

**BEFORE THE SECRETARY OF THE COMMERCE**

**PETITION TO LIST THE BLACK ABALONE (*HALIOTIS*  
*CHRACHERODII*) AS THREATENED OR ENDANGERED  
UNDER THE ENDANGERED SPECIES ACT**



Submitted December 21, 2006

## EXECUTIVE SUMMARY

The Center for Biological Diversity formally requests that the Secretary of Commerce, through the National Marine Fisheries Service (“NMFS” or “NOAA Fisheries”), list the Black Abalone (*Haliotis cracherodii*) as Endangered under the federal Endangered Species Act (“ESA”), 16 U.S.C. § 1531 – 1544. The Center also requests that black abalone critical habitat be designated concurrently with its listing.

The Black Abalone, an intertidal invertebrate ranging from Coos Bay, Oregon to Cape San Lucas, Baja California has declined by as much as 99% in large portions of its range. Once occurring at densities over 120 per m<sup>2</sup> in some areas, the species was among the most common and visible invertebrates in Southern California tidepools. The Black Abalone has now virtually disappeared from the Southern California mainland and from many areas of the Channel Islands where it was once most abundant.

The primary drivers of the decline of Black Abalone are commercial fishing, which severely depleted most populations, followed by the outbreak and spread of a disease, withering syndrome, which has devastated remaining populations in the Channel Islands and Southern California and is continuing to spread northward through the remaining range of the species.

While, in California at least, fishing of Black Abalone is now banned, withering syndrome has yet to be controlled and remains a dire threat to the continued existence of the species. Moreover, withering syndrome is more virulent in warm water conditions; as the sea temperatures off California and Oregon rise in the face of global warming, the deadly effects of withering syndrome are likely to spread to the currently unaffected abalone in the northern portion of the species’ range.

Black Abalone have declined precipitously from their historic numbers such that the species is now in serious danger of extinction. As a result of overharvest, Black Abalone had already declined significantly prior to 1985 when the effects of withering syndrome first appeared. Since then, declines have continued and the species is likely at less than 1% of its former abundance. Scientists have predicted that the species will have no hope of recovering without immediate and active intervention.

This Petition summarizes the natural history of the Black Abalone, the population information available on the species, and the threats to the species and its habitat. The Petition then shows that, in the context of the ESA’s five statutory listing factors, the severely depleted population status of the species and the ongoing threats to its continued existence leave NMFS with no choice but to list the species as Endangered under the ESA.

Once listed, the Black Abalone would join the White Abalone and the Elkhorn and Staghorn Corals as the only marine invertebrates protected under the ESA. Each of these species was protected under the ESA only following a similar Center petition.

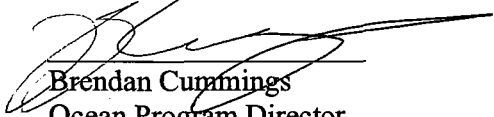
## NOTICE OF PETITION

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Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. § 1533(b), Section 553(3) of the Administrative Procedures Act, 5 U.S.C. § 553(e), and 50 C.F.R. § 424.14(a), the Center for Biological Diversity hereby petitions the Secretary of Commerce, through the National Marine Fisheries Service ("NMFS" or "NOAA Fisheries"), to list the Black Abalone (*Haliotis cracherodii*) as threatened or endangered under the federal Endangered Species Act ("ESA"), 16 U.S.C. § 1531-1544.

The Center for Biological Diversity ("Center") is a non-profit, public interest environmental organization dedicated to the protection of imperiled species and their habitats through science, policy, and environmental law. The Center has over 25,000 members throughout the United States.

In analyzing whether the Black Abalone warrants listing under the ESA, NMFS must examine whether the species is threatened or endangered throughout all or a significant portion of its range. In the event NMFS determines that the Petition fails to demonstrate that listing of the Black Abalone may be warranted in all of its range, we request that, in the alternative, NMFS consider whether the species is imperiled in "a significant portion of its range."

NMFS has jurisdiction over this Petition. This Petition sets in motion a specific process, placing definite response requirements on NMFS. Specifically, NMFS must issue an initial finding as to whether the Petition “presents substantial scientific or commercial information indicating that the petitioned action may be warranted.” 16 U.S.C. § 1533(b)(3)(A). NMFS must make this initial finding “[t]o the maximum extent practicable, within 90 days after receiving the petition.” *Id.* Petitioners need not demonstrate that listing of the Black Abalone is warranted, rather, Petitioners must only present information demonstrating that such listing may be warranted. While Petitioners believe that the best available science demonstrates that listing of the Black Abalone as endangered is in fact warranted, there can be no reasonable dispute that the available information indicates that listing the species as either threatened or endangered may be warranted. As such, NMFS must promptly make a positive initial finding on the petition and commence and complete a status review as required by 16 U.S.C. § 1533(b)(3)(B). The fact that NMFS has independently initiated a status review of the species (see 71 Fed. Reg. 61021, October 17, 2006) does not relieve the agency of its obligations to meet the statutory timelines of the ESA with regards to this Petition. See Center for Biological Diversity v. Norton, 254 F.3d 833 (9<sup>th</sup> Cir. 2001).

Petitioners also request that critical habitat be designated for the Black Abalone concurrently with the species being listed as threatened or endangered, pursuant to 16 U.S.C. § 1533(a)(3)(A) and 50 C.F.R. § 424.12.

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## **I. INTRODUCTION**

The black abalone (*Haliotis cracherodii*), an intertidal invertebrate ranging from Coos Bay, Oregon to Cape San Lucas, Baja California has declined by as much as 99% in large portions of its range. Once occurring at densities over 120 per m<sup>2</sup> in some areas, the species has virtually disappeared from the Southern California mainland and in many areas of the Channel Islands. The primary drivers of the decline of black abalone were commercial fishing, which severely depleted most populations, followed by the outbreak and spread of a disease, withering syndrome, which has devastated remaining populations in the Channel Islands and Southern California and is continuing to spread northward through the remaining range of the species. While, in California at least, fishing of black abalone is now banned, withering syndrome has yet to be controlled and remains a dire threat to the continued existence of the species. Moreover, withering syndrome is more virulent in warm water conditions; as the sea temperatures off California and Oregon rise in the face of global warming, the deadly effects of withering syndrome are likely to spread to the currently unaffected abalone in the northern portion of the species' range.

The reductions of black abalone populations caused by fishing and disease has left remaining abalone in many areas likely too far apart to successfully reproduce. As older surviving individuals die, the species will likely be extirpated from all or most of its range. Absent intervention, recovery of the species is impossible and extinction is likely. Black abalone clearly qualifies for listing under the Endangered Species Act (ESA).

This Petition summarizes the natural history of the black abalone, the population information available on the species, and the threats to the species and its habitat. The Petition then shows that, in the context of the ESA's five statutory listing factors, the severely depleted population status of the species and the ongoing threats to its continued existence, the National Marine Fisheries Service (NMFS) has no choice but to list the species as Endangered under the ESA.

## **II. NATURAL HISTORY AND STATUS OF THE BLACK ABALONE**

### **A. NATURAL HISTORY**

#### **1. Description**

Abalone are marine snails of the genus *Haliotis*. As many as seventy modern species have been described globally (Davis, 1996), with eight recognized species occurring off the mainland and islands of California (Haaker et al., 1986). More recently, Geiger (1999) in a review of the genus, reduced the number of global species to fifty-six and in California to seven. The black abalone is recognized as a full species in all taxonomies. Abalone species separate themselves roughly by depth and latitude in California (Davis, 1996). The black abalone is a relatively shallow water species occurring mainly in the intertidal and shallow subtidal zones throughout its range (Haaker et al., 1986). Other sympatric species are generally found in deeper waters. Black abalone historically ranged from Coos Bay, Oregon to Cape San Lucas, Baja

California (Cox, 1962).

The body and epipodium (shell) of abalone is usually characteristic to each species (Cox, 1960), although, black abalone have occasionally been mistaken for small red abalone under water (Howorth, 1978). Black abalone has a smooth, circular shell with five to nine open flush apertures along the left side of the shell. The spiral growth lines, indicative of the snails, is obvious at the posterior end of the upper side of the shell. The shell is black to slate blue, and often appears white when the outer layers are worn away. The inside of the shell is white (Haaker et al., 1986), with poorly defined or no muscle scar (Howorth, 1978). The shell may grow to 7.75 inches, but most reach only 5 to 6 inches. The mantle tissue, which overlays the shell and the upper foot, is black. Tentacles are black and are lobed and smooth in between (Cox, 1960).

A large foot is attached to the shell and the organs are positioned around the edge of the animal, under the shell. Locomotion is accomplished by an undulating motion of the foot. Most of the time abalone do not move around, but remain firmly attached to the substrate, using the muscular foot (California Department of Fish and Game, 1993).

In 1814 black abalone became the first eastern pacific abalone species to be formally described. A subspecies of the black abalone, *H. cracherodii californiensis*, has been described at Guadalupe Island off Mexico (Howorth, 1978).

## **2. Distribution**

Black abalone were historically found between Coos Bay, Oregon, and Cape San Lucas, Baja California (Cox, 1962). In California they occurred throughout southern, central, and northern California, but were rare north of San Francisco (Morris et al., 1980). Off the coast of California they were found in great abundance at all of the Channel Islands (Sheperd et al., 1992). In Baja California, black abalone were most abundant in the central coast of the peninsula from Cedros to Punta Asuncion (Guzman del Proo, 1992). As described below, black abalone have since vanished entirely from some portions of their range, and are in greatly reduced numbers in the remainder.

## **3. Habitat**

While the geographic range of black abalone is great, the presence of local populations depends upon several factors: suitable substrate; temperature ranges favorable to larvae, juveniles, and adults; sufficient food; and protection from unusually high predation, including human harvest (Leighton, 1974; Tutschulte, 1976).

Optimal habitat for the black abalone is the rocky intertidal zone in areas with protective crevices and moderate to heavy surf action. The substrate on which abalones live usually reflects the rocky character of the shoreline (Cox, 1962). Small abalone seek crevices during daylight hours to avoid predation, but are active at night. As they grow they are less susceptible to many predators, and are able to seek more open locations where food is more available

(Haaker et al., 1986). Depth distribution is usually from the intertidal to 3 meters deep. Different species of abalone have dissimilar but overlapping vertical distribution patterns, and surveys (Guzman del Proo et al., 1976 and 1992) show that maximum densities usually occur at slightly different depths, implying the evolution of different niches (Leighton, 1974).

Habitat of black abalone is essentially similar throughout the range. One difference is the ambient sea water and air temperature differences likely to be found when the range crosses a major zoogeographic province barrier such as near Point Conception. While local populations may be adapted to different temperature regimes, the overall ability of black abalone to tolerate broad temperature extremes is great (California Dept. of Fish and Game, 1993). Black abalone are able to tolerate a range in water temperature from forty-five to seventy-five degrees Fahrenheit (Howorth, 1978).

The intertidal zone is subject to intense competitive interactions. Black abalone must compete with numerous other species for food and space (Douros, 1987, Sheperd et al., 1992). Black abalone usually occurred in densely populated tide pools, often stacked on top of each other (Davis et al., 1996, Cox, 1960). Intraspecific competition for space and food has been hypothesized as a cause of stacking behavior. Densities historically ranged from 25-40 per m<sup>2</sup> on the central California mainland, to over 120 per m<sup>2</sup> in the Channel Islands (Douros, 1987). Other interspecific interactions may occur at the depth-habitat zone boundaries of green/black abalone (Parker et al., 1992). In addition, sea urchins *Strongylocentrotus purpuratus* and *S. franciscanus* occur throughout Baja California and compete for space and food with abalone. In the central part of the Baja peninsula abalone coexist on the same reefs with herbivorous gastropods such as *Astrea undosa* (Guzman del Proo et al., 1992).

#### **4. Feeding**

Abalone eat marine algae. The larvae begin by eating pelagic plankton. Following settlement, postlarvae feed on bacterial films, benthic diatoms (Cox, 1962; Ault, 1985), and coralline algae with their rasping tongues. In juvenile and adult form, abalone diets consist of macroalgae (Cox, 1962). The adults feed on loose pieces drifting with the surge or current. Adult black abalone prefer algae such as giant and feather-boa kelp although when hungry they will seize other types of algae which drift within their reach (Howorth, 1978). The color banding on many abalone shells is due to changes in the types of algae eaten. Abalone tend to stay in one location waiting for food to drift by. Two to three abalone have been seen pinning down and feeding on large pieces of algae. Due to their wait and grab method of capturing transient algae, their habitat may appear devoid of food. However, they will move daily or seasonally when food becomes scarce for a long period (Leighton, 1972).

#### **5. Movement**

Blecha (1992) found that black abalone exhibit distinct, size-related activity patterns. Small individuals (< 40 mm) are cryptic by nature, moving about actively within the protective confines of crevices. This behavior pattern is thought to be related to predation pressure and factors associated with feeding *Id.* Intermediate sizes (55-75 mm) are the most active, both as a



group and individually. This same pattern was noted by Tissot (1988b), as it affected immigration and emigration. Larger size classes are more sedentary. Individuals above 105 mm were observed to be predictably stationary. This size class was most frequently found in very open, exposed locations, while intermediate and small sizes preferred the protection of cracks and crevices. The change in movement behavior with growth suggests that a size is reached which provides refuge from many predators, permitting free movement into and ultimately colonization of open, less protected areas (Blecha et al., 1992). This essentially sedentary lifestyle makes repopulating depleted areas via migrating individuals very unlikely.

## **6. Reproductive Parameters**

Black abalone are broadcast spawners. Reproduction and successful recruitment for the black abalone is determined by a number of parameters including sex ratio, age to maturity, fecundity, duration and timing of spawning, spawning density, dispersal and settlement of larvae, and physiological condition of breeding stock. These factors are summarized below.

### **a. Sex Ratio**

The sexes are dioecious and can be distinguished in individuals as small as one inch when the gonads begin to develop (Haaker et. al., 1986). Sex can be determined by the color of the abalone's gonad: the male gonad is creamy beige, while the female gonad is green (Cox, 1962). In Baja California, the sex ratio, observed in samples from commercial catches (Guzman del Proo et al., 1976; Andrade, 1980), varies between zones and years. The normal ratio expected is 1:1(male:female).

### **b. Age at Sexual Maturity**

Determining the age of an individual abalone is difficult. Unlike the hard parts of some animals, abalone shells have no marks or bands suitable for assigning age. Under lab conditions, however, juvenile abalone in aquariums grow an inch or more per year for the first two years. Tagging studies have provided estimates of age for larger abalone in the wild. Studies of other species show the difficulty of assigning age to a given individual. For instance, a seven inch red abalone may be 7-10 years old, while a red abalone measuring only 3/4 of an inch may be 15 years or older (Haaker et. al., 1986).

Difficulty in assessing the age of abalone has led to the method of judging sexual maturity by shell length. Even these results are highly inconsistent among comparable studies. According to Parker et al. (1992), sexual maturity occurs at relatively small sizes, early in life. In California, black abalone are considered sexually mature when they grow to at least 40 mm. This shell length usually occurs during the third year of growth (Blecha et al., 1992). This compares with 5-7 years for green abalone (females 61-128 mm, males 89-128 mm), and 3-4 years in pink abalone (about 35mm) *Id.* Guzman del Proo et al. (1980) summarized previous work (e.g. Munoz and Camacho, 1976) and showed that the size of sexual maturity, defined as the size at which 50% of the population show mature gonads, decreases from north to south, suggesting sexual precocity in the southern populations. In Baja California, black abalone are

said to be sexually mature at 120 mm. The variability of these studies may suggest that sexual maturity is, in part, a function of environmental conditions.

### **c. Fecundity**

Fecundity increases exponentially with size. Newly mature females produce only a few hundred thousand eggs each year, whereas older individuals produce 10-15 million eggs (Hahn 1989). Black abalone in Baja California, as reported by Gonzalez and Ortiz (1986), had fecundities of 0.8 million eggs for individuals of 106 mm shell length to 12.1 million for those of 140 mm SL (Guzman del Proo et al., 1992). Variation in fecundity with depth or region is uncertain for black abalone, but is often related to food supply in other abalone species. Abalone living in shallower water may have reduced fecundity if food is limited. Tutschulte (1976) observed a deep population of pink abalone that did not appear to spawn in one year. As an intertidal species, black abalone may be more prone to food-limited variations in fecundity.

### **d. Duration and Timing of Spawning**

The duration of the spawning season can also influence reproductive success. Black abalone spawn during spring and summer (Cox, 1960). Synchronicity in the release of sperm and eggs is vital in ensuring that fertilization occurs successfully. What drives the synchronicity in spawning is not entirely clear. Cox (1962) and Morton (1967) believed that the release of sperm triggers the release of eggs. Spawning may also be a function of several environmental cues including elevated temperature (Cox, 1962; Young and DeMartini, 1970) and calm water conditions (Prince et al., 1987; Breen and Adkins, 1980).

### **e. Spawning Density**

To reproduce, abalone broadcast sperm and eggs into the sea, relying on high gamete densities for successful fertilization. This reproductive strategy requires densely aggregated adults for success (Davis, 1996). Aggregation through movement is one way to increase the local density at the time of spawning. At low overall densities, animals are not close enough for successful fertilization, and reproductive failure will occur. Research on urchins has shown a direct correlation between spawning density and successful fertilization (Pennington, 1985). A harvest-driven reduction in spawning density is considered one of the primary factors endangering the related white abalone (NMFS 2006). Similar declines in spawning density in the black abalone are likely affecting reproduction of this species as well.

### **f. Settlement and Recruitment**

Abalone recruitment is highly variable and unpredictable (Sheperd, 1990; Breen, 1992; Nash, 1992). Successful fertilization is only the first hurdle to successful recruitment. The fertilized eggs sink to the bottom, where they develop and hatch into larvae in about 10 to 72 hours, depending on the ambient temperature. After a week or two, settlement occurs and the larval abalone takes up its benthic existence (California Department of Fish and Game, 1993). The relatively short larval life span of all abalone species suggests that larval dispersal distances

are likewise limited. Limited dispersal means the recolonization of a depleted habitat will be extremely difficult once abalone density is low. Leighton (1972) concluded that the assumption of uniform growth within a population of juvenile *Haliotis* is untenable and that conclusions regarding settlement date estimated from sizes of members of a sample must be drawn cautiously.

Abalone are cryptic until they reach about 75-100 mm in length, occupying habitats such as the undersides of rocks and deep crevices (Cox, 1960). Above this size they emerge from these habitats, and are more easily visible. Animals that are visible without disturbing the habitat are classed as emergent in diving surveys. In the Baja California region there is little data on recruitment, because surveys have not recorded abalone less than 100 mm shell length (Guzman del Proo et al., 1992).

Growth is generally regular during the first two years, regardless of location. Thereafter, growth becomes more irregular and episodic, influenced in part by locality (Blecha et al., 1992). Over-exploitation of certain sizes of abalone for harvest may distort growth estimates. The size of capture in recent fisheries is much lower than the maximum size in unharvested populations (Guzman del Proo et al., 1992).

#### **g. Lifespan**

There is no direct measurement of black abalone lifespan. Shell length alone cannot be considered to be a good indication of the age of black abalone. They appear to be long-lived, generally in excess of 30 years (Blecha et al., 1992).

### **7. Natural Mortality**

Dramatic fluctuations in marine invertebrate populations are not uncommon, and appear to be increasing in frequency world-wide. Natural mortality for abalone can be due to disease, starvation, predation, competition or old age, as well as a variety of abiotic factors (Shepherd and Breen, 1992).

#### **a. Predators**

Black abalone face two different suites of predators: plankton-feeding animals preying on the free-swimming larvae and large animals feeding on rock-dwelling juveniles and adults (Miller and Lawrenz-Miller, 1993). Although juvenile abalone hide under rocks during the day, they are active at night. Crabs, lobsters, octopi, starfish, fish and predatory snails prey on them when they leave shelter (Haaker et. al., 1986). The striped shore crab (*Pachygrapsus crassipes*) and seastars are known to prey on juvenile abalone. While intertidal areas are flooded, some highly mobile benthic dwellers such as spiny lobster (*Panulirus interruptus*) may forage for small abalone. Intermediate sizes, which become vulnerable when they begin to forage for food, are preyed upon by octopus species, and fishes, including sheephead (*Semicossyphus pulcher*) and cabezon (*Scorpaenichthys marmoratus*)

Large abalone are not threatened by the predators of their earlier life, but larger, and often more efficient predators, become important as they age. During high tide periods in areas where sea otters forage, black abalone are subject to their predation. One reason the populations of black abalone grew to such densities was the elimination of the sea otter throughout much of the black abalone's range (Cox, 1962; Douros, 1987; Ogden, 1941; Miller, 1974). Black abalone populations along the central California coast did not attain the densities observed at the California islands, likely because of sea otter predation (California Department of Fish and Game, 1993). In historical times sea otters have had a significant effect on black abalone by reducing their density and shifting size distributions toward smaller sizes (Miller and Lawrenz-Miller, 1993). However, recent research suggests that otter predation was a factor in driving the evolution of North Pacific abalone to larger sizes than abalone elsewhere in the world (Estes et al., 2005).

#### **b. Disease**

West coast populations of abalone have been severely impacted by withering syndrome whose cause has only recently been identified. Withering syndrome is a chronic, progressive disease responsible for mass mortalities in wild populations of black abalone in southern California (Moore et al., 2000). Withering syndrome is a terminal condition caused by bacterium in the family Rickettsiaceae in the order Rickettsiales. The bacterium is found in the cytoplasm of abalone gastrointestinal epithelial cells. Withering syndrome affects all sizes of black abalone (California Department of Fish and Game, 1993). When infected, black abalone tissues atrophy and wither leading to an inability to hold to substrate and eventually to death. Abalone with withering syndrome are weak, lethargic, emaciated and may have a discolored epipodium. *Id.*

The effects of withering syndrome--dead and dying abalone--were first observed in black abalone in populations along the west end of Santa Cruz and Anacapa Islands in 1985 and 1986. The mortality spread west to Santa Rosa Island, and south to encompass all of Santa Cruz Island by 1987, and Santa Barbara Island by 1988. Black abalone at Diablo Cove, San Luis Obispo County, began to exhibit signs of withering syndrome in 1988. This outbreak resulted in an 85% decline in resident black abalone in the cove. The declines closely followed an outfall plume of heated water from the nuclear power plant. Later, withering syndrome affected other populations outside the cove not influenced by the heated water discharge (Blecha et al., 1992).

Black abalone populations at San Miguel Island have generally declined since 1988. In 1990, black abalone populations at one location at San Clemente Island were observed to be affected by withering syndrome. By 1991 they had declined by 50 to 60% and continued to decline in 1992. At the end of 1991, San Nicolas Island was the only island with large populations of black abalone, and no observed symptoms of withering syndrome. The disease reached San Nicolas Island in 1992. All of the Channel Islands have now been affected by withering syndrome. Since 1986, black abalone populations declined over 99% parkwide and only a few remnant populations remain mainly on San Miguel Island (Richards, 2000).

Warm temperature, although not associated with the initiation of withering syndrome, is

associated with increased rates of mortality (Lafferty & Kuris, 1993). Elevated water temperatures have been proven to accelerate mortality within laboratory conditions (Friedman et al., 1997). In wild conditions, withering syndrome caused mass mortalities within the immediate vicinity of warm water discharge at Diablo Cove while in adjacent cool water areas, mass death had not yet occurred (Altstatt et al., 1996). In trying to reestablish black abalone on Santa Cruz Island, temperature was indicated to be the single most important factor influencing population recovery (Tissot, 1995). As discussed below, increasing sea temperatures as a result of global warming are likely to exacerbate the impact of this disease.

While withering syndrome was thought to have reached its northernmost limit at Cayucos, recently, previously unaffected populations at Cambria along the Big Sur coast have been hit by the disease. The species is now clearly threatened by withering syndrome in all or a significant portion of its range.

### **c. Competition**

Competition for food and space may also result in black abalone mortality. Due to their similar habitat and food preferences, black abalone compete directly with urchins. Purple sea urchins and to a lesser extent, red sea urchins, and black abalones in California occupy crevice habitat, are drift algal nocturnal feeders, and show preferences for similar brown algae (Leighton, 1968; Tegner, 1989; Tegner and Levin, 1982). Competition with urchins is restricted to the lower intertidal region, as sea urchins do not tolerate emersion during low tide periods (California Department of Fish and Game, 1993). Food scarcity intensifies competition for food (Davis et al., 1996). Although abalone appear to be superior competitors when food is readily available, when food is scarce, urchins actively forage while abalone assume a feeding posture and wait (Tegner & Levin, 1982). Given altered food supplies, urchins may be able to exclude abalone competitively (Paine, 1974). High densities of urchins may limit the access of abalone, especially the smaller ones, to food and space (Miller and Lawrenz-Miller, 1993).

Sand castle worms (*Phragmatopoma californica*) are also potential competitors for space. In areas of abalone decline, colonies of tubes of the worm cement rocks to the substratum, eliminating the undersides of rocks as a refuge for abalone (Connell et al., 1988). These space holders could act to reduce the potential for black abalone to recruit back to their former habitat. The low recruitment rates observed for black abalone (VanBlaricom, 1993) reinforce this concern (Lafferty and Kuris, 1993). It is also possible that these filter-feeding worms could consume gametes of the black abalone (Miller and Lawrenz-Miller, 1993).

### **d. Other Mortality**

Various additional factors affect black abalone mortality at different life stages. A critical cause of natural mortality occurs at the larval free-swimming stage of nearshore invertebrates if they are carried away from their appropriate nursery or settlement habitat (Pechenik, 1990). Abalone larval mortality is assumed to be high, and survival was about 5% in lab studies (Leighton, 1972). Other abiotic factors influencing juvenile and adult mortality include storm-induced crushing, sanding or siltation of habitat, and fresh water run-off (Cox,

1962). In shallow waters, suspension of sediments may foul the gills of some abalone, leading to suffocation (Cox, 1960). Temperature has been shown to have direct effects on various aspects of abalone life: egg fertilization and development, growth and settlement, and growth and feeding of juveniles and adults. Indirect effects are also likely, such as on the susceptibility of individuals to disease or toxic effects of pollution (Miller and Lawrenz-Miller, 1993). Specific estimates of natural mortality rates have not been made for black abalone (California Department of Fish and Game, 1993).

## **B. POPULATION DECLINE OF BLACK ABALONE**

Black abalone are known to have declined anywhere there is available data. The decline in black abalone abundance can be inferred from both research surveys and fishery-related data. As the quantity and quality of data differs between California, Oregon and Mexico, these areas are dealt with separately.

### **1. California**

Black abalone survey data is limited both geographically and temporally. Nevertheless, this data indicates a catastrophic decline in numbers and density of the species.

Long term changes in the abundance of black abalone on the California Channel Islands reflect historical events. Evidence from Indian middens (Cox, 1962, Muratto, 1984) shows that Native Americans heavily fished the abundant black abalone populations. In the early 1800's, the reduction and/or removal of the Native population from much of the California coast (Johnson, 1982, Douros, 1985) and the extirpation of sea otters by Russian fur hunters (Van Blaricom and Estes, 1988) virtually eliminated predation on adult black abalone. As a result, throughout the twentieth century, black abalone attained high population levels on the Channel Islands and became one of the most abundant large invertebrates in the rocky intertidal zones (Douros, 1987).

The modern California fishery began in the mid-nineteenth century with exploitation of intertidal black abalone by immigrants. By 1879, annual harvest approached 2,000 metric tons (mt). Socio-economic factors shifted harvest to subtidal species in 1900. After serially depleting four subtidal species, the fishery returned to black abalone in 1968. Recreational harvests grew dramatically in the 1950's and 60's. By 1970, the recreational harvest was estimated to exceed the commercial harvest (Frey, 1971). Commercial landings in the 1970's were nearly 900 mt a year. Subtidal stocks were depleted, in part reflecting sea otter recovery. Intertidal black abalone thus became a major component of the commercial harvest, comprising 32 to 60% of the total landings from 1972-1988 (Davis et al., 1992). By the mid-1980's southern California black abalone fishery landings started to precipitously decline. Black abalone were virtually eliminated along the mainland coast of Southern California, apparently due to heavy fishing pressure, expanding coastal development and pollution (Altstatt et al., 1996). Commercial landings declined to 17.4 mt in 1992 as mortality from withering syndrome devastated remaining black abalone stocks throughout Southern California (Haaker, 1994). In 1993 harvest was suspended. In less than twenty years, black abalone that had dominated rocky

intertidal zones at densities of more than 100 per m<sup>2</sup> disappeared from most of their former range south of Point Conception (Davis, 1993).

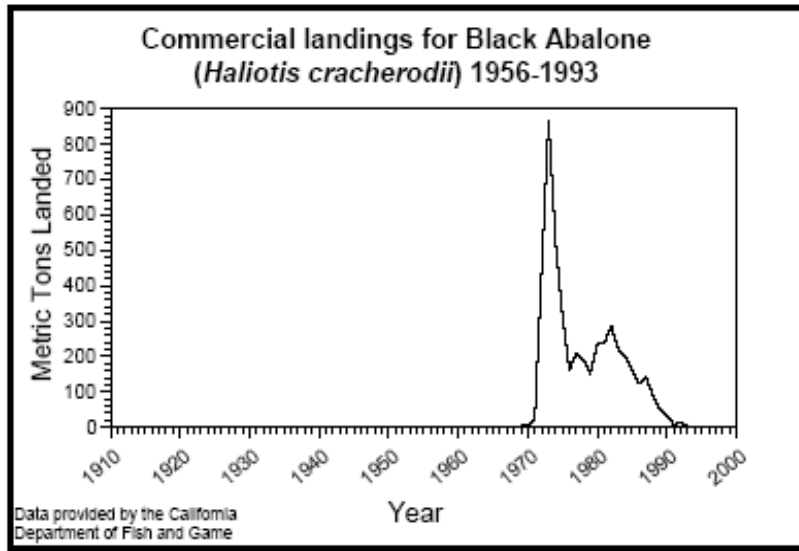


Figure 1: Commercial Landings of Black Abalone in California  
Source: NMFS 2004

While fishing was responsible for the decline of black abalone on the mainland and certainly had a large impact on island population, disease ultimately played an even greater role. Large numbers of empty shells and dying abalone were first documented on the southern shore of Santa Cruz Island in 1985. Similar die-offs subsequently happened on Anacapa, Santa Rosa, Santa Barbara, San Miguel, San Clemente, and San Nicolas islands (Lafferty and Kuris, 1993). A similar pattern occurred at Diablo Cove (Steinbeck et al., 1992).

Richards and Davis (1993) monitored the abundance and distribution of rocky intertidal black abalone within the Channel Islands National Park, California from 1985 to 1992. More than 99% of the black abalone vanished from Anacapa, Santa Barbara, and Santa Rosa Islands in less than five years, while other mollusks and plants remained unchanged at the same sites (Richards and Davis, 1993; Haaker et al., 1989). At the southeastern islands, in the warm waters of the Californian Province, 90% of the abalone died between 1985 and 1988, and the proportion of large individuals among survivors increased as the population declined to less than 1% of its 1985 level. Recruitment of juvenile abalone virtually ceased when adult populations dropped below 50% of their initial abundance. Withered and weak abalone were frequently observed. *Id.*

A similar black abalone mass mortality was reported along the mainland coast at Palos Verdes Peninsula in Southern California in the late 1950's (Cox, 1962). This mass mortality was attributed to starvation, precipitated by the loss of a neighboring kelp bed that was destroyed by a large El Nino event (Richards and Davis, 1993). From 1975 until 1991, Miller and Lawrenz-

Miller (1993) conducted a four-site study of the long-term trends of black abalone along the Palos Verdes Peninsula, California. The trends in all sites were the same: during the early years, there were relatively high densities with some fluctuations, followed by declines until black abalone were rare or nonexistent in the sample areas. The average density over the four sites decreased from 2.8 per m<sup>2</sup> during the period of 1975 to 1979 down to 0.03 per m<sup>2</sup> from 1987 to 1991. In recent years rarely have there been any individuals found, even outside the study quadrants. Miller and Lawrenz-Miller speculate that since the decline in offshore kelp beds was well underway along the Peninsula by the late 1950's the populations of abalone on the Peninsula may already have been suffering when their research was conducted.

There are now no known populations of black abalone in Southern California that do not exhibit symptoms of withering syndrome in some of its individuals (Ca. Dept of Fish and Game, 1993).

In order to test the hypothesis that the mass mortalities of black abalone were confined to the warmer, southern waters of California, Altstatt et al. (1996) conducted a study in the central mainland region of California throughout the early to mid 1990's. They found that the widespread mass mortality of the black abalone was no longer confined to Southern California. The northern progression of the deaths are consistent with the advancement expected by an infectious agent (Lafferty and Kuris, 1993). Unfortunately, little is known of the southward spread of withering syndrome into Baja California. Judging from past die-offs, declines will continue until more than 95% of the population has disappeared (Richards and Davis, 1993).

While for several years withering syndrome was thought to have reached its northernmost limit at Cayucos, recently, previously unaffected populations at Cambria along the Big Sur coast have been hit by the disease. The species is now clearly threatened by withering syndrome in all or at least most of its range.

To summarize the last century, huge biomasses accumulated after harvesting ceased in 1900, with densities often exceeding 125 per m<sup>2</sup> on the Channel Islands (Richards and Davis, 1993). When harvest resumed in 1968, annual landings quickly rose to 870 mt. By the mid-1980's, black abalone were found primarily on offshore islands and inaccessible sections of the coast north of Santa Barbara. Withering syndrome caused mass mortality in these remnant populations, beginning in 1985 on the Channel Islands, and spread to the mainland (Haaker et al., 1992). Relict populations of apparently disease resistant individuals survive on the islands at less than one percent of their former abundance (Davis, 1996).

## **2. Mexico**

Mexican data on the black abalone is quite limited, but shows similar declines in density and absolute abundance. Studies on abalone in Mexico have been in progress for a couple decades. The general focus of these studies has been related to the fisheries, especially monitoring of the catch and surveys to estimate abundance.

The Mexican abalone fisheries followed a similar boom and bust cycle to California's.



The harvest reached a peak of 6000 metric tons for all species in 1950 (Hobday and Tegner 1999). From 1929 until present the central region of Baja California has always been the mainstay of the fishery. Little data exists regarding black abalone specifically, as it composed only a small percentage of the total abalone catch composition. Of the five fishing zones in Baja California, black abalone was only caught in the northern two, comprising very little or none of the yearly catch results (Guzman del Proo et al., 1992). This may have been due, in part, to the low meat quality and value of the black abalone. Black abalone were mainly dried and used as bait by lobstermen (Cox, 1962). Catch declined sharply after 1976, stabilizing again after 1984 at around 1000 tons per year. The relative importance of each species varied between and within zones (Mureuta et al., 1996). Most of the historical abalone catch was red and pink abalone although the fishery was recently supported mainly by pink and green abalone, which comprised about 95-98% of the commercial catch (Leon and Muncino, 1996).

### **3. Oregon**

Virtually no information on black abalone in Oregon is available. While the species has been described as occurring as far north as Coos Bay, Oregon, we have been unable to find any survey data for the species in Oregon. It is presumed to occur in small numbers in suitable habitat although records of the species north of San Francisco, California are very limited. In any event, any populations in Oregon are small, isolated, and likely subject to similar threats as those facing the species in California. Moreover, the area of known declines of the species in California and Mexico clearly constitute “a significant portion of its range.”

Oregon has an active recreational and commercial fishery. Recreational abalone harvest requires an 8 inch minimum length for harvest. (Oregon Department of Fish and Wildlife, 2005). The only species of abalone in Oregon to commonly grow larger than 8 inches is the red abalone (*Haliotis rufescens*), although state fishery regulations do not differentiate between different abalone species. (Oregon Department of Fish and Wildlife 2005). Commercial abalone fishing is allowed for the Flat Abalone (*Haliotis walallensis*) under the Oregon Developmental Fisheries Program. The 2004 annual report listed landings for flat abalone totaling 2,180 pounds (Oregon Fish and Wildlife Commission 2004). Oregon Department of Fish and Wildlife Staff recognize that the biological data necessary to determine species health and fisheries management for the Flat Abalone is not currently available, yet commercial harvesting is continuing. (Oregon Developmental Fisheries Board 2004). While recreational size limits and the restriction of commercial harvest to flat abalone should act to prevent intentional harvest of black abalone, experience in California and Mexico demonstrate that misidentification of species and harvest of undersize individuals is common. Oregon abalone harvest regulation is therefore unlikely to truly protect black abalone in the state.

### **4. Implications of low population size for black abalone**

Since reduced to low population size, black abalone face further limits on survival and reproduction. This reduction in reproductive success below some threshold density is also known as the Allee effect. The removal of large animals and reduction of densities have been recognized as threats to the survival of various abalone species for many years (Edwards, 1913).

The remaining populations of black abalone are sparse but may represent individuals that are somehow resistant to withering syndrome (Lafferty and Kuris, 1993). The long-term ecological consequences of abalone loss in the rocky intertidal communities are not yet known, but the decline of a dominant space holder significantly alters the structure of the surrounding intertidal community (Altstatt et al, 1996). Black abalone are important structural components of rocky intertidal communities in Southern California. They are slow-growing, long-lived, occupy extensive areas, and constituted a large portion of the consumer biomass (Richards and Davis, 1993). Sand castle worms (*Phragmatopoma californica*) and scaled tube-snails (*Serpulorbis squmigeris*) invaded much of the space vacated by dying black abalone at many sites (Richards and Davis, 1993). Even if current declines were to stop, it would be decades before black abalone could become space-dominant elements of rocky intertidal communities on the California Channel Islands as they were in the early 1980's. *Id.*

Little is known about reproduction and early life history of black abalone, but in other abalone species recruitment may be patchy (Prince et al., 1987). Successful spawning may not occur at such low population densities because fertilization may only be successful when male and female abalone are within a few meters of each other (Breen and Adkins, 1980; Prince et al., 1987). Annual recruitment of juvenile black abalone declined steeply when adult populations dropped below half of initial densities (Richards and Davis, 1993). Densities required for spawning have been determined mainly for broadcast spawning sea urchins (Pennington, 1985), but are likely applicable to abalone (Hobday and Tegner, 1999). A field study of *H. laevigata* showed that fertilization success was related to separation of individuals, and fell below 50% as densities declined below 0.05m<sup>2</sup>. *Id.*

Black abalone recovery requires widespread black abalone recolonization, and the reestablishment of abalone with widely varying sizes in multiple cohorts. Such restoration of slow-growing, long-lived abalone to sustainable levels will take decades, once initiated. The reestablishment of a viable fishery for black abalone will take even longer. Given the prevalence of withering syndrome and prospects of climate change, recovery to historic levels may be impossible. Restoration of black abalone will require active intervention (Davis, 1996). In 1977 the Orange County shoreline was closed to abalone harvest in 1977 but populations did not recover with such “passive” management (Tegner, 1992). The number of healthy black abalone throughout the species range is likely too small to allow a natural recovery. The densities are likely too low to allow natural fertilization success (Haaker et al., 1995). Declines in abalone fertility with age are unknown but black abalone which survived the disease outbreaks of the 1980s and 90s are likely nearing the end of their lifespan. Immediate action is necessary to prevent the extinction of the black abalone..

### **III. CRITERIA FOR ENDANGERED SPECIES ACT LISTING**

#### **A. THE BLACK ABALONE IS A “SPECIES” UNDER THE ESA.**

The Endangered Species Act, 16 U.S.C. §§ 1531 - 1544, allows any species of fish or wildlife or plants to be listed under the provisions of the act. Section 3(8) of the ESA defines

“fish or wildlife” to mean "any member of the animal kingdom, including without limitation any mammal, fish, bird ..., *mollusk*, crustacean, arthropod or other invertebrate..."16 U.S.C. § 1532 (8) (emphasis added). The black abalone is a mollusk. The black abalone (*Haliotis cracherodii*) was formally described as a species in 1814 by Leach (Cox, 1962). Its taxonomy and validity as a species is uncontested. It qualifies as a “species” under the Act. Petitioners seek protection for the species throughout its range in Oregon, California and Mexico.

## **B. THE BLACK ABALONE IS ENDANGERED UNDER THE ESA.**

NMFS is required to determine, substantiated solely on the basis of the best scientific and commercial data available, whether a species is endangered or threatened in all or a significant portion of its range because of any of the following factors: (1) the present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific or educational purposes; (3) disease or predation; (4) the inadequacy of existing regulatory mechanisms; or (5) other natural or manmade factors affecting its continued existence. 16 U.S.C. §§ 1533(a)(1) and 1533(b).

Petitioners believe that all five of these factors have played a role in bringing the black abalone to its current perilous condition. The most immediate threat to its extinction is the extreme reduction in abundance and density of the species caused by overharvest and withering syndrome. While harvest has been curtailed, declines of the species continue. Consequently, all existing regulatory mechanisms have proven ineffective in protecting or recovering the species from its severely depleted numbers. As described below, there are other actual and potential impacts to the species that are also contributing to its decline and may impede its recovery. The remaining healthy, viable populations, if any, are small, vulnerable and isolated. The species is in dire need of the additional protections that only listing under the ESA can provide.

### **1. PRESENT OR THREATENED DESTRUCTION, MODIFICATION OR CURTAILMENT OF ITS HABITAT OR RANGE.**

Habitat loss has been a significant factor in the decline of black abalone on the mainland California coast, as coastal development and pollution have rendered large areas of intertidal habitat unsuitable for abalone (Haaker et. al., 1986). Pollution led to the loss of shallow water abalone habitat (*Macrocystis* kelp forests) along the Palos Verdes Peninsula which in turn led to the decline in some shallow water abalone populations (Tegner, 1993). The remnant black abalone along the mainland of Oregon, California and Mexico are susceptible to negative impacts from pollution, sewage, and potential oil spills. Proposed Liquified natural Gas facilities along the coast also could have significant localized impacts on abalone populations. As described above, the effects of withering syndrome are more pronounced in association with warm water such as from the outfall at the Diablo Canyon nuclear power plant (Altstatt et al., 1996). Numerous other outfall pipes occur along the California coast and could pose a threat to any nearby black abalone populations.

In the Channel Islands, direct habitat loss is not responsible for the severe reduction in black abalone population size. Nevertheless, the reduction in numbers of the species has

resulted in a “curtailment of its habitat or range.” As described in section II(B) above, the species simply cannot be found in many areas of its historic range.

Perhaps the most significant threat to abalone habitat comes from greenhouse gas emissions which are resulting in global warming, sea level rise, and ocean acidification. The effects of these factors on black abalone are described below.

## **2. OVERUTILIZATION FOR COMMERCIAL, RECREATIONAL, SCIENTIFIC OR EDUCATIONAL PURPOSES**

Over harvesting by both recreational and commercial fishing is addressed in section II(B) above. The practice of serial depletion observed in the California abalone fishery (Tegner, 1992; Davis et al., 1996) has lowered the density of black abalone adults to levels at which recruitment failure is highly likely (Miller and Lawrenz-Miller, 1993). In this multi-species abalone fishery, the incidental black abalone were undoubtedly collected as they were encountered while harvesting the more profitable abalone species that were the target of the fishery. This process of extreme depletion is likely continuing within the abalone fishery in Mexico. Overutilization is clearly a significant factor that helped to create the current endangered status of the black abalone.

## **3. DISEASE AND PREDATION**

### **a. Disease**

This criteria is dealt with in section II(A)(7)(b) above. Withering syndrome has been found in almost all populations of black abalone and continues to spread northward (and possibly southwards) from its origination in the Channel Islands, off the coast of southern California. This factor alone is sufficient to warrant listing the species under the ESA.

While withering syndrome has recently been discovered in other abalone species, no other has been hit as detrimentally as the black abalone. Withering syndrome was found to be the cause of mass mortality in the fishery-damaged populations of black abalone, beginning in 1985 on the Channel Islands. It has since then spread to the mainland (Haaker et al., 1992) and northward, traveling distances of 23 km in one year (Alstatt et al., 1996). Relict populations of apparently disease resistant individuals survive on the islands at less than one percent of their former abundance (Davis, 1996). In the more recent northern progression of withering syndrome, declines in black abalone populations are showing similar die-off patterns, where more than 95% of the population disappears in a matter of years (Richards and Davis, 1993). Unfortunately, little is known of the southward spread of withering syndrome into Baja California, Mexico.

Withering syndrome has proven more virulent in warmer waters as discussed in section I(A)(7)(b). As global warming results in warmer water throughout the species’ range, the spread of withering syndrome further northward is likely.

## **b. Predation**

This criteria is dealt with in section II(A)(7)(a) above. Sea otters are the primary non-human predator of adult abalone. While otter and black abalone do not overlap in the northern and southern ends of the abalone's range, the species co-occur in Central California. Any areas chosen for artificial aggregations of wild black abalone or for reintroduction of captive bred stock must take the presence and role of otters into consideration.

## **4. INADEQUACY OF EXISTING REGULATORY MECHANISMS**

The black abalone has reached its current status due, in part, to the failure of fisheries regulations in either California or Mexico to protect the species. The management goals for abalone in California have been to protect a large portion of the reproductive stock to provide for a continuing level of harvest. Minimum legal sizes have been the main tool used in an attempt to achieve this goal. Seasons, closed areas, gear restrictions and differential harvest sizes have been used for harvest efficiency and resource allocation purposes (Sheperd et al., 1992). Management strategies have failed to take into account the population density required for successful fertilization and the low survival rate among abalone larvae.

Davis (1996), writing about management of all species of abalone in southern California, provides a succinct explanation of the failure of the fishery:

Following a fishing hiatus during World War II, southern California abalone fisheries grew rapidly. Soon, readily available and well known abalone populations along mainland shorelines were exhausted. Then lightweight, mobile, inexpensive diving gear, fast boats, modern navigational aids, and improved knowledge of abalone and the coastal environment made available virtually all of the pristine abalone habitat on offshore reefs. After 25 years of apparently sustained fisheries, abalone landing began declining in the 1970's. A careful examination of this harvest shows it was not truly sustained, but rather the result of serial depletion. Fishery landings and fleet income were sustained at the expense of a series of abalone populations in different areas...

The success of serial depletion in sustaining fishery income obscured the need to restore severely depleted stocks and to protect more reproductive capacity of abalone populations. Denial that abalone populations were imperiled obstructed efforts to improve management. The virtual absence of fishery-independent information made it difficult to assess population status, and gave fishery landings data more credibility than they warranted. These strategies and beliefs delayed remedial actions, making restoration more costly, and perhaps impossible for some species.

Mexico has apparently yet to close its black abalone fishery. As in California, size and seasonal restrictions were insufficient to prevent a population collapse, much less aid in its recovery. Size limits also fail to protect sub-legal sized animals as upwards of 20% of such

individuals bleed to death from cuts sustained when divers temporarily remove them to measure them (Hobday and Tegner, 1999). Illegal harvesting is still a large problem in Mexico. Intentional capture of undersized abalone may also have acted to reduce the population size. In some Mexican surveys a substantial portion of the commercial catch was found to be undersized. *Id.* Similarly, recreational harvest of black abalone is not prohibited in Oregon, and the commercial harvest of flat abalone may result in incidental harvest of black abalone as well.

As described earlier, black abalone are now too limited in numbers and density to have any realistic chance of breeding successfully in the wild. The closure of the fishery alone will not restore the population. To date, abalone management has been reactive, responding to changes in the fishery and stocks after the fact, rather than based on actual stock productivity. Forward-looking management requires knowledge of stock, size, recruitment, mortality and growth. These parameters are incompletely understood for the black abalone (Parker et al., 1992). The remaining points of control for abalone resource managers are quite limited and do not appear to include factors most probably causing the mass mortalities: infectious agents and ecological conditions. The current population of black abalone is so reduced that it will require active management and human intervention to prevent extinction (Culver and Richards, 1992). Acting now to preserve the remaining populations will preserve the remaining genetic diversity of the species.

Existing regulatory mechanisms were clearly inadequate to prevent overharvest of black abalone. Likewise, they have not stopped the spread of withering syndrome which has decimated the species. As described below, no regulatory mechanisms are in place that adequately address greenhouse gas emissions.

## **5. OTHER NATURAL OR ANTHROPOGENIC FACTORS**

### **a. Competition**

This criteria is dealt with in section II(A)(7)(c) above. Black abalone compete both inter- and intraspecifically for food and space, impacting their distribution and abundance. Intrageneric competition with other abalone species is likely a factor in influencing the lower limits of black abalone occurrence (Parker et al., 1992). The density of most competitor species and abalone are low due to harvesting such that interactions are no longer likely to exert a strong effect on population dynamics (Hobday and Tegner, 1999). However, various competition pressures may further complicate restoration efforts. The removal of a dominant space-holder such as the black abalone clears the way for the invasion of species whose populations were kept in check via competition for space.

### **b. Hybridization**

Natural hybridization between California abalone species occurs (Owen et al., 1971). Hybridization of black abalone with other abalone species may act to lower population size. Frequency of adult abalone hybrids in the field is low, occurring in 0.02-0.37% of the

commercial catch considered by Owen et al. (1971). Hybridization is considered to be a minor threat to the persistence of the species.

### **c. Poaching**

In 1993, the collapse of the black abalone populations off Central and Southern California resulted in a harvesting moratorium (Daniels and Floren, 1998). Harvesting of green, pink, and white abalone ceased in 1996, with the commercial red abalone fishery closing in 1997. In contrast, the northern recreational fishery is expected by California resource managers to continue indefinitely. Because of the high demand, the financial incentives are creating a thriving poaching industry in Northern California. Law enforcement officials close to the situation estimate 4,800 abalone per diveable day are being poached from Northern California waters. Poaching, in all its forms - sport violations, commercial to commercial and sport to commercial - is expected to continue due to the escalating value of abalone. *Id.*

While most poaching targets red abalone, because the range of red and black abalone overlap, black abalone are likely to be opportunistically taken by poachers searching for red abalone. Sport violations are the most obvious poaching in Northern California. It consists of recreational harvesters committing violations of fish and game regulations involving undersized, over limit, or illegal possession of abalone out-of-shell. The over-all impact is an increase in pressure on stocks already subject to recreational harvesting. *Id.* At the other extreme of visible poaching activity is a small and elusive segment of the commercial diving industry that harvests abalone illegally in Northern California. With the May 1997 closure shutting down the commercial abalone fishery throughout the state of California, concern regarding this form of poaching has been reduced. However, sufficient evidence continues to accumulate to justify ongoing, close scrutiny of the commercial diving fleet. *Id.* Of much greater concern is the black market in poached abalone and those occasions where it has led to large-scale commercial operations. This is known as sport to commercial poaching, where an underground trade exists between sport licensees, and restaurants and markets. In some cases, small scale operations have tied in with international businesses involving millions of dollars in abalone poached from Northern California waters. *Id.*

### **d. Global Warming**

Global warming represents perhaps the gravest threat to the long-term survival of the black abalone. Global warming will likely affect black abalone in several ways. First, and perhaps most immediately, warmer water will increase the deadliness of withering syndrome and likely foster its spread northward. Second, global warming will likely lead to reduced overall productivity, including a reduction in the kelp species eaten by black abalone. Third, global warming will likely lead to more pronounced El Nino events which tend to negatively affect black abalone. Forth, global warming will lead to significant sea level rise, eliminating much of the black abalone's existing intertidal habitat. Finally, ocean acidification caused by the ocean's absorption of excess carbon dioxide may ultimately render the oceans inhospitable to shell-forming organisms such as abalone. Any of these factors alone would be sufficient to warrant

listing of the black abalone as Endangered. Collectively, unless address, they render the future survival of the species doubtful.

## **1. The Best Available Science and Global Warming**

The basic physics underlying global warming are as well established as any phenomena in the planetary sciences. The earth absorbs heat in the form of radiation from the sun, which is then redistributed by atmospheric and oceanic circulations and also radiated back to space (Albritton et al. 2001). The earth's climate is the result of a state in which the amount of incoming and outgoing radiation are approximately in balance (Albritton et al. 2001). Changes in the earth's climate can be caused by any factor that alters the amount of radiation that reaches the earth or the amount that is lost back into space, or that alters the redistribution of energy within the atmosphere and between the atmosphere, land, and ocean (Albritton et al. 2001). A change in the net radiative energy available to the global Earth-atmosphere system is called "radiative forcing" (Albritton et al. 2001). Positive radiative forcings tend to warm the Earth's surface while negative radiative forcings tend to cool it (Albritton et al. 2001).

Radiative forcings are caused by both natural and manmade factors (Albritton et al. 2001; ACIA 2004). The level of scientific understanding of these different forcings varies widely, and the forcings themselves and interactions between them are complex (Albritton et al. 2001). The primary cause of global warming, however, is society's production of massive amounts of "greenhouse gases" such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and halocarbons that cause positive radiative forcings (Albritton et al. 2001; IPCC 2001; ACIA 2004). Greenhouse gases are, in fact, the radiative forcing mechanism that is currently best understood (Albritton et al. 2001).

The Enhanced Greenhouse Effect is caused by increasing concentrations of these greenhouse gases in the earth's atmosphere. As greenhouse gas concentrations increase, more heat reflected from the earth's surface is absorbed by these greenhouse gases and radiated back into the atmosphere and to the earth's surface. Increases in the concentrations of greenhouse gases slow the rate of heat loss back into space and warm the climate, much like the effect of a common garden greenhouse (Albritton et al. 2001; ACIA 2004). The higher the level of greenhouse gas concentrations, the larger the degree of warming experienced.

By the time of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2001<sup>1</sup>, the atmospheric concentration of carbon dioxide had increased by 31%

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<sup>1</sup> The IPCC was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 (IPCC 2001a). The IPCC's mission is to assess available scientific and socio-economic information on climate change and its impacts and the options for mitigating climate change and to provide, on request, scientific and technical advice to the Conference of the Parties to the United Nations Framework Convention on Climate Change (IPCC 2001a). Since 1990, the IPCC has produced a series of reports, papers, methodologies, and other products that have become the standard works of reference on climate change (IPCC 2001a). The IPCC's comprehensive Assessment Reports are



since 1750, to a level that has not been exceeded during the past 420,000 years and likely not during the past 20 million years (IPCC 2001). The current rate of increase is unprecedented during at least the past 20 million years (IPCC 2001). About three fourths of manmade carbon dioxide emissions come from fossil fuel burning, and most of the remaining emissions are due to land-use changes, primarily deforestation (IPCC 2001). Carbon dioxide is considered the most important greenhouse gas overall because the volumes emitted dwarf those of all the other greenhouse gases combined. As of March, 2006, the atmospheric carbon dioxide concentration was 381 ppm, and rising at over 2 ppm per year (Shukman 2006).

The atmospheric concentration of methane, another important greenhouse gas, has increased by about 150% since 1750, continues to increase, and has not been exceeded during the past 420,000 years (IPCC 2001). About half of current methane emissions are manmade, and there is also evidence that current carbon monoxide (CO) emissions are a cause of increasing methane concentrations (IPCC 2001). Over a 100-year period, methane will trap about 23 times more heat than an equal amount of carbon dioxide (Albritton et al. 2001).

The atmospheric concentration of nitrous oxide has increased by about 17% since 1750, continues to increase, and has not been exceeded during at least the last 1000 years (IPCC 2001). About a third of current nitrous oxide concentrations are manmade. Over a 100-year period, nitrous oxide will trap about 296 times more heat than an equal amount of carbon dioxide (Albritton et al. 2001).

By 2001, the global average temperature has risen by approximately  $0.6^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$  ( $1.0^{\circ}\text{F} \pm 0.36^{\circ}\text{F}$ ) during the 20<sup>th</sup> Century (IPCC 2001). Important advances in the detection and attribution of global warming have demonstrated, beyond any legitimate scientific debate, that a significant portion of this observed warming is due to anthropogenic greenhouse gas emissions (Barnett et al. 2005, IPCC 2001).

Past anthropogenic greenhouse gas emissions have altered the energy balance of the earth by  $0.85 \pm 0.15$  watts per square meter (Hansen et al. 2005). Due to the lag time in the climate system, this energy imbalance commits the earth to additional warming of  $.6^{\circ}\text{C}$  ( $1^{\circ}\text{F}$ ) of warming that is already “in the pipeline,” even absent additional greenhouse gas emissions (Hansen et al. 2005).

Because greenhouse gas emissions are continuing to increase, warming is projected to accelerate. Based on differing scenarios of future greenhouse gas emissions and the world’s leading climate models, the IPCC has projected between  $1.4^{\circ}$  and  $5.8^{\circ}\text{C}$  ( $2.5^{\circ}$  - $10.4^{\circ}\text{F}$ ) of

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produced approximately every seven years and build upon and expand past IPCC products. The *Fourth Assessment Report* is scheduled for release beginning in February, 2007, and should be available for FWS’s use in its full status review for the petitioned penguin species. This Petition cites from the *Third Assessment Report* and from many more recent individual peer reviewed publications.

additional warming by the end of this century. The higher the level of greenhouse gas emissions, the more the world will warm.

As scientific understanding of global warming has advanced, so too has the urgency of the warnings from scientists about the consequences of our greenhouse gas emissions. Scientists are now able to tell us, with a high degree of certainty, that additional warming of more than 1° C (1.8° F) above year 2000 levels will constitute “dangerous climate change,” with particular reference to sea level rise and species extinction (Hansen et al. 2006a,b). Furthermore, scientists are able to tell us the atmospheric greenhouse gas level “ceiling” that must not be exceeded in order to prevent additional warming of more than 1° C (1.8° F) above year 2000 levels (Hansen et al. 2006a,b). In turn, scientists can tell us the limitations that must be placed on greenhouse gas emissions in order to not exceed this “ceiling” of approximately 450-475 ppm of carbon dioxide.

In order to stay within the ceiling, emissions must follow the “alternative,” rather than the “business as usual,” greenhouse gas emissions scenario (Hansen 2006; Hansen et al. 2006a,b; Hansen and Sato 2004). In the business as usual scenario, carbon dioxide emissions continue to grow at about 2% per year, and other greenhouse gases such as methane and nitrous oxide also continue to increase (Hansen 2006; Hansen et al. 2006a,b). In the alternative scenario, by contrast, carbon dioxide emissions decline moderately between now and 2050, and much more steeply after 2050, so that atmospheric carbon dioxide never exceeds 475 parts per million (Hansen 2006; Hansen et al. 2006a,b). The alternative scenario would limit global warming to less than an additional 1° C in this century (Hansen 2006; Hansen et al. 2006a,b).

Since the year 2000, however, society has not followed the alternative scenario. Instead, carbon dioxide emissions have continued to increase by 2% per year since 2000 (Hansen 2006; Hansen et al. 2006a,b). This rate of increase itself appears to be increasing (Black 2006). If this growth continues for just ten more years, the 35% increase in CO<sub>2</sub> emissions between 2000 and 2015 will make it impractical if not impossible to achieve the alternative scenario (Hansen et al. 2006a,b). Moreover, the “tripwire” between keeping global warming to less than 1° C, as opposed to having a warming that approaches the range of 2-3° C, may depend upon a relatively small difference in anthropogenic greenhouse gas emissions (Hansen et al. 2006a,b). This is because warming of greater than 1° C may induce positive climate feedbacks, such as the release of large amounts of methane from thawing arctic permafrost, that will further amplify the warming (Hansen et al. 2006a,b).

Just ten more years on current greenhouse gas emissions trajectories will essentially commit us to climate disaster. Dr. James E. Hansen, Director of the NASA Goddard Institute for Space Studies, and NASA’s top climate scientist, has stated: “In my opinion there is no significant doubt (probability > 99%) that . . . additional global warming of 2° C would push the earth beyond the tipping point and cause dramatic climate impacts including eventual sea level rise of at least several meters, extermination of a substantial fraction of the animal and plant species on the planet, and major regional climate disruptions” (Hansen 2006:30).

In order to avoid truly unacceptable consequences of global warming, we must stop the growth of greenhouse gas emissions, and, in relatively short order, begin reducing them. Achieving the reductions necessary to keep additional global warming between the years 2000-2100 within 1° C will be extremely challenging, and will require deep reductions in emissions from industrialized nations such as the United States.

## 2. Global Warming and the California Current

The increasing temperature of the Pacific Ocean is triggering a meltdown of carefully balanced interactions in the marine community. Water temperature is an important factor determining habitat ranges for many organisms and even minor changes are seriously disruptive. In the last 60 years, average ocean temperatures between 0-300 meters have increased by 0.31°C (0.56°F) (Field et al. 2000). Locally, water temperature increases have been even more significant.

Global warming is weakening the nutrient rich upwelling off the California coast (Pew 2002). An annual upwelling of cold water usually draws nutrients from the deep water, which in turn causes a bloom of phytoplankton. Increased stratification of surface and depth temperatures and changing weather have weakened the upwelling and the impacts are alarming. Between 1951 and 1993, researchers observed an 80 percent decline in zooplankton off the California coast due to surface waters warming up to 1.5°C (2.7°F) (McGowan 1998).

Tidal pools studied along the Monterey coast of California already demonstrate that species abundance and distribution is changing due to climate change. In just six decades, shoreline ocean temperatures warmed by 0.79° C (1.4° F) and Monterey tide pool species changed significantly with more warm water species present and a decline in cool water species (Sagarin 1999). Similar changes were also observed among southern California reef fish (McCarty 2001). As a result of these changing conditions, California's marine ecosystems are losing diversity and invasive species may gain an advantage over native species (Stachowicz 2002). Warming waters are devastating for species that are unable to migrate toward cooler waters because of habitat requirements, environmental barriers, or lack of mobility (Scavia 2002). These climatic changes are occurring at an unprecedented rate which also hinders the adaptation of many organisms.

Warmer waters also favor different species of phytoplankton, some of which are associated with "red tides" that shade ocean vegetation, deplete oxygen, and often have toxic properties (Smith 2000; Stephens 2006). Additionally, warmer waters hold less oxygen than cooler waters which may limit the range of species that require higher oxygen concentrations (Kennedy et al 2002)

Depleted of nutrients, warm waters cause the loss of *Macrocystis* canopies (Tegner, 1992). Kelp is the major food source for adult abalone and loss of the canopy will negatively affect the ability of the population to find food.

While global warming is clearly having significant impacts on the California marine ecosystem and these impacts are likely to increase in severity, the most direct impact on black abalone is the effect of elevated sea temperature on disease dynamics. Global warming has been linked to the spread or increased virulence of numerous marine pathogens (Harvell et al. 2002). As described above, withering syndrome becomes deadly to black abalone at higher temperatures (Altstatt et al., 1996; Friedman et al., 1997; Lafferty & Kuris, 1993; Tissot, 1995). Global warming is delivering those temperatures to the entire range of the species. Tissot (1995) found that temperature may be the single most important factor influencing black abalone population recovery. Natural oceanographic conditions that elevate temperatures like El Niño as well as global warming will have a strong negative impact on recovery of the black abalone population. *Id.*

### **3. El Niño Southern Oscillation (ENSO)**

Black abalone may be severely impacted by the El Niño Southern Oscillation (ENSO), which can produce changes in much of the near shore and offshore marine communities, including a reduction in upwelling of cold, nutrient-rich waters. When this upwelling is reduced, overall productivity declines.

ENSO years tend to bring more intense storm events that can directly damage black abalone habitat. As described above, a black abalone mass mortality was reported along the mainland coast at Palos Verdes Peninsula in Southern California in the late 1950's (Cox, 1962). This mass mortality was attributed to starvation, precipitated by the loss of a neighboring kelp bed that was destroyed by a large El Niño event (Richards and Davis, 1993).

ENSO years now appear to occur 2-7 times more frequently than they did 7,000-15,000 years ago, and this recent apparent increase in the frequency (and also severity) of ENSO events poses a threat to the black abalone. The 1983 and 1998 events were successively labeled the “El Niño of the Century” because the warming in the Eastern Equatorial Pacific was unprecedented in the past 100 years (Hansen et al. 2006a).

While atmospheric science theory does not provide a clear answer on the effect of global warming on ENSO, most climate models yield either a tendency towards a more ENSO-like state or no clear change (Hansen et al. 2006a). Some have hypothesized that during the early Pliocene, when the Earth was 3° C (5.4° F) warmer than today, a permanent ENSO-like condition existed (Hansen et al. 2006a). Leading climate scientists believe that near-term global warming will lead to an increased likelihood of strong ENSO events (Hansen et al. 2006a).

Anthropogenic warming, therefore, also has the potential to harm black abalone via increases in the intensity (and possibly in the frequency) of ENSO events. Regardless of the impact of anthropogenic greenhouse gas emission on their frequency and/or intensity, ENSO events are clearly a threat to the black abalone.

#### **4. Sea Level Rise**

In 2001 the IPCC projected that global sea level will likely rise between 10-90 cm in this century (Albritton et al. 2001). One of the most troubling of recent scientific findings is that this projection is almost certainly a substantial underestimate. Melting of the Greenland ice sheet has accelerated far beyond what scientists predicted even just a few years ago, with a more than doubling of the mass loss from Greenland due to melting observed in the past decade alone. (Rignot and Kanagaratnam 2006). The acceleration in the rate of melt is due in part to the creation of rivers of melt water, called “moulins,” that flow down several miles to the base of the ice sheet, where they lubricate the area between the ice sheet and the rock, speeding the movement of the ice towards the ocean (Hansen 2006). The IPCC projection of 10-90 cm in this century assumes a negligible contribution to sea level rise by 2100 from loss of Greenland and Antarctic ice, but leading experts have stated that that conclusion is no longer plausible due to multiple positive feedback mechanisms including dynamical processes such as the formation of moulins, reduced surface albedo, loss of buttressing ice shelves, and lowered ice surface altitude (Hansen et al. 2006a). Paleoclimatic evidence also provides strong evidence that the rate of future melting and related sea-level rise could be faster than previously widely believed (Overpeck et al. 2006).

While it has been commonly assumed that the response time of ice sheets is millennia, this may reflect the time scale of the forcings that cause the changes, rather than the inherent response time of the ice sheets (Hansen et al. 2006b). The forcing from continued unabated greenhouse gas emissions in this century could yield sea level rise of more than 1 m or more and a dynamically changing ice sheet that is out of our control (Hansen et al. 2006b).

Even sea level rise in line with the past underestimate from the IPCC would still inundate substantial areas of the coast and have far-reaching consequences for the black abalone. Yet just 2-3°C (3.6-5.4° F) of warming would likely cause sea level to rise by at least 6 m (18 feet) within a century (Hansen 2006).

Temperature changes of 2-3°C (3.6-5.4° F) are well within the range of estimates for this century provided by the IPCC (2001). Change of this magnitude is very likely if carbon dioxide concentrations exceed 475 ppm, and, if current greenhouse gas emission trajectories continue for just 10 more years, it will be difficult if not impossible to keep carbon dioxide levels below 475 ppm (Hansen 2006; Hansen et al. 2006a,b). For these reasons, sea level rise must be considered a very important future threat to the black abalone.

#### **5. Ocean Acidification**

The world’s oceans are an important part of the planet’s carbon cycle, absorbing large volumes of carbon dioxide and cycling it through various chemical, biological, and hydrological processes. The oceans have thus far absorbed approximately 30% of the excess carbon dioxide emitted since the beginning of the industrial revolution (Feely et al. 2004; WBGU 2006). The world’s oceans, in fact, store about 50 times more carbon dioxide than the atmosphere (WBGU

2006), and most carbon dioxide released into the atmosphere from the use of fossil fuels will eventually be absorbed by the ocean (Caldeira and Wickett 2003). As the ocean absorbs carbon dioxide from the atmosphere it changes the chemistry of the sea water by lowering its pH. The oceans' uptake of these excess anthropogenic carbon dioxide emissions, therefore, is causing ocean acidification (WBGU 2006).

Surface ocean pH has already dropped by about 0.1 units on the pH scale, from 8.16 in 1800 to 8.05 today -- a rise in acidity of about thirty percent (Orr et al. 2005; Ruttimann 2006). The pH of the ocean is currently changing rapidly at a rate 100 times anything seen in hundreds of millennia, and may drop to 7.9 by the end of this century (Ruttimann 2006). If carbon dioxide emissions continue unabated, resulting changes in ocean acidity could exceed anything experienced in the past 300 million years (Caldeira & Wickett 2003). Even if carbon dioxide emissions stopped immediately, the ocean would continue to absorb the excess carbon dioxide in the atmosphere, resulting in further acidification until the planet's carbon budget returned to equilibrium.

Ocean acidification from unabated anthropogenic carbon dioxide emissions poses a profound threat to marine ecosystems because it affects the physiology of numerous marine organisms, causing detrimental impacts that may ripple up the food chain. Changes that have been observed in laboratory experiments include impacts to the productivity of algae, photosynthesis of phytoplankton, metabolic rates of zooplankton and fish, oxygen supply of squid, reproduction of clams, nitrification by microorganisms, and the uptake of metals (WBGU 2006).

Perhaps most importantly, increasing ocean acidity also reduces the availability of calcium carbonate needed by marine life to build shells and skeletons (Ruttimann 2006). Phytoplankton, corals, coralline macroalgae, urchins, starfish, clams, oysters, crustaceans and many other organisms, including marine snails such as the black abalone, rely on calcium carbonate in the ocean to build skeletons (WBGU 2006). Normally, ocean waters are saturated with carbonate ions that marine organisms use to build skeletons (WBGU 2006). However, the acidification of the oceans shifts the water chemistry to favor bicarbonate, thus reducing the availability of carbonate to marine organisms (WBGU 2006). Already the ocean surface layer has lost 10% of its carbonate compared to preindustrial levels (WBGU 2006). Continuing carbon dioxide emissions could result in calcification rates decreasing by up to 60% by the end of this century (Ruttimann 2006). Acidic waters also dissolve existing protective carbonate skeletons and shells. Increased acidity may also harm larvae of sea organisms (Ruttimann 2006).

Severe impacts to the black abalone could begin from ocean acidification in as little as a few decades. By the close of this century, the acidification of the ocean will almost certainly have a significant impact on calcifying organisms if greenhouse gas emissions are not abated (WBGU 2006).

#### **IV. CRITICAL HABITAT**

Petitioners request the designation of critical habitat for black abalone concurrent with its listing. Black abalone have already vanished from many areas in their historic range. Critical habitat should encompass the area from Coos Bay, Oregon south to the Mexican border including the Channel Islands. The constituent elements would include all substrate in the intertidal zones down to 3 meters deep in the subtidal, the water column and the algal component. Because of projected sea level rise of upward of a meter by the end of the century, critical habitat should also include at least a one meter zone above the current high tide limit to capture this habitat as well

#### **V. CONCLUSION**

Several factors, both natural and anthropogenic, appear to have combined in complex ways to weaken black abalone, accelerate their mortality and cause subsequent declines. Based on the information presented above, it is clear that black abalone are in danger of extinction throughout their range, and therefore, are Endangered within the meaning of the ESA, 16 U.S.C. § 1532(6). Failure to act is likely to result in the extinction of this highly endangered species.

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