FINAL WHITE ABALONE RECOVERY PLAN

(*Haliotis sorenseni*)

Prepared by

The White Abalone Recovery Team

for

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Office of Protected Resources

October 2008

RECOVERY PLAN

FOR

WHITE ABALONE (*Haliotis sorenseni*)

Prepared by
National Marine Fisheries Service
Southwest Regional Office

Approved: _____

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EXECUTIVE SUMMARY

CURRENT SPECIES STATUS

White abalone (*Haliotis sorenseni)* was listed as an endangered species throughout its range, from Point Conception, California, USA to Punta Abreojos, Baja California, Mexico, under the Endangered Species Act (ESA) effective June, 2001 (NOAA 2001; 66 FR 29054, May 29, 2001). The listing came after completing a comprehensive status review of the species (Hobday and Tegner 2000). The status review identified an urgent need for human intervention in the recovery of white abalone because sub-threshold densities of the animals in nature, resulting in repeated recruitment failure, make it unlikely that the species will recover on its own. Without intervention, it was estimated that the approximately 1,600 remaining white abalone in the wild would disappear by 2010. Surveys conducted in Southern California since the time of the status review confirm the status review's conclusion that at least a 99% reduction in white abalone density has occurred between the 1970s and today. The National Marine Fisheries Service (NMFS) serves as the steward for the recovery and conservation of white abalone. White abalone is the first marine invertebrate to be listed under the ESA and the recovery of this highly fecund, long-lived species with a complex life history (pelagic larval stage and benthic adult stage) may be particularly challenging. Regulatory measures taken by the state of California during the past 30 years, including the closure of the white abalone fishery in 1996, and the closure of all abalone fisheries in central and southern California in 1997, have proven inadequate for the recovery of white abalone in the USA. White abalone abundance was driven to such low levels during the height of the commercial fishery that adults do not occur in high enough densities to successfully reproduce, contributing to repeated recruitment failure and an effective population size near zero. The white abalone population in Mexico is thought to be depleted based on commercial fishery data, but the status of the species in Mexico remains largely unknown.

HABITAT REQUIREMENTS AND LIMITING FACTORS

White abalone are currently reported to be most abundant between 30-60 m (˜100-200 ft depth), making them the deepest occurring abalone species in California. Historically, they occurred along the mainland coast, and at offshore islands and banks at depths as shallow as 5 m. Fishery dependent data collected in California from 1955-1993 by the California Department of Fish and Game (CDFG) suggest the highest percentage of total landings occurred at San Clemente Island and Tanner and Cortes Banks. White abalone are found in open low and high relief rock or boulder habitat that is interspersed with sand channels. Sand channels may be important for the movement and concentration of drift macroalgae, such as *Laminaria farlowii*, *Agarum fimbriatum*, and a variety of red algae, upon which white abalone are known to feed.

White abalone abundance has declined significantly throughout its range as a result of overutilization for commercial and recreational purposes during the 1970s. Due to their life history characteristics as long-lived, slow moving bottom dwellers with external fertilization and variable recruitment rates, abalone are particularly susceptible to the pressures imposed by intense commercial and recreational fishing. Overfishing reduced white abalone densities to

such low levels that males and females were too far apart from one another to successfully reproduce. It is evident to the Recovery Team members and abalone experts world-wide that the most significant threat to white abalone is related to the long-term effects that overfishing has had on the species. Population densities have declined to such low levels that the probability that successful fertilization and subsequent recruitment events in the future can restore the species throughout its range has become increasingly small.

Related to the fact that white abalone experienced significant declines in abundance throughout its range as a result of overutilization, is that fishing regulations for white abalone during the major period of its decline in the 1970s were clearly inadequate to conserve the species and maintain fishing at sustainable levels. Other measures taken during the late 1970s and 1980s to regulate the abalone fishery such as prohibiting fishing during a portion of the spawning season, bag limits for recreational fishermen, limited entry, and permit fees also proved ineffective. In 1996, the California Fish and Game Commission closed the California white abalone fishery to protect the surviving adults.

Loss or modification of habitat is not likely to have been a factor in the decline of white abalone. Estimates of natural or anthropogenic white abalone habitat losses are unknown. However, due to the isolation of the offshore islands of southern California and northern Baja California and the depth range of the species, anthropogenic impacts to white abalone habitat should be limited near the islands; however, the mainland habitat may have been affected to an ‘‘unknown extent’’ for a variety of unspecified land-based human activities. Indirect and direct effects of long-term climate change on white abalone habitat parameters are unknown. Estimates of available white abalone habitat are currently being revised. The results of ongoing habitat and abundance surveys may provide justification for the protection of specific habitats in the future. A better understanding of factors that affect larval dispersal distances and recruitment dynamics may also help in the construction of a sound conservation plan for the ecosystems upon which white abalone depend. The best available information to date suggests that factors such as disease or predation may have contributed to the decline of white abalone, but are not currently a major factor affecting the species’ continued existence.

RECOVERY STRATEGY

The primary goal of this recovery plan is to ensure the recovery of the white abalone population throughout its range, defined as the establishment of self-sustaining populations (those that have met the delisting criteria outlined below). In order to achieve this, the Recovery Team suggests that six actions be taken. It is important to note that this definition of white abalone recovery may not necessarily support a fishery.

1. Assess and monitor subpopulations of white abalone in the wild in cooperation with the state of California, other federal agencies, private organizations and the Mexican government.
2. Identify and characterize existing and potential white abalone habitat through acoustic remote sensing technology.

3. Protect white abalone populations and their habitat in the wild.
4. Continue and expand a captive propagation and enhancement program for white abalone in California.
5. Develop enforcement, public outreach and education plans.
6. Secure financial support for white abalone recovery.

By implementing these actions, surviving wild populations will be identified and the status and trends of these populations will be monitored. Surveys will quantify available white abalone habitat and generate better abundance estimates for the species throughout its range. Efforts to conserve and protect these populations through outreach/education programs and enforcement of Endangered Species Act (ESA) provisions will occur. A better understanding of the species' habitat requirements will result from field surveys and will help inform the selection of habitats for future enhancement efforts. By refining current estimates of total population size in the wild, the optimal number of animals for broodstock collection, without compromising the genetic integrity of captive populations or resulting in a negative impact on the wild population, will be ascertained. Collection of broodstock animals for genetic analysis and captive breeding programs at multiple locations (e.g., the Channel Islands Marine Resource Institute, the Bodega Bay Marine Laboratory, and the NOAA Southwest Fisheries Science Center), each with unique capabilities, will proceed. Factors that mediate larval and juvenile survival (e.g., temperature, diet, density, disease) will be examined in the laboratory using captive-bred animals. In order to determine the success of field planting captive-reared larvae and juveniles as an enhancement strategy, short- and long-term survival rates will be measured during experimental field planting of white abalone larvae and juveniles. Experimental field planting will involve stocking animals over a range of sizes, densities, and spatial scales at both near shore and island locations. Long-term monitoring of wild and captively generated animals will help determine if captive propagation and subsequent field planting is an effective enhancement strategy. If so, a full-scale field planting program will ensue along with continued long-term monitoring of populations in the wild. Finally, recovery implementation will not proceed without funding to support all of the recovery actions. NMFS and its recovery partners are committed to pooling resources when possible, working collaboratively, and taking advantage of competitive funding opportunities at state, federal and private institutions in order to implement recovery.

RECOVERY GOALS AND CRITERIA

The goal of the recovery plan is to increase white abalone abundance to viable and self-sustaining levels such that the species can be downlisted to threatened status and eventually removed from the Endangered Species List.

The recovery criteria are stated below and apply to populations of white abalone in both the USA and Mexico (for geographic reference see Figure 8).

Downlisting Criteria
Demographic Criteria

Criterion 1: Density and Abundance

A. Density of emergent (detectable by human observation without substrate disturbance) animals (short term) must be greater than 2,000 per hectare for 75% of the geographic localities.
B. Maintain a total of 380,000 animals (Rogers-Bennett et al. 2002; Butler et al. 2006) in the wild, distributed among all geographic localities in the USA and Mexico.

Criterion 2: Size Frequency

A. Proportion of size of emergent animals in 75% of geographic localities includes at least 85% intermediate-size animals (90 to 130 mm)
B. Proportion of size of emergent animals in 75% of geographic localities includes no more than 15% large animals (>130 mm)

Criterion 3: Trend

A. Achieve a stable or increasing estimate of geometric population growth ($\lambda \geq 1$) for >75% of the geographic localities over a ten year period.

Criterion 4: Changes in distribution/reoccupation of historical range

A. Reoccupation of white abalone over a spatial scale that encompasses their historic range such that 75% of the geographic localities in the USA and Mexico are reoccupied and meet the aforementioned recovery criteria.

Threats-Based Criteria

The threats criteria are organized according to the five ESA listing factors discussed in detail on pages 29-34 of this document.

Listing Factor 1: Destruction, Modification, or Curtailment of Habitat or Range

A. Destruction, modification, or curtailment of habitat or range was not an important factor in the decline of the species historically and is not believed to limit recovery of the population at this time. Currently, substrate destruction, suboptimal water temperatures, reduced food quantity and quality, and environmental pollutants/toxins are considered to be of relatively low severity and the effect of these threats on the species are relatively uncertain. In the future, potential risks imposed by substrate destruction may be averted through implementation of ESA Section 7 consultations and establishment of Marine Protected/Conservation Areas. The effects of long-term (or global) climate change on this species, either directly through water quality changes or indirectly through interactions with other species, including food items, is a potential threat

to white abalone that cannot be addressed through these regulatory measures. At this time, it is unclear what effect long-term climate change will have on the species.

Listing Factor 2: Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

A. In California, fishing for white abalone remains prohibited and regulations for other abalone species are designed to protect white abalone. In Mexico, no federal permits are issued that allow fishing for white abalone. These measures limit further reductions in density and genetic diversity; see Table 5. Enforcement of existing regulations and public outreach will help to minimize illegal harvest.
B. The CDFG Abalone Recovery and Management Plan (ARMP) remains in place and reflects updated information adequately to ensure that white abalone will be managed to maintain demographic numbers outlined in this plan. There are assurances of adequate regulatory authority and funding for the state to implement the plan.

Listing Factor 3: Disease/predation

A. Routine monitoring results indicate no evidence of withering syndrome (WS)-infected animals in wild populations.
B. The impact of any emerging disease has been evaluated and conclusions drawn that it is unlikely to significantly affect white abalone populations.
C. A minimum of 50% of the white abalone geographic localities meeting the aforementioned demographic criteria, fall outside the resident range of sea otters.

Listing Factor 4: Inadequate regulatory mechanisms

A. An interagency (state/federal) task force is established to enforce regulations to protect established subpopulations and effectively alleviate illegal take of white abalone.
B. Implementation of bilateral agreements with Mexico are continued and adequately deter illegal international trade.
C. Future abalone harvest is monitored by the CDFG's ARMP such that the health of the species is maintained and populations remain self-sustaining.
D. Populations of white abalone in Mexico are adequately protected by regulatory mechanisms implemented by the Mexican authorities.

Listing Factor 5: Other factors affecting the species' continued existence

A. Hybridization has been assessed and determined not to be a threat to the species.

Long-term Monitoring Criteria

Criterion 1: A monitoring program is in place and underway to evaluate population abundance and structure for a minimum of 50 years after downlisting.

Criterion 2: A monitoring program is in place and underway to evaluate threats for a minimum of 50 years after downlisting/delisting.

Criterion 3: A quantitative, long-term forecasting analysis plan is under development to ensure that probability of extinction in the wild is less than 10% in 100 years or 5 generations, whichever is longer.

Delisting Criteria
Demographic Criteria

Criterion 1: Density and Abundance

A. Density of emergent animals (short term) must be greater than 3,000 per hectare for 75% of the geographic localities (CDFG, 2005).

B. Maintain a total of 500,000 animals (Rogers-Bennett et al. 2002, Butler et al. 2006) in the wild, distributed among all geographic localities in the USA and Mexico. Maintenance of 500,000 animals is based on crude estimates of abundance necessary to sustain a 90% probability of persistence in 100 years, per IUCN guidelines. The model assumes a conservative estimate of $\lambda = 0.90$ (i.e., 10% decline per year). The threshold value of 500,000 animals should be updated when empirical estimates of λ become available.

Criterion 2: Size Frequency

A. Proportion of size of emergent animals in each geographic locality includes at least 85% intermediate-size animals (90 to 130 mm)

B. Proportion of size of emergent animals in each geographic locality includes no more than 15% large animals (>130 mm)

Criterion 3: Trend

A. Achieve a stable or increasing estimate of geometric population growth ($\lambda \geq 1$) for >75% of the geographic localities over a ten year period.

Criterion 4: Changes in distribution/reoccupation of historical range

A. Reoccupation of white abalone over a spatial scale that encompasses their historic range such that 75% of the geographic localities in the USA and Mexico are reoccupied and meet the aforementioned recovery criteria.

Threats-Based Criteria

The threats-based criteria are the same as for downlisting.

Long-term Monitoring Criteria

Criterion 1: A monitoring program is in place and underway to evaluate population abundance and structure for a minimum of 50 years after delisting.

Criterion 2: A monitoring program is in place and underway to evaluate threats for a minimum of 50 years after delisting.

Criterion 3: A quantitative, long-term forecasting analysis plan has been developed to ensure that the probability of extinction in the wild is less than <5% within 100 years or 5 generations, whichever is longer.

Criterion 4: If information collected during the long-term monitoring period suggests: a) the decision to delist was in error, or 2) the species' status has changed substantially, a status review of the species should be conducted.

ACTIONS NEEDED

1. Assess and monitor subpopulations of white abalone in the wild in cooperation with the state of California, other federal agencies, private organizations and the Mexican government.
2. Identify and characterize existing and potential white abalone habitat through acoustic remote sensing technology.
3. Protect white abalone populations and their habitat in the wild.
4. Continue and expand a captive propagation program for white abalone in California.
5. Plan and implement public outreach and education plans.
6. Secure financial support for white abalone recovery.

ESTIMATED COST OF CARRYING OUT RECOVERY ACTIONS DURING THE FIRST FIVE-YEARS

	Cost Estimate (*10^3)						
Year	**Action 1**	**Action 2**	**Action 3**	**Action 4**	**Action 5**	**Action 6**	**TOTAL**
FY1	305	0	10	463	10	0	**788**
FY2	450	0	10	468	10	0	**938**
FY3	587	0	15	473	10	0	**1085**
FY4	588	0	15	453	10	0	**1066**
FY5	589	0	20	458	10	0	**1077**
TOTAL	**2519**	**0**	**70**	**2315**	**50**	**0**	**4954**

ESTIMATED DATE AND COST OF RECOVERY

We are not able to project a recovery date and cost at this time because of uncertainty in our ability to carry out each of the recovery actions and whether they will directly lead to achieving the recovery criteria without time consuming adaptation. Specifically, the necessity of outplanting captive-reared abalone and uncertainties involved in doing so make it impossible to give a timeframe for recovery. However, we can predict that recovery is likely to take several decades and cost $20 million at a minimum (cost based on four times the first 5 years' cost) . The logistical and financial requirements for carrying out the recovery actions are burdensome and even if these challenges are resolved in a reasonable amount of time, we can not predict delays caused by other challenges that may arise as we learn more about the species and the methods most effective for recovering them.

LIST OF ACRONYMS AND ABBREVIATIONS

The following standard abbreviations for units of measurements and other scientific/technical acronyms and terms are found throughout this document.

CDFG-California Department of Fish and Game
CFR- Code of Federal Regulations
CIMRI-Channel Islands Marine Resource Institute
CPE-Catch Per Effort
ESA-Endangered Species Act
INP-Instituto Nacional de la Pesca
IUCN- The International Union for the Conservation of Nature and Natural Resources
MPA-Marine Protected Area
NMFS-National Marine Fisheries Service
NOAA-National Oceanic and Atmospheric Administration
NOS-National Ocean Service
NPS-National Park Service
PVA-Population Viability Analysis
ROV-Remotely Operated Vehicle
SIO-Scripps Institution of Oceanography
UCSB-University of California Santa Barbara
USA-United States of America
USGS-United States Geological Survey
UV-Ultra-violet

I. BACKGROUND

A. STATUS OF THE SPECIES

White abalone (*Haliotis sorenseni)* was listed as an endangered species throughout its range, from Point Conception, California, USA, to Punta Abreojos, Baja California, Mexico, under the Endangered Species Act (ESA) effective June, 2001 (NOAA 2001; 66 FR 29054, May, 29, 2001). White abalone is the first marine invertebrate to be listed under the ESA and the recovery of this highly fecund, long-lived species with a complex life history (pelagic larval stage and benthic adult stage) may be particularly challenging. The listing came after completing a comprehensive status review of the species (Hobday and Tegner 2000). The status review identified an urgent need for human intervention in the recovery of white abalone because sub-threshold densities of the animals in nature, resulting in repeated recruitment failure, make it unlikely that the species will recover on its own. Without intervention, it was estimated that the approximately 1,600 remaining white abalone in the wild would disappear by 2010. The National Marine Fisheries Service (NMFS) serves as the steward for the recovery and conservation of white abalone. Regulatory measures taken by the state of California during the past 30 years, including the closure of the white abalone fishery in 1996, and the closure of all abalone fisheries in central and southern California in 1997, have proven inadequate for the recovery of white abalone in the USA. White abalone abundance was driven to such low levels during the height of the commercial fishery that adults do not occur in high enough densities to successfully reproduce, contributing to repeated recruitment failure and an effective population size near zero. The white abalone population in Mexico is thought to be depleted based on commercial fishery data, but the status of the species in Mexico remains largely unknown.

Since the early 1990s, progress has been made on several fronts to learn more about the biology of white abalone in California and to develop a recovery strategy for the species. The state of California, federal agencies, academic institutions, non-governmental organizations and others have conducted or participated in efforts to determine which factors contributed to white abalone's decline, determine its current status, and discuss measures that should be taken to recover the species. In addition, this comprehensive recovery plan was developed by the white abalone recovery team to: 1) address threats across the species' entire range; 2) determine and prioritize the actions that should be taken to recover and conserve the species; 3) and state what criteria should be used to gauge when and if the species can be downlisted and eventually removed from the list.

B. SPECIES' DESCRIPTION AND TAXONOMY

Abalone are prosobranch marine gastropods, in the phylum Mollusca, that first appeared in the fossil record about 100 million years ago. According to Crofts (1929), abalone were first mentioned in the fourth century B.C. by Aristotle who said, "but in the case of the wild limpet (called by some the 'sea ear") the residuum escapes beneath the shell for the shell is perforated to give outlet." Aristotle was referring to the row of rounded shell perforations overlying the

respiratory cavity. These perforations or respiratory pores provide outlet for reproductive products and for feces and waste water that has flowed over the gills.

White abalone was the last member of the California Haliotids, of which there are seven (Geiger 1999), to be formally described. Bartch (1940) gives the first formal description of this deep-living (20-60 m) abalone, recounting the shell as thin and light, oval and highly arched (Figure 1). There are three to five open respiratory pores that are highly elevated above the shell's surface. Typically, the shell's interior is a pearly white and contains a poorly differentiated or absent muscle scar (Cox 1962). Adults attain a maximum shell length of approximately 25 cm. The epipodium is a mottled yellowish green and beige color, with foliose epipodial papillae edged in orange, and brown cephalic tentacles (Cox 1962, Leighton 1972). There is a possible subspecies of white abalone found at Guadalupe Island (Mexico), although it has not been formally described (Howorth 1978).

Figure 1. White abalone, *Haliotis sorenseni*

The taxonomic classification for white abalone is as follows:
Kingdom: Animalia
Phylum: Mollusca
Class: Gastropoda
Subclass: Prosobranchia
Order: Vetigastropoda
Superfamily: Pleurotomariacea
Family: Haliotidae (abalone)
Genus: Haliotis (Geiger 1999)
Species: sorenseni

C. POPULATION TRENDS AND DISTRIBUTION

HISTORIC AND CURRENT RANGE The historic range of white abalone extended from Point Conception, California, USA to Punta Abreojos, Baja California, Mexico (Figure 2) (Bartsch 1940, Cox 1960, 1962). In the northern part of the California range, white abalone were reported as being more common along the mainland coast. In the middle portion of the California range, they were noted to occur more frequently at the offshore islands (especially San Clemente and Santa Catalina Islands)(Cox 1962, Leighton 1972). At the southern end of the range in Baja California, Mexico, white abalone were reported to occur more commonly along the mainland coast, but were also found at a number of islands including Isla Cedros and Isla Natividad (Guzman del Proo 1992, Shepherd et al. 1998). It remains unknown whether this distribution pattern resulted because of lack of suitable habitat along the mainland coast in the middle portion of the range, or to overfishing in these more accessible mainland regions (Hobday and Tegner 2000).

Since the mid-1990s, extremely low numbers of isolated survivors have been identified along the mainland coast in Santa Barbara County and at some of the offshore islands and banks in the middle portion of the range, indicating the current range of white abalone in California may be similar to what it was historically. No recent information on current range is available for Baja California.

Figure 2. Historic range of white abalone from Point Conception, California, USA to Punta Abreojos, Baja California, Mexico.

EXPLOITATION HISTORY The first humans to harvest abalone in California were Native Americans in about 7000 BC (Croker 1931). Evidence from recovered middens on the Channel Islands suggest that few white abalone were taken perhaps due to the local accessibility of other species (e.g., intertidal black abalone). The California abalone fishery was dominated by Chinese and Japanese immigrants from the 1850's until the 1940's. Again, white abalone catches during this time may have been insignificant because white abalone occurred in relatively inaccessible (deeper) habitats and because commercial and recreational harvesting was most intense north of Point Conception. Exploitation of white abalone in California began in earnest in 1968 at a time when technological advances allowed better access to deeper water sites inhabited by white abalone and populations of other, more accessible species began to dwindle (Lundy 1997). Prior to 1970, when white abalone were added as a separate species on the CDFG commercial fish landing receipts, white abalone were likely reported as pink abalone in landings data. Despite the invocation of size limits, bag limits, permit fees, efforts to reduce fishing effort, and gear restrictions by the CDFG during the 1970s, white abalone catches continued to decline and in 1996 the CDFG closed the white abalone fishery throughout its range in California (Hobday and Tegner 2000).

The exploitation history of white abalone in Mexico is similar to that reported for California until the 1940's. The Mexican government closed the abalone fishery to foreign fishers at that time and gave exclusive fishing rights to local Mexican villages (Ramade-Villanueva et al. 1998). The Pacific coast of Baja California was divided into 19 cooperatives which were grouped into five larger management regions (Guzman del Proo 1992). Additional cooperatives have been added since the early 1990's and it is currently unclear how an increase in the number of cooperatives may be affecting abalone populations.

POPULATION TRENDS Estimates of the total population size of white abalone past and present have been difficult to calculate because most data are based on emergent (adult) individuals only. Cryptic (juvenile) white abalone have seldom been observed in nature, even prior to exploitation by the fishery. In addition to body size limitations, there is evidence from other abalone species that factors such as presence of predators and abundance of food may mediate cryptic behavior. The paucity of abundance data for cryptic animals prevents establishing links between the numbers of early and later life stages and thus, the reconstruction of recruitment histories for white abalone populations has not been possible. As a result, a poor understanding of population dynamics exists for white abalone. Given the limitations of fishery-independent and dependent data, only adult population abundance and density can be evaluated for changes through time and space.

Fishery-Independent Data

The earliest fishery-independent density estimates for California are provided by Tutschulte (1976). Because sample sizes in Tutschulte's study were small, applicability of these data to larger-scale population patterns is uncertain. The first estimate (0.23 abalone m^{-2}) is based on calculations made from only seven animals that were collected in three different quadrats (10 m^2) at three depths (20 m, 20 m, and 33 m) in southern California between 1969-1972. A fourth

quadrat (35 m^2), examined in 1967 in the Isthmus region of Santa Catalina Island yielded a density of 0.0857 abalone m^{-2}. Tutschulte (1976) purports that the historical density of white abalone is 1 m^{-2}, but this estimate has limited empirical support.

Only two fishery-independent surveys have been conducted in Mexico, both along the west coast and islands of Baja California. The first survey, 1968-1970, encompassed the whole coast while the second survey, 1977-1978, covered a much smaller area along the coast encompassing Punta Abreojos (Figure 8). Densities reported in 1968-1970 ranged between 0.07-0.149 m^{-2} and were similar to those reported by Tutschulte (1976) in California during a similar time period. No white abalone were found in 1977-1978 (Guzman del Proo 1992).

The National Park Service (NPS) with the help of the CDFG, conducted diving and submersible surveys in the Channels Islands from 1980-81 and from 1992-1993, at depths ranging from 24-37 m. Emergent white abalone density decreased by one order of magnitude from $2.1*10^{-3}$ m^{-2} in the early 1980s to $1.7* 10^{-4}$ m^{-2} in the early 1990s (Davis et al. 1996). The animals collected in 1980-81 (n=21) were not measured, but the three animals collected in 1992-93 were ≥ 137 mm. Empty shells were also sampled during the 1992-93 survey. Of the 119 white abalone shells identified, only one of them was < 50 mm. This led the authors to conclude that most of the white abalone shells and live individuals observed in the early 1990s were remnants of the last major recruitment event in California thought to have occurred in the 1970s (Davis et al. 1996). Although other invertebrate monitoring programs were conducted at the Channel Islands from 1966-1994, these surveys were largely conducted outside of known white abalone habitat (Burge et al. 1975). The presence of white abalone was rarely recorded and density estimates could not be calculated from these data (Hobday and Tegner 2000).

A consortium of institutions (NPS, CDFG, University of California Santa Barbara (UCSB), Scripps Institution of Oceanography (SIO), the United States Geological Survey (USGS), and NMFS) took part in submersible surveys during 1996-1997 and 1999 in the Channel Islands (Anacapa, Santa Barbara, Santa Cruz, Santa Catalina, San Clemente) and Osborn, Farnsworth, Tanner and Cortes Banks at depths ranging from 30-70 m (Davis et al. 1998, Hobday et al. 2001, Lafferty et al. 2004). Emergent white abalone densities were estimated at $1.2*10^{-4}$ m^{-2} in 1996-1997 and $2.7*10^{-4}$ m^{-2} in 1999. These densities are four orders of magnitude lower than those reported in 1972 by Tutschulte (1976)and represent a greater than 99% reduction in density. Nine animals, all > 150 mm, were observed in 1996 and 1997. In 1999, the mean length of measurable white abalone was 14.8 cm (SD = 2.63, N = 86). Mean length varied moderately, but significantly among the three sites with sufficient sample sizes to warrant comparison (Table 1).

Table 1. Abundance and size data for white abalone collected during submersible surveys in 1999 at the Channel Islands and offshore banks of southern California, USA (Behrens and Lafferty 2005).

Location	Size Range (cm)	Mean Size (cm)	SD (cm)	N
Tanner Bank	8.9-19.3	14.1	2.3	39
Cortes Bank	12.0-20.7	15.7	2.8	19
San Clemente Island	10.6-19.6	15.6	2.9	15

Smaller animals were recorded at Tanner Bank compared to Cortes Bank and San Clemente Island ($F_{2, 70} = 3.29$, $P = 0.04$, ANOVA; Kevin Lafferty, pers. comm.). The 1999 submersible survey also demonstrated that most of the identified animals were solitary (80%). No juveniles were observed, and no groups of more than 4 animals were observed. Although it is not possible to analyze temporal changes in the size structure of emergent white abalone due to lack of multiple, consecutive year data, it is clear that primarily large animals (> 140 mm) have been detected in recent surveys. The most recent surveys conducted in 2002 and 2003 off the coast of southern California revealed a similar size composition (91-190mm; Butler et al. 2006)as that reported by Behrens and Lafferty (2005).

Emergent white abalone population size, both prior to and post-exploitation, was determined by calculating a crude estimate of the total area of white abalone habitat from Pt. Conception, California to Punta Eugenia, Baja California, Mexico (3% of the ocean bottom between 25-65 m depth; (3% of the ocean bottom between 25-65m depth; Davis et al. 1998). Experts have pointed out problems with this estimate of available white abalone habitat, especially given the patchy distribution of white abalone and the limited coverage of survey areas upon which the extrapolation was based (Butler and Hunter 2002). Nonetheless, if it is assumed that approximately 966 ha of potential white abalone habitat exists throughout the species' former range and that this number has remained constant since the 1970s, Hobday and Tegner (2000) reported a pre-exploitation population size of between 700,000-4.2 million, depending on the source of the data. A more recent attempt to establish baseline abundances for white abalone in California assumed a habitat estimate of 752 ha in California and a pre-exploitation population size of 360,476 (Rogers-Bennett et al. 2002). Hobday et al. (2001) report that the current white abalone population size is 2,540 individuals, higher than the estimate (1,600) reported during the Hobday and Tegner (2000) status review.

In 2002 and 2003, remotely operated vehicle (ROV) and multi-beam sonar surveys on two banks off of the southern California coast revealed that the white abalone population on the banks may be larger than estimated by Hobday et al. (2001) for the entire range of the species. Observed densities and revised estimates of available white abalone habitat for the two banks were used to estimate the total population sizes for both banks (Tables 2, 3). The estimated total abundance is 12,818 for Tanner Bank and 7,365 for Cortes Bank (Butler et al. 2006). The sizes of animals on the two banks range from approximately 9-19 cm (Figure 3; Butler et al. 2006) and 94% of the animals were classified as singletons (> 2m from a conspecific) (Table 4; Butler et al. 2006).

Table 2. Density estimates and standard errors, estimates of area surveyed, total white abalone habitat area, and population size, by depth, for Tanner Bank during ROV and multi-beam sonar surveys conducted in July 2002.

Depth	Density (No/ha)	SE	Area surveyed (ha)	Habitat area (ha)	Population
30-40	6.5	2.1	3.5	245	1,592.5±514.5
40-50	19.8	4.3	5.0	425	8,415.0±1,827.5
50-60	4.08	1.8	2.3	689	2,811.1±1,240.2
Total				**1,619**	**12,818.6±3,582.2**

Table 3. Density estimates and standard errors, estimates of area surveyed, total white abalone habitat area, and population size, by depth, for Cortes Bank during ROV and multi-beam sonar surveys conducted in July 2003.

Depth	Density (No/ha)	SE	Area surveyed (ha)	Habitat area (ha)	Population
30-40	12.3	8.8	2.6	232	2,853.6±2,041.6
40-50	6.1	2.8	1.5	423	2,580.3±1,184.4
50-60	4.0	2.7	0.7	483	1,932.0±2,114.1
Total				**1,138**	**7,365.9±5,340.1**

Table 4. Number of white abalone by closest distances to another individual ranging from <1->50 m at all sites on Tanner and Cortes Banks (modified from Butler et al. 2006).

Distance (m)	Tanner Bank (2002)	Cortes Bank (2003)	Tanner Bank (2004)
<1	25	3	2
1	1	1	
2	6		1
3	4		
4	5		
5	4		
6-10	15		
11-20	33	1	4
21-30	27		2
31-40	8		
41-50	13		
> 50	57	16	33

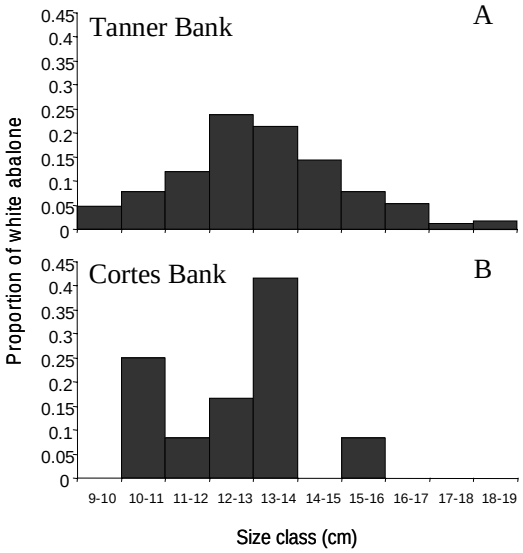

Figure 3. Size distribution of white abalone at Tanner Bank (A) in 2002 and Cortes Bank (B) in 2003. Modified from Fig. 5; Butler et al. (2006). Include N=180

Fishery-Dependent Data

Commercial and recreational exploitation of white abalone has occurred over the last 50 years in California (Haaker 1994). Because white abalone was not described until 1940, it is impossible to estimate white abalone landings prior to this time. In 1955 white abalone was named as a species that could be fished and unfortunately, designated refuges put in place to protect populations of other abalone species, did not encompass white abalone habitat. White abalone catches reached a peak between 1972-1974 and declined to near zero in just five years (Figures 4, 5). Due to this rapid and dramatic decline, the white abalone fishery was closed in March 1996. Since that time, poaching is thought to have played a role in the continued decline of the species.

The CDFG estimates that approximately 4,800 abalone per day are taken illegally in northern California. The relative proportions of each species contributing to the total illegal harvest in southern California are not known. Poaching continues to be an issue at present and will continue to be a problem as long as a strong monetary incentive for poaching exists ($100 per white abalone; Davis et al. 1998). Buyers of black market abalone include local restaurants and seafood markets as well as international businesses (Daniels and Floren 1998). Future designation of Marine Protected Areas/Conservation Areas or the closure/restriction of other fisheries (rockfishes) that may overlap with white abalone habitat could help to reduce illegal take of white abalone in California through increased enforcement and public awareness.

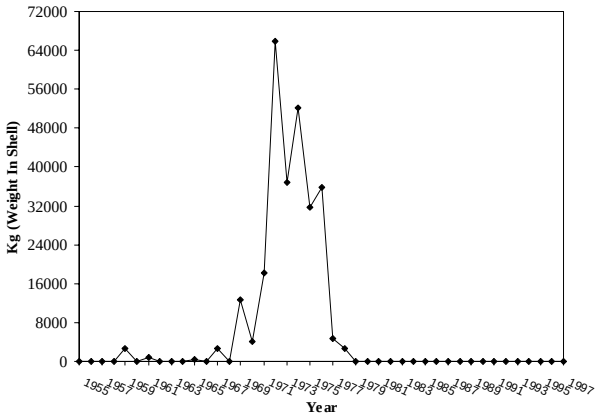

Figure 4. California commercial catch (weight in shell) of white abalone reported in CDFG bulletins for the period 1955-1997. From Hobday and Tegner (2000).

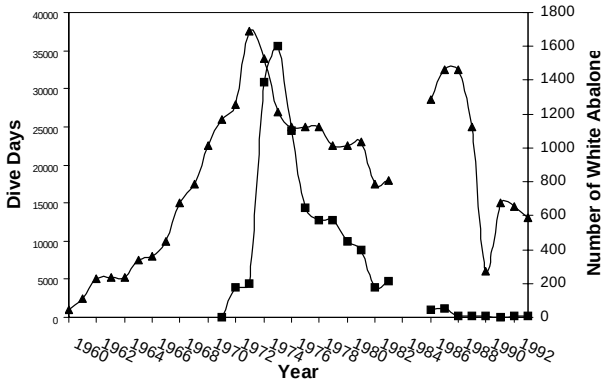

Figure 5. Number of white abalone (■) collected by recreational divers in California. The number of diver days (▲) is also shown as a rough measure of effort. From Hobday and Tegner (2000).

Five species of abalone, including white abalone, have been taken by the commercial fishery in Mexico. Recreational fishing for abalone in Mexico is prohibited and Hobday and Tegner (2000) hypothesized that artisanal gathering of white abalone is unlikely given the current depth distribution of the species. It is important to recognize that the historic and current depth distribution of white abalone has not been well characterized. Minimum size limits for white abalone have varied over time, but are currently between 110-140 mm throughout Baja California. White abalone collected from the USA/ Mexico border to 28 ^{o}N made up, on average, between 0-28% of the total abalone catch from 1990-1998 (Hobday and Tegner 2000). During the 1990s white abalone catches peaked in 1996 (approximately 12,500 kg; Figure 6). Based on the little information available, it is likely that the white abalone population in Mexico has experienced decline since the 1970s and some have suggested that densities have declined to a level at which recruitment failure has already occurred in some areas (Hobday and Tegner 2000). Complete and partial closures of the abalone fishery have been proposed in Mexico, but whether these proposals have been acted on remains uncertain.

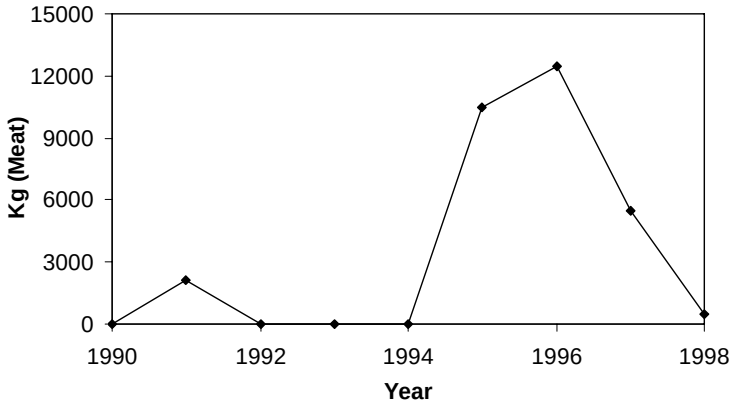

Figure 6. Commercial catch (meat weight) of white abalone in Mexico from the USA/ Mexico border to 28 °N from 1990-1998. From Hobday and Tegner (2000).

Illegal harvest of undersized white abalone is a problem in Mexico, but the extent of the problem is known only from scant data collected during three months in 1973. For example, white abalone made up 33.8 % of the total abalone catch in one area of Baja California during July of 1973. Of those white abalone collected, 98.8% of them were undersized individuals. Present day estimates of the number of white abalone taken illegally in Baja California are not available.

D. LIFE HISTORY/ECOLOGY

REPRODUCTION White abalone are dioecious, with separate sexes occurring in approximately a 1:1 ratio, and exhibit broadcast spawning (i.e. directly releasing gametes into the water column for external fertilization). Factors known to affect fecundity in abalone include organism size and food availability. For those species that have been examined, fecundity has been shown to increase linearly with increasing body size (Tutschulte 1976, Clavier 1992). Adult abalone of intermediate sizes are capable of spawning over two million viable eggs, indicating high reproductive potential (Leighton 2000). Fecundity has been shown to decrease in several species of abalone (*H. laevigata* and in *H. fulgens*) when food is limited (Tegner and Dayton 1987, Shepherd and Breen 1992), and nutrition is essential for the production of fully viable gametes.

Gonads of white abalone mature on an annual cycle, and the spawning season of white abalone is of limited duration (Leighton 2000). Synchronization of gonadal maturation and spawning are critical to successful fertilization. In white abalone, gonads ripen and spawning occurs in winter months, although sometimes spawning extends into the spring. Most of the other abalone species in California spawn during the late-spring through mid-autumn months. White abalone exhibit a high degree of spawning synchronicity relative to other California species; however, the environmental cues and the mechanism for synchronization are not yet known (Hobday and Tegner 2000, Leighton 2000). Temperature changes, lunar cycles and sea conditions have been associated with spawning episodes of other California abalone, but have not been unequivocally demonstrated as spawning cues (Ino 1952, Owen et al. 1971, Leighton 1977). The duration of an individual spawning event in white abalone is unknown (Hobday and Tegner 2000). In *H.*

tuberculata, spawning events last 40-80 minutes and, in males, consist of 30-70 pulses of sperm release every 30-45 seconds. Males release 2- 3 x 10^9 sperm cells per pulse (Clavier 1992). Experimental evidence suggests that fertilization rates are maximized when substantially more than one sperm contacts an egg, and the probability of this occurring increases significantly as the distance between individuals decreases (Leighton 2000).

In addition to the duration and the degree of synchronization of spawning, the concentrations of gametes and the density of spawning individuals will affect the fertilization success rate and recruitment. Studies indicate that fertilization success in several abalone species is optimal when concentrations of sperm are $10^5 – 10^6$ /ml (Leighton and Lewis 1982, Clavier 1992). Experiments conducted with sea urchins indicate, however, that even with high concentrations of eggs and sperm, fertilization rates will be very low (< 10%) when individuals are separated by as little as 1 m (Pennington 1985, Levitan 1991). Experiments conducted in the field with the Australian abalone, *H. laevigata*, indicated that fertilization rates ranged from 87.6% ±5.5% at the point of sperm release to 48%± 1.7%, 2 m downstream, and to 2.8%±0.7%, 16 m downstream (Babcock and Keesing 1999). Based on these experiments and observations in the field, the effective nearest-neighbor distance for successful fertilization in *H. laevigata* is estimated to be 1- 2 m (Shepherd and Browne 1993, Babcock and Keesing 1999). Although adults are considered relatively sedentary, aggregating behavior has been reported for a few abalone species (Newman 1968, Breen and Adkins 1980, VanBlaricom 1993), and several abalone species (e.g. *H. sorenseni* and *H. fulgens*) have been observed in a laboratory setting to become very active immediately prior to spawning (Leighton 2000). Aggregating and spawning events, however, have rarely been observed in the field, and environmental cues for aggregating behavior have not been identified.

No field studies of white abalone fertilization success have been conducted. In the laboratory, fertilization success rates of 96-100% have been achieved (Leighton 1972). Fertilized white abalone eggs are about 190-200 microns in diameter and are negatively buoyant (Hobday and Tegner 2000). As evidenced by current information on white abalone population size structure, no evidence of recent recruitment exists. It is estimated that the last successful white abalone recruitment occurred during the 1970s (Davis et al. 1996, Hobday and Tegner 2000). Information is required to determine if the spatial relations of remnant populations allow successful spawning.

LARVAL STAGE, SETTLEMENT, AND METAMORPHOSIS Duration of the larval stage is temperature dependent (Leighton 1974), but generally lasts for about 1-2 weeks. Temperature influences survival of larvae (Leighton, 1974 , Tutschulte, 1976). Survival of white abalone larvae and growth of post-larvae was greatest at 18°C, and settlement rate was greatest at 15-16°C (Leighton 1972). Dispersal distances of abalone larvae may vary depending on the species, habitat characteristics and hydrodynamic conditions. Studies have shown that under either high or low current and wave-energy regimes, settlement occurred < 50 m away from parent abalone (Prince et al. 1987, McShane et al. 1988). In contrast, Shepherd et al. (1992) found no relationship between recruitment of *H. laevigata* and adult densities, and larval transport

occurred over hundreds of meters. No data on dispersal distances of white abalone larvae currently exist. Given that larval lifetime of white abalone larvae is relatively long (7-14 days; Hobday and Tegner 2000) and that larvae drift passively in water currents, the potential for transport does exist.

Abalone larvae are lecithotrophic and do not actively feed while in the plankton (Leighton 2000). Chemical cues associated with suitable substrate have been found to induce settlement, and a combination of chemical, biological and physical factors are thought to be involved in triggering metamorphosis (Morse and Morse 1988, Leighton 2000). Recognition and acceptance of a suitable substrate are events critical for recruitment and survival of subsequent life stages.

JUVENILE STAGE Generally, abalone are cryptic and photophobic in nature until they are about 3-5 years old or when they reach a size of 75-100 mm (Cox 1962). Juveniles of this size and smaller occur in rock crevices, under rocks and even under the cover of adult red sea urchin (*Strongylocentrotus franciscanus)* spines (Tegner 1989). Small juveniles feed on benthic diatoms, bacterial films and other benthic microflora. Densities of cryptic white abalone have not been measured directly (Hobday and Tegner 2000). Tutschulte (1976) reported that juvenile white abalone <130 mm were rare in undisturbed areas in 1971, and more recent surveys by Davis et al. (1996) failed to detect any live juveniles. Martin Ortiz-Quintanilla observed juvenile white abalone in boulder habitat at depths of 5-10 m around near-shore islands between Ensenada and Cedros Island in Baja California, Mexico (unpublished data). Abalone larger than about 100 mm are classified as “emergent” abalone as they leave sheltered habitats and move to more open habitat to forage on attached or drifting macroalgae. Juveniles are more active than adults and are also more active at night based on laboratory observations (Leighton pers. comm.).

In California, only four white abalone <100 mm in size have been observed since 1970. Three of these were observed by SCUBA divers at Yellowbanks, Santa Cruz Island, CA and one was observed during ROV surveys at Tanner Bank (See below). The three juveniles (32, 38 and 29 mm; D. Kushner pers. com.) were cryptic animals that were located in artificial recruitment modules used by Channel Islands National Park kelp forest monitoring program. In addition, at Yellowbanks, three fresh white abalone shells <100 mm were also found during the same time that live white abalone were found. Thus, there have been so few observations of juveniles, that preferred juvenile habitat has yet to be accurately characterized. Even though juvenile white abalone are cryptic, if recruitment were occurring, one would still expect to observe shells as is the case with other abalone species, especially in areas where currents are not so strong that they would wash shell debris away. This has not been the case for white abalone.

Information on growth rates of juveniles is limited; however, in the laboratory, growth rates were 29.2 ±15.0 mm / year for juveniles (n=5) fed on *Macrocystis* (Tutschulte 1976). Growth rate is influenced by temperature, and different species achieve maximum growth rates at different temperatures. No field estimates of juvenile mortality rates have been reported for white abalone

(Hobday and Tegner 2000). The juvenile stage lasts, in general, for about 1-2 years, and ends upon reaching sexual maturity.

ADULT STAGE White abalone become sexually mature when they reach sizes of approximately 88-134 mm or ages of 4 –6 years (Tutschulte and Connell 1981). Adult white abalone reach a maximum size of 200-254 mm (Cox 1960), and are estimated to live for about 35-40 years (Tutschulte 1976). Adult white abalone found in the wild are usually 13-20 cm long and inhabit substrate with little complexity (i.e. few cracks and crevices). Growth rates for adults (n=3) fed on *Macrocystis* have been measured at 16.4 ± 7.8 mm/ year in the laboratory (Tutschulte 1976). Adult abalone feed primarily on drift algae but will also feed on attached macroalgae, using their radula and mouth parts to graze algae from rocky substrates. Drift algae is captured with the anterior portion of the foot and brought to the mouth. Cephalic and epipodial tentacles are equipped with sensory capabilities for detecting the arrival of drifting alga fragments.

Field estimates of mortality rates for adult white abalone have not been reported (Hobday and Tegner 2000). Natural sources of mortality include factors such as predation, disease, old age, and starvation. Abalone face a variety of predators, whose importance varies with location and the size-class of abalone. For example, filter-feeders will consume abalone at the egg and larval stages. Predation mortality by small crustaceans, sea stars and protozoans, however, is greatest during the post-larval stages (Leighton 2000). Typical predators on juveniles and adults include, cabezon (Gotshall 1977), starfishes, octopuses, spiny lobsters, crabs, sheephead, moray eels, bat rays, sea otters and humans. Field data on the predation pressure of non-human predators on white abalone are lacking. Abalone are important prey of sea otters; however, there is no evidence that sea otter predation has resulted in extirpation of abalone. For example, in Central California several abalone species (red, flat, pinto and black) co-exist with sea otters (Lowry and Pearse 1973, Cooper et al. 1977, Hines and Pearse 1982, Rogers-Bennett 2007). Similarly, the presence of sea otters may limit white abalone populations to small individuals that are restricted to cryptic habitats.

Mortality due to senescence is thought to occur as white abalone approach ages between 35-40 years. Many of the wild white abalone identified during the 1990s are thought to be >25 years old (Davis et al. 1996) and thus may be approaching the end of their expected life span. If these assumptions are true, a large proportion of the white abalone identified in nature during the 1990s will die within the next decade (Hobday and Tegner 2000).

Diseases associated with mortality of abalone in nature include withering syndrome, which resulted in mortality of >90% of the black abalone population in many areas (Friedman et al. 1997). This bacterial disease infects the gastrointestinal epithelia of abalone and results in lethargy and loss of pedal mass. Withering syndrome occurs in other California abalone, including white abalone, but has been successfully treated with antibiotics in the laboratory. Withering syndrome is not, at present, considered a major factor in the decline of white abalone. However, the spread and virulence of withering syndrome is enhanced by higher than average sea water temperatures. Warmer water conditions associated with climate change and El Niño

events may thus result in increased manifestation of withering syndrome.

Warmer water conditions associated with climate change and El Niño events may also be associated with decreased kelp growth (Tegner et al. 2001) as nutrient availability (e.g. nitrogen) is often inversely related to sea water temperature. Consequently, increased water temperature may deplete a major food source for adult white abalone (Tegner et al. 2001). Severe storms may also result in loss of standing stocks of kelp. Declines in growth or abundance of white abalone as a result of low food availability, however, have not been reported to date.

Abundance and distribution of white abalone may have been affected by competition with sea urchins (*Strongylocentrotus* spp. and *Lytechinus* spp.) and sympatric abalone species. Past competition with pink abalone (*H. corrugata*) has been implicated in restricting the upper depth distribution of white abalone (Tutschulte 1976). Sea urchins and abalone are both herbivorous, thus increased abundance of sea urchins can result in increased competition for available macroalgae. Sea urchins and white abalone may also compete for available crevice space, since both are known to take refuge in rocky crevices. Alternatively, it has been suggested that sea urchins and abalone have a commensal relationship whereby urchins assist abalone in the capture of drift kelp. Densities of these co-inhabitants in areas where white abalone currently reside are low, and thus interactions with white abalone are thought to be minimal at this time.

E. HABITAT CHARACTERISTICS

DISTRIBUTION Adult white abalone occur in open, low relief rocky reefs or boulder habitat surrounded by sand (Hobday and Tegner 2000). Suitable habitat is patchy, thus, the distribution of white abalone is also patchy. The historical range of white abalone extended from Point Conception, California to Punta Abreojos, Baja California, Mexico, with the historical population center located at the California Channel Islands.

Adult white abalone may be found between 5-60 m depths, (Cox 1960), but current remnant populations are most common between 30-60 m depth. A recent survey by Butler et al. (2006), found the highest densities of white abalone at 40-50m depth. Factors controlling the depth distribution of white abalone are poorly known. Biological factors, such as competition and predation, have been implicated as factors controlling the upper limit, while water temperature and food availability have been implicated as factors controlling the lower limit (Hobday and Tegner 2000). Tutschulte (1976) speculated that white abalone may have been restricted to deeper waters (> 25 m) as a result of sea otter predation or competition from pink abalone. Human fishing activities may have also contributed to this deeper depth distribution.

Whether the same habitat is used, or preferred, by both adult and juvenile white abalone, is unknown. There is some evidence that abalone may shift their depth distribution as they age. For example, studies in Australia suggest that *H. roei* juveniles (3-4 m depth) and adults (deeper depths) occupy physically different, and distant, habitat (Wells and Keesing 1990). In California, *H. fulgens* may move into deeper water with increasing age (Leighton pers. comm.).

Good adult habitat is presumed to be where they are currently found: at the sand/rock interface, in water deeper than 30 m. Historically, white abalone were described as a deep-water species (Cox 1960) although they have reportedly been found in water as shallow as 7 m on the mainland coast (Tutschulte 1976). Interviews with former commercial abalone divers also indicate that the majority of adult white abalone taken during the fishery occurred at the sand/rock interface and were located and targeted during daylight hours. The CDFG suggested that white abalone may have been lumped with the landings of pink abalone, because of miss-identification or lack of reporting requirements, and therefore the range and specific locations of white and pink abalone may be different than what we currently infer from the CDFG landing data. For this reason and because fishing effort can not be expressed for the CDFG abalone data, the reported commercial landings of white and pink abalone in California may not accurately reflect their historic distributions and abundance.

Current distribution and habitat use may be residual only, or may be indicative of where abalone successfully settled (e.g., preferred habitat). Some current sites may reflect longer-range transport (e.g., via floating kelp; Bushing 1994, McCormick et al. 2008), and not "historically preferred habitat". For example, red and pink abalone have been observed, rafting on floating kelp, presumably as a result of kelp detachment while the abalones were foraging (Bushing 1994).

ABUNDANCE AND QUALITY OF SUITABLE HABITAT The amount of suitable white abalone habitat is not well known. The bathymetry and substrate characteristics through much of the species' range have not been adequately mapped. Estimates of the amount of available habitat have been based on the assumption that 3% of the sea floor is rocky substrate (Thompson et al. 1993). Davis et al. (1998) estimated the area of rocky reef habitat at 25-65 m depths within the historic range of the species to total 966 ha and to total 752 ha within southern California. A more recent survey by Butler et al. (2006) found >3,000 ha of rocky substrate between 30-60 m in a limited area off the southern California coast.

Impacts on and losses of white abalone habitat as a result of natural and anthropogenic factors are unknown (Hobday and Tegner 2000). Degradation or loss of habitat is not likely to have been a factor contributing to the decline in white abalone abundance. Factors such as pollution, harvesting of algae (e.g. *Macrocystis pyrifera*) and climate change have the potential to affect abalone habitat, but are not known to have affected white abalone habitat. For example, pollution may have led to the loss of kelp forest along the Palos Verdes Peninsula in the 1950s-1960s (Tegner 1989, 1993). Pollution leading to the loss of food, along with other factors such as kelp harvest and poaching by recreational divers, and unusually high recruitment rates of sea urchins leading to competition between urchins and abalone, contributed to the decline of some shallow-water abalone populations (Leighton 1966). Climate change and related increases in sea-surface temperatures may also impact abalone via declines of giant kelp as a consequence of reduced nutrient levels (Tegner 1989). The effect of temperature, however, on white abalone or algal abundance at the depths where white abalone occur, is unknown.

F. CRITICAL HABITAT

Critical habitat has not been designated under section 4(a)(3)(A) of the ESA because it was determined to be "not prudent" to do so. The not prudent determination was made because there was concern that identifying critical habitat would disclose to the public those limited areas where surviving white abalone currently exist and that such an action would increase the threat of poaching to white abalone (66 FR 29048).

G. REASONS FOR LISTING/CURRENT THREATS

LISTING FACTORS AND CURRENT THREATS

(1) The Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

Loss or modification of habitat is not likely to have been a factor in the decline of white abalone. Hobday and Tegner (2000) conclude that natural or anthropogenic white abalone habitat losses are unknown. Due to the isolation of the offshore islands off southern California and northern Baja California, anthropogenic impacts to white abalone habitat should be limited near the islands; however, the mainland habitat may have been affected to an ''unknown extent'' by a variety of unspecified land-based human activities. The potential impacts of future projects that could destroy, alter or curtail habitat, such as dredging operations, cable repairs/construction, liquefied natural gas terminal installation, and nearshore military operations, will have to be analyzed on a case by case basis. The protections afforded by the ESA should help to limit the threats posed by these types of anthropogenic activities and ensure that they do not pose a significant threat to the current or future status of white abalone. Historically, pollution did affect shallow water abalone habitat (i.e., giant kelp forests) along the Palos Verdes Peninsula in the 1950s which resulted in a decline in certain shallow water abalone populations (Leighton 1966). Even though the source of that pollution (DDT) has been controlled, its long-term affects on abalone habitat in that area remain unknown. The effects of other heavy metal industrial pollution and the depths to which pollutants may have an impact, along the Palos Verdes Peninsula in particular, are unknown.

Long-term or short-term changes in ocean conditions, particularly as they relate to water temperature, could affect both larval and adult abalone (Hobday and Tegner 2000), but neither direct nor indirect effects have been documented in the wild. Leighton (1972) examined the effect of water temperature on white abalone larval growth, settlement and survival and found that larval growth and survival were optimized between 14-18 ^{o}C, but that larvae were not successful at 10-12 ^{o}C. Short-term changes in ocean conditions due to El Niño events might raise sea surface temperatures (SSTs) above the optimum for larval growth and survival, and, due to cascading effects stemming from a decline in the *Macrocystis* canopy, could lead to poorer condition of adults (Tegner 1989). The long-term warming trend in SST in the eastern Pacific Ocean (Hayward 1997) may actually increase larval survival as SST approaches the optimum (14-18 ^{o}C) for larval survival in the laboratory; however, SST rise could have a

negative effect on adults for the same reasons mentioned above. The previous discussion is based on effects due to changes in SST and assumes that long- and short-term changes in ocean conditions affect changes in water temperature at depth similarly. The influence of disease (i.e. withering syndrome) may increase during periods of warm water conditions (Moore et al. 2000). Overall the Recovery Team viewed suboptimal water temperatures as posing a moderate threat to white abalone, but had a low level of certainty that this threat was imposing high mortality risk.

Reduced food and/or substrate quality and quantity may have been a factor in the decline of white abalone because of competition for food and space with sea urchins and other abalone species. For instance, increasing trends in abundance of sea urchins (*Strongylocentrotus purpuratus* and *S. franciscanus*) could have limited the amount of algae available for juvenile or adult white abalone consumption (Hobday and Tegner 2000). Although these potential ecological interactions may have had an impact historically, the densities of these potential competitors are currently low in areas where white abalone remain and are no longer likely to limit white abalone abundance (Hobday and Tegner 2000).

(2) Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

White abalone abundance has declined significantly throughout its range as a result of overutilization for commercial and recreational purposes. Hobday and Tegner (2000), as well as others (Estes and VanBlaricom 1985), suggest that white abalone in California were subject to ‘‘serial depletion’’ by the commercial fishery during the early 1970s. Serial depletion occurs as fishermen shift from exploited to unexploited fishing areas due to local depletion. Due to their life history characteristics as long-lived, slow moving bottom dwellers with external fertilization, abalone are particularly susceptible to local and subsequent serial depletion. If female abalone are not within a few meters of males when they both spawn, the sperm will be too diluted by diffusion to fertilize the eggs (Davis et al. 1996). As local abalone density declines, the probability of successful fertilization and subsequent recruitment decreases. It is evident to recovery team members and abalone experts world-wide that the most significant threat to white abalone is related to the effects of low population density on continued white abalone reproduction, survival and recovery.

White abalone catch data from California indicate that over 80 percent of the white abalone landings were taken from San Clemente Island. The offshore Tanner Bank and Cortes Bank-Bishop Rock region provided 13 percent of the total catch. Between 1965 and 1975, over 25 percent (average 43 percent) of the white abalone catch in each area came from a single year (Hobday and Tegner 2000). If harvest was sustainable, the portion of catch harvested each year at each location should have been more consistent over a period of years. Region-wide landings of white abalone peaked at 144,000 lbs (65,318 kg) in 1972 after only 3 years of commercial exploitation, and declined to less than 10,000 lbs (4,535 kg) in 1977. By 1978, white abalone landings were so negligible (<1,000 lbs or 454 kg) that CDFG no longer collected landings data for the species. It has been suggested that the increasing value of abalone may have contributed

to increased fishing pressure (Estes and VanBlaricom 1985, Hobday and Tegner 2000, Karpov et al. 2000). For example, the price of white abalone increased from about $2.50 per pound in 1981 to about $7 per pound in 1993. As the catch of all abalone declined, the total and per-unit value of the harvest continued to increase. White abalone was usually the most valuable species and by 1988, white abalone was worth twice the value of other abalone species (Davis et al. 1996).

According to studies conducted by Babcock and Keesing (1999), recruitment failure occurred in *H. laevigata* when densities of adults fell below 0.3-0.15 per m^2 or when males and females were greater than 2 m apart from one another. Assuming that these critical densities for *H. laevigata* populations are similar to those required for self-sustaining white abalone populations, intense fishing pressure is likely the primarily cause for producing critically low densities in populations throughout most of white abalone's historic range in Southern California. Low density has likely led to repeated recruitment failure and reduced genetic diversity within and across populations of white abalone in California.

(3) Disease or Predation

Withering syndrome is a fatal disease of abalone, *Haliotis* spp. (Haaker et al. 1992) caused by a ricksettia-like bacterium that affects the digestive epithelium of abalone (Friedman et al. 2000). Disease transmission is thought to be density dependent (Friedman and Moore, pers. obs.). First detected in 1985, withering syndrome disease has significantly affected west coast abalone species, especially the black abalone. Withering syndrome also occurs in pink, red, and green abalone (Altstatt et al. 1996). Although no wild white abalone have been observed with withering syndrome or its causative agent (the intracellular bacterium, "*Candidatus xenohaliotis californiensis*", Friedman et al. 2000), this species is susceptible to the disease in captive settings (Moore, Robbins, and McCormick pers. obs). Hobday and Tegner (2000) suggest that large numbers of empty white abalone shells should have been detected during the abalone surveys of the late 1980s if white abalone were significantly affected by withering syndrome. During the early 1990s, a few freshly dead white abalone with undamaged shells were observed near Santa Catalina (Tegner et al. 1996), but the cause of mortality is uncertain. To date only seven wild white abalone have been sampled for withering syndrome (all have tested negative) and information on susceptibility is based on captive progeny from wild brood stock. A large number of captively-bred white abalone at the Channel Islands Marine Resource Institute (CIMRI) recently (2002-2005) died and showed symptoms of withering syndrome. While withering syndrome may affect white abalone at some frequency in a captive setting, it is unlikely to have been a major factor in the decline of the species in the wild.

Laboratory studies have confirmed that temperature is important in transmission and development of clinical disease (Friedman et al. 1997, Moore et al. 2000). Red abalone exposed to temperatures ~18° C develop clinical disease, while those held at ~15 °C remained healthy (Moore et al. 2000). Recent data from McCormick et al. (unpubl. data) indicated that white abalone reared at temperatures $\leq$12° C, while infected with the withering syndrome-bacterium, remained free of clinical disease. However, those reared at 15 or 18° C developed withering

syndrome and had heavy bacterial infections as compared to those held at 12° C. These data combined with the magnitude of losses experienced by white abalone that were not treated with a therapeutant to reduce bacterial infections suggest that this species is highly susceptible to this pathogen and this must be considered in the recovery plan. In addition, these data suggest that habitat selected for white abalone supplementation should consider the temperature regime of outplant sites as well as the health status and density of sympatric abalone. Although disease was not considered as a threat to the declines that led to listing of white abalone, it is clear that disease (especially withering syndrome) is a threat to effectively recovering the species. Withering syndrome research is necessary to determine: 1) what habitat parameters might lessen the likelihood of infection in the wild; 2) whether resistant animals exist in the population; and 3) which treatment protocols are most effective in eliminating the spread of withering syndrome from infected to healthy animals.

Several abalone predators have been documented, including sea stars, fish (e.g. cabezon, sheephead), crabs, octopuses, and sea otters (O'Connell 1955, Gotshall 1977, Hobday and Tegner 2000). Although increases in abundance of these predators could be related to declines in white abalone abundance, no information is available on the density of the invertebrate predators in white abalone habitat. Predation by sea otters is not likely to have been a major factor in the decline of white abalone due the absence of sea otters within the range of white abalone during their decline. In summary, there is no evidence that disease or predation contributed to the decline of white abalone, and the extent to which predation will influence recovery potential remains unclear (see section I. Known Biological Constraints/Needs).

(4) The Inadequacy of Existing Regulatory Mechanisms

White abalone experienced significant declines in abundance throughout its range as a result of commercial over harvesting, therefore harvest regulations for white abalone during the major period of its decline in the 1970s were clearly inadequate to conserve the species and maintain white abalone harvest at sustainable levels. The establishment of minimum size limits has been a strategy used worldwide to manage the harvest of abalone on a sustainable basis (Hobday and Tegner 2000). In California, minimum size limits were established for abalone that were greater than the size of sexual maturity which should have allowed for several years of reproduction before the animals reached legal harvest size. However, successful reproduction does not necessarily occur every year. If reproductive failure persists for several years, mature abalone could attain legal size and be removed by the fishery without having successfully reproduced.

Other measures were taken to regulate the abalone fishery. California prohibited abalone harvest during a portion of the spawning season (January through March). While this measure was likely ineffective for most species of abalone, the closure period did overlap substantially with the white abalone spawning period. Other regulations, such as bag limits for recreational fishermen, and limited entry, were also implemented by California as abalone management measures. In 1970, California established a permit fee of $100 for both divers and crew members (Burge et al. 1975, cited in Hobday and Tegner 2000). The diver fee increased to $200

in 1975 and finally reached $330 in 1991. Relative to permit fees charged by other countries to harvest abalone (e.g., Tasmania, South Australia), these relatively low fees did not promote sustainable abalone fishing in California. In fact, none of these measures prevented serial depletion of white abalone nor promoted sustainable harvest practices in the 1970s. In 1996, the California Fish and Game Commission closed the California white abalone fishery to protect the surviving adults (Davis et al. 1998).

NMFS does not have formal documentation that Mexico has closed its commercial white abalone fishery or limited white abalone fishing, although in a meeting convened in Ensenada, Baja California, Mexico in June 2003, the Instituto Nacional de la Pesca (INP) stated that Mexico currently does not issue permits for harvesting white abalone. In addition, the INP presented preliminary results from a status review of white abalone. The INP has identified areas along shore and at the offshore islands and banks that did or currently do contain white abalone based on responses to questionnaires that were sent out to the local abalone management zones (cooperatives). The INP, in cooperation with the cooperatives, and possibly NMFS, would like to ground truth these qualitative data by surveying specific locations with remotely operated vehicles and multi-beam sonar.

The intentional capture of sub-legal abalone (i.e., poaching) before they contributed substantially to the population could have reduced the reproductive potential of white abalone (Hobday and Tegner 2000); however, this is not likely to have been a major factor in the decline of white abalone in California because the State required all commercially caught abalone to be landed in the shell. In Mexico, during a survey in 1973, a substantial portion of the commercial white abalone catch was found to be undersized. The impact of illegal white abalone harvesting as a factor of the species' decline is difficult to evaluate in Mexico, but was probably not a major factor in California. Poaching could be a problem in California in the future if recovery actions are successful and populations recover and expand. Also, as we continue to learn more about white abalone populations in Mexico, we may learn that poaching was and is a factor affecting the species' viability. Unintentional take of abalone may have resulted from accidental, severe, cutting of sub-legal sized white abalone (Burge et al. 1975) because abalone do not have blood clotting ability and may suffer mortality as a result (Cox 1962, Hobday and Tegner 2000). Even undersized abalone that are handled and replaced without being cut suffer a 2 –10 % mortality in the field due to increased capture rates by predators on individuals that have not yet had a chance to reattach to the substrate.

Inadequate enforcement is another factor that may have contributed to the decline of white abalone and could continue to do so should populations recover and expand. The combined enforcement staff for the State and the Federal agencies is small and their ability to monitor potential poaching activities is very limited given the difficulty of accessing areas where white abalone currently persist and where they may be outplanted in the future. Increased funding and better coordination among the agencies may help resolve future enforcement challenges.

(5) Other Natural or Manmade Factors Affecting Their Continued Existence

Some argue that hybridization of white abalone with other more abundant California abalone species could potentially lower white abalone population size (Hobday and Tegner 2000). Natural hybridization between other California abalone species and white abalone has been observed. Owen et al. (1971) found that disturbance, high sea urchin frequency, and low abundance of one parent species increased the frequency of abalone hybrids. However, because large numbers of white abalone hybrids have not been found in the wild, Hobday and Tegner (2000) conclude that hybridization of white abalone with other abalone species is unlikely to have led to a decline of the species.

Now that it is known that white abalone are highly susceptible to withering syndrome (and potentially other pathogens) in captive settings, another emerging threat to the species is that of spreading disease through supplementing wild populations with captive-reared animals. As mentioned above, under "Listing Factor (3) - Disease or Predation", the risk due to this threat can be minimized if directed research efforts reveal: 1) what habitat parameters might lessen the likelihood of infection in the wild; 2) whether resistant animals exist in the population; and 3) which treatment protocols are most effective in eliminating the spread of withering syndrome from infected to healthy animals.

Another factor that has hindered the recovery of white abalone is an inability to implement conservation and research efforts for a variety of reasons including: limited funding; and lack of coordination among the agencies, academia, and non-governmental organizations.

CURRENT THREATS

The following threats currently put the white abalone at risk of extinction and are listed in order of their magnitude (high to low). These threats will be considered during the recovery planning process. In addition, the recovery plan will identify critical research questions that must be answered in order to gain a better understanding of the basic biological and ecological needs of the species and ultimately, ensure its continued existence.

- Critically low levels of abundance (< 0.1 % of the estimated pre-exploitation population size) resulting in increased distance between individuals and repeated recruitment failure (Allee Effects; Allee 1931).
- Inability to implement conservation and research efforts
- Inadequate enforcement
- Reduced genetic diversity resulting in lower reproductive potential and fitness of wild populations
- Spread of disease through supplementation
- Illegal harvesting
- Habitat modification through human activities
- Habitat modification through environmental/climate change

Table 5. Threats assessment table for the wild population of white abalone in California. A=adult, J=juvenile, L=larval, H=historic, C=current, F=future. Historic threats are those that occurred historically, but do not occur at present. Current threats are those occurring now. Future threats are those likely to affect white abalone over the next ten years. VH=very high, H=high, M=medium, L=low. Overall rankings range from 1-10, with 1 being the highest priority and 10 being the lowest priority. The recovery actions refer to the actions listed in Part IV of the recovery plan.

Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historic, Current or Future**	**Severity**	**Geographic Scope**	**Level of Certainty that Species is affected**	**Recovery Action**	**Likelihood of Recovery Actions Reducing Threat**	**Overall Ranking**
Habitat destruction, modification, or curtailment	Substrate Destruction	Dredging Cable Repairs Nearshore military operations Benthic community shifts Long and short-term climate change	Mortality Reduced growth	A, J, L	C, F	L	L	L	2, 3	H	7
	Suboptimal water temperatures and water quality	Anthropogenic thermal (+ or -) effluent Long and short-term climate change	Mortality Reduced growth	A, J, L	C, F	M	H	L	2, 3	M	8
	Reduced food quantity and quality	Long and short-term climate change Kelp harvest Competition	Mortality Reduced growth	A, J, L	F	M	M	M	2, 3	L	9
	Environmental pollutants/toxins	Sewage Agricultural runoff Industrial waste	Mortality Reduced growth	A, J, L	C, F	L	L	L	2, 3	L	9
Overutilization	Low density	Historic overfishing Current distribution pattern	Reproductive potential	A	H, C, F	VH	VH	VH	1, 3, 4	M	1
	Reduced genetic diversity	Historic overfishing Current distribution pattern	Reproductive potential Mortality	A	H, C, F	M	H	M	1, 3	H	4
Disease and Predation	Disease	Endemic bacterium and unknown	Mortality	A, J	F	M	M	M	4	L	9
	Predation	Sea Otter, Fishes, Invertebrates	Mortality Behavior Reduced growth	A, J	H (sea otter), C (fishes, inverts.), F (all predators)	M	M	M	3, 4	L	9

Listing Factor	Threat	Source	Key Ecological Attributes Affected	Life Stage Affected	Historic, Current or Future	Severity	Geographic Scope	Level of Certainty that Species is affected	Recovery Action	Likelihood of Recovery Actions Reducing Threat	Overall Ranking
Inadequate Regulatory Mechanisms	Inadequate Enforcement	Inadequate funding and lack of coordination between agencies	Indirect mortality	A, J	H, C, F	H	H	M	5, 6	M	3
	Illegal Take	Poachers/Accidental take	Reproductive potential Mortality	A, J	H, C, F	H	H	H	3, 5, 6	L	6
	Inability to Implement Conservation and Research Efforts	Inadequate funding and lack of coordination between agencies	Indirect mortality	A, J, L	H, C, F	VH	H	H	1-6	M	2
Other	Hybridization	Close proximity to congeners	Reproductive potential Behavior Genetic integrity	A, J, L	C, F	L	L	L	1, 3	L	10
	Supplementation	Disease transfer between captive and wild populations	Mortality	A, J	F	L-H*	H	H	4	M	5
		Genetic interactions between captive and wild populations	Reduced fitness	A,J, L	F	L	H	L	4	H	9

Table 6. Threats assessment table for the captive population of white abalone in California. A=adult, J=juvenile, L=larval, H=historic, C=current, F=future. Historic threats are those that occurred historically, but do not occur at present. Current threats are those occurring now. Future threats are those likely to affect white abalone over the next ten years. VH=very high, H=high, M=medium, L=low. Overall rankings range from 1-4, with 1 being the highest priority and 4 being the lowest priority. The recovery actions refer to the actions listed in Part IV of the recovery plan. * Recall that some captive facilities are relying on ambient seawater for spawning and rearing white abalone.

Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historic, Current or Future**	**Severity**	**Level of Certainty that Species is affected**	**Recovery Action**	**Likelihood of Recovery Actions Reducing Threat**	**Overall Ranking**
Habitat destruction, modification, or curtailment	Suboptimal water temperatures*	Long and short-term climate change	Mortality Reduced growth	A, J, L	C, F	H	M	4	M	3
Overutilization	Reduced genetic diversity	Historic overfishing	Reproductive potential Mortality	A, J, L	H, C, F	H	H	4	H	2
Disease and Predation	Disease	Endemic bacterium and unknown	Mortality	A, J	C, F	VH	H	4	H	1
Other	Catastrophic events	Equipment failure Human error	Mortality	A, J, L	H, F	H	H	4	H	2
	Inadequate security	Illegal take Human error	Mortality	A, J,L	H	M	M	4, 5	M	4
	Hybridization	Breeding between congeners	Reproductive potential Behavior Genetic integrity	A, J, L	C, F	L	L	4	VH	4

H. CONSERVATION MEASURES

The following are conservation measures that have been undertaken for white abalone. In some cases these conservation efforts are relatively new and may not have had time to demonstrate their biological benefit. In such cases, provisions for adequate monitoring and funding of conservation efforts are essential to ensure intended conservation benefits are realized.

PRIVATE-PUBLIC PARTNERSHIPS

Due to concern over the depleted status of white abalone, a consortium of scientists, fishermen, conservation organizations, universities, federal and state agencies, and mariculturists in private enterprise joined together to develop and execute a plan to restore white abalone populations (Davis et al. 1998). The White Abalone Restoration Consortium (Consortium) developed a four-step restoration plan: (1) Locate surviving white abalone by surveying historical habitat; (2) collect brood stock; (3) breed and rear a new generation of juveniles and ultimately, brood stock; and (4) reestablish refugia of self-sustaining brood stocks in the wild. Because nearly 25 years of artificially producing and outplanting juvenile and younger red abalone in California have failed to demonstrate effective population restoration, the Consortium advocated that captive-born white abalone be reared until 4 years of age (>100 mm or 4 inches).

Federal, state, and private grants and funds have recently supported white abalone submersible surveys and the establishment of an aquaculture facility specifically designed to breed white abalone in captivity and rear offspring to adulthood for outplanting to the wild.

NATIONAL MARINE FISHERIES SERVICE CONSERVATION MEASURES FOR WHITE ABALONE

The NMFS, following the recommendations of the Consortium, has led efforts to locate surviving white abalone by surveying historical habitat in Southern California and Baja California, Mexico. In addition, NMFS has collaborated with partners to collect brood stock for a captive propagation and enhancement program, identified and characterized habitat that may be targeted for future enhancement efforts, and promoted outreach and education efforts by helping to develop displays at local aquaria.

NATIONAL PARK SERVICE CONSERVATION MEASURES FOR WHITE ABALONE

The Channel Islands National Park has been monitoring natural variation in recruitment of abalone through the use of cinder block test modules since 1989 at a variety of locations and this monitoring has revealed important information regarding where to focus future enhancement efforts. The Channel Islands National Park has also collaborated with members of the Consortium to collect brood stock for a captive propagation and enhancement program and achieve outreach and education goals.

NATIONAL MARINE SANCTUARY CONSERVATION MEASURES FOR WHITE ABALONE

The Channel Islands National Marine Sanctuary has provided important logistical and staff support for members of the Consortium to monitor abalone recruitment, collect broodstock for a captive propagation and enhancement program, and promote outreach and education goals for white abalone within the Sanctuary.

STATE OF CALIFORNIA CONSERVATION MEASURES FOR WHITE ABALONE

Because the State required that abalone fishermen submit landings data, the precipitous decline of white abalone in the 1970s was documented. As mentioned previously, the State closed white abalone fishing in 1996, thereby eliminating the factor most responsible for the species' decline. The closure of all abalone fisheries in southern California in 1997 has also reduced the likelihood of accidental harvest or poaching of white abalone in California.

The CDFG has conducted and/or participated in several SCUBA and submersible surveys documenting the distribution and abundance of white abalone (1980-81, 1992-93, 1996-97, and 1999). The data and information gathered from these surveys have contributed to a better understanding of the decline of white abalone.

Despite these state conservation measures, the species may not survive without human intervention because most of the remaining individuals are too far apart to successfully reproduce.

MEXICAN CONSERVATION MEASURES FOR WHITE ABALONE

There is information indicating that Mexico has closed its white abalone fishery; however, NMFS is unaware of other conservation measures that Mexico may be implementing to protect the species. Pursuant to 50 CFR 424.16, NMFS provided Mexico with a notification that it had published a Federal Register document proposing to list the white abalone which occurs along the coast of both the USA and Mexico, and also invited Mexico to provide any information or comments it may have on the proposal. In addition, NMFS requested that Mexico provide the agency with information on any conservation measures it may have implemented to protect the white abalone.

In June 2003, a meeting convened in Ensenada, Baja California, Mexico between NMFS and the INP. The INP stated that Mexico currently does not issue permits for harvesting white abalone. Also, the Mexican Abalone Cooperativos (local abalone management zones) have generally not permitted white abalone harvest since about 1996. The INP presented preliminary results from a status review of white abalone. The INP has identified areas along shore and at the offshore islands and banks that did or do contain white abalone based on responses to questionnaires that were sent out to the Abalone Cooperativos. The INP, in cooperation with the Abalone Cooperativos, and possibly NMFS, would like to ground truth these qualitative data by surveying

specific locations with remotely operated vehicles and multi-beam sonar.

I. KNOWN BIOLOGICAL CONSTRAINTS/NEEDS

The main biological constraint for white abalone is that self-sustaining wild populations cannot be maintained, nor can damaged populations be restored, when adult densities drop below critical values. Indeed critically low densities have led to poor recruitment success over a period of three decades. Data collected by the National Park Service annually at the northern Channel Islands since the mid-1980's and from ROV/Submersible cruises conducted from 1980-1981, 1990-1991, 1996-1997, 1999, and 2002 (Davis et al. 1996, Davis et al. 1998, Hobday et al. 2001, Lafferty et al. 2004, Butler et al. 2006) suggest that recruitment has been negligible since the early 1970s. The low numbers of surviving animals identified over the past 23 years (< 300 animals summed over all years), absence of emergent adults in the smallest detectable size class, and the detection of primarily solitary animals that are greater than 150 mm and over 10 years old (Tutschulte 1976), lend evidence to support the "negligible recruitment" argument. In addition, aggregative behavior has never been observed in any of the California species (Leighton 2000). The white abalone fishery ended in the late 1970s according to CDFG records, even though it took another 15 years to officially close the fishery. Thus, cryptic stage juveniles, if there were any, should have been detected in surveys conducted over the past 30 years. The chances of successful recovery of the species are near zero if we do not take action now. The data that exist to date provides evidence that recruitment is negligible throughout most of the former range of white abalone and the current data on density from areas where they have been located suggest that they are not close enough together to spawn (85% of the animals identified in 2002 were separated by linear distances that exceeded 10 m).

White abalone suffer from a variety of disadvantages many of which link back to the fact that this species has rarely been the focus of scientific investigation. White abalone habitat was remote enough to make scientific investigation logistically difficult, but not remote enough to deter commercial and recreational fishers from exploiting them. Thus, much of what we know about white abalone is inferred from research that has been conducted with other species. Some of the most pressing questions that remain for white abalone are: 1) What is the minimum size of a viable white abalone population? 2) What is the current genetic connectivity between surviving populations and what kind of connectivity might have existed historically? and 3) What ecosystem parameters are required for promoting healthy larvae, juveniles and adults that can survive in the wild? These questions are the most pertinent because they directly affect the course that recovery planning should take.

With regard to question 1), it has been suggested for *H. laevigata* that densities between 2000-3000 animals per hectare, maintained throughout the spatial extent of the population, are necessary to sustain the population under fishing pressure. For *H. rufescens* along the northern coast of California, 1000 animals per hectare is not viable, but 8300 per hectare is viable and sustains a recreational fishery (Rogers-Bennett pers. comm.).

With respect to question 2) an examination of the connectivity among existing populations of white abalone can be assessed using population genetic data. Levels of connectivity are determined by analyses of multiple genetic markers scored on individuals sampled from different geographic locations. Some species of abalone show extensive population differentiation (hence low connectivity), while others show no genetic differentiation of populations (high connectivity). Recent studies suggest that connectivity of black abalone populations over large spatial scales is relatively low (Hamm and Burton 2000), but is likely maintained by occasional chance large-scale dispersal events, and connectivity on smaller spatial scales (i.e. between sites at San Nicolas Island) is somewhat greater (Chambers et al. 2005, Chambers et al. 2006). The situation in white abalone cannot be assessed until samples become available from multiple geographic locations. If genetic samples are available for animals collected prior to the fishery are available, then historic levels of connectivity can be estimated. It is unlikely, however, that enough historic samples exist to conduct these analyses.

With respect to question 3), while we know something about temperature optima for white abalone larval survival and settlement in the laboratory, very little else is known about abiotic (e.g., temperature, current speed and direction, substrate type and rugosity) and biotic (prey availability, predation, competitive interactions) factors that may affect growth and survival of early life stages. It is possible that otters (and other predators) may influence the future recovery potential of white abalone. This concept, where prey species are regulated at very sparse densities by their predators, is known as a "predator pit" (Holling 1959, Morris 1963). "Predator pits" have been documented for a number of recovering species (zebras, rabbits, ungulates) and in at least one marine system (Baltic Sea cod; Bakun 2006). It is possible that this interaction may be relevant to predicting sea otter predation on abalone, however there is uncertainty about the likely patterns of interaction between sea otters and abalone in the context of abalone recovery.

Three major limitations for the recovery of white abalone are 1) lack of funding for a captive propagation and enhancement program; 2) persistent disease problems at CIMRI since 2002; and 3) an inability to identify mechanisms (i.e. adequate funding and streamlining of the permitting process) for establishing multiple scientific research and enhancement facilities, even though a team of international abalone experts has been recommending this approach since 2001. Time delays created by these issues have caused additional biological constraints for this species because most animals identified during the 1980's, 1990's and 2000's (roughly 80%) are now approximately 30 years old according to 1) Tutschulte's (1976) growth model; and 2) evidence suggesting negligible recruitment since the 1970's. White abalone may live 40 years (Tutschulte 1976), thus it was predicted that the species could go extinct within 10 years in the status review (Hobday and Tegner 2000).

II. RECOVERY STRATEGY

A. KEY FACTS AND ASSUMPTIONS

Although the state of California implemented a variety of fishing restrictions in the 1970s, 1980s and 1990s in an attempt to protect and conserve white abalone, the total population decreased to <0.1% of its estimated pre-exploited size by the late 1990s. Overfishing by commercial and recreational fishers and inadequate regulation of the fishery led to the decline of white abalone. In spite of the fact that the fishery has been closed since 1996, illegal take of the animals, disease, predation, and habitat degradation through long-term climate change pose the greatest threats to the conservation and recovery of the species.

Research conducted during the 1990s suggested that even with the closure of the white abalone fishery in 1996 that: 1) white abalone remaining in nature were primarily > 2 m apart from one another (Davis et al. 1998); 2) most survivors observed were ≥ 13 cm in shell length (Davis et al. 1998, Behrens and Lafferty 2005); and 3) the highest estimated densities recorded during the 1990s were at least two orders of magnitude lower than estimated densities prior to the fishery (Hobday et al. 2001). During the 2000s ROV and multi-beam sonar surveys of two shallow banks off of the southern California coast revealed that the white abalone population may be higher on just two offshore banks in southern California (approximately 12,820 for Tanner Bank and approximately 7,360 for Cortes Bank) than was thought during the 1990s for California and Mexico combined (approximately 2, 600 animals; Hobday et al. 2001). In spite of the revised population estimate, the viability of animals in the wild remains uncertain because: 1) primarily large (>13 cm in shell length) animals were detected on the two offshore banks; and 2) most animals were >2 m apart from their nearest neighbor.

Based on this information, the following conclusions were made: 1) surviving white abalone are too far apart from one another and occur in densities too low for successful spawning and therefore, their reproductive potential is near zero; 2) the size distribution of survivors and the morphology of their shells suggests that a major recruitment event has not been observed since the early 1970s and the animals are approaching the end of their lives. If these conclusions are to be accepted, then the following assumptions must be true: 1) observations of white abalone in nature are an accurate portrayal of the species occurrence, distribution and abundance in the wild (i.e., no size-dependent sampling biases); and 2) white abalone do not move enough (on the order of 10's of meters) to form aggregations dense enough to spawn successfully. These assumptions lead to the ultimate assumption that animals in the wild are not reproductively viable and that substantial recruitment in nature has not and will not occur in the future.

B. PRIMARY FOCUS AND JUSTIFICATION OF RECOVERY EFFORTS

The proposed recovery approach serves to address the most pressing gaps in our knowledge and targets the elimination of threats so that the recovery goals outlined in this plan have the greatest likelihood of being achieved. The recovery effort for white abalone will entail several foci, some

of which will be conducted simultaneously and some of which will necessarily follow others. The first of these is the assessment and monitoring of wild white abalone populations. This is crucial to the recovery effort because more accurate estimates of abundance, habitat availability, growth and mortality, and a better understanding of the spatial distribution of animals, metapopulation and genetic stock structure, and habitat requirements are necessary for guiding the course of enhancement activities and protecting surviving populations. For instance, the course that enhancement of the wild population with captive animals will take is directly dependent on the outcome of monitoring studies and the outcome of studies that will be conducted with captive-reared animals. More accurate estimates of white abalone fecundity and fertilization success, effects of temperature, diet and habitat type on growth and survival, and a better understanding of the impacts of disease (withering syndrome) on captive and wild populations will provide insight on minimum viable population size and conditions for promoting optimal health of animals in the wild.

Field monitoring of populations and their habitat will significantly improve our understanding of the current status of the white abalone population in California and optimistically, throughout the full extent of the white abalone range into central Baja California, Mexico. Carrying out this action is a high priority because the course of the other recovery actions will be defined by the outcome of long-term field monitoring. Improving the accuracy of available habitat estimates will provide better confidence in both historic and current estimates of abundance and density. Evidence of whether surviving populations are viable will become evident as emergent recruits are detected by sampling gears. Because successful recruitment may occur at a decadal scale, and because new recruits may be cryptic for a relatively long period of time (2-3 years), it is crucial that the surveys be conducted at multiple locations (areas where surviving white abalone populations have been identified in the recent past), annually, over the course of at least ten years. Better estimates of minimum viable population size will be derived over time as survey data accumulates. Understanding the size and age structure of white abalone populations will enable us to better evaluate recruitment, growth, and population integrity for conservation of this species. In addition, these data will provide information necessary to develop enhancement protocols. A better understanding of the existing genetic structure of the population is crucial for determining how many and over what spatial extent, populations should be established in order to consider delisting. If extant populations are identified at workable SCUBA diving depths, additional research priorities include: tagging studies to estimate individual rates of movement, growth and mortality and nearest neighbor analysis to determine the importance of spatial structure on viability of populations in the wild (Allee Effects; Allee 1931).

Existing and potential white abalone habitat will be identified and characterized through acoustic remote sensing technology. Abiotic and biotic characteristics of the habitat that white abalone occupy (e.g., habitat type, temperature, current speed and direction, other species present) will also be collected during surveys to better understand which characteristics are important for promoting white abalone growth and survival at all life stages.

Protection of populations and their habitat in the wild will occur by promoting the establishment of Marine Protected Areas (MPAs) that overlap with surviving populations and potential outplanting sites. Securing the financial support for the establishment of a stronger state and federal enforcement presence in the near-coastal waters of Southern California would promote the protection of surviving populations and populations that may be established in the future. Protection will be achieved through state and federal regulations that focus on populations in California. Pursuant to Section 3(16) of the ESA, white abalone is listed throughout their range from Pt. Conception, CA, USA, to Punta Abreojos, Baja California, Mexico. There will be a concerted effort to establish a white abalone technical advisory team within Mexico and to build relations with the Mexican government and Abalone Cooperativos over time to ensure the conservation and protection of white abalone populations in Mexico. The execution of this recovery action is crucial for eliminating or lessening the effects of threats on white abalone (i.e. habitat modification, illegal harvest). This action also promotes the protection and conservation of the entire kelp forest ecosystem of which white abalone are an integral part and upon which they depend for long-term survival. Long-term protection will also depend on public understanding and stewardship of the species. This will be accomplished through a public outreach program (see below).

Captive propagation for enhancement of wild populations will occur by continuing the effort begun prior to ESA listing to spawn captive white abalone and rear their progeny. Captive propagation of healthy white abalone is of equal importance to monitoring because most of the evidence to date suggests that white abalone are locally extinct throughout a significant portion of their range and because there is no evidence to suggest that surviving populations of white abalone in the wild are viable. The white abalone recovery team recommends that multiple scientific research and enhancement facilities, namely CIMRI, the Bodega Bay Marine Laboratory (BML), and the NOAA Southwest Fisheries Science Center (SWFSC), carry out these pertinent studies for white abalone because 1) each facility provides a unique set of scientific and culture expertise; 2) each facility possesses different capabilities in managing water quality, and therefore may possess different capabilities in maintaining healthy captive animals; and 3) housing captive animals in multiple locations offers a safeguard against losing all animals in the case of a catastrophic event. Captive propagation of white abalone will occur simultaneously with monitoring activities because of the time it will take to develop techniques for the production of healthy animals. The captive rearing program will expand by attaining additional broodstock to better reflect existing genetic diversity in natural white abalone populations. Reestablishment of white abalone throughout its former historic range, in densities high enough to be self-sustaining, will be achieved by placing captive-reared animals in the wild. This focus is directly dependent on conducting pertinent studies with captive-bred animals that determines the factors most important for promoting the health, growth, and survival of all life stages of white abalone.

A captive propagation program is currently underway at CIMRI. This program which has been underway since 2000, has achieved broodstock holding, maturation, and spawning. Larvae, juveniles, and adult animals are being successfully raised on a large scale. There are currently

five pedigreed families of abalone in the hatchery ranging in age from two months to two years. Care has been taken to maximize genetic diversity; however, the nascent breeding program is now seriously restricted by the present availability of only six wild broodstock. The decay in genetic diversity is inversely proportional to the effective population size and given this effective population size, each generation produced from these individuals will result in an approximate 10% loss of genetic diversity (Hedrick et al. 2000). Recently, McGinnity et al. (2003) determined that in farmed raised populations of Atlantic salmon, attaining a broodstock population of at least 50 breeding pairs (single parent crosses = 1 male x 1 female) reduced losses in genetic diversity to 1% per generation. In order to maximize chances for survival and ability to adapt to environmental changes, it is important to maximize the genetic diversity (or avoid in-breeding) in captive populations. Although abalone are highly fecund individuals and are capable of producing over 100,000 progeny per spawn, it is necessary to retain adequate numbers from each spawn to attain recovery goals (achieve numbers for supplementation while maximizing genetic diversity). The ultimate goal of the captive propagation program is to produce white abalone for eventual outplanting.

The recovery team recognizes that the collection of additional broodstock from the wild is necessary in order to maintain the genetic integrity of the captive propagation and enhancement program, but also realizes that this recovery action may pose risks of 1) further reducing wild white abalone density, and genetic diversity in California; and 2) further altering the age structure of the wild white abalone population in California. The recovery team built a simple deterministic model to assess the risk of extinction associated with removal of white abalone broodstock from the wild population in California over the next 100 years. The model assumes both optimistic (N=34,000; Butler et al. 2006) and pessimistic (N=1600; Hobday and Tegner 2000) estimates of total population abundance and optimistic $\lambda=1.0\pm0.1$ and pessimistic $\lambda=0.9\pm0.3$ finite rates of population increase (Figure 7). For scenarios with captive management (B, C), the recovery team used values proposed by Scientific Research and Enhancement Permit applicants T. McCormick and J. Butler. In particular, the models assumes that 50 animals are removed in years 1-3, 20 animals are removed in year 4, and 500 and 1000 animals are reintroduced in years 5-6 and 7-15, respectively. This model predicted that the cumulative probability of extinction increases from 0 to 1 at a faster rate when no supplementation of the wild population (scenarios A, D) occurs regardless of whether optimistic or pessimistic values of N and λ are chosen. Even under the optimistic scenario, with no supplementation, extinction was likely to occur by year 50. Supplementation of the wild population with captive animals did not stabilize the population; however, this condition did extend the probable time to extinction by at least an additional 40 years. This analysis suggests that a captive propagation program would not likely cause the population to reach extinction at a faster rate than it would without supplementation and in fact, might extend the time to extinction in the wild.

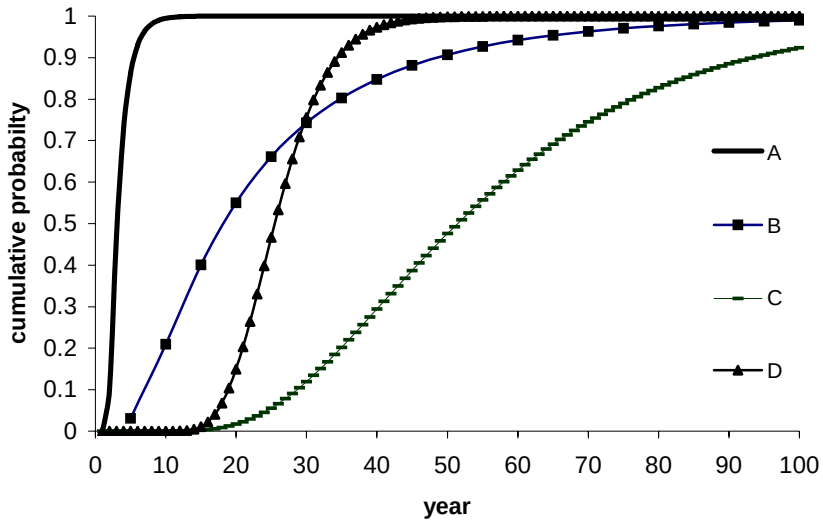

Figure 7. Cumulative probability of extinction (CPE) for white abalone. CPE was estimated using a diffusion approximation of simulated time series based on 4 scenarios: with captive management (B,C) and without captive management (A,D) for optimistic (C,D) and pessimistic (A,B) scenarios regarding population status. For optimistic scenarios (C, D), we assumed λ=1, standard deviation for λ =0.1, and No=34,000. For pessimistic scenarios (A,B), we assumed λ =0.9, standard deviation for λ =0.3, and No=1600. For scenarios with captive management (B, C), we used values proposed by Scientific Research and Enhancement Permit applicants T. McCormick and J. Butler. In particular, 50 animals are removed years 1-3, 20 animals are removed year 4, and 500 and 1000 animals reintroduced for years 5-6 and 7-15, respectively.

The Team also recognizes that this model makes another important assumption; captive animals introduced into the wild have the same reproductive fitness and survivorship as wild white abalone and outplanted individuals used for enhancement will help achieve self-sustaining populations in the wild. McCormick et al. (1994) provides a review of the success of abalone outplanting studies up until 1992 (see his Table 2). Percent survival in these studies ranges from 0-90% and seem to indicate that abalone outplanted at sizes > 40mm have the highest survival rates (but see Tegner and Butler 1985). Table 7 provides a summary of more recent studies (post-1993) that have reported survival rates of field planted, captive-reared abalone. If 500 animals are outplanted for two years and then 1,000 animals are outplanted for each year thereafter (these are conservative numbers based on what was proposed by Scientific Research and Enhancement Permit applicants), it would take five years, with an annual outplanting survival rate of 5%, to replace the 170 broodstock removed from the wild. The list of references supplied below in Table 7 indicate that an annual survival rate of 5% is possible, especially given new methods being used around the world in abalone enhancement programs (e.g., improved condition of hatchery-reared animals, field planting at larger sizes, and new field planting modules). In addition, the broodstock would be replaced with younger animals that could potentially have higher reproductive potential than those removed from the wild.

Table 7. Summary of results of abalone field planting studies conducted around the world since 1993. N= the number of abalone used to enhance the wild population. EPI= the estimated population increase presumably due to enhancement activities.

Citation	**Species**	**Location**	**Size range (mm)**	**N**	**Survival**	**EPI**
Lapota (unpub. data)	*Haliotis fulgens*	Pt. Loma, CA	70-100	200	77% after 2 months	
Rogers-Bennett and Pearse (1998)	*Haliotis rufescens*	Northern CA	mean 8	50000	0-0.21% after two years	126
McCormick et al. (1994)	*Haliotis fulgens*	Santa Catalina	mean 25	8000	40% after 3 months	
Lee et. al.(2002)	*Haliotis diversicolor*	NE Taiwan			3.59% in 1997 5.13% in 1998	16176 20513
Schiel (1993)	*Haliotis iris*	New Zealand	3-30	80000	Annual range 1.2-72.4% over two years	
Kojima (1995)	*Haliotis discus discus* *H. d. hannai* *H. diversicolor aquatilis* *H. d. diversicolor* *H. sieboldii*	Japan	15-40		12-51% between 1980-1985	
Seki and Taniguchi (2000)	*Haliotis discus hannai*	Japan	mean 16.5-24.5	166000	26.7% after three years (1996-1998)	
James (2005)	*Haliotis rubra*	Australia	10-20	360	9% after three years (2000-2003)	
			13-26	940	32% after 8 months	
James (2005)	*Haliotis laevigata*	Australia	15-30	800	15% (artificial reef) and 10% (natural reef), after 2 years (2001-2003)	
Shepherd (2000)	*Haliotis laevigata*	Australia	50-60	50	Mean annual survival 80% over six years	
Dixon et al. (2006)	*Haliotis laevigata*	Australia	28	8000	47-57% over nine months	

Development of an enforcement, public outreach and education plan will help to establish multi-directional sharing of information between the federal government, state and local government, constituent groups, academia, and the general public. This program will be established by encouraging the addition of staff and equipment to marine/coastal state and federal enforcement programs and by forming partnerships with local aquaria (e.g., Aquarium of the Pacific, Long Beach California, USA; Cabrillo Aquarium, San Pedro, California, USA; The Ocean Institute, Dana Point, California, USA) and non-profit organizations (e.g., CIMRI, Oxnard, California, USA). The primary goals of the program will be to: 1) educate the public on the important role abalone play in the kelp forest ecosystem; 2) reduce the occurrence of poaching and accidental take; and 3) aid in the protection of existing wild populations though public involvement in long-term monitoring. A public outreach and education program will help to raise awareness of the ecological and economic importance of abalone species with a focus on white abalone. Through an ecosystem-based initiative, a heightened sense of stewardship towards white abalone would naturally be incorporated into a program that focuses on the broader importance of maintaining healthy marine habitats that encompass the deeper rocky substrata habitats near the California coastal islands and outer banks (Pikitch et al. 2004). The program will aim to establish relationships with representatives from Congress, news media, constituent groups, state and local government, the Mexican government, environmental education and interpretive centers, academia, and the general public by convening workshops that focus on the program's primary goals.

Securing financial support for white abalone recovery must be underscored as a very important part of the recovery strategy. Without adequate financial support, few, if any, of the recovery activities outlined in this Plan will be implemented. Financial support can be achieved through federal and private grants and this has been and is currently being done in a number of cases (e.g., Hobday and Tegner 2000, Lafferty et al. 2004), however, these grants do not support long-term recovery and monitoring efforts. The costs associated with the recovery of white abalone are large and recovery, therefore, will depend on the acquisition of long-term funding.

III. RECOVERY GOALS, OBJECTIVES, AND CRITERIA

A. RECOVERY GOAL

The goal of the recovery plan is to increase wild white abalone abundance in California to viable and self-sustaining levels such that the species can be downlisted to threatened status and subsequently removed from the Endangered Species List.

B. RECOVERY OBJECTIVES

The first objective of the recovery plan is to improve our knowledge of the current status of white abalone in the wild so that extinction risks can be estimated and a plan can be developed for carrying out recovery actions in a way that will most efficiently achieve the delisting criteria. Achieving this objective is dependent upon identifying and monitoring white abalone populations and their habitat. Monitoring wild populations over time will yield more accurate information on spatial and temporal distribution, size structure, genetic structure, individual and population growth and mortality estimates, and habitat requirements of surviving white abalone. Captive propagation of white abalone will yield laboratory-derived information on the effects of abiotic (e.g., temperature, habitat type) and biotic (e.g., predator presence, food type, disease) factors on the growth and survival of white abalone from fertilization through maturation. In addition, these studies will provide estimates of fecundity and fertilization success. All of this information will help in defining minimum viable population size, establishing predictive models that can estimate risk of extinction, and will guide the course of the artificial enhancement program.

The second objective of the recovery plan is to reduce or eliminate existing threats to white abalone in the wild. The most significant threat to white abalone is its low abundance and density in the wild. By continuing to monitor wild populations, more information concerning the severity of this problem will become available. Alleviating the problem will occur by enhancing wild populations with captive bred animals until a viable and sustainable population size is achieved. Inability to implement conservation and research and inadequate enforcement due to lack of coordination and funds will be one of the most difficult threats to overcome. The hope is that through outreach and education, public awareness of the white abalone's plight will be raised and this will motivate state, federal and private organizations to work together and develop a budget framework that provides long-term financial support for white abalone recovery. The threat of disease (withering syndrome) will be minimized by conducting studies that aim to learn more about the effects of withering syndrome on captive bred white abalone and by designing a sound enhancement plan that ensures the release of only healthy animals into the wild. Preventing illegal take of white abalone through enforcement and the establishment of protected areas through state and federal legislation has already begun. Federal (ESA) and state (Abalone Recovery Management Plan) protections currently in place are helping to protect habitat that is being utilized by white abalone in the wild. Potential designations of protected

areas and critical habitat will be considered as the spatial extent of enhancement activities becomes fully conceived.

The third objective of the recovery plan is to downlist and eventually delist white abalone by defining a safe population level (i.e., delisting criteria) which includes viable/sustainable subpopulations at a number of locations through out the former range of the species. In theory, this objective can be achieved most effectively, after the first objective has been accomplished. In reality, it is understood that this objective will have to be addressed prior to the completion of the first objective. Given this, adjustments in the definition of a viable and sustainable population and the number and locations of these populations will be made after more information is collected through implementation of the recovery plan. Once viable populations are established in the wild, their sustainability will need to be assessed through long-term monitoring and their protection will need to be ensured through enforcement and/or by establishing protected areas.

C. RECOVERY CRITERIA

Recovery criteria apply to populations of white abalone in both the USA and Mexico (for geographic reference see Figure 8). The best available information must be used in order to ascertain whether the species has met the recovery criteria and all the criteria must be met in order to delist/downlist the species.

Downlisting Criteria
Demographic Criteria

Criterion 1: Density and Abundance

A. Density of emergent (detectable by human observation without substrate disturbance) animals (short term) must be greater than 2,000 per hectare for 75% of the geographic localities.
B. Maintain a total of 380,000 animals (Rogers-Bennett et al. 2002; Butler et al. 2006) in the wild, distributed among all geographic localities in the USA and Mexico.

Criterion 2: Size Frequency

A. Proportion of size of emergent animals in 75% of geographic localities includes at least 85% intermediate-size animals (90 to 130 mm)
B. Proportion of size of emergent animals in 75% of geographic localities includes no more than 15% large animals (>130 mm)

Criterion 3: Trend

A. Achieve a stable or increasing estimate of geometric population growth ($\lambda \geq 1$) for >75% of the geographic localities over a ten year period.

Criterion 4: Changes in distribution/reoccupation of historical range

A. Reoccupation of white abalone over a spatial scale that encompasses their historic range such that 75% of the geographic localities in the USA and Mexico are reoccupied and meet the aforementioned recovery criteria.

Threats-Based Criteria

The threats criteria are organized according to the five ESA listing factors discussed in detail on pages 29-34 of this document.

Listing Factor 1: Destruction, Modification, or Curtailment of Habitat or Range

A. Destruction, modification, or curtailment of habitat or range was not an important factor in the decline of the species historically and is not believed to limit recovery of the population at this time. Currently, substrate destruction, suboptimal water temperatures, reduced food quantity and quality, and environmental pollutants/toxins are considered to be of relatively low severity and the effect of these threats on the species are relatively uncertain. In the future, potential risks imposed by substrate destruction may be averted through implementation of ESA Section 7 consultations and establishment of Marine Protected/Conservation Areas. The effects of long-term (or global) climate change on this species, either directly through water quality changes or indirectly through interactions with other species, including food items, is a potential threat to white abalone that cannot be addressed through these regulatory measures. At this time, it is unclear what effect long-term climate change will have on the species.

Listing Factor 2: Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

A. In California, fishing for white abalone remains prohibited and regulations for other abalone species are designed to protect white abalone. In Mexico, no federal permits are issued that allow fishing for white abalone. These measures limit further reductions in density and genetic diversity; see Table 5. Enforcement of existing regulations and public outreach will help to minimize illegal harvest.
B. The CDFG Abalone Recovery and Management Plan (ARMP) remains in place and reflects updated information adequately to ensure that white abalone will be managed to maintain demographic numbers outlined in this plan. There are assurances of adequate regulatory authority and funding for the state to implement the plan.

Listing Factor 3: Disease/predation

A. Routine monitoring results indicate no evidence of withering syndrome (WS)-infected animals in wild populations.

B. The impact of any emerging disease has been evaluated and conclusions drawn that it is unlikely to significantly affect white abalone populations.
C. A minimum of 50% of the white abalone geographic localities meeting the aforementioned demographic criteria, fall outside the resident range of sea otters.

Listing Factor 4: Inadequate regulatory mechanisms

A. An interagency (state/federal) task force is established to enforce regulations to protect established subpopulations and effectively alleviate illegal take of white abalone.
B. Implementation of bilateral agreements with Mexico are continued and adequately deter illegal international trade.
C. Future abalone harvest is monitored by the CDFG's ARMP such that the health of the species is maintained and populations remain self-sustaining.
D. Populations of white abalone in Mexico are adequately protected by regulatory mechanisms implemented by the Mexican authorities.

Listing Factor 5: Other factors affecting the species' continued existence

A. Hybridization has been assessed and determined not to be a threat to the species.

Long-term Monitoring Criteria

Criterion 1: A monitoring program is in place and underway to evaluate population abundance and structure for a minimum of 50 years after downlisting.

Criterion 2: A monitoring program is in place and underway to evaluate threats for a minimum of 50 years after downlisting/delisting.

Criterion 3: A quantitative, long-term forecasting analysis plan is under development to ensure that probability of extinction in the wild is less than 10% in 100 years or 5 generations, whichever is longer.

Delisting Criteria

Demographic Criteria

Criterion 1: Density and Abundance

A. Density of emergent animals (short term) must be greater than 3,000 per hectare for 75% of the geographic localities (CDFG, 2005).
B. Maintain a total of 500,000 animals (Rogers-Bennett et al. 2002, Butler et al. 2006) in the wild, distributed among all geographic localities in the USA and Mexico. Maintenance of 500,000 animals is based on crude estimates of abundance necessary to sustain a 90% probability of persistence in 100 years, per IUCN guidelines. The model assumes a conservative estimate of $\lambda = 0.90$ (i.e., 10% decline per year). The

threshold value of 500,000 animals should be updated when empirical estimates of λ become available.

Criterion 2: Size Frequency

A. Proportion of size of emergent animals in each geographic locality includes at least 85% intermediate-size animals (90 to 130 mm)
B. Proportion of size of emergent animals in each geographic locality includes no more than 15% large animals (>130 mm)

Criterion 3: Trend

A. Achieve a stable or increasing estimate of geometric population growth ($\lambda \geq 1$) for >75% of the geographic localities over a ten year period.

Criterion 4: Changes in distribution/reoccupation of historical range

A. Reoccupation of white abalone over a spatial scale that encompasses their historic range such that 75% of the geographic localities in the USA and Mexico are reoccupied and meet the aforementioned recovery criteria.

Threats-Based Criteria

The threats-based criteria are the same as for downlisting.

Long-term Monitoring Criteria

Criterion 1: A monitoring program is in place and underway to evaluate population abundance and structure for a minimum of 50 years after delisting.

Criterion 2: A monitoring program is in place and underway to evaluate threats for a minimum of 50 years after delisting.

Criterion 3: A quantitative, long-term forecasting analysis plan has been developed to ensure that the probability of extinction in the wild is less than <5% within 100 years or 5 generations, whichever is longer.

Criterion 4: If information collected during the long-term monitoring period suggests: a) the decision to delist was in error, or 2) the species' status has changed substantially, a status review of the species should be conducted.

Figure 8. Geographic localities of historic and/or current subpopulations of white abalone in the USA and MX based on fisheries catch data from the CDFG and the Mexican INP and Abalone Cooperativos. Oval shapes provide a general reference for geographic localities. Progressing from north to south the first locality covers the coastal region off of Santa Barbara and Ventura Counties. The next two localities comprise the Northern Channel Islands (offshore-San Miguel and Santa Rosa Islands; inshore-Santa Cruz and Anacapa Islands). The next group of localities are part of the Southern Channel Islands: San Nicolas, Santa Barbara and Catalina Islands (offshore to inshore, respectively), and San Clement Island to the south of Catalina. The next locality covers the coastal region off of southern San Diego County and the last locality in the USA encompasses Tanner and Cortes Banks. The northernmost locality in MX encompasses the Coronados Islands. The next locality covers the coastal region from south of Ensenada to Erendira. The next four localities encompass the islands of Isla San Martin, Guadalupe Island, Isla Cedros, and Isla Natividad. The final locality encompasses the coastal region of Bahia Tortugas.

IV. RECOVERY PROGRAM

A. STEP-DOWN OUTLINE

1 Assess and monitor white abalone subpopulations in the wild in cooperation with the state of California, other federal agencies, private organizations and the Mexican government
- 1.1 Develop an assessment and monitoring program to identify current status of and track changes in wild subpopulations
  - 1.1.1 Assess extant subpopulations in the wild
  - 1.1.2 Monitor extant subpopulations in the wild
- 1.2 Tag extant individuals belonging to multiple subpopulations
- 1.3 Determine value of translocation to establish viable subpopulations and translocate if appropriate
- 1.4 Conduct genetic analyses of wild population structure
  - 1.4.1 Determine extent of genetic differentiation among wild subpopulations to provide insight into structure
  - 1.4.2 Determine the best captive propagation, field planting and translocation design that serves to maintain the current genetic structure of the wild population
- 1.5 Develop population data and demographic population viability analysis (PVA) models
  - 1.5.1 Evaluate and improve estimates of abundance, reproduction, survival, and growth for use in PVA models
  - 1.5.2 Develop population models to assess threats and identify key life history stages or demographic processes
  - 1.5.3 Conduct a PVA to determine time to extinction probabilities, trends to forecast the impact of threats, and the prospects for recovery
  - 1.5.4 Expand PVAs to incorporate demographic and environmental stochasticity
- 1.6 Maintain and enhance communications with the Mexican government
  - 1.6.1 Establish a technical advisory team through the Instituto Nacional de la Pesca (INP) and invite the team to participate in workshops/meetings
  - 1.6.2 Participate in international conferences (e.g., International Abalone Symposium, MEXUS)
  - 1.6.3 Collaborate with Mexico to help improve our understanding of the status of extant subpopulations throughout the range and to help conserve and protect them
- 1.7 Develop a Post-Delisting Monitoring Plan

2 Identify and characterize existing and potential white abalone habitat through acoustic remote sensing technology
- 2.1 Identify existing and potential habitat using multibeam sonar generated bathymetry data and quantify and revise estimates of habitat availability in California

- 2.2 Generate ROV transect data to assess biological and physical attributes of habitat
- 2.3 Determine the level of risk associated with habitat degradation/destruction that existing and potential viable populations (will) face
- 2.4 Collaborate with Mexican researchers in assessing and monitoring white abalone habitat in Mexico

3 Protect white abalone populations and their habitat
- 3.1 Enforce State of California protections
- 3.2 Enforce Federal ESA protections
- 3.3 Protect white abalone populations and habitat as they are discovered or established through enhancement
  - 3.3.1 Continue state and federal review of permitted activities to minimize impacts to white abalone habitat
  - 3.3.2 Evaluate current and establish new conservation measures (e.g., fishing restrictions, conservation areas, etc.) to afford viable wild populations appropriate protection from habitat destruction and illegal take
    - 3.3.2.1 Support establishment of Marine Protected Areas in the northern Channel Islands
    - 3.3.2.2 Support maintenance of rockfish conservation areas
    - 3.3.2.3 Uphold objectives of the CDFG Abalone Recovery Management Plan
  - 3.3.3 Establish an interagency (state/federal) enforcement task force that can monitor areas containing viable populations on a semi-regular basis and protect them from illegal take
- 3.4 Enhance degraded habitat through restoration or mollifying anthropogenic impacts through mitigation, as necessary

4 Continue, refine and expand a captive propagation and enhancement program for white abalone in California with the goal of artificially enhancing populations in the wild
- 4.1 Identify factors that may reduce the risk of mortality associated with the removal, handling and transport of wild white abalone to rearing facilities
- 4.2 Determine the number of rearing facilities and broodstock animals needed to meet the goals of NMFS' global management plans (e.g., Genetics, Disease, Disposition of Excess Individuals, and Field Planting; See Appendices B-E)
- 4.3 Establish a standard for security measures at facilities housing broodstock and captive-reared animals
- 4.4 Comply with and periodically update NMFS' global management plans for a captive propagation and enhancement program
  - 4.4.1 Comply with updated genetics management plan
  - 4.4.2 Comply with updated disease management plan
  - 4.4.3 Comply with updated management plan for the disposition of excess white abalone
  - 4.4.4 Comply with updated field planting management plan

4.5 Encourage partnerships with potential permit applicants who may be interested in participating in furthering the goals of the captive propagation program
4.6 Enhance wild populations by outplanting captive-bred white abalone in selected sites throughout the range of the species

5 Plan and implement public outreach and education plan
5.1 Reduce likelihood of poaching by raising public awareness through outreach to regional fisheries management councils, industry groups, dive clubs/shops, and public media
5.2 Develop educational displays and materials by cooperating with NGOs, aquaria, secondary schools, and universities
5.3 Establish relationships with volunteer-based programs that can take part in various aspects of the captive propagation program (e.g., maintenance at hatcheries, research assistance, monitoring of captive-reared animals placed in the field etc.)

6 Secure financial support for white abalone recovery
6.1 Seek out and apply for federal, state, and private grants
6.2 Form cooperative funding agreements among state, federal and private entities

B. NARRATIVE

RECOVERY ACTION 1. ASSESS AND MONITOR SUBPOPULATIONS IN THE WILD IN COOPERATION WITH THE STATE OF CALIFORNIA, OTHER FEDERAL AGENCIES, PRIVATE ORGANIZATIONS AND THE MEXICAN GOVERNMENT. Our current understanding of white abalone population structure in the wild is minimal. Abundance and density estimates need refining and the long-term viability of surviving wild subpopulations is questionable. In order to establish recovery criteria for this species, a better understanding of the status of existing subpopulations in nature must be determined and then monitored over a period of time. This section of the recovery plan identifies the specific activities needed to establish confidence in the current status of the species and to better predict how wild populations will fare over short- and long-term time scales.

1.1 Develop an assessment and monitoring program to identify current status of and track changes in wild subpopulations. NMFS, in association with other partners, will design an ROV survey program that focuses on the identification of surviving animals, recording individual position and size, and calculating reliable density estimates for white abalone in the wild.

1.1.1 Assess extant subpopulations in the wild. White abalone are difficult to sample in the wild (most often occurring below depths of 30m at present) and therefore remote technologies must be relied upon to conduct surveys. Depth-stratified random ROV sampling over the course of 5 years will provide a standardized method for characterizing size-structure and estimating density of extant subpopulations. SCUBA surveys will also be designed for areas that contain safe diving depths. Estimates of the amount of available habitat (see Recovery Action 2) in the wild in combination with reliable density estimates will improve current estimates of total population size in the wild.

1.1.2 Monitor extant subpopulations in the wild. Once locations containing wild white abalone subpopulations have been identified during the assessment period, a plan for revisiting particular sites every 3 years over a ten to fifteen year period will be devised. NMFS in conjunction with the State of California will take the lead in organizing the agencies and their partners to conduct regular monitoring of the sites using ROV and SCUBA technology. Detection of changes in size distribution, abundance, and habitat will be the primary goal of the monitoring program.

1.2 Tag extant individuals belonging to multiple subpopulations. If wild subpopulations of white abalone are detected in areas where SCUBA divers can access animals, NMFS and other partners will apply for a scientific research permit under Section 10 (a)(1)(A) of the ESA to tag individuals and track their movements and growth at least annually over a

three year period. These pieces of information are critical to determining the viability of wild populations.

1.3 Determine the value of translocation to establish viable subpopulations and translocate if appropriate. Translocation of wild white abalone may be attempted by the CDFG, NPS, NMFS, and other partners if 1) areas that support wild white abalone are identified; 2) subpopulations occur in areas that are amenable to repeated assessment; 3) existing data suggests that the viability of the subpopulation is low if left unmanipulated; and 4) areas where predation and poaching pressures are minimal. Translocation experiments would involve tagging animals and translocating them so that the distances between the translocated individuals would be no greater than 2 m (Babcock and Keesing 1999). Translocated populations will be monitored for size-structure, abundance, individual movements and individual growth on at least an annual basis over a five year period and then every two years for an additional five years.

1.4 Conduct genetic analyses of wild population structure. Few data currently exist regarding the genetic structure of natural white abalone populations. Samples of approximately 20 field-collected animals, almost exclusively from a single southern California population, have been obtained and analyzed by Gruenthal and Burton (2005). Analysis of genetic variation at five nuclear microsatellite loci and partial sequences of one nuclear and two mitochondrial DNA genes suggests that significant genetic variation remains in natural populations. Variation at these marker loci (and others under development) can be used to assess the extent of population differentiation once samples from multiple locations become available. Genetic information is required for decision-making along two lines of recovery planning: 1) for determining whether there is high or low connectivity among surviving populations in the wild; and 2) for designing a sound captive propagation, field planting and translocation program where broodstock contamination is prevented and genetic markers are developed to track outplanted, captive-bred animals and their wild-bred progeny (Gruenthal and Burton 2005).

1.4.1 Determine extent of genetic differentiation among wild sub populations to provide insight into structure. Collect tissue samples from at least 10 wild individuals belonging to each subpopulation. Sequence mtDNA and score polymorphic microsatellite loci. High levels of differentiation would suggest that connectivity of populations is low and that successful recovery of individual populations may not lead to recovery across other locales over decadal time scales. Such population differentiation also presents the possibility that geographically isolated populations may be locally adapted.

1.4.2 Determine the best captive propagation, field planting and translocation design that serves to maintain the current genetic structure of the wild population. If high levels of population differentiation are detected, it would be undesirable to mix subpopulations during captive-breeding and field planting

activities as these actions could potentially disrupt local adaptation and produce animals of unknown suitability to any locale. Hence, statistically significant allelic frequency differences will necessitate maintenance of separate stocks in the culture facilities and for subsequent field planting.

1.5 Develop and refine population data and demographic PVA models. Quantitative methods are essential for recovery planning efforts. Population viability analyses (PVA) are a suite of tools that incorporate quantitative methods to predict population status. PVA may be used to assess extinction threats and guide the recovery and management process. In this plan, we have a need for improving the data needed for modeling efforts. Once these data are available they can be incorporated into population viability analyses to evaluate threats, population trends and make predictions about future trends. Elasticity analyses of matrix elements can be conducted to determine which elements impact population growth the most in the model. Identification of the most sensitive size classes and vital rates are valuable for the quantitative evaluation of research priorities, management policies and conservation strategies (Morris and Doak 2004).

1.5.1 Evaluate and improve estimates of abundance, reproduction, survival, and growth for use in PVA models. There is a lack of data on white abalone abundances as well as population vital rates. Vital rates (growth, reproduction and survival rates) may be based more on animal size than on animal age as has been found for other abalone species. To build structured population models, which can add additional information compared with unstructured models, size specific vital rate data should be collected. Size specific vital rate data are available to estimate reproduction from one locale in southern California (Tutschulte 1976). Currently, there is a lack of data on growth and mortality. A research emphasis needs to be placed on acquiring growth and survival data for use in PVA. If these data can be collected for different size classes this would facilitate the creation of size structured population models. Estimates of variation around mean vital rates need to be expressed to facilitate the creation of stochastic PVAs. When possible, inclusion of sources of variation around the means need to be a priority. Evaluating stochasticity will be facilitated by knowing the mean vital rates examined for different size classes and different years. Identifying potential temporal stochasticity of the data collected needs to be included as a goal. Knowledge of how vital rates vary in response to different types of stochasticity can be incorporated into stochastic PVA.

1.5.2 Develop population models to assess threats and identify key life history stages or demographic processes. For white abalone, we are hindered by the lack of quantitative data available for incorporation into population models, however there are some data available for congeners. Data from closely related congeners have been used for the construction of matrix models where data has been lacking (e.g. harbor porpoise populations) (Caswell et al. 1998). Size-based

vital rate data information can be incorporated into deterministic matrix models to explore the impacts of different threats and recovery actions (Caswell et al. 1998, Ebert 1999, Morris et al. 1999). Perturbations of these models can reveal which rates influence population growth of the model the most (Benton and Grant 1999 and references therein). These perturbations, prospective sensitivity analysis (Caswell 2000) have had far-reaching consequences for endangered species management. For example, perturbation analyses of loggerhead sea turtles, *Caretta caretta,* matrix models lead to a redirection of conservation efforts away from "headstarting" hatchlings (enhancing the survival of eggs in nests) toward the use of turtle exclusion devices in fishing nets (reducing adult mortality) (Crouse et al. 1987, Crowder et al. 1994).

Abalone are long-lived, slow-growing species that may have similar population dynamics to sea turtles responding to perturbations in a stereotypical way (Heppell et al. 2000, Saether and Bakke 2000, Gerber and Heppell 2004). For management and recovery of white abalone it is critical to know which is higher, juvenile or adult survival elasticities. This has been identified as a research priority. The threats identified in this recovery plan include some that would impact certain vital rates and specific size classes. Perturbations of these elements in the matrix model can reveal which would have the most impact on population growth rate (λ). Those with the most impact on population growth would then be ranked higher then those with less of an impact. Similarly, perturbing different vital rates from different size classes can also be conducted to rank the potential efficacy of recovery actions assuming the model population.

1.5.3 Conduct a PVA to determine time to extinction probabilities, trends to forecast the impact of threats and the prospects for recovery. Basic population viability analyses utilize count or abundance estimate data to examine trends in populations. To examine whether populations are growing or declining a minimum number of 10 years of population abundance estimates have been suggested (Morris and Doak 2004); although for long-lived species, such as white abalone, more than 10 years of estimates may be required. At this point, we do not have 10 or more years of abundance estimates, however we are working to establish a regular population survey program at areas with known wild populations. We have two years of abundance estimates generated for Tanner Bank, a key area for current remnant populations in the southern California Bight (Butler pers. comm.). Once a time series of abundance data is generated, these can be examined for trends. These trends can then be projected into the future to examine the probability of extinction over time. These types of extinction estimates will be critical for helping define recovery and delisting criteria as well as quantify the success or failure of recovery efforts. Quantifying recovery goals is an essential component of recovery planning.

1.5.4 Expand PVAs to incorporate demographic and environmental stochasticity. Multi-site PVAs can incorporate metapopulation dynamics. Once deterministic PVA models are constructed for white abalone these may be expanded to include more realistic information such as demographic and environmental stochasticity; if the data these models require exist. Knowledge of correlations between the variation in vital rates and their contribution to population growth rate will be needed. For red abalone, we know that growth and reproduction are impacted by environmental stochasticity such as El Niño events and more long term environmental fluctuations. In the event spatially explicit demographic data is collected from multiple sites, these data may be used to construct multi-site PVAs. These types of models can be developed with and without information about movement between sites.

1.6 Maintain and enhance communications with the Mexican government. A major need to restore wild white abalone populations throughout the former historic range of the species is to learn as much as possible about the historic and current status of white abalone populations in Mexico and efforts being made there to conserve and protect surviving white abalone, and to combine efforts (such as those outlined in 1.1-1.5) to conserve the species. At the National level, the INP designs, implements, and evaluates areas for commercial abalone fishing and aquaculture in Baja California, Mexico. The INP also prepares status reviews of species, recommends programs for use in issuing administrative orders to regulate fishery resources, and issues permits to local cooperatives that manage the fishery. Although the INP ceased issuing permits to allow commercial take of white abalone in 2001, the current status of populations in Mexico is largely unknown.

1.6.1 Establish a technical advisory team through the INP and invite the team to participate in workshops/meetings. In order to learn more about the status of white abalone and conservation efforts currently underway in Mexico, NMFS will work through appropriate channels to request the formation of a Mexican technical advisory team. This team will be invited to participate in recovery team meetings so the recovery team can incorporate relevant information into recovery planning.

1.6.2 Participate in international conferences (e.g., International Abalone Symposium, MEXUS). Through participation in international conferences, NMFS biologists and associated partners will maintain and expand contacts with abalone experts from inside as well as outside the INP. These connections will be extremely important to the recovery program in that research underway at universities, by local government, and other entities may be relevant to the recovery goals and criteria laid out in the recovery plan. In addition, participation at conferences will serve to inform Mexico of the efforts underway in the USA and potentially be the first step in establishing future collaborations.

1.6.3 Collaborate with Mexico to help improve our understanding of the status of extant subpopulations throughout the range and to help conserve and protect them. Establishing a collaborative partnership between the USA and Mexico would be particularly beneficial to this species. Because of limited knowledge of the status of extant populations, the remoteness of their habitat, and limitations on funding sources in both countries, collaborations would help to better achieve goals for both countries including those laid out in this recovery plan. The time and financial burdens associated with assessing and monitoring extant populations throughout their range and ensuring the protection and conservation of those populations if discovered would undoubtedly be lessened if the two countries would work collaboratively.

1.7 Develop a Post-Delisting Monitoring Plan. Section 4(g) of the ESA requires that NMFS work with the States to monitor the status of all species delisted due to recovery for a minimum of five years. The purpose of the post-delisting monitoring (PDM) plan is to confirm that white abalone does not require relisting as threatened or endangered during the period following removal of ESA protections.

RECOVERY ACTION 2. IDENTIFY AND CHARACTERIZE EXISTING AND POTENTIAL WHITE ABALONE HABITAT THROUGH ACOUSTIC REMOTE SENSING TECHNOLOGY. Multibeam sonar generated high resolution (1 m) bathymetry maps can be used to accurately quantify the physical characteristics of habitats that support remaining wild white abalone. Calculating estimates of how much current and potential habitat exists is crucial to determining densities and to generating estimates of total population abundance. Creating maps that cover a large proportion of the historic range of the species will aid in determining where and how much suitable habitat remains. These elements are crucial to optimizing monitoring survey effort and to designing a successful enhancement program. ROV transects carried out through Recovery Action 1 will provide a visual record of the transect that can be reviewed for other physical and biological attributes of white abalone habitat. This data will also be important for selecting optimal sites for enhancement. Collection of water temperature, depth, and current speed and direction data will also contribute to the mix of physical attributes that may be used to better define suitable white abalone habitat.

2.1 Identify existing and potential habitat using multibeam sonar generated bathymetry data and quantify and revise estimates of habitat availability in California. The physical characteristics of suitable white abalone habitat must be better defined in order to prioritize habitat protection efforts and to establish foci areas for reestablished populations**.** Estimates of existing white abalone populations are based on applying observed densities to estimates of habitat area. The status review estimated a total of 750 hectares of white abalone habitat in California. Multi-beam mapping of only three localities has revealed more than 3,000 hectares over the last three years. At least nine more localities remain to be mapped, which will increase the estimate of total white

abalone habitat. Additional mapping will also provide information about potential field planting habitats that are more conveniently located for hatchery field planting operations.

2.2 Generate ROV transect data to assess biological and physical attributes of habitat. ROV video tapes provide an inventory of associated fauna and flora. These tapes can be reviewed to identify other grazing invertebrates, potential abalone predators and food sources including red, brown and coralline algae. Habitat will also be classified by depth, substrate, algal cover, percent sand, and size of cobble and boulders. This information will be critical to choosing appropriate outplanting sites.

2.3 Determine the level of risk associated with habitat degradation/destruction that existing and potential viable populations (will) face. A complete inventory of white abalone habitat and populations throughout Southern California will allow managers to assess the current and future sublethal and lethal risks associated with the degradation or destruction of habitat.

2.4 Collaborate with Mexican researchers in assessing and monitoring white abalone habitat in Mexico. Little is known about white abalone habitat or populations in Mexico. Previous meetings with Mexican officials have revealed a willingness on the part of the INP to cooperate in abalone recovery activities. Multibeam mapping technology and Remotely Operated Vehicles are not commonly available in Mexico and could be the basis of cooperative research programs.

RECOVERY ACTION 3. PROTECT WHITE ABALONE POPULATIONS AND THEIR HABITAT. As identification of extant white abalone populations occurs and populations of captive-reared animals are established, measures must be taken to protect those populations and the habitats they depend upon.

3.1 Enforce State of California protections. Protection of white abalone populations and habitat in the wild through State of California regulations is possible given that sport and commercial take of all abalone species is prohibited (since 1997) south of San Francisco (5522 California Fish and Game Code). This should conserve and protect remaining white abalone populations in southern California directly and also indirectly by ensuring that no accidental take of white abalone, mistaken for another species occurs. As of the date of this publication, all abalone fisheries south of San Francisco remain closed. As state laws are reevaluated in the future, measures to ensure conservation of white abalone will be taken.

3.2 Enforce Federal ESA protections. Federal protection is provided by the ESA, most notably Section 9 whereby taking (i.e. harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, or collecting) a listed species by any person within U.S. waters is prohibited. It is also unlawful to attempt such acts, solicit another to

commit such acts, or cause such acts to be committed. Regulations implementing the ESA (50 CFR §222.102) further define "harm" to include significant habitat modification or degradation that results in the killing or injury of wildlife by significantly impairing essential behavior patterns including, breeding, ,spawning, rearing, migrating, feeding or sheltering. Section 10 and Section 7 of the ESA and related regulations provide for an evaluation of federal and non-federal activities that may affect listed species and in some cases permission may be granted to authorize activities, otherwise prohibited under Section 9 of the ESA. For example, under Section 10 of the ESA, permits may be issued that allow scientific research and enhancement of a listed species. Section 10 also allows permits to be issued for take that is "incidental to, and not the purpose of, carrying out an otherwise unlawful activity" if NMFS determines that certain conditions have been met. Section 7 of the ESA requires federal agencies to consult with NMFS prior to authorizing, funding, or carrying out activities that may affect listed species. Section 7 also requires that these agencies use their authorities to further the conservation of listed species.

3.3 Protect white abalone populations and habitat as they are discovered or established through enhancement. All known naturally-breeding and outplanted populations of white abalone should be protected. Natural subpopulations represent the only known source of viability for the species, and outplanted subpopulations are a key component of the recovery program for the species and their persistence is thus crucial to the recovery of the species. Therefore all regulatory power provided by the ESA and by the State should be utilized, and voluntary activities by private and public entities should be encouraged.

3.3.1 Continue state and federal review of permitted activities to minimize impacts to white abalone habitat. Multibeam mapping will provide new information on potential white abalone habitat. The resulting maps will provide detailed information to managers who must review permit applications for activities that may impact white abalone.

3.3.2 Evaluate current and establish new conservation measures (e.g., fishing restrictions, conservation areas, etc.) to afford viable wild populations appropriate protection from habitat destruction and illegal take. A number of pre-existing conservation activities (proposed and underway) are designed to protect viable white abalone populations in the wild. However, each of these activities should be examined further to ensure they are as effective as possible. For example, management areas should be considered in the case that predation by sea otters or other predators is likely to inhibit recovery of abalone. An in-depth examination of these activities may also conjure suggestions for minor changes to pre-existing activities, which if adopted by the controlling entity(ies), would benefit white abalone without additional financial or logistical burden. In addition, conservation measures should be expanded, as appropriate.

3.3.2.1 Support establishment of Marine Protected Areas in the northern Channel Islands. Multibeam mapping of MPAs and ROV surveys will provide important inventories of habitat and endangered species within the MPAs. These inventories will help guide management as well as the design of future MPAs.

3.3.2.2 Support maintenance of rockfish conservation areas. Multibeam mapping and ROV surveys will augment similar activities focused on rockfish resources. Coordinating mapping activities will increase the efficiency of both efforts. Critical habitat for white abalone exist within the Cowcod Conservation Area. These areas are rarely visited by enforcement officers; however, the co-location of an endangered species and protected fish populations reinforces the enforcement activity.

3.3.2.3 Uphold objectives of the CDFG Abalone Recovery Management Plan (ARMP). The State ARMP serves to manage all of California's abalone fisheries, prevent further population declines throughout California, and to ensure that current and future populations will be sustainable. Supporting many of the activities outlined in the ARMP will directly and indirectly contribute to the goals of white abalone recovery.

3.3.3 Establish an interagency (state/federal) enforcement task force that can monitor areas containing viable populations on a semi-regular basis and protect them from illegal take. Poaching has been recognized as a serious threat to all abalone species including the white abalone. An identification of goals and strategies needs to be established between state and federal agencies. Clear definition of roles and responsibilities will prevent duplication of enforcement efforts. Abalone poachers must be prosecuted to the fullest extent of the law to discourage future poaching. It is also important to note that a primary role of enforcement is that of education.

3.4 Enhance degraded habitat through restoration or mollifying anthropogenic impacts through mitigation, as necessary. Although habitat degradation was not identified as a significant threat to white abalone in the past or currently, future monitoring (habitat mapping and population assessment) may reveal areas that have been degraded. If these areas are occupied by surviving wild white abalone, or if they are potential outplanting sites because of other qualities they possess (e.g., logistical), then efforts may be made to restore the habitat to a state that would adequately support growth, reproduction and survival of white abalone. Additional restoration of degraded white abalone habitat, should it be identified, may also occur as mitigation for lost habitat due to any number of nearshore development projects (e.g., pipeline repair/construction, pier removal, liquefied natural gas terminal installation). Establishing and protecting areas that provide a high

water quality refuge (i.e. in terms of water temperature or pH, for example) for white abalone may become increasingly important as the effects of long-term climate change manifest. In order to achieve this it may be appropriate to include the establishment and protection of such areas as mitigation for degraded water quality due to any number of nearshore activities (e.g., power plant operations, sewage outfall).

RECOVERY ACTION 4. CONTINUE, REFINE AND EXPAND CAPTIVE PROPAGATION AND ENHANCEMENT PROGRAM FOR WHITE ABALONE IN CALIFORNIA WITH THE GOAL OF ARTIFICIALLY ENHANCING POPULATIONS IN THE WILD.

4.1 Identify factors that may reduce the risk of mortality associated with the removal, handling and transport of wild white abalone to rearing facilities. A preliminary plan (White Abalone Collection and Handling Protocol; see Appendix A) outlining the measures that must be taken in order to reduce the risk of mortality associated with the removal, handling and transport of wild white abalone to rearing facilities has been developed and will be updated over time. Given that opportunities to collect broodstock may be severely limited, there is a strong need for identifying factors that will maximize survival rates of broodstock at captive rearing facilities.

4.2 Determine the number of rearing facilities and broodstock animals needed to meet the goals of NMFS' global management plans (e.g., Genetics, Disease, Disposition of Excess Individuals, and Field Planting; see Appendices B-E). The above-mentioned management plans have guided and will continue to guide decisions on the number of rearing facilities and broodstock animals necessary for the recovery of the species. The White Abalone Recovery Team recommends that multiple scientific research and enhancement facilities, such as CIMRI, BML, and the NOAA SWFSC, be designated for white abalone rearing because 1) each facility provides a unique set of scientific and culture expertise; 2) each facility possesses different capabilities in managing water quality, and therefore may possess different capabilities in maintaining healthy captive animals; and 3) housing captive animals in multiple locations offers a safeguard against losing all animals in the case of a catastrophic event.

4.3 Establish a standard for security measures at facilities housing broodstock and captive-reared animals. A plan outlining the security measures that must be taken at all facilities housing broodstock and captive-reared animals will be developed and updated over time. There is a strong need for developing these standards in order to prevent the introduction and/or spread of disease and to eliminate the possibilities of mortality due to catastrophic events. See Appendix A and C for a summary of some measures that are already being taken.

4.4 Comply with and periodically update NMFS global management plans for a captive propagation and enhancement program. After consultation with experts on genetics, disease and disposition of excess individuals, field planting management plans will be

revised to guide various aspects of the captive breeding program in accordance with ESA section 10 (a)**.**

4.4.1 Comply with updated genetics management plan. Consideration should be given to the genetic aspect of the enhancement program. Captive breeding programs should reflect the genetic structure of wild abalone populations. If this is not possible, care should be taken to maximize the genetic diversity of hatchery-raised abalone and consider the potential genetic influence (e.g. dilution) of the number of abalone planted in any area. Genetic variability should be maintained within the pool of hatchery-raised abalone. To achieve this, the pool of broodstock should be maximized and single parent matings used to create individual families. In addition, pedigrees of all family lines should be maintained to avoid inbreeding among hatchery stocks. To ensure approximately equal representation of each family created, approximately equal numbers of offspring from all pair crosses should be maintained until planting in the wild. However, genetic diversity of broodstock should not limit the continuation and expansion of captive propagation. When appropriate, captive-bred animals should be returned to field locations. Although it is impossible to prevent genetic adaptation to hatchery conditions, one may minimize these impacts through the maintenance of family lines and planting equal numbers from each family thereby allowing natural selection in the field to ensue. See Appendix B for further detail.

4.4.2 Comply with updated disease management plan. In order to reduce disease risks culturists must adhere to established husbandry protocols outlined in the Disease and Parasite Management Plan (see Appendix C). Technicians working with broodstock will be trained to practice good husbandry techniques. Water flowing into tanks should be filtered and UV irradiated at levels safe for larvae and very early life stages. Water quality will be monitored (e.g., temperature, salinity, dissolved oxygen) on a daily basis. New broodstock will be quarantined for a period of six weeks, tested for disease, and treated if infected. A subsample of captive-bred individuals will be tested on a semi-annual basis for disease (e.g., by histology). The likelihood of introducing pathogens will be reduced by surface cleaning kelp with freshwater prior to placement in tanks. Heritability of resistance traits will be ascertained and if observed the use of such families for outplanting will be evaluated. Access to captive rearing facilities will be limited to only authorized personnel and approved visitors. All potential holding facilities will be required to be free of specific diseases and parasites (e.g., withering syndrome, sabellid worms).

4.4.3 Comply with updated management plan for the disposition of excess white abalone. White abalone are broadcast spawners, producing millions of embryos during a single spawn. In the course of hatchery operation, it is common that more abalone are produced than can be utilized for outplanting or can be

reasonably maintained within the hatchery. Valid uses of surplus animals include experimental stocking in the ocean as postlarvae and juveniles (0.3 – 35 mm shell length), life history research (e.g. estimates of fecundity, fertilization success rates, and recruitment rates under a range of biotic and abiotic conditions), and public display. Experimental outplanting will provide useful information regarding stock enhancement practices. Research is needed to provide crucial data on biological and environmental requirements (e.g. effects of temperature, diet, substrate type, and presence of predators) in a laboratory setting for drawing inferences about growth and survival in the wild. See Appendix D for more detail.

4.4.4 Comply with updated field planting management plan. To assess the optimal approach to outplanting, a program of research should be implemented that will determine: 1) optimal size at stocking under a range of conditions in order to minimize risk of mortality at outplanting; 2) prior to outplanting, variables such as benthic habitat type, depth, food availability, predators and conspecifics should be characterized to aid in the selection of outplanting sites; 3) survivorship and population structure should be evaluated following release into the wild, as part of a post-release monitoring program; 4) release modules should be used to minimize abalone stress and protect them from predation during the initial 24 hour release period; and 5) a plan should be developed in cooperation with the state, other federal agencies, and private industry to monitor the effectiveness of the field planting program and the recovery rate of enhanced/established subpopulations. See Appendix E for more detail.

4.5 Encourage partnerships with potential permit applicants who may be interested in participating in furthering the goals of the captive propagation program. The recovery team has recommended that the captive propagation program be comprised of multiple facilities because: 1) each facility provides a unique set of scientific and culture expertise; 2) each facility possesses different capabilities in managing water quality, and therefore may possess different capabilities in maintaining healthy captive animals; and 3) housing captive animals in multiple locations offers a safeguard against losing all animals in the case of a catastrophic event. Also, as enhancement efforts proceed and expand, the participation of multiple partners in tracking the survival of outplanted animals both over the short- and long-term will become ever more important.

4.6 Enhance wild populations by outplanting captive-bred white abalone in selected sites throughout the range of the species. A program of research is being implemented to determine: 1) optimal size at stocking under a range of conditions in order to minimize risk of mortality at outplanting; 2) the selection of outplanting sites based on which benthic habitat types, depths, food quality and quantity levels, and predator and conspecific densities lead to highest survival rates; 3) survivorship and population structure following release into the wild, as part of a post-release monitoring program; 4)

which type of release modules minimize abalone stress and protect them from predation during the initial 24 hour release period; and 5) how to develop a cooperative plan that monitors the effectiveness of the field planting program and the recovery rate of enhanced/established subpopulations. See Appendix E for more detail.

RECOVERY ACTION 5. PLAN AND IMPLEMENT A PUBLIC OUTREACH AND EDUCATION PLAN. Public outreach and education are vital to the recovery of white abalone. These activities raise awareness and promote individual responsibility and stewardship of the species. These activities should include both visual and audio elements to reach the greatest number of individuals.

5.1 Reduce the likelihood of poaching by raising public awareness through outreach to regional fisheries management councils, industry groups, dive clubs/shops, and the public media. Identify potential stakeholders and interest groups for outreach efforts. Participate at meetings and conferences to establish and solidify relationships with partners. There is an immediate need for an information brochure to distribute to the public through cooperating partners.

5.2 Develop educational displays and materials by cooperating with NGOs, aquaria, secondary schools, and universities. The NOAA Public Affairs Office and Southwest Regional Office should work to promote abalone issues on a nationwide and regional basis highlighting the global perils that abalone species face and the fact that white abalone is the first marine invertebrate to be listed as endangered under the ESA. Efforts to develop white abalone videos for distribution to the media and for placement on web sites should be promoted to help raise public awareness. Public aquaria have been identified as potential grow out facilities for research and enhancement activities and this will also serve to raise public awareness. Although collection of broodstock is being restricted to captive propagation/outplanting programs, the progeny may be utilized in public education programs. These programs must be incidental to research and enhancement activities, but are recognized as an avenue for furthering outreach and education goals.

5.3 Establish relationships with volunteer-based programs that can take part in various aspects of the captive propagation program (e.g., maintenance at hatcheries, research assistance, monitoring of captive-reared animals placed in the field etc.). A goal of each captive rearing facility should be to participate in education and outreach efforts. Volunteer-based programs have been recognized as a vehicle for securing low cost support from the members, enabling the public to become active participants in the recovery effort. Responsibilities of the individual will be determined based on the person's qualifications.

RECOVERY ACTION 6. SECURE FINANCIAL SUPPORT FOR WHITE ABALONE RECOVERY. A strong financial base is crucial to accomplish the criteria established in this plan. Assessment and monitoring of wild populations, conducting a captive propagation program, and developing

an outreach program will require considerable funding to achieve this plan's goals and objectives. Currently available funding is inadequate, and must be increased, particularly in the area of monitoring and propagation, which involves ship time, reliance on equipment that requires maintenance and upkeep, and the holding of numerous abalone for long periods. Funding has been unreliable in the past and a long-term financial commitment to continuing field monitoring and a propagation program must be consistent in order to recover this species. Below we identify potential sources for obtaining necessary funding support.

6.1 Federal, state, and private grants. Currently, the white abalone program has obtained funding from a variety of federal, state, and NGO sources, including in-kind matching funds. Examples of funding sources include Saltonstall-Kennedy Funds, National Undersea Research Program, California Sea Grant, National Fish and Wildlife Foundation, Marine Conservation Biology International, The Nature Conservancy, and various oil and power company mitigation funds. Unfortunately, single entities alone cannot support the entire white abalone recovery effort. Typically, the funding scope of one grant can cover the costs of only a subset of the actions necessary to recover the species. As the white abalone recovery program is implemented, there will be an increasing need to secure long-term funding for monitoring the species' status over a timeframe that encompasses several decades.

6.2 **Cooperative funding agreements among state, federal and private entities.** Cooperative agreements formed between and within state, federal, and private programs, where resources and expertise are pooled, may help avoid redundancy in effort and extend the scope of available funds.

V. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines recovery actions and estimated costs for the recovery program for the white abalone over a five-year period. The Implementation Schedule provides projections on which actions may continue beyond year five, but because we can not predict the recovery date for white abalone at this time, we can not state the exact duration of some of the recovery actions. The Implementation Schedule is a specific guide for carrying out recovery actions over a five-year period in terms of action priorities, action numbers, action descriptions, duration of actions, the parties responsible for actions (either funding or carrying out), and estimated costs in order to meet the recovery goals outlined in this plan. Parties with authority, responsibility, or expressed interest to implement a specific recovery action are identified in the Implementation Schedule. When more than one party has been identified, the proposed lead party is indicated by an asterisk (*). The listing of a party in the Implementation Schedule does not require the identified party to implement the action(s) or to secure funding for implementing the action(s).

Recovery actions and descriptions reflect the actions as numbered in the Stepdown Outline and Recovery Narrative. Priorities in the Implementation Schedule are assigned as follows:

Priority 1 – An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2 – An action that must be taken to prevent significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3 – All other actions necessary to provide for full recovery of the species.

KEY TO IMPLEMENTATION TABLE ABBREVIATIONS

Abalone Recovery and Management Plan	ARMP
Bodega Bay Marine Laboratory	BBML
Cabrillo Aquarium	CA
California Department of Fish and Game	CDFG
Channel Islands Marine Resources Institute	CIMRI
Channel Islands National Marine Sanctuaries	CINMS
Endangered Species Act	ESA
Instituto Nacional de la Pesca	INP
Long Beach Aquarium of the Pacific	LBAOP
Montana State University	MSU
National Marine Fisheries Service	NMFS
National Park Service	NPS
Non-governmental Organizations	NGOs
Population Viability Analysis	PVA

Remotely Operated Vehicle	ROV
Santa Barbara Museum of Natural History	SBMNH
Self-Contained Underwater Breathing Apparatus	SCUBA
University of California San Diego	UCSD
University of Washington	UW
Withering Syndrome	WS

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
1.1	Develop an assessment and monitoring program to identify current status of and track changes in wild subpopulations		FY1-FY5 and beyond	NMFS, CDFG, NPS, CINMS,	See breakdown of costs below 1.1.1-1.1.2					
1.1.1	Assess extant subpopulations in the wild (ROV and SCUBA)	1	FY1-FY5 and beyond		250	250	250	250	250	Federal and State program funds and private sources if available
1.1.2	Monitor extant subpopulations in the wild (ROV and SCUBA)	1	FY2-FY5 and beyond			150	150	150	150	
1.2	Tag extant individuals belonging to multiple subpopulations	2	FY1-FY5	NMFS, CDFG, NPS	10	5	5	6	6	
1.3	Determine value of translocation to establish viable populations	3	FY1-FY5		5	5	6	6	7	
1.4	Conduct genetic analyses of wild population structure		FY1-FY5	UCSD	See breakdown of costs below 1.4.1-1.4.2					
1.4.1	Determine extent of genetic differentiation among wild subpopulations to provide insight into structure	1	FY1-FY5	UCSD	25	25	25	25	25	Provide support via contract
1.4.2	Determine the best captive propagation, field planting and translocation design that serves to maintain the current genetic structure of	1	FY1-FY5	UCSD, NMFS, CIMRI	10	10	10	10	10	Provide support for best captive propagation, field planting

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
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					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
	the wild population									and translocation design
1.5	Develop population data and demographic PVA models		FY3-FY5 and beyond	NMFS, CDFG, NPS, CIMRI, BBML, MSU	See breakdown of costs below 1.5.1-1.5.4					
1.5.1	Evaluate and improve estimates of abundance, reproduction, survival, and growth for use in PVA models	2	FY3-FY5 and beyond	NMFS, CDFG, NPS, CIMRI						No additional costs. Information gathered as part of 1.1-1.4
1.5.2	Develop population models to assess threats and identify key life history stages or demographic processes	2	FY3-FY5	BBML, NMFS			45	45	45	Contract with researcher at BBML
1.5.3	Conduct a PVA to determine time to extinction probabilities, trends to forecast the impact of threats, and the prospects for recovery	2	FY3-FY5	MSU			45	45	45	Contract with researcher at MSU
1.5.4	Expand PVAs to incorporate demographic and environmental stochasticity	2	FY3-FY5 and beyond	BBML			45	45	45	Contract with researcher at BBML
1.6	Maintain and enhance		FY1-FY5	NMFS, INP	See breakdown of costs below 1.6.1-1.6.3					

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					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
	communications with the Mexican government		and beyond							
1.6.1	Establish a technical advisory team through the INP and invite them to participate in workshops and meetings	2	FY1-FY5 and beyond							No additional costs
1.6.2	Participate in international conferences	2	FY1-FY5 and beyond		5	5	6	6	6	Federal program funds
1.6.3	Collaborate with Mexico to help improve our understanding of the status of extant subpopulations throughout the range and to help conserve and protect them	2	FY1-FY5 and beyond							No additional costs. Part of assessment and monitoring program.
1.7	Development of Post-Delisting Monitoring Plan	3	Beyond FY1-FY5	NMFS, INP, CDFG						No additional costs for development, but will require funds for implementing
TOTALS FOR RECOVERY ACTION 1					305	450	587	588	589	2519
2.1	Identify existing and potential habitat using multibeam sonar	1	FY1-FY5	NMFS						No additional costs. Part of

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
	generated bathymetry data and quantify and revise estimates of habitat availability in California									assessment and monitoring program.
2.2	Generate ROV transect data to assess biological and physical attributes of habitat	1	FY1-FY5 and beyond	NMFS						
2.3	Determine the level of risk associated with habitat degradation/destruction that existing and potential viable populations (will) face	2	FY1-FY5 and beyond	NMFS, CDFG						
2.4	Collaborate with Mexican researchers in assessing and monitoring white abalone habitat in Mexico	2	FY1-FY5 and beyond	NMFS						
TOTALS FOR RECOVERY ACTION 2					0	0	0	0	0	0
3.1	Enforce State of California protections	2	FY1-FY5 and beyond	CDFG						No additional costs. Carried out by in-state regulatory agencies.
3.2	Enforce Federal ESA protections	1	FY1-FY5 and beyond	NMFS						No additional costs; Current range of abalone in Federal

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
										waters
3.3	Protect white abalone populations and habitat as they are discovered or established through enhancement		FY1-FY5 and beyond	NMFS, CDFG, NPS, CINMS	See breakdown of costs below 3.3.1-3.3.3					
3.3.1	Continue state and federal review of permitted activities to minimize impacts in the wild	1	FY1-FY5 and beyond							No additional costs. Carried out by in-country regulatory agencies.
3.3.2	Evaluate current conservation measures (e.g., fishing restrictions, conservation areas, etc.) to afford viable wild populations appropriate protection from habitat destruction and illegal take		FY1-FY5 and beyond							
3.3.2.1	Support establishment of Marine Protected Areas in the northern Channel Islands	2	FY1-FY5 and beyond							
3.3.2.2	Support maintenance of rockfish conservation areas	2	FY1-FY5 and beyond							
3.3.2.3	Uphold objectives of the CDFG Abalone Recovery Management	2	FY1-FY5 and beyond							

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
	Plan									
3.3.3	Establish an interagency (state/federal) enforcement task force that can monitor areas containing viable populations on a semi-regular basis	1	FY1-FY5 and beyond	NMFS, CDFG	10	10	15	15	20	Provide support for in-country law enforcement efforts
3.4	Enhance degraded habitat through restoration or mollifying anthropogenic impacts through mitigation, as necessary	3	Beyond FY1-FY5	NMFS						Costs To Be Determined.
TOTALS FOR RECOVERY ACTION 3					10	10	15	15	20	70
4.1	Identify factors that may reduce the risk of mortality associated with the removal, handling and transport of wild white abalone to rearing facilities	1	FY1-FY3	NMFS, CIMRI, UW	20	20	20			Support research through private contracts
4.2	Determine the number of rearing facilities and broodstock animals needed to meet the goals of NMFS global management plans	1	FY1-FY5	NMFS, CDFG						No additional costs.
4.3	Establish a standard for security measures at facilities housing broodstock and captive-reared animals	1	FY1-FY3	NMFS, CIMRI	5	5	5			Support for installation of appropriate security

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Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
4.4	Comply with and periodically update NMFS global management plans for a captive propagations and enhancement program		FY1-FY5 and beyond	NMFS, UCSD, CIMRI, UW, BBML, CDFG, NPS	See breakdown of costs below 4.4.1-4.4.4					
4.4.1	Comply with updated genetics management plan	1	FY1-FY5	NMFS, UCSD, CIMRI						No additional costs. See 1.4
4.4.2	Comply with updated disease management plan	1	FY1-FY5 and beyond	NMFS, CIMRI, UW, BBML	43	43	43	43	43	Support via contract
4.4.3	Comply with updated management plan for the disposition of excess white abalone	2	FY1-FY5 and beyond	NMFS, CDFG, NPS, CIMRI, CINMS, BBML, LBAOP, CA, SBMNH	180	180	180	180	180	NMFS ESA Program Funds and private sources if available
4.4.4	Comply with updated field planting management plan	1	FY1-FY5 and beyond	NMFS, CDFG, NPS, CINMS, CIMRI	50	50	50	50	50	Federal and State Program funds and private sources if available
4.5	Encourage partnerships with potential permit applicants who	2	FY1-FY5	NMFS, LBAOP	15	15	15	15	15	Support for submission of

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
	may be interested in participating in furthering the goals of the captive propagation program									permit, upkeep on captive animals
4.6	Enhance wild populations by outplanting captive-bred white abalone in selected sites throughout the range of the species	1	FY1-FY5 and beyond	NMFS, CIMRI, CDFG, NPS, CINMS						Federal and State Program funds and private sources if available
TOTALS FOR RECOVERY ACTION 4					463	468	473	453	458	2315
5.1	Reduce likelihood of poaching by raising public awareness through outreach to regional fisheries management councils, industry groups, dive clubs/shops, and public media	2	FY1-FY5 and beyond	NMFS, CDFG, LBAOP, CA, SBNHM						No additional costs. See 4.4.3
5.2	Develop educational displays and materials by cooperating with NGOs, aquaria, secondary schools, and universities	2	FY1-FY5 and beyond	NMFS, CDFG, LBAOP, CA, SBNHM						No additional costs. See 4.4.3
5.3	Establish relationships with volunteer-based programs that can take part in various aspects of the captive propagation program (e.g., maintenance at	3	FY1-FY5 and beyond	NMFS, LBAOP, CA, SBNHM	10	10	10	10	10	Support via contract

IMPLEMENTATION SCHEDULE White Abalone (*Haliotis sorenseni*)										
Recovery Action Number	**Action Description**	**Priority Number**	**Action Duration**	**Responsible Parties**	**Estimated Fiscal Year Costs $ K**					**Comments**
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
	hatcheries, research assistance, monitoring of captive-reared animals placed in the field etc.)									
TOTALS FOR RECOVERY ACTION 5					10	10	10	10	10	50
6.1	Seek out and apply for federal and private grants	1	FY1-FY5 and beyond	NMFS, CDFG, NPS, CINMS, UW, BBML, UW, CIMRI, UCSD, MSU, LBAOP, CA, SBNHM						No cost
6.2	Form cooperative funding agreements among state, federal and private entities	1	FY1-FY5 and beyond	NMFS, CDFG, NPS, CINMS, UW, BBML, UW, CIMRI, UCSD, MSU, LBAOP, CA, SBNHM						No cost
TOTALS FOR RECOVERY ACTION 6					0	0	0	0	0	0
TOTAL FOR IMPLEMENTATION DURING THE FIRST FIVE YEARS					**788**	**938**	**1085**	**1066**	**1077**	**4954**

VI. LITERATURE CITED

Allee, W. C. 1931. Animal Aggregations. A Study in General Sociology. University of Chicago Press, Chicago.

Altstatt, J. M., R. F. Ambrose, J. M. Engle, P. L. Haaker, K. D. Lafferty, and P. T. Raimondi. 1996. Recent declines of black abalone *Haliotis cracherodii* on the mainland coast of central California. Marine Ecology Progress Series **142**:185-192.

Babcock, R., and J. Keesing. 1999. Fertilization biology of the abalone *Haliotis laevigata*: Laboratory and field studies. Canadian Journal of Fisheries and Aquatic Sciences **56**:1668-1678.

Bakun, A. 2006. Wasp-waist populations and marine ecosystem dynamics: Navigating the ''predator pit'' topographies. Progress in Oceanography **68** (2006): 271–288.

Bartsch, P. 1940. The West American Haliotis. Proceedings of the United States National Museum **89**:49-58.

Behrens, M. D., and K. D. Lafferty. 2005. Size frequency measures of white abalone, implication for conservation. Institute for Wildlife Studies, Ventura, CA.

Benton, T. G., and A. Grant. 1999. Elasticity analysis as an important tool in evolutionary and population ecology. Trends in Ecology and Evolution **14**(12): 467-471.

Breen, P. A., and B. E. Adkins. 1980. Spawning in a British Columbia population of northern abalone, *Haliotis kamtschatkana*. The Veliger **23**:177-179.

Burge, R., S. Schultz, and M. Odemar. 1975. Draft report on recent abalone research in California with recommendations for management. . California Department of Fish and Game.

Bushing, W. W. 1994. Biogeographic and ecological implications of kelp rafting as a dispersal vector for marine invertebrates. In Halverson, W. and G. Maender (eds.) Proceedings of the Fourth California Islands Symposium: Update on the Status of Resources, March 22-25, 1994. Santa Barbara Museum of Natural History (Santa Barbara, CA). pp. 103-110.

Butler, J., M. Neuman, D. Pinkard, R. Kvitek, and G. R. Cochrane. 2006. The use of multibeam sonar mapping techniques to refine population estimates of the endangered white abalone (*Haliotis sorenseni*). Fishery Bulletin **104**:521-532.

Butler, J. L., and J. R. Hunter. 2002. White Abalone Restoration, Workshop Report

California Department of Fish and Game. 2005. Abalone Recovery and Management Plan. Sacramento, California - The Resources Agency.

Caswell, H. 2000. Prospective and retrospective perturbation analysis: Their roles in conservation biology. Ecology **81**:619-627.

Caswell, W., S. Brault, A. J. Read, and T. D. Smith. 1998. Harpor porpoise and fisheries: An uncertainty analysis of incidental mortality. Ecological Applications **8**:1226-1238.

Chambers, M. D., H. Hurn, C. S. Friedman, and G. R. VanBlaricom. 2005. Drift card simulation of larval dispersal from San Nicolas Island, California, during black abalone spawning season. Pages 421-434 *in* D. K. Garcelon and C. A. Schwemm, editors. Proceedings of the Sixth California Islands Symposium, December 1-3, 2003, Ventura, CA. National Park Service Technical Publication CHIS-05-01, Institute for Wildlife Studies, Arcata, CA.

Chambers, M. D., G. R. VanBlaricom, L. Hauser, F. Utter, and C. S. Friedman. 2006. Genetic structure of black abalone (*Haliotis cracherodii)* populations in the California islands and central California coast: Impacts of larval dispersal and decimation from withering syndrome. Journal of Experimental Marine Biology and Ecology **331**:173-185.

Clavier, J. 1992. Fecundity and optimal sperm density for fertilization in the ormer (*Haliotis tuberculata* L.). Pages 86-92 *in* S. A. Shepherd, M. J. Tegner, and S. A. Guzmán del Próo, editors. Abalone of the world: Biology, fisheries, and culture. Proceedings of the 1st International Symposium on Abalone. Blackwell Scientific Publications Ltd., Oxford, U.K.

Cooper, J., M. Wieland, and A. Hines. 1977. Subtidal abalone populations in an area inhabited by sea otters. The Veliger **20**:163-167.

Cox, K. W. 1960. Review of the abalone of California. California Department of Fish and Game, Marine Resources Operations.

Cox, K. W. 1962. California abalones, family haliotidae. California Department of Fish and Game, Fish Bulletin **118**:1-132.

Crofts, D. R. 1929. Haliotis. Pages 174 *in* Liverpool Marine Biology Committee Memoirs XXIX. University Press of Liverpool.

Croker, R. S. 1931. Abalones. Division of Fish and Game, Fish Bulletin **30**:58-72.

Crouse, D. T., L. B. Crowder, and H. Caswell. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology **68**:1412-1423.

Crowder, L. B., D. T. Crouse, S. S. Heppell, and T. H. Martin. 1994. Predicting the impact of turtle excluder devices on loggerhead sea-turtle populations. Ecological Applications **4**:437-445.

Daniels, R., and R. Floren. 1998. Poaching pressures on northern California's abalone fishery. Journal of Shellfish Research **17**:859-862.

Davis, G. E., P. L. Haaker, and D. V. Richards. 1996. Status and trends of white abalone at the California Channel Islands. Transactions of the American Fisheries Society **125**:42-48.

Davis, G. E., P. L. Haaker, and D. V. Richards. 1998. The perilous condition of white abalone, *Haliotis sorenseni*, Bartsch, 1940. Journal of Shellfish Research **17**:871-875.

Dixon, C. D., R. W. Day, S. M. Huchette, and S. A. Shepherd. 2006. Successful seeding of hatchery-produced juvenile greenlip abalone to restore wild stocks. Fisheries Research **78**:179-185.

Estes, J. A., and G. R. VanBlaricom. 1985. Sea otters and shellfisheries. Pages 187-235 *in* R. Beverton, J. Beddington, and D. Lavigne, editors. Conflicts between marine mammals and fisheries. George, Allen, and Unwin, London, U.K.

Friedman, C. S., K. B. Andree, K. A. Beauchamp, J. D. Moore, T. T. Robbins, J. D. Shields, and R. P. Hedrick. 2000. '*Candidatus Xenohaliotis californiensis*', a newly described pathogen of abalone, *Haliotis* spp., along the west coast of North America. International Journal of Systematic and Evolutionary Microbiology **50**:847-855.

Friedman, C. S., M. Thomson, C. Chun, P. L. Haaker, and R. P. Hedrick. 1997. Withering syndrome of the black abalone, *Haliotis cracherodii* (Leach): water temperature, food availability, and parasites as possible causes. Journal of Shellfish Research **16**:403-411.

Geiger, D. L. 1999. Distribution and biogeography of the recent Haliotidae (Gastropoda: Vetigastropoda) worldwide. Boll. Malacologico **35**:57-120.

Gerber, L. R., and S. S. Heppell. 2004. The use of demographic sensitivity analysis in marine species conservation planning. Biological Conservation **120**:121-128.

Gotshall, D. W. 1977. Stomach contents of northern California dungeness crabs, Cancer magister. California Fish and Game.

Gruenthal, K. M., and R. S. Burton. 2005. Genetic diversity and species identification in the endangered white abalone (*Haliotis sorenseni*). Conservation Genetics **6**:929-939.

Guzman del Proo, S. A. 1992. A review of the biology of abalone and its fishery in Mexico. Pages 341-359 *in* Case studies of abalone fisheries.

Haaker, P. L. 1994. Assessment of abalone resources at the Channel Islands. The Fourth California Islands Symposium.

Haaker, P. L., D. O. Parker, H. Togstad, D. V. Richards, G. E. Davis, and C. S. Friedman. 1992. Mass mortality and withering syndrome in black abalone, *Haliotis cracherodii*, in California. Pages 608 *in* S. A. Shepherd, M. J. Tegner, and S. A. Guzmán del Próo, editors. Abalone of the world: Biology, fisheries, and culture. Proceedings of the 1st International Symposium on Abalone. Blackwell Scientific Publications Ltd., Oxford, U.K.

Hamm, D. E., and R. S. Burton. 2000. Population genetics of black abalone, *Haliotis cracherodii*, along the central California coast. Journal of Experimental Marine Biology and Ecology **254**:235-247.

Hayward, T. L. 1997. Pacific ocean climate change: atmospheric forcing, ocean circulation and ecosystem response. Trends in Ecology & Evolution **12**:150-154.

Hedrick, P. W., V. K. Rashbrook, and D. Hedgecock. 2000. Effective population size of winter-run chinook salmon based on microsatellite analysis of returning spawners. Can. J. Fish. Aquat. Sci. **57**:2368-2373.

Heppell, S. S., H. Caswell, and L. B. Crowder. 2000. Life histories and elasticity patterns: Perturbation analysis for species with minimal demographic data. Ecology **81**:654-665.

Hines, A. H., and J. S. Pearse. 1982. Abalones, Shells, and Sea Otters - Dynamics of Prey Populations in Central California. Ecology **63**:1547-1560.

Hobday, A. J., and M. J. Tegner. 2000. Status review of white abalone (*Haliotis sorenseni*) throughout its range in California and Mexico. NOAA Technical Memorandum NOAA-TM-SWR-035, U.S. Department of Commerce, National Oceanic and Atmospheric Administration. National Marine Fisheries Service, Long Beach, CA, USA.

Hobday, A. J., M. J. Tegner, and P. L. Haaker. 2001. Over-exploitation of a broadcast spawning marine invertebrate: Decline of the white abalone. Reviews in Fish Biology and Fisheries **10**:493-514.

Holling, C. S. 1959. Some characteristics of simple types of predation and parasitism. Canadian Entomologist **91**:385-398.

Howorth, P. C. 1978. The abalone book. Naturegraph Publishers, Inc., Happy Camp, CA.

Ino, T. 1952. Biological studies on the propagation of Japanese abalone (genus *Haliotis*). Bull. Tokai Reg. Fish. Res. Lab. **5**:1-102.

James, D. 2005. Abalone enhancement on artificial reefs in Port Phillip Bay, Victoria. Deakin University, Victoria.

Karpov, K. A., P. L. Haaker, I. K. Taniguchi, and L. Rogers-Bennett. 2000. Serial depletion and the collapse of the California abalone fishery. Pages 11-24 *in* A. Campbell, editor. Workshop on rebuilding abalone stocks in British Columbia. Canadian Special Publications, Fish and Aquatic Sciences.

Kojima, H. 1995. Evaluation of abalone stock enhancement through the release of hatchery-reared seeds. Marine and Freshwater Research **46**:689-695.

Lafferty, K. D., M. D. Behrens, G. E. Davis, P. L. Haaker, D. J. Kushner, D. V. Richards, I. K. Taniguchi, and M. J. Tegner. 2004. Habitat of endangered white abalone, Haliotis sorenseni. Biological Conservation **116**:191-194.

Lee, Y. C., H. H. Kuo, and Y. G. Chen. 2002. Discrimination and abundance estimation of wild and released abalone Haliotis diversicolor using stable carbon and oxygen isotope analysis in north-eastern Taiwan. Fisheries Science **68**:1020-1028.

Leighton, D. L. 1966. Studies of food preference in algivorous invertebrates of Southern California kelp beds. Pacific Science **20**:104.

Leighton, D. L. 1972. Laboratory Observations on Early Growth of Abalone, Haliotis-Sorenseni, and Effect of Temperature on Larval Development and Settling Success. Fishery Bulletin of the National Oceanic and Atmospheric Administration **70**:373-381.

Leighton, D. L. 1974. The influence of temperature on larval and juvenile growth in three species of southern California abalones. Fishery Bulletin **72**:1137-1145.

Leighton, D. L. 1977. Some problems and advances in culture of North American abalones (*Haliotis*). *in* Proc. First Symp. Latin Amer. Aquaculture Assoc. , Maracay, Venezuela.

Leighton, D. L. 2000. The Biology and Culture of the California Abalones. Dorrance Publishing Co., Pittsburg, PA.

Leighton, D. L., and C. A. Lewis. 1982. Experimental hybridization in abalones. International Journal of Invertebrate Reproduction **5**:273-282.

Levitan, D. R. 1991. Influence of body size and population density on fertilization success and reproductive output in a free-spawning invertebrate. The Biological Bulletin **181**:261-268.

Lowry, L. F., and J. S. Pearse. 1973. Abalones and Sea-Urchins in an Area Inhabited by Sea Otters. Marine Biology **23**:213-219.

Lundy, A. 1997. The California abalone industry - A pictorial history. Best Publishing Company, Flagstaff, Arizona.

McCormick, T. B., K. Herbinson, T. S. Mill, and J. Altick. 1994. A Review of Abalone Seeding, Possible Significance and a New Seeding Device. Bulletin of Marine Science **55**:680-693.

McCormick, T. B., L. M. Buckley, J. Brogan, and L. M. Perry. 2008. Drift macroalgae as a potential dispersal mechanisms for the white abalone *Haliotis sorenseni.* Marine Ecology Progress Series **362**: 225-232.

McGinnity, P., P. Prodohl, A. Ferguson, R. Hynes, N. O Maoileidigh, N. Baker, D. Cotter, B. O'Hea, D. Cooke, G. Rogan, J. Taggart, and T. Cross. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, Salmo salar, as a result of interactions with escaped farm salmon. Proc. Roy. Soc. Lond. B.

McShane, P. E., K. P. Black, and M. G. Smith. 1988. Recruitment processes in *Haliotis rubra* (Mollusca: Gastropoda) and regional hydrodynamics in southeastern Australia imply localized dispersal of larvae. Journal of Experimental Marine Biology and Ecology **124**:175-203.

Moore, J. D., T. T. Robbins, and C. S. Friedman. 2000. Withering syndrome in farmed red abalone *Haliotis rufescens*: Thermal induction and association with a gastrointestinal Rickettsiales-like prokaryote. Journal of Aquatic Animal Health **12**:26-34.

Morris, R. F. 1963. The dynamics of epidemic spruce budworm populations. Mem. Entomol. Soc. Can.

Morris, W. F., and D. F. Doak. 2004. Buffering of life histories against environmental stochasticity: Accounting for a spurious correlation between the variabilities of vital rates and their contributions to fitness. American Naturalist **163**:579-590.

Morse, D. E., and A. N. C. Morse. 1988. Chemical signals and molecular mechanisms- Learning from larvae. Oceanus **31**.

Newman, G. G. 1968. Growth of South African abalone *Haliotis midae*. Investigational Report Republic of South Africa Department of Industries, Division of Sea Fisheries.

NOAA. 2001. Endangered and threatened species: endangered status for white abalone. 66 Federal Register 29046-29055.

O'Connell, C. 1955. The life history of the cabezon Scorpaenichthys marmoratus (Ayres). California Department of Fish and Game. Fish Bulletin 93. 76 pp.

Owen, B., J. H. McLean, and R. J. Meyer. 1971. Hybridization in the eastern Pacific abalone (*Haliotis*). Bulletin of the Los Angeles County Museum of Natural History Science **9**:1-37.

Pennington, J. T. 1985. The ecology of fertilization of echinoid eggs: the consequences of sperm dilution, adult aggregation, and synchronous spawning. Biological Bulletin (Woods Hole) **169**:417-430.

Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope, and K. J. Sainsbury. 2004. Ecosystem based fishery management. Science **305**:346-347.

Prince, J. D., T. L. Sellers, W. B. Ford, and S. R. Talbot. 1987. Experimental evidence for limited dispersal of haliotid larvae (genus: *Haliotis*: Gastropoda: Gastropoda). Journal of Experimental Marine Biology and Ecology **106**:243-263.

Ramade-Villanueva, M. R., D. B. Lluch-Cota, S. E. Lluch-Cota, S. Hernandez- Vazquez, A. Espinoza-Montes, and A. Vega-Velazquez. 1998. An evaluation of the annual quota mechanism as a management tool in Mexican abalone fishery. Journal of Shellfish Research **17**:847-851.

Rogers-Bennett, L. 2007. Is climate change contributing to range reductions and localized extinctions in northern (*Haliotis kamtschatkana*) and flat *(Haliotis walallensis*) abalones? Bulletin of Marine Science **81**:283-296.

Rogers-Bennett, L., P. L. Haaker, T. O. Huff, and P. K. Dayton. 2002. Estimating baseline abundances of abalone in California for restoration. CalCOFI Reports **43**:97-111.

Rogers-Bennett, L., and J. S. Pearse. 1998. Experimental seeding of hatchery-reared juvenile red abalone in Northern California. Journal of Shellfish Research **17**:877-880.

Saether, B. E., and O. Bakke. 2000. Avian life history variation and contribution of demographic traits to the population growth rate. Ecology **81**:642-653.

Schiel, D. R. 1993. Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. Marine Ecology Progress Series **97**:167-181.

Seki, T., and K. Taniguchi. 2000. Rehabilitation of northern Japanese abalone, *Haliotis discus hannai*, populations by transplanting juveniles. Pages 72-83 *in* A. Campbell, editor. Workshop on rebuilding abalone stocks in British Columbia. Canadian Special Publication of Fisheries and Aquatic Sciences.

Shepherd, S. A. 2000. Review on enhancement of abalone in Australia. Can. Spec. Publ. Fish. Aquat. Sci. **130**:84-97.

Shepherd, S. A., and P. A. Breen. 1992. Mortality of abalone: Its estimation, variability, and causes. Pages 276-304 *in* S. A. Shepherd, M. J. Tegner, and S. A. Guzmán del Próo, editors. Abalone of the world: Biology, fisheries, and culture. Blackwell Scientific Publications Ltd., Oxford, U.K.

Shepherd, S. A., and L. D. Browne. 1993. What is an abalone stock: Implications for the role of refugia in conservation. Canadian Journal of Fish and Aquatic Sciences **50**:2001-2009.

Shepherd, S. A., D. Lowe, and D. Partington. 1992. Studies on southern Australian abalone (Genus *Haliotis*): Larval dispersal and recruitment. Journal of Experimental Marine Biology and Ecology **164**:247-260.

Shepherd, S. A., J. M. Turrubiates Morales, and K. Hall. 1998. Decline of the abalone fishery at La Natividad, Mexico: overfishing or climate change? . Journal of Shellfish Research **17**:839-846.

Tegner, M. J. 1989. Chapter 17: The California abalone fishery: Production, ecological interactions, and prospects for the future. Pages 401-420 *in* J. F. Caddy, editor. Marine invertebrate fisheries: Their assessment and management. J. Wiley and Sons, New York.

Tegner, M. J. 1993. Southern California Abalones - Can Stocks Be Rebuilt Using Marine Harvest Refugia. Canadian Journal of Fisheries and Aquatic Sciences **50**:2010-2018.

Tegner, M. J., L. V. Basch, and P. K. Dayton. 1996. Near extinction of an exploited marine invertebrate. Trends in Ecology & Evolution **11**:278-280.

Tegner, M. J., and R. A. Butler. 1985. Drift-tube study of the dispersal potential of green abalone (*Haliotis fulgens*) in the Southern California Bight: Implications for recovery of depleted populations. Marine Ecology Progress Series **26**:73-84.

Tegner, M. J., and P. K. Dayton. 1987. El Niño effects on southern California kelp forest communities. Advances in Ecological Research **17**:243-279.

Tegner, M. J., P. L. Haaker, K. L. Riser, and L. I. Vilchis. 2001. Climate variability, kelp forests, and the southern California red abalone fishery. Journal of Shellfish Research **20**:755-763.

Thompson, B., J. Dixon, S. Shoeter, and D. J. Reish. 1993. Benthic Invertebrates. U. Calif. Press, Berkely, CA.

Tutschulte, T. C. 1976. The comparative ecology of three sympatric abalone. University of California, San Diego.

Tutschulte, T. C., and J. H. Connell. 1981. Reproductive biology of three species of Abalones (*Haliotis*) in Southern California. The Veliger **23**:195-206.

VanBlaricom, G. R. 1993. Dynamics and distribution of black abalone populations at San Nicolas Island, California. Pages 323-334 *in* F. G. Hochberg, editor. Third California Islands Symposium: recent advances in research on the California Islands. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Wells, F. E., and J. K. Keesing. 1990. Population characteristics of the abalone *Haliotis roei* on intertidal platforms in the Perth metropolitan area. Journal of the Australian Malacological Society **11**:65-71.

APPENDIX A.

WHITE ABALONE BROODSTOCK COLLECTION AND HOLDING PROTOCOL

As recommended by Thomas B. McCormick, Channel Islands Marine Resource Institute and Dr. Carolyn Friedman, School of Aquatic and Fishery Sciences, University of Washington

Seven species of abalone are found in rocky habitat in coastal waters of California. Five of these species, the red, pink, green, black, and white, have been the subject of commercial and sport take for the last 150 years. Over-exploitation has led to the demise of abalone stocks not only in California but around the world. Stocks of the white abalone (*Haliotis sorenseni*) have fallen so low that it has been listed as the first endangered marine invertebrate in the U. S.

Efforts have begun to establish a hatchery breeding program that will produce the next generation of broodstock for outplanting in the wild. The first step in this program involves the collection of wild animals to will serve as breeding stock. This document provides information on the collection, shipment, and holding of white abalone. The intent is to minimize stress and maximize survival during this process.

White Abalone Habitat: The deepest living California abalone, white abalone were historically reported to occur at depths of 5 to 60 meters and are currently most abundant at 30 to 60 meters (Cox , 1960). Shallow populations were more easily removed by fishing pressure during the 1970's leaving remnants of the population at mean depths of 48 meters (Haaker et al., 2000). Diving to and retrieving abalone from these depths presents a formidable challenge. White abalone are found on rocky habitat, on low relief rock or boulders at the sand interface (Tutschlute, 1976; Davis et al., 1996).

Collection of Abalone: Once abalone have been located great care must be taken to avoid cutting the soft parts of this marine gastropod during removal from the substrate. Removal of any wild abalone intact from its rocky substrate is always a challenge. Like all other abalone species, white abalone move about and adhere to the rock substrate with their large muscular foot. When disturbed the abalone will use its foot to pull the shell down tightly against the rock substrate for protection. Once in this defensive position it is very difficult to remove the abalone without injuring it.

Traditionally abalone taken for commercial, sport, aquaculture, and research activities have been removed form the substrate with an abalone iron. The iron consists of a thin metal blade 1 – 2" across and 1/8 – ¼" thick that is inserted between the substrate and the foot of the abalone. A swift upward motion of iron's handle is used to remove the animal from the substrate. In the hands of an experienced diver, the abalone iron is a quick and efficient tool for obtaining abalone. One disadvantage of this method is that the rocky substrate on which the abalone is perched may be uneven and the abalone iron may nick or cut the foot. Burge et al. (1975) found

that commercial fisherman cut 12.6% of the pink abalone that they collected. Sports divers deeply cut 38% of the abalone in their bag limits.

Abalone often succumb to wounds suffered during removal from the substrate. Abalone blood has no clotting ability (Cox, 1962) and relatively minor cuts can cause loss of haemolymph, resulting in mortality. Burge et al. (1975) showed that mortality in sub-legal red abalone from half-inch cuts was 60% in the laboratory.

To minimize stress and trauma to the animals during collection and transport, the following methods are suggested.

Underwater – Removing abalone from substrate:
When collecting abalone there are several options for removing animals alive and in good condition from submerged rocky outcrops as follows:

Kelp "bait": Wave a frond of kelp directly in front of the abalone. If the abalone has not been previously disturbed, the smell or touch of the kelp will cause the abalone to raise its shell and extend the front of its foot in a feeding posture. While in this position, the abalone can be easily removed from the substrate by swiftly inserting a hand under the foot and pulling upward, removing it from the rock.

Predator "Scare": To avoid predation by the sunflower star (*Pycnopodia helianthoides*) abalone may attempt to outrun this highly mobile sea star. Although the sunflower star is not as abundant in southern California as it is to the north, it may be possible to obtain a sea star and place it directly in front of the abalone. This should cause the abalone to make an evasive move. When the abalone is actively moving across the substrate it can be easily removed with a rapid motion.

Use of Anesthetics: Anesthetics can be utilized to make abalone relax their grip on the substrate. Several anesthetics have been shown to be effective for abalone. For collection activities, anesthetics have two disadvantages: first, at colder temperatures (12-16°C) anesthetics are slow acting. The solution containing the anesthetic must be in contact with the abalone for 5 – 25 minutes. At depths where abalone are found, setting up an apparatus to administer an anesthetic and then waiting for it to take effect will require later decompression stops for the divers. The second, disadvantage is that it will be necessary to develop a means of exposing the abalone to the anesthetic for an extended period. It may be possible to develop a plastic bag or other container that can be pressed against the substrate to form a tight seal around the abalone. The anesthetic could then be introduced into this containment.

Two anesthetics that have been shown to be effective for abalone are Tricane Methanesulfonate (MS-222) and (Ethyl-paraminobenzoate (EPAP). Neither of these chemicals is approved by the FDA for use in food animals, however, this is not an issue

for white abalone. A saturated solution of carbon dioxide (CO_2) is almost as effective at loosening abalone from the substrate. Like the anesthetics, long exposure times are needed. Carbon dioxide is considered a low-regulator drug by the FDA.

Abalone iron: This is the traditional way to remove abalone from the rock substrate. In order to minimize cuts and trauma the collector should follow the following guidelines:

> **Approach:** Abalone are sensitive to water motion and changes in light. Approach an abalone slowly and do not cast a shadow so that the abalone does not go into a defensive posture.
>
> **Point of insertion for the Abalone Iron:** Injury to the head and anterior portion of the foot should be avoided. The abalone iron should be inserted along the sides or back of the shell. Look for an area of rock that is smooth and free of crevices so that the iron does not cut into the foot where it has
>
> **Handling of the abalone iron:** When the diver is in position, hold the iron with the concave side down. Press the tip of the iron against the rock substrate and slide quickly forward into a gap between the shell and the substrate. Still pressing downward, slide the iron 2-4" under the shell. Quickly pull upward on the handle end of the iron to pop the abalone off the substrate. This entire motion should be done quickly. The element of surprise is essential. If the iron is inserted too slowly the abalone will clamp down, and in the resulting struggle the abalone will invariably sustain damage to the foot.
>
> **When not to use the iron:** When the abalone is in a normal resting posture the shell of the abalone will be raised 0.25 – 0.5" above the rocky substrate with the epipode protruding from beneath the shell. The soft epipode is black and white with the distal ends fringed, much like that of a pink abalone. Small tentacles protrude from the epipode and provide the abalone with a sense of touch. When the abalone is disturbed, the epipode will be withdrawn and the shell pulled down against the rock. In this position, it is almost impossible to pry the abalone off the rock without injury. It is better to wait 10 – 20 minutes for the abalone to resume a normal resting posture before trying a removal attempt.

Following Removal – Use of an Artificial Substrate: Once the abalone has been removed from the rock it will be transferred to a holding tank or ice chest at the surface and then transferred again to the holding facility. The number of times that an abalone is removed from the substrate can be minimized if an artificial substrate is provided. A thin piece of plastic, such as the top to a 1 to 5-gallon bucket, can act as portable substrate for the abalone. Once the abalone is removed from the ocean floor it can be placed directly on the plastic. The abalone can stay on the plastic in the holding tank and ice chest.

Seawater Temperature: The temperature of the seawater where the abalone are collected should be noted (in advance if possible) so that the temperature of the holding tank on board ship can be brought as close as possible to this temperature, plus or minus 2°C.

Transport to surface: Avoid thermal shock on the trip to the surface by placing each abalone in a sealed plastic bag filled with seawater. A 1-Gallon Zip-Lock bag works well. Caution: Do not keep the abalone in the bag for more than 15 - 20 minutes as the animal will consume all available oxygen.

Holding Facilities on Board Vessel: There are several options for holding abalone on board a vessel, depending upon the length of the cruise, the amount of deck space, availability of flowing seawater and electricity. Temperature control is essential. Surveys or seawater temperatures in white abalone habitat at 20 m depths off Santa Catalina Island range indicate that yearly temperatures range from 13 to 18°C (Tsuchulte and Connell, 1981). Temperatures of the holding tanks should be kept within two degrees of those at the collection site.

Different options for holding abalone on board ship are:

1) Ice chest with gel packs: for holding times of up to 24 hours. This is the simplest and least expensive holding and transport system. Both juvenile and adult abalone from farms are routinely transported in this manner. The principal is to keep the animals cool and moist. Frozen gel packs are used for cooling but should never come into direct contact with the abalone. Individual gel packs should be wrapped with newspaper in order to avoid extremely low temperatures followed by thawing of the gel. To wrap each gel pack, start with 6 – 8 sheets of newspaper. Fold the newspaper lengthwise so that it is one inch longer than the gel pack. Wrap the newspaper around the gel pack so that the two ends are open. Fasten the newspaper in place with packing tape. To insure that only the ends of the gel pack provide cooling keep the newspaper dry. Used in this manner the gel pack will last 24 to 30 hours. The ratio of abalone weight to gel pack weight should be 2.5:1, that is, 2.5 pounds of abalone for every one pound of frozen gel pack (wrapped in newspaper). Gel packs should be placed on the bottom of the ice chest standing on edge against the walls of the ice chest. A large plastic bag (13 gallon or more) should be placed in the ice chest. Slightly moistened absorbent material, such as foam rubber or paper towels, should be placed in the bottom of the plastic bag to absorb excess water from the abalone. If available, a layer of kelp on top of the absorbent will give the abalone something to adhere to and provide moisture. For short transport times (8 – 12 hours) leave the bag open at the top to allow air into the bag. For transport times in excess of 12 hours the bags should be filled with oxygen and sealed. Components required are: Ice chest, gel-ice packs, plastic bags, foam rubber, and paper towels. It may also be necessary to purchase or rent an oxygen tank and regulator.

2) Self-Cooling Ice Chest: For short holding times a self-cooling portable ice chest may be suitable to transport abalone. This system eliminates the need for frozen gel packs. Caution should be taken to determine the chilling capacity of the ice chest in advance of any collection activities. Packing of the abalone is similar to that outlined in 1), above. System components should include: Self-cooling Ice Chest: These recreational coolers require a 12 VDC power source, converter for ship board 24 VDC power, plastic bags, foam rubber, and paper towels.

3) Place abalone in boat's live well. For multi-day trips during periods when surface seawater temperatures are less than 17°C, and close to that of where the animals were collected, place abalone in the boat's live holding tanks. Make sure that water circulation is maintained constantly. Shipboard seawater pumping systems often use brass or bronze pumps or plumbing. The copper in these metals is toxic to abalone and an alternative water supply should be used.

4) Flowing seawater tank with chiller: For multi-day collection trips it will be necessary to keep the abalone at temperatures close to those of the collection site. A small plastic, stainless steel, or titanium pump can be used to obtain water from any depth when coupled to a flexible 1" intake pipe hung overboard. If surface water is used, an appropriately sized chiller with a titanium heat exchanger can be used to maintain the desired water temperature. Holding system components should include: Seawater pump, titanium chiller, insulated holding tank with top, miscellaneous PVC plumbing, small air pump and airstones, and a maximum / minimum thermometer.

5) Flowing seawater from depth - This system is similar to the one above but has no chiller. The end of a flexible intake hose is lowered to a depth of 20 – 50 m to reach the desired water temperature. The disadvantage of this system is that cool water can not be pumped in while underway. If there is a long trip to port during the summer, temperatures can be controlled with frozen gel packs. Components are the same as above except for the chiller.

Tagging, Data Acquisition, and Tissue Sampling:

Tags: It essential to tag abalone immediately upon bringing on board ship. The longest lasting tag is made of a stainless steel washer (approximately 5/8" in diameter) that has been stamped with an identifying number (Haaker et al., 1986). The tag is held in place with stainless steel wire by passing the wire through the top-most respiratory pores and through the tag. The wires are then twisted together so that the wire is tight against the shell and does not move. Trim the excess wire and bend the end against the shell so there is no sharp projection.

Data Acquisition: Once the abalone have been tagged the shell length, total weight, and sex should be recorded. The data sheet should also note the GPS location of site, depth,

bottom temperature, bottom type, types of kelp observed, the person who collected the abalone and any other relevant details.

Tissue Sampling: Tissue samples will provide valuable genetic information about the population structure of the white abalone. It will also be useful to track lineage in hatchery raised stocks. A non-lethal tissue sampling methodology has been developed that uses one of the abalone's many epipodal tentacles. While this sampling method poses minimal risk to the abalone, it should only be carried out by someone skilled in handling abalone. The method is as follows: With a pair of tweezers grasp the end of one of the epipodal tentacles on the sides or posterior of the animal. While gently pulling the tentacle taught use a nail clipper to cut the tentacle 1 – 2 mm from its base. Place the tentacle in a microfuge tube with 1-2 ml of a high salt buffer 5XNET, pH 8 solution. Seal the top of the tube and record the animal number, location, and date on the tube label. Refrigerate the tube. This buffer will preserve the DNA in the sample indefinitely. Materials: 100 ml Buffered 5XNET, pH 8 solution, composed of 2.5 Molar NaCl, 0.25 Molar EDTA, 0.25 Tris pH 8. Also 4 Plastic containers with tops 50 ml., 10 plastic droppers, and 50 microfuge tubes.

Transport to Holding Facilities:

Recommended transport times: When properly packed, abalone can be shipped without water for 24 hours with 100% survival. Shipping times for wild caught white abalone should be kept to only a few hours to minimize stress.

Packaging: Careful attention should be given to packing the animals for transport. Packing procedure – Prior to handling the animal, prepare the shipping bag. Immerse three pieces of foam rubber sheet (18" X 18", or appropriate size to fit the plastic bag) into the cold seawater of the holding tank. Squeeze the excess water from two pieces of foam then place them in a plastic bag (2' X 2'6", 13 gallons or larger). Remove abalone from the temporary holding tank and drain excess water for 30 seconds. Place the abalone foot down on the two layers of foam. Several abalone can be placed side by side on the foam. Place the third piece of damp foam over the abalone. For trips shorter than 12 hours, no supplemental oxygen is required. Loosely close the plastic bag with a rubber band so that a small amount of gas exchange can occur. Oxygen may be added for trips greater than 8 hours. To fill the bag with oxygen, gather the open end and insert the tube from the oxygen regulator into the bag while holding the bag shut around the tube. Fill the bag with oxygen then press all the oxygen out of the bag, and fill again. Seal the bag by twisting it, making a small loop and securing the loop with a strong rubber band to prevent the escape of any gas. Once the abalone are sealed into the plastic bags, they should be placed in a Styrofoam box or ice chest. Place the abalone in a single layer in the container. Cooling is provided by frozen gel packs. The quantity and handling of gel packs is the same as that described for holding facilities onboard vessel – ice chest with gel packs.

Holding Facilities:

Health and Gonad Examination: Upon arrival of the abalone at the holding facility the health and spawning condition of the abalone should be assessed. The soft tissues of the foot and epipode should be examined for any nicks, cuts or abrasions resulting from collection. Any findings should be noted on a data sheet that contains the abalone number, and the date and location of collection. The total weight and shell length should be noted along with information about the appearance of the shell. For example, if the growing edge of the shell is sharp, this indicates that the animal has recently grown. If the edge is rounded, it indicates that some time has past since the shell grew. The extent of fouling of the shell should be noted.

The gonad index (GI) of each abalone should be noted. Several methods have been developed to measure gonad ripeness. Uki and Kikuchi (1982) developed a convenient scale as follows:

Gonad Ranking	Description of Gonad and Spawning Activity
0	No gonad observed. Not possible to determine sex. Abalone will not spawn.
1	Small volume of gonad observed. Possible to determine sex of abalone by gonad color. Males have a light tan or creamy colored gonad; females have a darker gonad from brown to green in color. Abalone will not spawn.
2	Larger volume of gonad. Easy to distinguish sexes. Gonad bulk visible. Abalone may spawn.
3	Volume of gonad quite large, may extend below the lower plane of the shell. Abalone will probably spawn.

After abalone are placed in the holding systems, the gonad index should be checked no more often than once a month since the process of removing the abalone from the tank and handling it is stressful and will inhibit growth.

Quarantine: Newly acquired abalone should be held separately from those already in the facility for a period of three to six weeks. This will provide enough time for the new abalone to undergo an antibiotic treatment for withering syndrome. During the quarantine period, all equipment should be washed with 100 ppm chlorine and rinsed with seawater after use in the new abalone tanks. Note: Technicians should observe good husbandry practice and wash hands in freshwater before and after working in each tank.

Withering Syndrome Inoculation Protocol: Dr. Carolyn Friedman, pathologist at the University of Washington has developed an antibiotic treatment for the control of a rickettsiales-like-protozoan or RLP (Gardner et al., 1995) that causes withering syndrome in white abalone. Oxytetracycline is an effective treatment when nine injections are administered over a five-week period. Oxytetracycline can also be incorporated in the feed at up to 6.0 g active oxytetracycline per 100 pounds body weight per day for 14 days to control withering syndrome.

If abalone appear to be shrunken they will be will be inoculated as per Dr. Friedman's protocol (carolynF@U.Washington.edu). Treatments should be effective for 6 – 12 months, particularly if influent water is UV sterilized. Withering syndrome now appears to be endemic throughout southern California.

Waxing Protocol: The calcium carbonate shells of abalone are a perfect substrate for boring organisms such as clams, (*Pholadidea conradi*), sponges (*Cliona* spp.) and the mud worm (*Polydora* spp.). These organisms may weaken the shell and cause irritation as the abalone repairs the inside of the shell. It is possible to eliminate many of these invaders without harming the abalone. Only heavily infested animals should be treated, since some stress is associated with this procedure.

A method of sealing the outer shell with wax was developed by Trevelyan et al. (1994) as a means of combating exotic sabellid polychaetes in commercial farms. Warm liquid wax is brushed onto the shell of the abalone, completely covering the openings of the invaders. The wax is allowed to harden then the abalone is returned to its tank. The infesting organisms, now sealed under the wax will die in a day or so.

The technique consists of four steps: Anesthesia, shell drying, wax coating, and incubation as follows:

Anesthesia: See notes on anesthesia in the Handling section below.

Shell Drying: It is important to have the shell dry in order for the wax mixture to adhere to it. After the abalone have been removed from the side of the tank, scrub the shell with a stiff brush to remove silt and fouling organisms. Rinse the shell in seawater. Place the animal on a material from which it can easily be removed, by laying shade cloth, netting or cloth in a water table and introducing a trickle of seawater. The seawater will keep the foot moist. Use a dry towel to remove excess moisture from the shell. A fan run at moderate speed can be used to accelerate the drying process.

Wax coating: A mixture of three ingredients is used in order to reduce the working temperature of the liquid phase an increase the flexibility of the hardened solid wax. The type and amount of the ingredients are:

Paraffin	55%
Petrolatum (petroleum jelly)	35%
Bees Wax	10%

The ingredients can be easily be melted in a microwave oven by placing them in a small plastic container of the type that yogurt or cottage cheese comes in. Place the small container in a larger container. Pour water into the larger container until it is half full. Both containers are then placed in the microwave oven and heated until all the wax is melted. The heated water in the large container will help to melt the wax and keep it warm when coating the abalone. NOTE: Always heat the wax in a water bath. Never place only the wax mixture in the microwave as this may result in a fire.

Once the wax is melted and the abalone shell appears dry, apply the liquid wax with a 2 – 3" wide brush. The respiratory pores can be covered in wax without a deleterious effect on the animal. Once applied the wax cools quickly and will not burn the tissue of the abalone or the technician. After being waxed the abalone can be immediately returned to its holding tank.

Incubation: After being returned to the holding tank the wax coating is allowed to incubate for 3 – 7 days. During this time the shell under the wax turns anaerobic, killing the biofouling organisms. Following incubation, the shells are vigorously aerated and sprayed to remove the wax coating. A black anaerobic layer on the outside of the shell can be observed. This layer quickly disappears.

Holding Conditions: Conditions under which white abalone are held should mimic day to day and seasonal variations in the natural habitat. Consideration should be given to control temperature, dissolved oxygen, feeding, waste removal, bacteria, lighting conditions, and handling methods.

Temperature: As noted above, the annual range of seawater temperatures at 20 m off southern California range from 10°C - 18°C. The desired range for holding is 14°C - 17°C. Temperatures as low as 10°C may be used to stimulate gonad maturation. The effect of temperature on the occurrence of withering syndrome must be considered. In red abalone, withering syndrome is exacerbated or even induced in rickettsiaeles injected animals when held at water temperatures greater than 15 °C. Prior to holding abalone a temperatures of 16°C - 17°C, animals should be treated with antibiotics as in the Withering Syndrome Inoculation Protocol, described previously.

Dissolved Oxygen: Dissolved oxygen should be at or within 10% of saturation. Aeration can be used to both provide oxygen and water movement within the holding tank.

Feeding: The types of feed used, the frequency of feeding, amount of feed consumed, and treatment of the kelp should be considered as follows:

Feed Types: The dietary preferences of white abalone broodstock are not clearly understood. *Laminaria* and *Macrocystis* probably make up a large portion of the diet. The reddish brown color of the shell indicates that white abalone also consume some type of red algae throughout their life.

Frequency of feeding: The frequency of feeding should be once or twice a week depending upon the rate of consumption and condition of the kelp.

Quantity of Feed: Abalone are not aggressive feeders and should be fed *ad libitum*. It is important to measure the quantity of feed consumed to get a feeling for the health of the abalone. One of the first signs of withering syndrome is loss of appetite.

Kelp treatment: Prior to feeding to abalone, kelp should be immersed for 5 minutes in freshwater. This will remove unwanted epibionts and may also reduce the introduction of pathogenic bacteria, such as rickettsia.

Water Flow: Flowing water provides aeration while removing solid and dissolved waste products. Water should be provided to the holding tank at a rate of 10% of tank volume per hour per kilogram of abalone weight.

Waste Removal: A byproduct of protein metabolism, the ammonium ion (NH_3-N), is extremely toxic to abalone. An adequate supply of flowing seawater should be used to remove ammonia from the holding tanks. Solid waste should be prevented from accumulating on the tank bottom since this it can quickly turn anaerobic and produce toxic ammonia compounds. A self-cleaning tank is optimal. This can be achieved by using a small pump to recirculate water within the tank. If the holding tank is not self-cleaning waste should be removed with a siphon daily.

Bacteria: Pathogenic bacteria, such as rickettsiae may enter the abalone holding system in the water flow. To reduce the number of bacteria in the culture system water should be filtered and passed through an ultra violet (UV) sterilizer. A minimum dosage of 15,000 μW sec/cm^2 should be applied.

Lighting Conditions: Lighting levels at the 20 – 50 m depths where white abalone are found are much lower than at the surface. Low wattage bulbs of 40 watts or less should be used to illuminate in the holding tanks. To induce gonad maturation lights should be placed on a timer to simulate the change of seasons.

Handling Methods: Abalone must be handled with great care since their tenacious hold on the substrate and tender flesh make a combination that may result in nicks or cuts in the hands of an unpracticed worker. To reduce the possibility of wounding an abalone, only people skilled in the handling of abalone should move the abalone. If abalone are held in plastic or fiberglass tanks a thin metal or plastic kitchen spatula can be an effective tool to quickly remove abalone from a tank. If a spatula is used it should be inserted from the rear or sides of the animal. Never insert a spatula under the head. Should abalone prove difficult to move anesthetics should be used as follows:

Anesthesia: To reduce the chances of cutting abalone when they handled for gonad inspection, measurement or spawning, it is advisable to anesthetize them first. Several anesthetists are available:

Carbon Dioxide (CO_2): Seawater saturated with carbon dioxide makes a suitable anesthetic for abalone. To produce a saturated carbon dioxide solution, bubble carbon dioxide through seawater for 15 minutes. Pressurized CO_2 is supplied from a cylinder via a regulator, tube and 6" – 10"airstone. It is best if the saturated solution can be made in a separate tank. Once the solution is saturated, drain the normal seawater from the white abalone holding tank and pour in the saturated seawater. The abalone should loose its grip in 4 – 5 minutes. Immersion in the CO_2 saturated seawater should be limited to 10 minutes otherwise suffocation may result. After the abalone have been removed from the tank, place them in normal seawater to revive them. Discard the saturated water and refill the holding tank with seawater. NOTE: Although CO_2 is a low regulatory drug, it is not currently FDA approved for abalone.

Ethyl-para-amino-benzonate (Epab) has been used as an effective anesthetic for abalone. Efficacy of this drug is dependent upon water temperature and dosage. At 15 °C, a dosage of 30 ppm for 15 minutes is effective. Longer times are required at colder temperatures. Do not exceed a 30-minute exposure. A related chemical compound, Tricane Methanesulfonate, marketed as MS-222 is also an effective anesthetant for abalone. The dosage of MS-222 should be twice that of Epab. NOTE: Neither Epab nor MS-222 are FDA approved for farmed abalone.

Tools: To remove abalone from the substrate, a plastic kitchen spatula is effective. Look for a wide blade and thin profile. To prevent the possibility of cutting or nicking the abalone, sand down the front of the spatula.

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References

Burge, R., S. Schultz, M. Odemar. 1975. Draft report on recent abalone research in California with recommendations for management. Dept. of Fish and Game.

Cox, K.W. 1960. Review of the abalone of California. Calif. Fish & Game Bull. 46:381-406.

Davis, G.E., P.L. Haaker and D.V. Richards. 1996. Status and trends of white abalone at the California Channel Islands. Trans. Am. Fish. Soc. 125(1), 42-48.

Haaker, P.L., D.V. Richards, and I. Taniguchi. 2000. White abalone program. October 9 – 25, 1999 Cruise Report. CSFG, 330 Golden Shore, Suite 50, Long Beach, CA 90802.

Haaker, P.L., D.O. Parker, and K.C. Henderson. 1986. Red abalone size data from Johnsons Lee, Santa Rosa Island, collected from 1978 to 1984. Calif. Dept. Fish. Game, Mar. Res. Tech. Rep. No. 53, 56 pp.

Trevelyan, G.A., R.C.Fields, P.F.Arthur, and F. Oaks, 1994. The use of wax to control shell parasites of red abalone, Haliotis rufescens. Report to the California abalone industry. 6 pp.

Tsuchulte, T. 1976. The comparative ecology of three sympatric abalones. Ph.D. dissertation. University of California, San Diego, Calif.

Tutschulte, T.C. and J.H. Connell. 1981. Reproduction biology of three species of abalones (Haliotis) in southern California. Veliger 3:195 – 206.

Uki, N. and S. Kikuchi, 1982. Influence of food levels on maturation and spawning of the abalone. VII. Comparative examinations of rearing apparatus for conditioning of adult abalone. Bull. Tohoku Reg. Fish. Res. Lab., No. 45:45-53.

APPENDIX B.

NATIONAL MARINE FISHERIES SERVICE WHITE ABALONE GENETICS MANAGEMENT PLAN

Ex situ conservation of white abalone requires a genetics management plan to ensure the long-term conservation of the species. Healthy species normally contain much genetic diversity, both within local breeding populations and between them (National Research Council 1996). Genetic diversity represents the basis for adaptive evolution. Loss of this diversity, through extirpation of local populations, fragmentation of previously inter-connected populations, and careless selection of breeding stock for hatcheries, represents a serious threat to long-term species survival (National Research Council 1996).

This Genetics Management Plan is designed to reduce the following risks: 1) loss of within-population variability; 2) loss of among-population variability; 3) genetic adaptation to hatchery conditions; and 4) extinction. Loss of genetic variability within cultured populations will be avoided by using a large broodstock size (approximately 100 individuals), and by maximizing the numbers of different males and females participating during each spawning attempt. If genetically distinct populations are identified from field sampling, aquaculture regimes will maintain population-specific stocks. Subsequent field planting activities will be designed to ensure that juveniles are returned to appropriate locations depending on their parentage. To prevent genetic adaptation to hatchery conditions, approximately equal numbers of offspring from all pair crosses will be maintained through at least the first year of life, the period when most mortality is experienced. Although the separate culture of many different broods is somewhat inefficient, it is required to prevent a lab-adapted strain from outcompeting broods which may, in fact, be better adapted to natural conditions. These measures will serve to reduce the risks of inbreeding depression, genetic drift, artificial selection, and extinction (National Research Council 1996).

Given that white abalone are in an extremely perilous state, with densities below those required for successful reproduction, a team of abalone biologists recommended in November 2001 that broodstock for a captive breeding program be collected immediately. The consensus was to obtain the broodstock by taking all abalone encountered in groups of five or less animals. They advised taking all isolated individuals, and taking all animals in any group of less than 30 animals within 10 m^2, up to the quota (approximately 100 broodstock among all hatcheries combined).

Our lack of understanding of white abalone population genetics makes us unable, at this time, to outline the mating protocol in detail. Studies with black abalone, an intertidal species, suggest significant genetic differences among populations from different areas throughout the species range (Hamm and Burton 2000), but red abalone, a coastal species, are believed to be panmictic, with low levels of genetic differentiation among populations across the species range (Burton and Tegner 2000). As broodstock are collected during 2003, tissue samples will be taken from

white abalone epipodia as has been done with the 11 animals currently in captivity. Methodologies for collection and preparation of the tissue samples are provided in Hamm and Burton (2000) and Burton and Tegner (2000). Protein electrophoresis, microsatellite analyses, and mitochondrial DNA sequencing will help to provide a better understanding of white abalone population genetic stock structure by 2004, prior to implementation of any field planting program. Initial investigations (18 white abalone tissue samples on-hand from pre-listing collections) have revealed three mtDNA haplotypes (based on 512 bp of the COI gene), and 5 alleles at each of three microsatellite loci (from those developed for pinto abalone by Miller et al. 2001).

If no distinct genetic differences among broodstock collected from different locations are identified, white abalone will be induced to spawn using the methods described by Morse et al. (1978) and McCormick (2000) multiple times a year. Single pair (one male and one female) crosses will be performed so that the genetic histories of F1 generations are known and every attempt will be made to use different adults during each spawning attempt. Each cross could produce a maximum of approximately 100,000 juveniles based on the first spawning attempt conducted by McCormick and UCSB in 2001. Optimal grow-out densities and size ranges of F1 generation individuals, based on growth rates and survivorship, will be determined (this information is currently being recorded by McCormick). Based on these determinations, a portion of the progeny will be held in the hatchery until the time of field planting and others could be used in a variety of ways (e.g., stocked in the ocean, transferred to other hatcheries, laboratory studies; see White Abalone Disposition of Excess Individuals Plan).

If distinct genetic wild populations are identified and great enough numbers of broodstock are collected, we will modify our general plan to attempt to maintain this structure in the hatcheries. This will be accomplished by following the same procedures as outlined above except that crosses will be performed between broodstock from the same wild population in order to produce population-specific juveniles.

Genetic research and tools may also prove valuable for the development of a genetic marker for monitoring the growth and survival of captive-bred white abalone that are field planted at sizes too small (< 10 mm) for traditional tagging methods to be used. Dr. Ron Burton, geneticist at Scripps Institution of Oceanography believes that with a sufficient number of nuclear and mitochondrial genetic markers, it may be possible to distinguish broodstock and their offspring from wild abalone. Such an approach might be based on identification of rare mitochondrial DNA haplotypes in females and uncommon microsatellite DNA alleles. Ideally, broodstock with distinct genetic markers would be pre-selected for breeding so that offspring genotypes would be extremely uncommon in natural populations. It remains uncertain whether enough broodstock will be collected to afford the program this luxury.

References

Burton, R.S. and Tegner, M.J. 2000. Enhancement of red abalone *Haliotis rufescens* stocks at San Miguel Island: reassessing a success story. *Marine Ecology Progress Series* 202: 303-308.

Hamm, D.E., and Burton, R.S. 2000. Population genetics of black abalone, *Haliotis cracherodii*, along the central California coast. *Marine Ecology Progress S*eries 202: 303-308.

McCormick, T.B. 2000. Abalone (*Haliotis spp*.) aquaculture: present status and a stock assessment tool. *In* Workshop on Rebuilding Abalone Stocks in British Columbia. Edited by A. Campbell. *Canadian Special Publication Journal of Fisheries and Aquatic Sciences* 130:55-60.

Miller, K.M., Laberee, K., Kaukinen, K.H., Li, S., Withler R.E. 2001. Development of microsatellite loci in pinto abalone (*Haliotis kamtschatkana*). *Molecular Ecology Notes. 1:315-317.*

Morse, D.E., Hooker, N., and Morse, A. 1978. Chemical control of reproduction in bivalve and gastropod molluscs, III: an inexpensive technique for mariculture of many species. *Proceedings of the World Maricultural Society* 9: 543-547.

National Research Council. 1996. *Upstream: Salmon and Society in the Pacific Northwest*. The National Academy of Sciences, Washington, D.C.

APPENDIX C.

NATIONAL MARINE FISHERIES SERVICE WHITE ABALONE DISEASE AND PARASITE MANAGEMENT PLAN

The purpose of this document is to outline protocols that all hatcheries engaged in the captive maintenance and/or propagation of white abalone must adhere to in order to prevent the spread of disease and parasites. These protocols may be expanded or altered in the future as knowledge is gained regarding captive propagation of white abalone and their susceptibility to disease and parasites in the hatchery and nature.

Withering Syndrome Prevention and Treatment

It has been known since the 1990s that species closely related to white abalone (*Halitois sorenseni*), including black (*H. cracherodii*), red (*H. rufescens*) and green (*H. fulgens*) abalone, are adversely affected by a disease called withering syndrome (WS). The etiological agent was recently identified as an intracellular rickettsial bacterium (RLP) that was placed in a new taxon and has been given the provisional status of "*Candidatus Xenohaliotis californiensis*" (Friedman et al. 2000). In addition, temperature-induced stress (> 18 ^{o}C) may render *Haliotis* spp. more susceptible to the disease (Moore et al. 2000).

In September 2002 it was confirmed that white abalone are susceptible to the RLP that causes WS (T. McCormick and James Moore, pers. comm.). Because the RLP appears to occur in the water column throughout white abalone's range and the possibility exists that the RLP could be introduced into the hatchery environment, even with stringent measures to treat incoming water (e.g. through food sources), measures must be taken to test broodstock and captive-bred white abalone for WS regularly. Dr. Carolyn Friedman, a pathologist at the University of Washington and member of the white abalone recovery team, suggests quarterly testing by feces polymerase chain reaction (PCR) and periodic lethal testing if deemed necessary. Given that the primary purpose of captive propagation for the endangered white abalone is to generate animals that will replenish the heavily depleted wild population (see NMFS White Abalone Field Planting Plan; Appendix E), the National Marine Fisheries Service (NOAA Fisheries) will, to the best of its abilities, ensure that: 1) preventative measures are taken by all hatcheries to reduce the likelihood of introducing WS into hatchery environments; and 2) animals placed into the wild are RLP-free and pose no risk to abalone in the wild.

Preventative Measures:

1) Technicians working with brood stock will receive training in good husbandry practice before and after working in each tank.

2) Water flowing into tanks will be filtered ($\leq$5 μm for larvae and early juveniles, $\leq$60 μm for adults) and ultra violet irradiated (at least 15,000 μW sec/cm^2 for all life stages). These irradiation levels appear to be safe for larvae and very early stages (T. McCormick pers. comm.).
3) Water quality (e.g., temperature, salinity, dissolved oxygen) will be tested on a daily basis.

4) All new brood stock will be quarantined for a period of six weeks, tested for WS, and treated with injections if they are infected with the RLP (protocol outlined below).

5) Equipment used in quarantine tanks will be rinsed in 100 ppm chlorine and rinsed well with freshwater and dried between uses. Ideally, each tank should have its own equipment.

6) White abalone will be tested on a quarterly basis by feces PCR analysis for WS. Prior to field planting, a subset of animals (n = 300) should be held at higher temperatures (approx. 18 ^{o}C for at least 8 weeks) to increase the potential for detecting the presence of the WS bacterium. A minimum of 300 animals per production unit must be sacrificed for detection of the WS bacterium. If WS is detected in captive-bred animals, those animals will not be field planted until the animals are RLP-free.

7) Kelp will be surface cleaned with freshwater and possibilities of artificially propagating of food will be explored.

8) Testing animals for resistance to WS and selecting those for field planting may be explored.

9) There will be limited and monitored access to hatcheries by authorized personnel only.

10) Transfers between holding facilities may only occur if both facilities are demonstrated to be free of specific diseases and parasites

Treatment of RLP-infected abalone:
Prior to placing animals in the wild, captively propagated abalone must be proven to be free of the RLP. Work with this pathogen in other species, combined with preliminary data from white abalone, indicates that it should be possible to eliminate the RLP from captively reared white abalone.

White abalone infected with the RLP must be treated with a proven, safe inoculation protocol that has been developed for closely related species (C. Friedman pers.comm.) to completely eliminate the pathogen. In red abalone oxytetracycline (OTC) injections can be 100 % effective in eradicating the RLP from infected abalone, depending on the animal's level of infection prior to treatment (Friedman et al. 2003). The following procedures for OTC injection treatment of infected individuals will be followed prior to release (T. McCormick, pers. comm. and Friedman et al. 2003):

Antibiotic Treatment Protocol for the Control of Rickettsiales-Like-Prokaryotes in the Gastrointestinal Epithelia of Abalone: For Laboratory Use Only

As recommended by Dr. Carolyn Friedman, Assistant Professor, School of Aquatic and Fishery Sciences, University of Washington, (206) 543-9519.

Drug Preparation:

Drug: Liquamycin LA-200 (OTC), Oxytetracycline Injection, 200 mg/l concentrate (Pfizer), found at veterinary supply centers.

Prepare prior to each use a 10 mg/l solution from the 200 mg/l stock (1:20) dilution in 2% saline using distilled water. No pH adjustment.

Drug Calculation:

Previous experiments determined the need to achieve a 21 mg/kg dose of oxytetracycline in tissue weight (Friedman et al. 2003). Previous sampling of red abalone at the Bodega Bay Marine Laboratory has yielded a mean percent (%) tissue weight of approximately 54.85% for healthy black abalone and 67.47% for healthy red abalone. Percent tissue weight was determined by total weight minus shell weight, divided by total weight X 100. As proportional shell weight varies between species and with age, the % tissue weight to total weight (shell and tissues) needs to be determined prior to dosing, if possible.

Example calculation for a 90 g red abalone:
90 g x 0.6747 = 60.723 g tissue weight.
60.723 g tissue weight = 0.060723 kg tissue weight.
0.060723 kg x 21 mg/kg = 1.275 mg oxytetracycline needed for that animal to achieve a 21 mg/kg dose.
Solve for a where;
a (10 mg/ml) = 1.275 oxytetracycline
a= 1.275 mg/10 mg/ml = 0.1275 ml or 127.5 ul for a 90g animal.

Suggested Injection Regime:

Inoculations will be administered to incoming wild brood stock that have tested positive for withering syndrome to prevent the spread of the disease throughout the hatchery. Inoculations will be administered to captive-bred white abalone that have tested positive for withering syndrome prior to field planting to prevent the spread of the disease to healthy animals in the hatchery and in the wild.

Using a sterile 1 ml, 27 G-1/2 syringe for each animal, withdraw the appropriate amount of diluted oxytetracycline. Remove any air bubbles and slowly inject the oxytetracycline into the pedal muscle of the abalone. Rotate injection sites for subsequent injections. Needle-depth insertion should be curbed somewhat for smaller animals.

A total of 9-12 injections is necessary to eliminate or significantly reduce infections of the RLP, according to results from experiments performed at the Shellfish Health Laboratory at Bodega Bay Marine Lab (Friedman et al. 2003).

It is suggested that the first three injections are given on a Monday, Wednesday, and Friday followed by a two-week post-injection recovery period. Repeat this sequences again until 9-12 total injections have been administered.

Unfortunately, the injection treatment is time consuming, labor-intensive, expensive and invasive. Recently, the efficacy of an oral (*per os*) administration of OTC to control losses due to WS was tested with red and black abalone (Friedman et al. 2003). Abalone were fed to excess for 14 consecutive days with floating medicated, alginate-based feed made at the Abalone Farm, Inc. in Cayucos, CA. Survivorship, biomass, RLP intensity and degree of WS in abalone fed a medicated diet were compared to those fed kelp (*Macrocystis pyrifera*, as a control). A *per os* delivery of OTC was effective in reducing the prevalence and intensity of infection of RLPs in abalone, however, some RLPs did survive the *per os* treatment. Despite the fact that this treatment did not completely eradicate the disease from infected individuals, bacterial burdens were substantially reduced for at least one year after a single (14-d) treatment regime (Friedman et al. 2003). This treatment could prove promising for white abalone and deserves future consideration given as it is not invasive, is less time consuming, less labor intensive, and less expensive than the injection treatment.

The Friedman et al. (2003) paper also discusses possible risks associated with development of antibiotic resistance among animals that are administered drug treatments and remarks that these concerns warrant further study. Atlantic salmon that received a similar OTC therapy as that used in the Friedman et al. (2003) study showed no evidence for selection of antibiotic resistance in salmon digestive tract flora during a 28 d study (Kerry et al. 1997).

Sabellid-worm Prevention and Treatment:

Another potential threat to brood stock, cultured white abalone, and wild populations upon field planting of cultured animals, is an exotic polychaete worm (*Terebrasabella heterouncinata*) that inhabits the shells of abalone where it lives in tubes. The sabellid worm was introduced into California abalone farms during the mid- to late-1980's with imported South African abalone. The parasite causes shell deformities that weaken the shells of abalone, thereby reducing growth rates and production (Culver et al. 1995?, Leighton 2000). Since the introduction of this non-indigenous polychaete worm to aquaculture facilities, the state of California requires that any abalone to be planted in State waters must originate from a hatchery that has been certified as sabellid-free. The State will conduct regular inspections of all aquaculture facilities used in the recovery program to certify that they are, in fact, sabellid-free. Although these measures greatly reduce risks associated with the parasite, it remains remotely possible that wild white abalone have been exposed to this organism. Also, Polydora polychaetes, boring clams and sponges, and other epicommensal organisms may be present on wild animal shells and should be reduced or eliminated prior to removal from quarantine. In order to prevent introduction of the sabellid pest into unaffected facilities, as well as other epicommensal organisms known to have adverse affects on abalone (other polychaetes, mollusks, and sponges), a non-invasive procedure of applying a wax mixture to the shells may be performed on incoming broodstock that are heavily infested with boring organisms (Oakes et al. 1995)

Preventative Measures:

In addition to the measures listed above for the prevention of WS, the following measures will be taken at all facilities in order to avoid the spread of sabellid parasites (T. McCormick pers. comm.; J. Butler pers. comm.).

1) All new brood stock will be quarantined for a period of six weeks and visually examined for sabellid infestation.

2) Perform shell waxing procedure on broodstock (McCormick and Friedman in prep.).

3) Hatcheries will adhere to State requirements on sabellid-testing.

References

Friedman, C.S., Andree, K.B., Beauchamp, K.A., Moore, J.D., Robbins, T.T., Shields, J.D., and Hedrick, R.P. 2000. "*Candidatus Xenohaliotis californiensis*" a newly described pathogen of abalone, *Haliotis* spp., along the west coast of North America. *Int. J. Syst. Evol. Microbiol.* 50(2):847-855.

Friedman, C.S., G. Trevelyan, T.T. Robbin, E.P. Mulder, and R. Fields. 2003. Development of an oral administration of oxytetracycline to control losses due to withering syndrome in cultured red abalone *Haliotis rufescens*. *Aquacult.*

Kerry, J., NicGabhainn, S, and Smith, P. 1997. Changes in oxytetracycline resistance of intestinal microflora following oral administration of this agent to Atlantic salmon (*Salmo salar* L.) smolts in a marine environment. *Aquacult*. 157(3-4):187-193.

Leighton, D.L. 2000. The Biology and Culture of California Abalone. Dorrance Pub. Co. Pittsburgh, PA.

Moore, J. D., T. T. Robbins, and C. S. Friedman. 2000. Withering syndrome in farmed red abalone Haliotis rufescens: Thermal induction and association with a gastrointestinal Rickettsiales-like prokaryote. *J. Aquat. An. Health* 12:26-34.

APPENDIX D.

NATIONAL MARINE FISHERIES SERVICE WHITE ABALONE PLAN FOR DISPOSITION OF EXCESS INDIVIDUALS

The intent of a captive breeding program is to produce larval and juvenile abalone which can be transferred to grow-out facilities for eventual field planting. Because white abalone produce millions of gametes during each spawning event, hatcheries will develop more progeny than they can safely and economically maintain. Disposing of excess individuals, typical in many hatchery settings, will be performed to: 1) enhance the growth rates of cultured individuals (by reducing negative density-dependent effects); 2) minimize maintenance costs of the hatchery, while maximizing survival; and 3) provide animals for experimental field and laboratory testing. Excess animals will be selected based on their size and will encompass the range of sizes that define each life stage (0.2-0.3 mm larvae; 0.3-2 mm postlarvae; 2-4 mm early juveniles; 5-25 mm juveniles, Dave Leighton, pers. comm.). Thus, both the culled and retained animals will be comprised of slow- and fast-growing individuals and will mimic the size and presumably, genetic structure of the original population.

Depending on funding and the production rates of white abalone at the culture facility, excess healthy animals (disease- and parasite-free) will be: 1) stocked in the ocean as postlarvae and juveniles (0.3-25 mm size range; see White Abalone Field planting Plan); 2) subjects in diet and density-dependent growth experiments, thermal tolerance experiments, predator/competitor response experiments, or genetic experiments (5-25 mm size range; see White Abalone Genetics Management Plan); 3) transferred to permit-approved laboratories at other institutions to answer other critical research questions (e.g., susceptibility to withering syndrome, habitat preferences); 4) transferred to additional, permit-approved settlement and grow-out facilities; 5) transferred to permit-approved aquaria for educational/outreach purposes; or 6) destroyed. The possibility of storing white abalone gametes is an area that requires further investigation and the Protected Resources Division/Permitting Office of NOAA Fisheries will receive an addendum to this protocol, outlining details of the plan, before any action is pursued.

Option 1 will test the effects of various habitat parameters (e.g., depth, distance to shore, temperature) and field planting size on the survival of juvenile white abalone. This option would require monitoring of experimental field plant sites to estimate survival and could involve public participation as an outreach effort. Option 1, in combination with the primary field planting program, would help to address a number of critical research questions including: 1) development of measurable standards for assessing recovery in white abalone, such as recruitment and survival rates and viable population and aggregation sizes; 2) investigation of habitat character effects on recruitment and survival of white abalone; and 3) investigation of the occurrence and magnitude of juvenile migration in white abalone using acoustic tags.

Option 2 would address critical research topics in a laboratory setting: 1) investigation of the effects of temperature, diet and density on the survival and growth of larvae and juveniles; 2) investigation of how the intermittent exposure of cultured individuals to predator and competitor cues might affect the recruitment potential and survivability of individuals and; 3) development of appropriate genetic techniques for assessing population structure, and marking and identifying captive-bred individuals.

Option 3 describes moving animals to permit-approved facilities, that have met the requirements set forth by the State and NOAA Fisheries, to address very specific research questions in the laboratory regarding the susceptibility of white abalone to withering syndrome, possible treatments for the disease, and controlled experiments that examine growth and survival of white abalone inhabiting a variety of habitat types. To develop a successful field planting program, it is critical that scientists investigate the effects of withering syndrome, a disease caused by a naturally-occurring Rickettsiales-like prokaryote (see Disease and Parasite Management Plan), on white abalone, and the effects of a variety of habitat parameters on the growth and survival of white abalone. The necessary expertise and equipment required to answer these questions will likely not be available at the hatcheries and therefore excess, test animals should be transferred to other facilities (e.g., the University of California Bodega Bay Marine Laboratory) where experts are well-equipped to conduct these investigations.

Option 4 would involve transferring excess animals to additional permit-approved facilities to rear captive-bred animals until they reach sizes suitable for field planting. These facilities would have to meet the requirements set forth by the State and NOAA Fisheries prior to receiving animals. Spreading captive-bred animals among multiple rearing facilities would enhance growth and survival of white abalone by ameliorating economic pressures at any one facility, space limitations at any one facility, and the potential for losing all of the program's animals due to a catastrophic event at any one facility.

Option 5 would involve the transfer of excess white abalone to permit-approved educational/outreach facilities that would develop exhibits focusing on the biological and socioeconomic importance of abalone and their habitats to California and Baja California, Mexico.

Option 6 would be invoked as a last resort if other methods of disposing of excess individuals are eliminated as viable options

APPENDIX E.

NATIONAL MARINE FISHERIES SERVICE WHITE ABALONE FIELD PLANTING PLAN

A team of international experts in abalone biology and culture met at the Southwest Fisheries Science Center in La Jolla, California, from November 8-9, 2001 to discuss a rebuilding strategy for white abalone. The consensus of the group was that hatchery production and stocking of cultured white abalone was the preferred option for rebuilding the population despite mixed results reported from planting efforts for related species in California (Leighton 1985, Tegner and Butler 1985, Leighton 2000, McCormick 2000, Tegner 2000). Factors that affect stocking success are handling in transit, method of planting, size at release, stocking density, small scale structure of the natural substratum, and predation (Leighton 1989, McCormick et al. 1994, Preece et al. 1997, Saito 1979, Saito 1984, Kojima 1995, Rogers-Bennett and Pearse 1998). These factors are taken into account in the White Abalone Field Planting Plan outlined below.

Summary

Stocking of white abalone raised in a hatchery will be conducted with three major goals 1) to enhance wild white abalone populations and 2) to learn more about the best ways to enhance the growth and survival of stocked white abalone and 3) to stock disease and parasite-free abalone. Stocking will be conducted as rigorous studies involving the release of young abalone from multiple life history stages; late-stage larvae, smaller juveniles, advanced juveniles and young adults (to 10 cm). Earlier research has shown survival of planted abalone increases with age and size at release (Saito 1984), but economics favor release of greater numbers of younger stages (Leighton 2000). Size-structured matrix models of white abalone show that increasing the numbers of larger juvenile abalone have more of an impact on population growth than increasing the numbers of smaller juveniles (Rogers-Bennett and Leaf 2006). Monitoring success of stocked abalone with different age and size groups will require surveys and sampling of both the exposed rock surfaces (most easily accomplished with ROV, day and nighttime observations) and the under rock environment, especially for postlarvae and early juveniles (by diving and turning rocks). Small boulders may be collected to assess the survival of late stage larvae. Adult white abalone are typically emergent, occupying exposed surfaces of bottom rock, while younger stages are cryptic.

Recognition of the “ideal nursery habitat”, and therefore the locations seeding will most likely be successful in terms of growth and survival, will be important to the choice of preferred project sites. Knowledge of substrate and food requirements for early stages will be especially important for future efforts to enhance seeding success by habitat modification and optimization. Specific locations have been identified as superior recruitment environments from previous years for red abalone (e.g., southern Point Loma shelf; Leighton 1968) and for green abalone (e.g., south La Jolla shallow subtidal; Leighton 1985) and for white abalone (e.g. San Clemente Island) (Rogers-Bennett et al. 2002). However, much of the benthic terrain supporting adult white

abalone populations today on offshore banks is mature established boulder and sand patch substrate with little micro-relief to provide shelter for postlarval and juvenile stages. In such areas it will be important to find small rock piles or reef outcrops which in their structure provide adequate protective shelter for young stages. As an important extension of the immediate program, efforts to improve juvenile white abalone habitat may be necessary.

Success of stocking may be judged by, the discovery of live, healthy and growing young and the absence of empty shells in the area using appropriate sampling methods. Sampling procedures will in most cases involve turning of small flat rock (those having open space beneath). Where such elements of the substratum are lacking, crevices and cavities between rocks may be explored, but destructive habitat surveys will be avoided. Most ideal natural substratum consists of pieces of flat sedimentary rock, with minimal over-growth of algae and other organisms, situated over bed rock, but providing open beneath-rock space.

Site Selection and Habitat Improvement

Success rates of abalone stocking programs have been mixed worldwide (Tegner and Butler 1989, Schiel 1993, McCormick et al. 1994) and much of this variation has been attributed to site-specific conditions. In Japan, large-scale stocking programs have been underway for years. In 1979, more than 10 million juvenile abalone were produced and stocked by fishing cooperatives (Tegner and Butler 1989). Survival rates however in this program vary widely from 1-80% (Saito 1984, Tegner and Butler 1989, Kojima 1995). Similarly, in New Zealand survival of stocked juvenile abalone ranged from 1-72% (Schiel 1993). Much of this variability in stocking survival has been attributed to major differences between sites. Some sites yield good survival rates while others do not. More juvenile red abalone survived in stocking experiments in northern abalone at sites with red sea urchin spine canopy than sites without (Rogers-Bennett and Pearse 1998). This same result has been observed for juvenile abalone stocked in sites with sea urchins in South Africa (Mayfield ref). Small scale variation in micropredators in southern California sites have been reported and these small predators have been shown to consume large numbers of newly settled and juvenile red abalone in laboratory experiments (Svedlund, Rogers-Bennett and Caselle, in prep). More research is needed to help identify key site variables critical for the survival of stocked juvenile white abalone. This white abalone recovery program is science-based and therefore designed to learn more about survival rates at various sites and the parameters which are linked to survival.

White abalone habitats vary with location in terms of bottom topography, geologic structure and algal community composition. Typically islandic environments present a combination of larger rock outcrops with expanses of low relief bed rock and sand zones. Aside from the common encrusting and articulated coralline red algal species and occasional red algae (e.g., *Rhodymenia* spp.), attached brown algae include *Laminaria farlowii*, *Agarum fimbriatum*, and in shallower water, *Pterygophora californica* and *Eisenia arborea*. *Macrocystis pyrifera* is often present as bottom drift. Around Isla Natividad in Baja California, Mexico, white abalone have been

observed on sheet rock at 12-27m with the following dominant algae: *Eisenia arborea*, *Macrocystis pyrifera*, *Gelidium robustum*, and calcareous algae (Turrubiates; pers. comm.). For mainland sites such as Point Loma, *Pelagophycus porra*, which attaches at a depth of 25-40 m, is a good indicator of potential white abalone habitat. Fronds of this alga may join drift of *Macrocystis* fragments to serve as food for deep-living abalone. The best indication of white abalone habitat is to find the animals themselves, or the knowledge that populations existed there within the past few decades. Fishery data has been used to identify areas that were once very productive for white abalone during the fishery. San Clemente Island produced the most white abalone per unit of suitable habitat (1.44mt/Ha.), Tanner and Cortez banks were the next most productive followed by Santa Barbara Island (Rogers-Bennett et al. 2002). Relevant information can also be gathered in the laboratory by subjecting excess, captive-bred animals to a variety of habitat types along with the associated food and monitoring their growth and survival under different conditions over time (see Disposition of Excess Individuals Plan).

Preferred habitat is probably size- and age-specific and may also depend on the presence or absence of other species (Sweijd et al. 1998, De Waal and Cook 2001). The possibility exists that formerly preferred habitat for white abalone (juveniles and adults) has been altered in their absence, and may no longer be suitable for seeding. Community changes including co-competitors (sea urchins), invasive species which may feed on abalone larvae (brittle stars), and substrate changes (e.g., overgrowth by articulated coralline algae, sponges and colonial tunicates) may require that extensive habitat restoration will be necessary to create appropriate features of the small-scale habitat for planting of cultured white abalone juveniles and larvae. Similar changes in habitat rendering it unsuitable have been documented once black abalone populations declined following mass mortalities due to disease (Miner et al. 2007). The use of metamorphic, talus rock at seeding sites not only would create suitable habitat, but also increase juvenile survival and permit easy sampling in monitoring procedures.

Healthy, mid-size, white abalone broodstock will be collected from oceanic banks known through a recent ROV survey conducted during July 2002. While oceanic seamounts and banks may provide broodstock for the propagation program, initial seeding exercises will be most efficiently conducted in locations more accessible from the mainland and the Channel Islands. Depth range for the mainland sites would be 20-40 m and for islandic locations, 20-50+m. To ensure that genetic contamination of the wild population does not occur and to minimize risks associated with hybridization an objective of preliminary stocking will be to reintroduce white abalone into habitat that was previously occupied by the species, but that has undergone local extinction. This strategy will also aid in the ability of researchers to monitor the growth and survival of filed planted animals (see “Monitoring the Performance of a Field Planting Program” below). Additional permits will be sought if planting locations fall within National Marine Sanctuary boundaries.

Environmental parameters to be examined at each site will include temperature distribution, substrate composition, bottom topography on a meso- and micro-scale, macro- and micro floral

elements, predator populations and potential competitors. Environmental conditions at one site may be more appropriate for larval seeding (e.g., relatively smooth and barren rock with sparse algal turf, abundant microrelief and beneath-rock space, few sea stars, ophiuroids, and other predators), while another area may be better suited for stocking young adults (e.g., higher relief, boulder and sand patch bottom with common macroalgae, such as *Laminaria farlowii*).

Lack of suitable larval recruitment habitat may be an important factor limiting abalone population growth. Both physical and biotic elements of the bottom in potential white abalone habitat may conspire to preclude successful settlement and metamorphosis of planktonic larvae. Juvenile survival may be restricted by inadequate crevice shelter, open foraging area, and predation. Certain ophiuroid and other filter-feeding species may capture larvae, while sea stars, amphipods, other benthic predators may seek out recently settled postlarvae or larger juveniles. A mature reef community typically supports an abundance of predators and competitors for space and food. Articulated coralline algae often form a continuous cover on exposed rock surfaces, while sponges, bivalves, crabs and other species occupy spaces between and beneath rocks.

Abalone Recruitment Modules (ARMS) have been used to examine the success of stocked juveniles as well as the set of wild juveniles. Installing ARMs provides uniform substrates with known surface area that can be readily sampled for the presence of cryptic juveniles (Davis 1995, Rogers-Bennett et al. 2004). ARMs will be used to help establish substrate for juveniles being stocked into the wild and to aid in surveys to recover these juveniles to quantify growth and survival.

Studies are needed to compare survival using natural, enhanced natural habitats, and fully artificial habitats. The chief difficulty is that the list of potential variables that could be important is very long and the costs of monitoring success of a particular treatment quite high. Hence, good judgments of what variables to select among the many as well as strong experimental protocols are needed. Clearly an important criterion for selecting one set of variables over another is the potential cost effectiveness of a particular strategy.

Size-at-planting

Studies conducted around the world suggest that the highest annual survival rates of planted abalone are approximately 75% (Leighton 1989, Saito 1984, Sweijd et al. 1998, McCormick et al. 1994, Davis 1995). Some of these studies suggest that small abalone (< 90 mm) experience higher mortality rates than larger abalone, while other studies report the opposite. Survival rates for planted abalone may be biased by the inability of the investigator to get accurate counts on cryptic, small abalone inhabiting complex habitats. Other influences on juvenile survival include emigration and predation.

Initially, a tag evaluation study using surrogate species first, and ultimately juvenile and young adult white abalone of the sizes that will be planted (0.3-100 mm), will be conducted. In this way, monitoring field plant survival will be possible. Experimental planting of individuals (< 100 mm) will be conducted with excess animals (see White Abalone Disposition of Excess Individuals Plan) or with a surrogate species if excess individuals are not available, to determine which variables (e.g., size, age, bottom habitat type, depth) are most important to the recruitment success of the surrogate abalone. The primary, but not the first, field planting program will utilize larger-sized animals (10 cm; ~4-year-old) based on the assumptions that larger abalone would be immediately able to contribute to the reproducing population, exhibit lower natural mortality, and be easier to monitor. In the experimental seeding program, many field plants with larvae, postlarvae, and young and advanced juvenile white abalone will be carried out during the second and third years of the program. If the experimental planting program indicates that abalone of smaller sizes exhibit acceptably high survival relative to plants with larger abalone, then the sizes of individuals used in the primary planting program will be modified.

Study Plan

Southern California mainland and Channel Island sites will be surveyed for bottom type, topography, algal community and potential predator and competitor species. Most appropriate sites will be located by GPS, marked by submerged buoys and bottom transect lines, and thoroughly mapped. Initially these areas will be relatively small (100 m^2). This restriction should facilitate direct observations by ROV and divers working at depths exceeding 30 m.

Late stage larval plants

Initial spawnings in the hatchery will produce larvae for introduction to the juvenile rearing system and for studies on thermal tolerance, substrate acceptance, and food utilization. As stocking densities in larval settling tanks reach optimal levels (ca 0.1/cm^2), excess larvae may be available for use in the first experimental field plants.

Larvae 5-10 days old, cultured at 15 - 18^oC, are competent to settle and metamorphose to the postlarval stage. Settlement may be delayed by holding larvae at a lower temperature (e.g., 12^oC) thereby acclimating to temperatures at the stocking sites. At that stage larvae may be transported to the field in plastic bags, taken to the bottom site by divers, inverted (turned inside-out) and placed on the bottom beneath a small rock. Most larvae will release immediately while others clinging to the bag will likely be dislodged soon thereafter to attach to the local substrate. Spot releases of about 10,000 larvae/bag will provide a concentration sufficient to yield, at a 5% survival rate, 500 juveniles dispersed broadly over the surrounding bottom. These progeny could be detectable after six months as juveniles approximately 1 cm in shell length. Earlier sampling, if the area

provides an abundance of small rock which could be placed in sealed plastic bags for return to the laboratory, will allow detection of postlarvae and early juveniles.

The particular approach taken for larval seeding will depend on the characteristics of the bottom at a given site. Preliminary study will suggest specific locations where larvae and early juveniles will encounter appropriate microenvironment and shelter and will suggest planting densities that yield the highest survival rates. Greatest value will be realized from stocking which are well planned and allow careful monitoring to establish survival, dispersal and growth. These efforts will be part of the white abalone restoration program. Very possibly graduate students will be enticed to conduct research focused on the ecology of seeded white abalone.

Juvenile seeding strategies

In earliest attempts to plant juvenile hatchery-reared abalone in California and Mexico extreme site-specific losses occurred due to predation during and shortly after release (Tegner and Butler 1985 Rogers-Bennett and Pearse 1998). Studies have shown that juvenile abalone transported to the field and planted on the sea bottom within protective shelters are not handled, experience minimal stress, and may show high survival (Leighton 1985, 1989). In one study, time-lapse photography was employed to study the behavior and activity of potential predator species when juvenile abalone were planted using a "trickle filter cube." Juveniles moved out of the shelters within 24-48 hours to find natural shelter among rock and crevices on the bottom. Sheltered temporarily from opportunist predation, losses were negligible. No empty shells were found in follow-up surveys; a typical result when these multilevel substrates are used. This style shelter, as well as others that may be developed, will be used for white abalone field plants. Each cubic foot trickle filter cube will hold several hundred 1 cm juveniles. These structures are placed on the bottom near appropriate rock outcrops. A given seeding operation will use many planting modules and accommodate thousands of seed.

Larger juveniles and young adults (to 10 cm) can also be released during the white abalone population enhancement program. Results from matrix models of white abalone show that enhancing larger juveniles had more of an impact on population growth than enhancing smaller juveniles (Rogers-Bennett and Leaf 2006). Stocking modules may be composed of many different sizes and configurations. Larger abalone merely require planting modules with larger internal structuring. If larger abalone are planted singly onto the natural substratum, tests must be performed to show opportunist predation is not a threat to their survival. Larger abalone should also be tagged to identify them as part of the abalone enhancement program.

Behavior

Hatchery-produced or captive abalone may exhibit behavioral deficiencies (e.g., reduced foraging capability, reduced ability to migrate, insensitivity to certain predator species) (Osumi, 1999). In spite of these possible deficiencies, evidence suggests that captive abalone could be trained to better avoid predators and to forage by acclimating hatchery-reared animals to a more natural setting prior to planting (e.g., presence of substrate and other organisms; Schiel and Welden 1987). For example, abalone may be induced to rear up from the substrate and "capture" kelp, their primary food source. It is also possible that exposure to known predators, such as the sun star *(Pycnopodia helianthoides*), may induce an escape response, scaring the abalone into moving away from the predator. The possibility of better acclimatizing cultured white abalone prior to field planting requires that their behavioral responses after exposure to prey, predators and competitors can be assessed (see White Abalone Disposition of Excess Individuals Plan).

Genetics

More genetic studies are needed however population densities of white abalone in the field are so low that genetic considerations of stocking F1 generation individuals into areas where their parents were captured will be a lower priority for the recovery plan (see White Abalone Genetics Management Plan). Once the stocking program has been successful and more genetic information is gained concerns regarding the genetic background of families may become a higher priority.

Stocking Modules

Past failures in California with planting juvenile and young adult abalone may in part have been due to high mortality resulting from poor release methods (Tegner and Butler 1985, Tegner 2000). High planting mortality was circumvented when protective shelters or planting modules were used to transfer and plant young abalone (Leighton 1985, 1989, 2000). This approach appears to substantially reduce initial stocking mortality by minimizing predator-signaling secretions previously caused through stress by excessive handling and improper treatment in transfer from hatchery to ship to planting site (Leighton 1989). The use of planting modules is now also being tested elsewhere with abalone up to 2.5 inches (6.25 cm) (e.g., in South Africa and Australia, Sweijd et al. 1998). Use of modules of various designs have reduced the costs (time and money) in the field planting effort. Secured to the bottom such structures serve as landmarks identifying the release spots and facilitate subsequent monitoring strategies.

The use of numerous, small modules allows the distribution of small numbers of seed into more protected habitat over a wider area, but requires more effort. The use of larger modules requires less effort, and concentrates larger numbers of juveniles into a smaller area, with potentially less protection. Subsequent survival and growth are affected by the location of planting modules with respect to the availability of food, cryptic habitat, and predators. If structured to accommodate a range of sizes of abalone, modules themselves may also serve as preferred habitat. This needs to be scientifically assessed. Much larger and permanent modules of precast

concrete as are employed in Japan (Sheehy and Vik 1981) would also allow for containment of instrumentation to monitor environmental variables (e.g., temperature, salinity, currents).

A wide variety of designs and structures of juvenile abalone planting modules have been tested here and in South Africa such as those formed from small chicken-wire enveloped tubes, filled with rocks or shell, and empty PVC tubes with small holes drilled through their top surface to allow juveniles to be introduced to the module and allow their emigration, once planted. In some tests, juvenile abalone are anaesthetized from grow-out tanks, counted and poured into tube modules. They are allowed to recover in a high water flow environment for 24-48 hours. Divers then place the tubes, with the young abalone, into cracks and crevices in suitable habitats. Some modules of other design, such as the trickle filter cubes, are placed in grow-out tanks where the abalone aggregate within the structures on their own. In other studies, box structures with 3x6 inch spring-operated doors held with magnesium-wire timed releases, have been similarly tested. Nested semi-circular tubes attached to a steel plate have also been used successfully (Sweijd et al. 1998, De Waal and Cook 2001). However, simplicity, commercial availability, cost and efficiency favor the use of "trickle filter" PVC planting modules described by Leighton (1985, 1989, 2000).

The use of modules as a survival/recruitment assessment tool is promising. Assuming abalone will utilize these artificial habitats as they do co-existing natural habitat, the modules can be outfitted with instrumentation, retrieved for top-side assessment, and returned to the bottom for future sampling. Channel Islands National Park has deployed and monitors 7-15 modules that contained red abalone, *Haliotis rufescens*, at each of more than 10 locations. They were first tested in 1989, and the relatively massive cinder block test modules are still in place and monitored regularly (Davis 1995). While the maximum retention time for red abalone in these prototype modules was 2-3 years, design improvements and modifications of deployment protocol may improve retention times in modules currently deployed by the CDFG. These modules are also being used to monitor red abalone recruitment in northern California (Rogers-Bennett et al. 2004) and northern abalone in Canada (DeFrietas 2003). Additional effort is planned in southern California as part of the white abalone recovery plan at Santa Rosa Island. The results from these studies should reveal natural variation in recruitment and help in the planning of white abalone stocking.

Monitoring the Performance of a Field Planting Program

Clearly, monitoring performance of the stocking program and ultimately the rate of recovery is of key importance. To monitor performance planting sites will be surveyed on a regular basis and all planted animals must be marked to distinguish them from wild stock. Genetic research and tools may also prove valuable for the development of a genetic marker for monitoring the growth and survival of captive-bred white abalone that are field planted at sizes too small (< 10 mm) for traditional tagging methods to be used (see details in Genetics Management Plan). Dietary banding is used to mark juvenile abalone in the hatchery (Leighton 1985, 2000). Hatchery-produced juveniles are easily distinguished from natural recruits using this technique.

Stainless steel tags have successfully been applied to abalone larger than 2 inches (5 cm), and have survived on at least one abalone for 16 years (Haaker and Tanaguchi 1996). Bee tags have been glued to the outside of smaller individuals however their longevity in the field has not been tested. Much as red and brown algae are fed to create dietary bands, specific food additives may be developed for use in hatchery animals that result in distinct and unnatural color markers in abalone shells. Florescent tags which bind to newly deposited calcium have also been used to tag hatchery produced juveniles. Other possibilities for marking advanced juveniles include coded wire tags, artificial and pure dyes, (although there is concern that strangely colored shells might increase predation), radiochemical markers, and even acoustic transponders. These and other approaches differ in cost per individual, tag longevity, and the size of animal for which the tag is appropriate, as well as the method of detection.

The ability to measure growth, survival, reproductive output of field planted animals can be achieved if animals are planted in areas where white abalone were known to have occurred, but have gone locally extinct. The ability to collect these data will be enhanced if genetic markers can be developed that distinguish broodstock and their offspring from wild animals (see Genetics Management Plan).

References

Davis, G.E. 1995. Recruitment of juvenile abalone (*Haliotis* spp.) measured in artificial habitats. *Mar. Freshwater Res.* 46: 549-554.

DeFreitas, B. 2003. Estimating juvenile northern abalone (*Haliotis kamtschatkana*) abundance using artificial habitats. J. Shellfish Res. 22:819-823.

De Waal, S. and P. Cook. 2001. Quantifying the physical and biological attributes of successful ocean seeding for farm-reared juvenile abalone (*Halitotis midae*). *J. Shellfish Res*. 20: 857-861.

Estes, J.A., and G.R. VanBlaricom. 1985. Sea-otters and shellfisheries. pp. 187-235. *In* J.R. Beddington, R.J.H. Beverton, and D.M. Lavigne (eds.). Marine mammals and fisheries. George, Allen, and Unwin, London, United Kingdom.

Gotshall, D.W. 1977. Fishwatcher's guide to the inshore fishes of the Pacific coast. *Sea Challengers*. Monterey, California.

Haaker, P.L. and Taniguchi, I.K. (1996) A red abalone tag return after 16 years at liberty. *California Fish and Game* 82(3) 141-143.

Kojima, H. 1995. Evaluation of abalone stock enhancement through the release of hatchery reared seeds. pp. 689-695. *In* S. A. Shepherd, R. W. Day, and A. J. Butler (eds.). Progress in Abalone Fisheries Research. *Mar. Freshw. Res.*

Leighton, D.L. 1968. A comparative study of food selection and nutrition in the abalone, *Haliotis rufescens* Swainson, and the sea urchin, *Strongylocentrotus purpuratus* (Stimpson). Ph.D. Dissert., Univ. Calif. San Diego.

Leighton, D.L. 1985. Early growth of the green abalone in hatchery and field. Diving for Science. *Proc. Joint Internat. Scientif. Diving Symp.*, La Jolla, Calif. :235-246.

Leighton, D.L. 1989. Abalone (genus *Haliotis*) mariculture on the North American Pacific Coast. U.S. Dept. Commerce, *Fishery Bulletin* 87:689-702.

Leighton, D.L. 2000. Seeding for fishery enhancement and sea floor ranching. Chapter XIV *In*: *The Biology and Culture of the California Abalones*. Dorrance Publ. Co. Pittsburgh, PA.

McCormick, T.B., Herbinson, K., Mill, T.S., and Altick, J. 1994. A review of abalone seeding, possible significance, and a new seeding device. *Bull. Mar. Sci*. 55(2-3), 680-693.

McCormick, T.B. 2000. Abalone (*Haliotis* spp.) aquaculture: present status and a stock enhancement tool. *In* Workshop on Rebuilding Abalone Stocks in British Columbia. *Edited by* A Campbell. *Can Spec. Publ. Fish. Aquat. Sci.* 130. pp. 55-60.

Miner, M.C., Altstatt, J.M., Raimondi, P.T. and T.E. Minchinton 2007. Recruitment failure and shifts in community structure following mass mortality limit recovery prospects of black abalone. Mar. Ecol. Prog. Ser. 327:107-117.

Osumi, K. 1999. Stock enhancement and habitat association of juvenile paua (*Haliotis iris*) in northeastern New Zealand. M.Sc. University of Auckland, New Zealand.

Preece, P.A., Shepherd, S.A., Clarke, S.M. and Keesing, J.K. 1997. Abalone stock enhancement by larval seeding: effect of larval density on settlement and survival. *Moll. Res*. 18(2), 265-273.

Rogers-Bennett, L. and R.T. Leaf. 2006. Elasticity analyses of size-based red and white abalone matrix models: Management and conservation. Ecological Applications 16:213-224.

Rogers-Bennett, L., Allen, B.L. and G.E. Davis. 2004. Measuring abalone (*Haliotis* spp.) recruitment in California to examine recruitment overfishing and recovery criteria. J. Shellfish Res. 23:1201-1207.

Rogers-Bennett, L., P.L. Haaker, K.A. Karpov and D. J. Kushner. 2002. Using spatially explicit data to evaluate Marine Protected Areas for abalone in southern California. Conservation Biology 16:1308-1317.

Rogers-Bennett, L. and J.S. Pearse. 1998. Experimental seeding of hatchery-reared juvenile red abalone *Haliotis rufescens* in northern California. J. Shellfish Res. 17:877-880.

Saito, K. 1979. Studies on the propagation of Ezo abalone, *Haliotis discus hannai*, analysis of the relationship between transplantation and catch in Funka Bay coast. *Bull. Japan. Soc. Sci. Fish*. 45:695-704.

Saito, K. 1984. Ocean ranching of abalones and scallops in northern Japan. *Aquaculture* 39, 361-373.

Schiel, D.R. and Welden, B.C. 1987. Responses to predators of cultured and wild red abalone, *Haliotis rufescens* , in laboratory experiments. *Aquaculture* 60 (3-4): 173-188.

Schiel, D.R. 1993. Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. Mar. Ecol. Prog. Ser. 97:167-181.

Sheehy, D., and S, Vik. 1981. *Aquaculture: Developments in East Asia*. Water Spectrum., Fall (1981):26-37.

Sweijd, N., Snethlage, Q., Harvey, D., and Cook, P. 1998. Experimental abalone (*Haliotis midae*) seeding in South Africa. *J. Shellfish Res.* 17(3), 897-904.

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. pp. 61-71.

Tegner, M.J. and R. Butler. 1985. The survival and mortality of seeded and native red abalone, *Haliotis rufescens*, on the Palos Verdes Peninsula. *Calif. Fish and Game* 71:150-163.

Tutschulte, T.C. 1976. The comparative ecology of three sympatric abalones. PhD dissertation. University of California, San Diego.

VanBlaricom, G.R. 1993. Dynamics and distribution of black abalone populations at San Nicolas Island, California. Pages 323-334 *In* Third California Islands Symposium: Recent advances in research on the California Islands. *Edited by* F.G. Hochberg. Santa Barbara Museum of Natural History, Santa Barbara, California.