non-fished site in northern California using data from a tag recapture study. These growth estimates are not influenced by fishing since large adults are present in the data set. (3) Finally, estimates of L inf can be made from the largest abalone in the population rather than the von Bertalanffy estimate and this has been done in published work elsewhere when estimate of L inf from tag recapture data have been unsatisfactory. Examples of unsatisfactory L inf values include values where the L inf is smaller than the legal size as this is not a useful outcome. Therefore, we agree with the reviewers that there are a number of tools that we can use to further examine this issue and methods to explore a variety of potential growth rate estimates; however, using the data from Johnson's Lee with its potential bias would not lead to more conservative fishing policies.

**5.5 Recruitment Data:**

**5.5.1 Replacement Densities:**

The density of new recruits to the fishery can be estimated from survey results and individual growth rates as has been done for northern abalone in British Columbia (Breen 1986). Using this method, the density of abalone that are newly recruited to the fishery in one year (now at legal size) are estimated and compared with the number that would die from natural mortality. The population is assumed to be at equilibrium. In this case, we use the legal size class of 203mm. We use density data from the 2006 survey at each of the three zones NW, SE and SW. We assume a natural mortality rate of M=0.15 as has been done throughout this stock assessment. We find from the tag and recapture data at Johnson's Lee that 23% of the 197-202 size class will grow into the 203 + size class in one year. Therefore, 23% of the 197-202 size class are available to replace the legal size abalone dying of natural mortality in the year. With no fishing, the density of new recruits (Rd) required to replace individuals dying of natural mortality would be:

$$Rd = D\,(1-\exp(-M))$$

Where D is the density of legal size adults and M is natural mortality.

Using the density values of legal size red abalone (203+mm) from the 2006 survey we find for the SW zone that there is a density of 486 legal size abalone per Ha. We estimate that we need a replacement density of 68 new recruits to the fishery/Ha. When we look at the observed densities in the SW zone for new recruits to the fishery we see there are fewer than this estimate: there are 34 new recruits to the fishery/Ha. Observed densities in 2006 from the SE and NW are also less than the estimates of abalone needed for replacement in each of these zones. Results using survey data from 2007 were comparable with those from 2006, with replacement densities for the SW zone of 66 new recruits/Ha. and observed densities of new recruits less than this at 35/Ha. Fishing should be conducted on abalone in excess of those needed for natural mortality replacement, which we do not find in these analyses.

### 5.5.2 Abalone Recruitment Modules:

To further explore this aspect of abalone biology, we examine the number of young of the year (YOY) red abalone (size 1-20mm) found inside abalone recruitment modules at Miracle Mile, San Miguel Island from 2002 to 2008. We compare these with modules deployed at Van Damme, in northern California 2001-2008. Modules are sampled once per year (late summer or early fall) by the kelp forest monitoring program in cooperation with Jim Marshall and the CAA in the south and CDFG and UC research divers in the north.

In the first year of the sampling in the south, less than 1.0 YOY red abalone were found per module comparable to what we see in the north. In the subsequent years 2003-2005 less than 0.5 YOY were found per module in the south. In the past 3 years (2006-2008) no small red abalone less than 21mm were found in the modules at SMI. Most years in northern California we find 0.5 YOY per module, although in 2005 more than 2.0 YOY were observed and YOY have been observed every year. While adult densities at Miracle Mile SMI are more dense than at many other sites on the island, this may not translate into successful recruitment every year. Clearly, more work needs to be done to examine red abalone recruitment at San Miguel Island and elsewhere.

### 5.6 Monitoring Program and Sampling Power:

A power analysis was conducted using data from San Miguel Island in 2006 in three regions of the island the Northwest (NW), Southwest (SW) and Southeast (SE). This was done to determine what effect size can be detected given a limited number of transects (sample size), alpha level (probability of a type I error, rejecting the null hypothesis when it is true) and beta level (probability of a type II error, rejecting a false hypothesis). Alpha levels are generally set at 0.05 so we examined this level as well as relaxed this to a less stringent level of 0.1. Beta levels are generally set at 0.8.

In the SW region, more than 130 transects would be needed to detect a 30% change in mean abalone density in the region given an alpha level of $p<0.1$ and a beta level of 0.8. This number increases to more than 300 transects needed to detect a 20% change in density. By way of comparison, the most transects that have been sampled in one zone was 183 transects in the SW in 2006. In the SE zone more than 200 transects would be needed to detect a 30% change in mean abalone density in the region given an alpha level of $p<0.1$ and a beta level of 0.8. This compares with the 157 transects that were completed in the zone in 2006. Finally, in the NW zone more than 400 transects would be needed to detect a 30% change in mean abalone density in the region given an alpha level of $p<0.1$ and a beta level of 0.8. More transects would be needed in order to detect less than a 30% change in density or to increase the alpha or beta levels.

Therefore, a sampling program with the same level of effort as the 2006 SMI sampling program would be able to detect changes in density ranging from 30-50%. Increasing the number of surveys over time (years) will increase the precision in order to detect smaller changes in density. The Review Committee emphasizes the need for trend data of at least 5 years before reliable inferences are possible. To date, there have been 3 years of SMI survey data (2006-2008).

**5.7 Experimental Fishery**

One definition for an experimental fishery would be as per Carl Walters, perturbing populations by fishing to learn about the behavior or sustainability of the population. These fishing experiments require feedback from population monitoring, frequently in-season. The previous section, 5.6 Monitoring Program and Sampling Power, suggests that feedback from monitoring in this case will be course grained at best. That is, it will only be able to detect gross changes in density within a fished region on the order of 30% declines. This limits our ability to respond to the “experiment” by changing fishing practices if they negatively impact the local stock and limits our ability to adaptively manage the fishery. In particular, it has been argued (Walters 1986) that adaptive management should begin with a concerted effort to integrate existing scientific and fishery information into dynamic models that make predictions about the impacts of alternative policies. This step is critical to the success of most plans and we suggest this approach be part of the TAC framework (see section 2.0 above). Also critical to the validity of this experiment is that removals are known precisely, or at least that the amount of illegal or unreported take does not change during the experiment and can be estimated with some accuracy.

The timing of the start of the experimental fishery needs to be examined. Within the Review Committee’s recommendations are suggestions that the fishery can begin while other management actions are conducted in parallel. A more precautionary approach we would argue would be to have the TAC Framework, Risk Analyses, BRP, management methods and sampling methods determined prior to the opening of any fishery. With the amount of work that has been completed within the TP and the AAG this would not be an onerous task and could be accomplished within 6 months with funding.

Alternative “experimental fishery” approaches might be considered in regions where densities are higher and or there are more viable local populations to work with so that controls and replicates can be established as are needed for good experimental design. This alternative approach may be possible given red abalone are fished elsewhere in the state where there is an active monitoring program in place. A failed fishery experiment at SMI could put in jeopardy the spatial recovery of red abalone elsewhere on the island, at neighboring islands, and potentially in the region. Fishing a population that is in a recovery phase will slow down population growth locally and may impact recovery in the region (see spatial recovery and population genetics considerations).

**5.8 Enforcement Perspective on TAC at SMI: Capt. Roland Takayama**

Enforcement issues relative to abalone fisheries range across a number of issues including enforcing regulations such as size limits, depth restrictions, area closures and seasonal closures as well as preventing black market sales. Without more specific knowledge as to how the proposed SMI fishery will be configured, it is difficult to comment on how Enforcement would be impacted.

- **Seasons**: Generally, shorter open seasons are better for enforcement as both patrol boat and shore side warden resources would be directed toward the fishery during the open season.
- **Legal Abalone Tracking**: A fool-proof method of tagging commercially caught abalone along with a logbook system should be implemented to prevent abalone from non-permit holders and recreational divers from entering the market.
- **San Miguel Island Patrols**: San Miguel Island is fairly remote and long running times are required to reach the island from either Santa Barbara or Morro Bay. Enforcement Division currently patrols to San Miguel on a roughly monthly basis. Should a commercial abalone fishery be implemented, this effort would need to be expanded. Permit fees need to be configured to help pay for additional patrols. Overflights by department aircraft, as well as, NOAA and USCG aircraft would provide additional fishery monitoring. Tentative plans for a remote video surveillance system are being discussed at the Channel Islands, with Point Bennett being one of the proposed sites. Should this system be installed, real time monitoring of the abalone grounds may be possible. At any rate, additional patrols of the outer island are anticipated and a commercial abalone fishery is a possible funding source to augment current MPA enforcement efforts.

A limited quota such as 8,300 or 6,700/ year could alleviate many problems associated with size limits, seasons and area closures, the thought being that any individual quota would be filled in the Southwest area of San Miguel. This could make the risk/benefit ratio unreasonably high for activities such as the take of undersize abalone or abalone from closed areas.

A limited fishery in southern California needs to be structured with sufficient documentation, as to not markedly expand black market opportunities. In northern California, black market sales of abalone from recreational take and other commercial fisheries such as sea urchin divers exist and will continue to do so.

**5.9 Potential Revenues**

Revenues are difficult to judge *apriori* but we can make some estimates of potential revenues from the fishery. An initial proposed landing fee of $6 per abalone was floated in Appendix H of the ARMP. If each abalone weighs approximately 3.75 pounds (45 pounds per dozen) then this would be $1.6 per pound. If a TAC of 6700 is adopted then this would generate $40,200/year. If the landing fee is raised to $10 per abalone this is $67,000/year. This would need to pay for tag production and distribution, surveys (partial costs are borne by the industry and other user groups), data entry and analysis and backup. These fees would also need to pay for resource management and enforcement. By comparison, the northern California recreational fishery is managed using fees from abalone punchcard sales; which in 2007 cost $17.00 each and generated $675,000 (in 2006 the fees generated were $598,000). The cost of printing abalone tag/report card for the north coast was $45,450 in 2008. The TP recommends that the cost of management and enforcement be considered while developing plans for a TAC.

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**7.0 Acronyms**

AAG – Abalone Advisory Group
ARMP – Abalone Recovery and Management Plan
BRPs - Biological Reference Points
CDFG – California Department Fish and Game
MPA – Marine Protected Area
MVP – Minimum Viable Population
TAC – Total Allowable Catch
WS – Withering Syndrome (disease)
TP- Technical Panel