Black Abalone
(*Haliotis cracherodii*)

Five-Year Status Review: Summary and Evaluation

July 2018

Photo Credit: Susan Wang, NMFS

National Marine Fisheries Service
West Coast Region
Protected Resources Division
Long Beach, California

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5-YEAR REVIEW
Black Abalone (*Haliotis cracherodii*)
Current Classification: Endangered

1.0 GENERAL INFORMATION

1.1 Reviewers

Lead Regional or Headquarters Office: National Marine Fisheries Service (NMFS) West Coast Region (WCR) – Chris Yates, Assistant Regional Administrator for Protected Resources, 562-980-4007

Cooperating Science Center(s): NMFS Southwest Fisheries Science Center – Kristen Koch, Science and Research Director, 858-546-7081

1.2 Methodology used to complete the review

This five-year review was led by the NMFS West Coast Region. Much of the updated information on the species' biology and habitat was compiled by two student interns in the summer of 2016: Alyssa Braciszewski and Lara Slatoff. The primary sources of information and data for this review came from reports, publications, and information available from ongoing studies and reviews that have become available since the status review completed by VanBlaricom et al. (2009). We gathered information through: 1) literature searches on various search engines (e.g., Google Scholar, Research Gate, Web of Science); 2) publication of a Federal Register (FR) notice soliciting new information about black abalone; and 3) email and phone contact with abalone experts at universities and state and federal government agencies. Section 2.3 (Updated Information and Current Species Status) was reviewed by the Black Abalone Recovery Team (BART), to ensure that this Section accurately presents the best available information that has become available since the 2009 Status Review on the species' biology, habitat, status, and threats. The BART consists of research biologists and resource managers representing several agencies and institutions with expertise on abalone, rocky intertidal and subtidal habitats, and conservation.

1.3 Background

1.3.1 FR Notice citation announcing initiation of this review

81 FR 93902; 22 December 2016

1.3.2 Listing history

<u>Original Listing</u>

Federal Register notice: 74 Federal Register 1937

Date listed: January 14, 2009
Entity listed: Species
Classification: Endangered

1.3.3 Associated rulemakings

Critical Habitat Designation: 76 Fed. Reg. 66806, October 27, 2011

1.3.4 Review History

This is the first, formal five-year review for black abalone. The original status review was completed in 2009 (VanBlaricom et al. 2009) for the final listing decision.

1.3.5 Species' Recovery Priority Number at start of five-year review

Black abalone have a Recovery Priority Number of 5[1], based on criteria in the Recovery Priority Guidelines (55 FR 24296, 15 June 1990). The Recovery Priority Number is based on three criteria: the magnitude of threat, potential for recovery, and potential for conflict with economic activities. Black abalone were assigned a Recovery Priority Number of 5 out of a range of 1 (high) to 12 (low), based on the species' moderate extinction risk, high recovery potential (e.g., primary threats are disease and the resulting low densities, which may be addressed by monitoring, management, and population enhancement efforts), and potential for conflicts with economic interests (e.g., if restrictions are needed to minimize or avoid effects on rocky intertidal habitats and coastal water quality).

1.3.6 Recovery Plan or Outline

The Recovery Plan Outline for black abalone was published in 2016 (NMFS 2016). NMFS is currently developing the Draft Recovery Plan for black abalone.

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) Policy

2.1.1 Is the species under review a vertebrate?

______Yes.
__X**__No**.

[1] On 31 May 2017, NMFS published draft revised Listing and Recovery Priority guidelines (82 FR 24944). Applying the draft guidelines, black abalone would have a new proposed Recovery Priority Number of one, based on the species' high demographic risk and high recovery potential.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?

____ Yes

__X_ No *(a draft recovery plan is in development).*

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history

Black abalone are marine snails, with one shell and one large muscular foot used for locomotion and adhering to rocky substrates. They are relatively long-lived (estimated to live up to 30 years), have separate sexes, and are "broadcast" spawners, meaning that both sexes shed their gametes into the sea and fertilization is entirely external. Successful reproduction is dependent on spatial and temporal synchrony among spawning individuals; that is, males and females in close proximity to one another (within meters) and spawning simultaneously have a higher likelihood of reproductive success. An experimental simulation of black abalone spawning employed release of inert neutrally-buoyant particles in two size categories similar in size to eggs and sperm in black abalone habitat at San Nicolas Island in southern California (Blaud 2013). Data were consistent with the premise that probability of fertilization may increase if spawning males and females are within four to five meters of one another.

Natural recovery of severely-reduced abalone populations is likely a slow process, because having few reproductive adults reduces reproductive success and eventual recruitment of larval abalone. Studies indicate that a critical minimum adult density is needed to support successful reproduction and recruitment, though estimates of this critical density vary (Babcock and Keesing 1999: 0.15 – 0.20 abalone per m^2; Neuman et al. 2010: 0.34 abalone per m^2; Tissot 2007: 0.75 – 1.1 abalone per m^2). However, successful fertilization and recruitment is possible in populations that are below this minimum density (likely due to their aggregative nature or habitat preferences), as has been observed at some populations in southern California where the abundance and density of black abalone had declined severely due to withering syndrome. Recruitment and increasing numbers of black abalone have been observed at several sites throughout southern California (Richards and Whitaker 2012, Eckdahl 2015, VanBlaricom 2017, unpublished data).

Little new information on black abalone biology or life history has become available since the 2009 Status Review. Studies on other abalone species have been published that may inform us about black abalone reproductive biology and immunity. Studies involving green abalone (*Haliotis fulgens*) and red abalone (*H. rufescens*) may be most relevant given similarities with black abalone in their habitat use, because they also inhabit intertidal and shallow subtidal habitat along the California coast. Vélez-Arellano (2016) studied the movement of nutrients in green abalone during gonad development and found that as the gonads develop, the concentration of lipids, proteins, and carbohydrates decreases in the foot and increases in the gonad and digestive gland. This is consistent with observations in black abalone indicating that the foot muscle shrinks during increased gonad development (Webber 1970). New information from red abalone studies explains some of the chemical signaling that occurs during spawning to increase fertilization and prevent hybridization. Krug et al. (2009) found that eggs have high concentrations of tryptophan to attract sperm to conspecific eggs, even to the extent of altering the sperm's swimming behavior. Fertilization success peaks during the 30 minute period following spawning and decreases to low levels at 50 minutes, corresponding with when the release of tryptophan stops (Krug et al. 2009).

Research on captive breeding of black abalone is ongoing and will likely provide additional information on the species' biology and life history in the future. Other studies are also ongoing to examine abalone vision, digestive physiology, and the genetic components of resistance to withering syndrome. Results for these studies are not currently available, but may be incorporated into the next review.

2.3.1.2 Abundance, population trends, demographic features, or demographic trends

Long-Term Population Monitoring

Long-term monitoring of black abalone populations has been conducted throughout the coast of California and is ongoing. These monitoring efforts are largely coordinated by the Multi-Agency Rocky Intertidal Network (MARINe), a partnership of agencies, universities, and private groups that not only conducts intertidal surveys, but provides this information to the public. Monitoring has been conducted since the mid-1970s and 1980s in some areas and provides valuable information on population trends and the progression of withering syndrome along the coast. Since the ESA listing of black abalone, population monitoring has expanded to include new sites (e.g., Golden Gate National Recreation Area, Point Reyes National Seashore Area, and the Farallon Islands; Eckdahl et al. 2012, Roletto et al. 2015), as well as revisiting areas that have not been surveyed in over 10 years, providing a more comprehensive understanding of the species' status.

Population Trends

Black abalone are believed to be naturally rare at the northern and southern extremes of their range, with the highest abundances historically south of Monterey, particularly at the Channel Islands off southern California. Beginning in the mid-1980s, black abalone populations began to decline dramatically due to the spread of withering syndrome. Overall, the disease caused declines of more than 80% in populations throughout southern California and as far north as Cambria in San Luis Obispo County; in populations south of Point Conception, declines of more than 90% have occurred (Neuman et al. 2010). Less severe declines (approximately 50%) have been documented even further north, into southern Monterey County (Miner 2017, unpublished data).

Most black abalone populations affected by withering syndrome remain at low densities, below the estimated levels needed to support successful reproduction and recruitment (Babcock and Keesing 1999: 0.15 – 0.20 abalone per m^2; Neuman et al. 2010: 0.34 abalone per m^2; Tissot 2007: 0.75 – 1.1 abalone per m^2). Data for 2002-2006 indicate that population densities exceed this threshold value in areas not yet affected by the disease (north of Cambria; densities ranged from 1.1 to 10.5 abalone per m^2), whereas population densities fall below this threshold value, many significantly so, in areas severely affected by the disease (south of Cambria; densities range from 0 to 0.5 abalone per m^2) (Neuman et al. 2010). However, despite these low densities, researchers have observed evidence of recent recruitment and increases in abundance at several locations throughout southern California, including the Palos Verdes Peninsula, Laguna Beach, Santa Cruz Island, San Miguel Island, and San Nicolas Island (Richards and Whitaker 2012, Eckdahl 2015, VanBlaricom 2017, unpublished data).

The disease has also affected populations in Baja California, but little is known about the species’ status in Mexico. According to Searcy-Bernal et al. (2010) black abalone virtually disappeared from mainland Baja California but were still present on Isla Guadalupe and supported fishery harvest in 2004-2008. In more recent years, anecdotal evidence suggests that populations are beginning to recover in mainland areas (pers. comm. with Ricardo Searcy-Bernal, Universidad Autonoma de Baja California (UABC), 16 Aug 2016; pers. comm. with Fabiola Lafarga de la Cruz, Center for Scientific Research and Higher Education of Ensenada (CICESE), 18 Aug 2016). In particular, evidence of recruitment events was observed at mainland sites in 2014 (pers. comm. with Ricardo Searcy-Bernal, UABC, 22 Aug 2016) and 2016 (pers. comm. with Fabiola Lafarga de la Cruz, CICESE, 20 Oct 2016).

Demographic Trends and Effects of Withering Syndrome

Observations of recruitment and increasing numbers despite low densities indicate that factors other than the number of abalone per square meter need to be considered when assessing population viability. Population growth appears to be directly correlated with decreasing distance between individuals (Blaud 2013). Black abalone tend to be found in aggregations; reasons for this can include an increased ability to capture drift algae (for food), a preference for similar habitat qualities, reduced predation risk, or a response to other environmental cues (Richards and Whitaker 2012, Blaud 2013). This tendency to form aggregations increases fertilization success, because individuals are in close proximity to one another, and has likely contributed to the successful reproduction and recruitment observed in populations despite their low densities (Richards and Whitaker 2012, Blaud 2013, Eckdahl 2015, VanBlaricom 2017, unpublished data).

Withering syndrome continues to affect populations, although disease-related mass mortalities have not been observed in the wild since the 1990s (Neuman et al. 2010). The pathogen that causes withering syndrome (*Candidatus* Xenohaliotis californiensis, or *Ca*.Xc) is a bacterium called a Rickettsiales-like organism that has been detected in all coastal marine waters of central (Friedman and Finley 2003) and southern California (Moore et al. 2002) up to south Sonoma County (Bodega Head; pers. comm. with Jim Moore, California Department of Fish and Wildlife (CDFW)/Bodega Marine Lab (BML), 20 Nov 2015), and has also been found at Southeast Farallon Island (pers. comm. with Jim Moore, CDFW/BML, cited in VanBlaricom et al. 2009).

Disease transmission and manifestation is intensified when local sea surface temperatures increase by as little as 2.5 ºC above ambient levels (i.e., to over 17-18°C) and remain elevated over a prolonged period of time (i.e., a few months or more) (Friedman et al. 1997, Raimondi et al. 2002, Harley and Rogers-Bennett 2004, Vilchis et al. 2005). Recent data suggest that fluctuating water temperatures can also increase transmission of *Ca*.Xc in black abalone (Ben-Horin et al. 2013). During the 2015-2016 El Niño event, researchers found more withered black abalone than in the previous 5-10 years, including potentially withered black abalone at sites north of Cambria, near Santa Cruz, but did not report mass mortalities (pers. comm. with Karah Ammann, University of California Santa Cruz (UCSC), 8 Mar 2016). A bacteriophage has been discovered that infects the pathogen, reduces its pathogenicity, and improves the survival of infected abalone (Friedman and Crosson 2012, Crosson et al. 2014, Friedman et al. 2014a, b). Genetically-based disease resistance may also exist and is the subject of ongoing studies at the University of Washington (VanBlaricom et al. 2009, Friedman et al. 2014a).

Disease research has continued to advance our knowledge of withering syndrome and its effects on black abalone and other abalone species along the coast. Development of a quantitative PCR method has allowed detection of the pathogen in water samples and in individual abalone (Crosson et al. 2014, Friedman et al. 2014b). Research is ongoing to evaluate the role of *Ca*.Xc effluent (from abalone facilities) in disease transmission and the role of the bacteriophage in the disease's effects on abalone populations and will likely provide valuable information in the coming years.

2.3.1.3 Genetics, genetic variation, or trends in genetic variation

The mass mortalities caused by withering syndrome may have reduced the species' genetic diversity, although studies have not yet been conducted to evaluate this potential loss of diversity. Genetic diversity has been evaluated at broad spatial scales across the species' range in California using allozymes, mitochondrial DNA sequencing, and microsatellite genotyping (Hamm and Burton 2000, Chambers et al. 2006, Gruenthal and Burton 2008, Beldade et al. 2012). Larval dispersal appears to be limited, with populations composed predominately of locally spawned and recruited individuals, resulting in genetic differentiation between island populations and mainland populations (Hamm and Burton 2000, Chambers et al. 2006, Gruenthal and Burton 2008). Beldade et al. (2012) developed and applied a set of eight microsatellite markers to test for polymorphism in two black abalone populations, one affected by the disease and one not affected by the disease. They found high genetic diversity in both populations, likely due to historically-large population sizes at both locations, but no significant differences in genetic diversity between populations (Beldade et al. 2010). The markers can be used to evaluate changes in genetic diversity in the future. New methods, such as single nucleotide polymorphisms (SNPs), may also be applied to the species to examine genetic connectivity and structure (Gruenthal et al. 2014).

2.3.1.4 Taxonomic classification or changes in nomenclature

There have been no changes in nomenclature or taxonomic classification for black abalone. VanBlaricom et al. (2009) describes a previously identified subspecies *Haliotis cracherodii californiensis* found at Guadalupe Island off Baja California, but states that the most recent assessment considered all previously described subspecies to be varieties representing ecomorphs or examples of shell deformations that are synonymous with a single species, *H. cracherodii*. Since the last review, there has been no additional information that would change this classification.

2.3.1.5 Spatial distribution, trends in spatial distribution, or historic range

Historically, black abalone were documented to occur from Crescent City (Del Norte County, California) to southern Baja California (Geiger 2004), but the current range is estimated to extend from Point Arena, California, south to Bahia Tortugas, Mexico, including offshore islands (Figure 1; 74 FR 1937, 14 January 2009). Black abalone occupy rocky intertidal habitats from the upper intertidal to 6 meters depth, but are most commonly observed in the middle and lower intertidal, in habitats with complex surfaces and deep crevices that provide shelter for juvenile recruitment and adult survival. At sites along the central California coast, black abalone have been found in areas with more crevice habitat, possibly as a result of increased sea otter populations (Raimondi et al. 2015). Other factors may also contribute to the higher abundances of black abalone observed in crevices or habitats with more refuge. For example, crevice habitat may provide thermal refugia to reduce the risk of thermal stress in the intertidal (Duncan 2017).

Long-term black abalone monitoring continues throughout the California coast and shows that black abalone continue to occupy sites throughout their range, although they persist at low densities or were locally extirpated at sites along the southern California and Baja California mainland due to the disease. However, as mentioned in Section 2.3.1.2, black abalone focused surveys have been conducted in recent years and have found animals in areas along the southern California and Baja California mainland where they had not been observed since the 1990s (Eckdahl 2015, pers. comm. with Ricardo Searcy-Bernal, UABC, 16 Aug 2016; pers. comm. with Fabiola Lafarga de la Cruz, CICESE, 18 Aug 2016). At Santa Catalina Island, two survey efforts were conducted, but have not found any live black abalone (Neuman et al. 2011, Obaza et al. 2016). Monitoring efforts need to be expanded to sufficiently evaluate the presence of black abalone throughout their range.

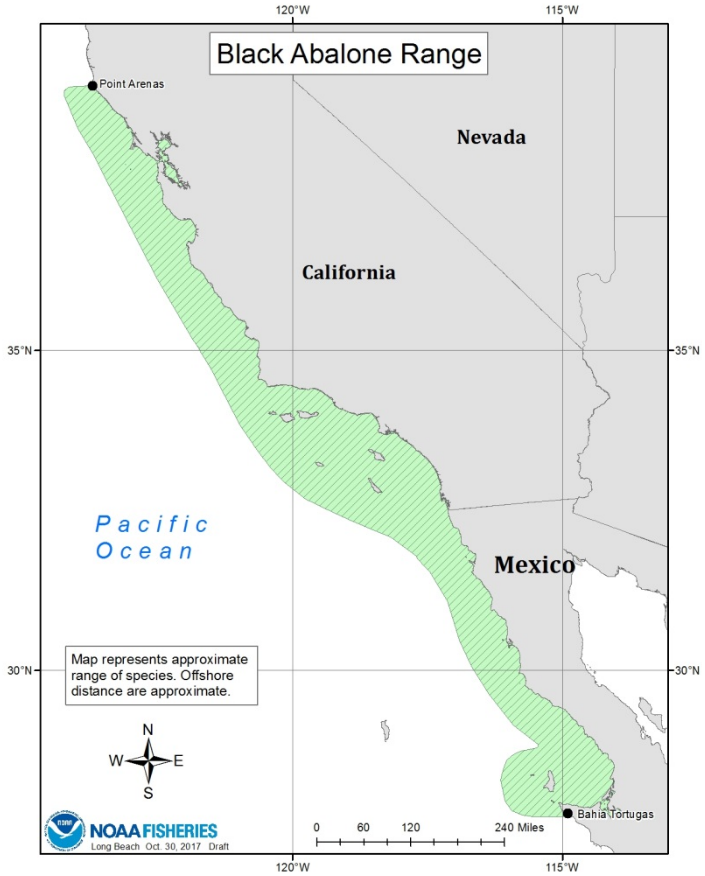

Figure 1. Current geographic range of black abalone.

2.3.1.6 Habitat or ecosystem conditions

NMFS designated critical habitat for black abalone on 27 October 2011 (76 FR 66806; Figure 2). The designation encompasses rocky intertidal and subtidal habitat within five segments of the

California coast between the Del Mar Landing Ecological Reserve and the Palos Verdes Peninsula, as well as on the Farallon Islands, Año Nuevo Island, San Miguel Island, Santa Rosa Island, Santa Cruz Island, Anacapa Island, Santa Barbara Island, and Santa Catalina Island. San Nicolas Island and San Clemente Island also contain good quality habitat that supports black abalone populations; however, both islands are owned or controlled by the U.S. Navy and have Integrated Natural Resource Management Plans (INRMPS) in place that have been determined by NMFS to provide protections and benefits to black abalone. Under the ESA, such areas are not eligible for designation as critical habitat. In addition, critical habitat was not designated within segments of the southern California coast where black abalone may have occurred historically, but had not been observed in the period from 2005 to 2010. The critical habitat designation may be revised as the species recovers and more information becomes available.

Physical or biological features include rocky substrate (e.g., rocky benches formed from consolidated rock or large boulders that provide complex crevice habitat); food resources (e.g., macroalgae); juvenile settlement habitat (rocky substrates with crustose coralline algae and crevices or cryptic biogenic structures); suitable water quality (e.g., temperature, salinity, pH) for normal survival, settlement, growth, and behavior; and suitable nearshore circulation patterns to support successful fertilization and larval settlement within appropriate habitat. Critical habitat areas north of Cambria were generally identified as areas of high conservation value, because they support stable populations; contain habitat of good to excellent quality for black abalone; and serve as a refuge from the effects of withering syndrome due to cooler water temperatures. South of Cambria, changes to critical habitat features have occurred following the decline in black abalone. For example, increased growth of encrusting species like sponges, possibly a result of diminished space use by declining black abalone populations, may reduce the surface area for crustose coralline algae to grow, thereby reducing the quality of larval settlement habitat (Miner et al. 2006, VanBlaricom et al. 2009, NMFS 2011). However, in general, these critical habitat areas continue to represent high conservation value to the species, because they contain black abalone habitat of good to excellent quality (NMFS 2011).

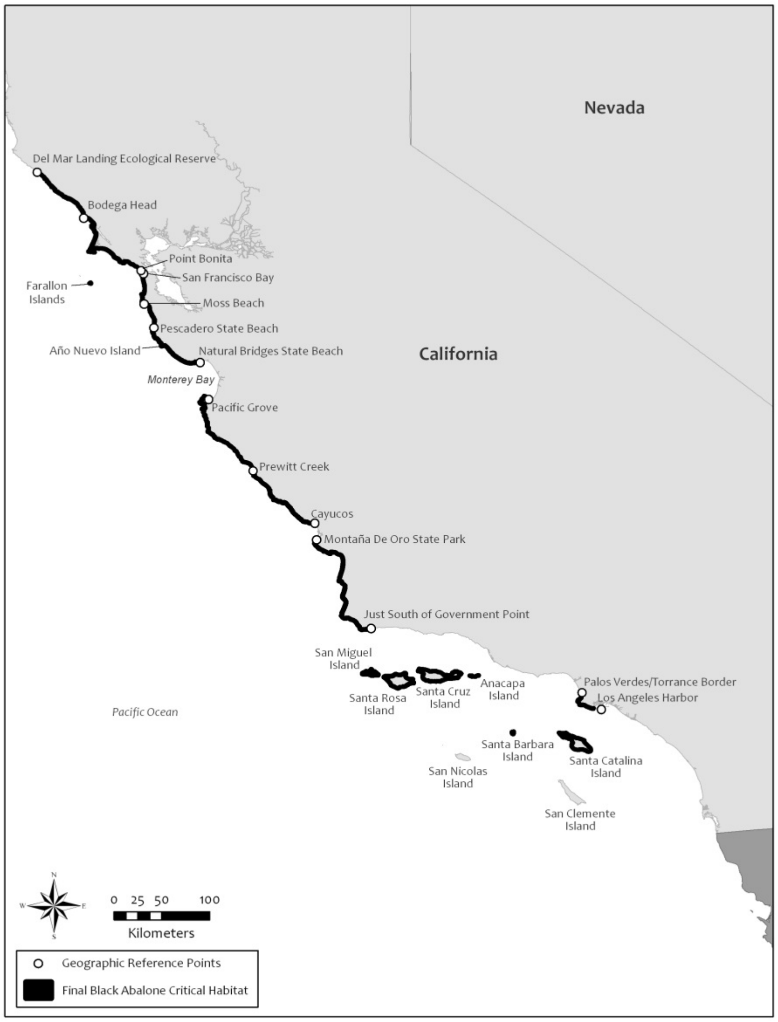

Figure 2. Designated critical habitat for black abalone.

2.3.2 Five-Factor Analysis (threats, conservation measures, regulatory mechanisms)

This section summarizes the best available information, including new information since the 2009 Status Review, regarding the ESA's five listing factors, which must be considered when determining whether a species is endangered or threatened. The five factors must also be evaluated when reclassifying or delisting any listed species:

(a) The present or threatened destruction, modification or curtailment of its habitat or range;
(b) Overutilization;
(c) Disease or predation;
(d) Inadequacy of existing regulatory mechanisms; and
(e) Other natural and manmade factors.

This analysis discusses the five listing factors and any relevant new information regarding the magnitude and imminence of previously identified threats to the species or emerging threats to the species. Overall, the threats of greatest concern include the following existing and emerging threats:

- Low densities and potentially reduced genetic diversity due to historical overfishing and mass mortalities caused by withering syndrome
- Disease impacts on wild populations, particularly the continued spread of withering syndrome, but also the spread of other pathogens or invasive species known to affect abalone, via aquaculture and research, food, and hobby markets
- The effects of oil spills, landslides, and response activities on black abalone and their habitat
- Continued illegal take of black abalone despite prohibitions on harvest
- Elevated water temperatures associated with El Niño/Southern Oscillation (ENSO) events and other ocean-atmosphere processes reflected by indices such as the Pacific Decadal Oscillation (PDO)
- Ocean acidification, associated with long-term climate change

This analysis also considers regulatory mechanisms and conservation measures that have been established and implemented for black abalone.

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range

Two threats of particular concern regarding the species' habitat or range are: contaminant spills and associated response activities, and increased water temperatures.

Regarding contaminant spills and spill response activities, we primarily focus on oil spills but recognize that spills of other materials could also affect abalone habitat. Sources of oil spills could include offshore drilling platforms, pipelines, or various types of vessels. Thus, oil spills could occur anywhere within the species' range. Habitat impacts include destruction of other intertidal organisms that black abalone rely upon for settlement cues (e.g., coralline algae), food (e.g., diatoms, macroalgae), and shelter. The magnitude of impacts may vary widely, depending on the type of material involved in the spill and local habitat features and conditions. For example, black abalone intertidal habitat is characterized by high wave energy, so some contaminant materials may be washed out naturally by waves, whereas other materials may persist in cracks and crevices, prolonging exposure and effects to the habitat as well as to individual abalone. Also, we cannot predict when, where, and how often spills will occur, although risk may be greater in areas adjacent to offshore oil fields and shore-based pipelines (e.g., Santa Barbara), or large, industrial coastal cities (e.g., Los Angeles) that experience intense vessel traffic. Careful planning and coordination are needed to guide spill response and post-monitoring activities, to minimize and assess damage to abalone and their habitat. For example, response activities involving dispersants or the movement of personnel/equipment through the intertidal could affect black abalone habitat. Damage assessment should include monitoring of impacts to black abalone habitat from both the spill and the response activities. Spills and associated response activities can also directly affect the health and survival of individuals (see Section 2.3.2.5 Other Natural or Manmade Factors).

Increased water temperature can result from: (1) anthropogenic thermal effluent (e.g., thermal discharges from power plant facilities); and (2) long-term and short-term climate change (e.g., global climate change, El Niño-Southern Oscillations (ENSO) events). Increased water temperatures can pose a risk to black abalone by reducing the quantity and quality of food resources (e.g., kelp; Vilchis et al. 2005) as well as inducing disease expression, accelerating transmission of the pathogen, and increasing disease-related mortality (Friedman et al. 1997, Moore et al. 2000, Raimondi et al. 2002, Harley and Rogers-Bennett 2004, Braid et al. 2005, Vilchis et al. 2005, Ben-Horin et al 2013). Compromised immune function as a result of long-term changes in salinity and temperature may also affect the relationship between temperature and withering syndrome (Morash and Alter 2015). Exposure to higher water temperatures resulted in significantly greater mortality caused by withering syndrome and halted growth and reproduction in red abalone (Vilchis et al. 2005). These results suggest that warming ocean temperatures are likely to have negative effects on abalone species that are adapted to cooler water temperatures or, in the case of black abalone, are particularly susceptible to withering syndrome.

During the 2015-2016 El Niño event, researchers observed greater numbers of withered black abalone as compared to prior years with normal ocean temperatures, but fewer than what had been anticipated given the warm water temperatures. Researchers also observed evidence of recruitment in certain areas despite the warmer water (pers. comm. with Karah Ammann, UCSC, 8 Mar 2016; pers. comm. with Black Abalone Recovery Team (BART), 27 July 2016). The presence of the bacteriophage may contribute to reducing the disease's effects on black abalone populations. Individuals that survived the mass mortalities in the 1980s and 1990s may also be more resistant to the disease, but genetically-based resistance has been identified only in laboratory settings (Crosson et al. 2014, Friedman et al. 2014a). Further study and monitoring are necessary to understand the effects of increased water temperatures on the species.

Most of the other threats to black abalone habitat are of lower concern because they occur infrequently; have a narrow geographic scope; or have uncertain, indirect, and/or low potential impacts on black abalone. Examples of these threats include nearshore military operations, vessel groundings, coastal development (e.g., shore stabilization projects), cable repairs, recreational access, and benthic community shifts (e.g., due to the absence or reduced presence of abalone).

Some of the threats including sedimentation (e.g., landslides, storm-generated burial), fluctuations in food quality or quantity (naturally or due to factors such as kelp harvest, ocean warming, or non-native species), and sea level rise may have broader impacts. However, the effects on black abalone are uncertain and/or low. For example, sea level rise likely will occur over a long period of time, which may allow for abalone to adapt to changes in their habitat. Abalone species are also likely able to alter their foraging strategies to account for changes in their food supply (Kiyomoto et al. 2013). We note that in May 2017, a large landslide at Mud Creek on the Big Sur coast buried approximately 1,700 ft (~518 m) of coastline, likely including black abalone critical habitat. Continued erosion of the landslide has resulted in increased sedimentation and burial of black abalone habitat adjacent to the landslide (Raimondi et al. 2017); the spatial and temporal extent of sedimentation effects is being monitored.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes

Commercial and recreational harvest of black abalone contributed to their decline. The black abalone fishery in California closed in 1993, but the effects of both the fishery and disease (e.g., reduced local abundance and density of black abalone) remain and continue to affect the species' recovery. Illegal harvest of black abalone continues to pose a threat to the species' recovery. CDFW has documented 13 black abalone poaching cases between 2007 and 2012, involving a total of 387 black abalone (Taniguchi 2015, unpublished data). We likely do not have a complete record of black abalone poaching cases for this time period, as cases of poaching are difficult to detect and pose substantial challenges to law enforcement and judicial institutions. Continued high demand for abalone on the black market and illegal personal use provides a strong incentive for poaching. To better understand the level of poaching that is occurring and assess the impacts to black abalone, collection of these data and collaboration with enforcement must continue. Additional actions, such as increased penalties for poaching, may also be needed to deter illegal harvest.

In Baja California, populations of black abalone have been depleted to such low levels that they are likely rarely taken. From 2004 to 2008, the species was only harvested on Isla Guadalupe because they could not be found in harvestable numbers on the Baja California mainland (Searcy-Bernal et al. 2010). Currently, fishery regulations in Mexico prohibit recreational harvest of abalone and any harvest of intertidal abalone (pers. comm. with Miguel del Rio Portilla and Fabiola Lafarga de la Cruz, CICESE, 20 July 2017). Since at least 2012, catch quotas for black abalone, white abalone, and red abalone have not been authorized along the west coast of Baja California, Mexico (Carta Nacional Pesquera 2012). Illegal harvest continues to pose a risk to black abalone populations in Baja California (e.g., "Restaurant owner admits to smuggling forbidden seafood from Mexico" by Cassia Pollock, NBC 7 San Diego, published 29 September 2017), and this risk may increase over time if black abalone abundance begins to increase.

2.3.2.3 Disease or predation

Withering Syndrome

Withering syndrome was identified as the primary threat to black abalone survival and recovery (VanBlaricom et al. 2009) and continues to threaten the species. At the same time, other diseases have been identified that affect abalone species worldwide and pose a threat to black abalone.

Withering syndrome caused mass mortalities and near extirpation of black abalone throughout southern California and continues to spread northward along the California coast (Neuman et al. 2010). Elevated water temperatures -- resulting from anthropogenic sources or long-term and short-term climate change -- allow for northward spread of both the pathogen and disease, and accelerate transmission (Friedman et al. 1997, Moore et al. 2000, Raimondi et al. 2002, Harley and Rogers-Bennett 2004, Braid et al. 2005, Vilchis et al. 2005, Ben-Horin et al 2013). Increased abundance and density of black abalone as populations recover may also increase disease transmission. Discharge of effluent from abalone farms could also facilitate transmission of the pathogen (Lafferty et al. 2013). DNA of *Ca*.Xc has been found in effluent discharged from abalone farms as well as in waters adjacent to abalone populations; however, it is not clear whether the DNA represents live pathogens that can infect animals (Friedman et al. 2014b, Crosson et al. in manuscript). In a recent field study, equal numbers of abalone became infected with *Ca*.Xc when planted near an abalone farm outfall and near wild abalone populations in southern California, suggesting that the presence of infected abalone (farmed or wild) may pose similar infection risks in locations with warm ocean temperatures (Fuller 2017).

Three factors may reduce the impacts of withering syndrome on black abalone. First, researchers have discovered a bacteriophage that infects *Ca*.Xc and reduces its pathogenicity. The phage alters the morphology and therefore some of the functions of the pathogen (Friedman and Crosson 2012), such that abalone with phage-infected bacterial cells have a smaller pathogen load and reduced response to infection, subsequently resulting in less mortality (Friedman et al. 2014a). There is potential for phage-therapy in wild populations but it is unknown how the phage is transmitted. Second, genetic resistance to withering syndrome is consistent with some laboratory experimental data, but has not been confirmed in wild populations (Friedman et al. 2014a). In studies where progeny of black abalone that had and had not been previously exposed to the disease were then infected with the pathogen, the animals that had not been previously exposed had a greater pathogen load and greater mortality rate, though the difference in mortality was not significant (Friedman et al. 2014a). Finally, since 2003, there has been mounting evidence that oxytetracycline (OTC) treatments (e.g., baths, injections, or oral administration) are effective at removing *Ca*.Xc from abalone and can provide protection from reinfection for prolonged periods (up to several months; Friedman et al. 2007, Rosenblum et al. 2008), though this OTC treatment has only been applied to captive animals and not to animals in the wild (Friedman et al. 2003, Garcia-Esquivel et al. 2011, Moore et al. 2015). In the context of potential conservation tools, it should be noted that removal of *Ca*.Xc by OTC treatments does not make the treated abalone immune to subsequent infection by the pathogen. Further research on withering syndrome and continued monitoring of its effects on wild populations will be necessary for black abalone recovery.

Other Abalone Diseases

Other abalone diseases have emerged over the past several decades, including Herpes (agent of ganglioneuritis), sabellidosis, infection with the protozoan parasite *Perkinsus olseni*, and vibriosis. To date, these diseases have not been observed in wild black abalone populations along California and Baja California. However, black abalone may be susceptible to these diseases and multiple pathways exist for these diseases to be introduced, such as through the movement of infected organisms for aquaculture, research, and hobby/food markets (see Section 2.3.2.4 Inadequacy of existing regulatory mechanisms). Research on the effects and severity of these diseases to black abalone is needed, as well as consideration of preventative measures to minimize the risk of introducing them to the species.

Predation

Predation is not currently considered a primary threat to black abalone. Many animals such as octopuses, lobsters, fishes, other gastropods, birds, and sea stars prey on abalone (Ault 1985, Estes and VanBlaricom 1985, Shepherd and Breen 1992). Some of these species may become a greater threat than others in the future depending on how each species is affected by climate change. For example, warmer water temperatures cause an increase in the feeding rate for the sea star *Pisaster ochraceus* and potentially other intertidal predators (Sanford 2002). However, the mass die-offs of sea stars beginning in 2013 due to sea star wasting disease have reduced sea star predation pressure, at least temporarily. Predation is an important factor for potential enhancement efforts such as aggregation, translocation, and outplanting. Enhancement efforts may need to focus on larger individuals that can better withstand predation pressure or, if feasible, may be aided by temporary relocation of predators from an area targeted for abalone restoration.

Sea otter presence is also a factor in black abalone recovery efforts. Along the central California coast in areas not yet affected by withering syndrome, as well as at San Nicolas Island, a positive correlation has been observed between sea otter and black abalone populations (Raimondi et al. 2015; VanBlaricom 2017, unpublished data). Proposed theories to explain these observations include a positive relationship between: 1) sea otter presence and complex rocky habitat with refugia (e.g., crevices) effective in limiting otter predation on abalone; 2) both sea otters and black abalone with large kelp forests, given that kelp is an important habitat feature for the two species; and 3) sea otters and kelp abundance, because sea otters prey on and control sea urchin populations that consume kelp (Raimondi et al. 2015). Although sea otter predation is known to reduce the abundance of red abalone (Fanshawe et al. 2003), the relationship between sea otters and black abalone is not completely understood and may change as populations of sea otters and black abalone increase. Factors to consider are recovery rates, population abundance, habitat type, and predation rate. Recovery efforts for black abalone should be closely coordinated with recovery efforts for sea otters. NMFS has established an agreement with the United States Fish and Wildlife Service (USFWS) to ensure the exchange of information and coordination of recovery actions for the two species (NMFS 2013 Memorandum of Understanding).

2.3.2.4 Inadequacy of existing regulatory mechanisms

Two threats of particular concern that are associated with inadequate regulatory mechanisms are illegal harvest and the potential introduction of pathogens and invasive species. Despite prohibitions on black abalone harvest in California since 1993, illegal harvest of black abalone continues to occur. From 1993 – 2012, most documented poaching cases occurred in San Luis Obispo and Monterey Counties (Taniguchi 2015, unpublished data). Thus, poaching presents a potentially serious risk to populations unaffected by disease and located in areas with public access along the central coast of California. Poaching could also increase as black abalone populations recover, counteracting the benefits of natural recovery or enhancement efforts. Regulatory measures have been established, but continued efforts to enforce the regulations, monitor and document poaching cases, and deter poaching (e.g., via increased penalties, outreach, and education) are needed. CDFW has prioritized enforcement against abalone poaching. Current penalties for poaching include a fine between $15,000 and $40,000, possible imprisonment for up to one year, and forfeiture of any licenses, equipment, and vehicles used in the poaching incident. CDFW has also developed a database to document poaching cases along the coast and evaluate the magnitude of the threat to black abalone populations (Taniguchi 2015, unpublished data). Revisions and additions to Southern California Marine Protected Areas under the CDFW Marine Life Protection Act in 2012 likely afford additional protections for black abalone through increased enforcement.

The introduction of pathogens or invasive species could pose a high risk to black abalone, given the devastating effects these diseases have had on abalone in other parts of the world. Strict regulations are needed to ensure adequate monitoring whenever animals are moved (e.g., imports, transporting between facilities) for aquaculture, research, and/or food/hobby markets, to protect wild populations from pathogens and invasive species. In California, state regulations and policies are in place that require regular abalone health monitoring at aquaculture facilities, control the transfer of abalone between facilities, and restrict out-planting of abalone from facilities that have not met certification standards. Some improvements to existing regulations are needed to further protect the species. For example, although a permit is required to import non-native abalone species for terminal markets or the aquarium trade into California, a permit is not needed to import native abalone species, even if the source of those abalone is outside of the U.S. This presents a potential risk because some abalone species native to California are cultured in several locations outside of California, and because live abalone imported into the State could carry pathogens to which black abalone are susceptible.

2.3.2.5 Other natural or manmade factors affecting its continued existence

Spills and Spill Response Activities

Section 2.3.2.1 discussed the potential effects of contaminant spills and spill response activities on the quality and quantity of black abalone habitat. Contaminant spills and spill response activities may also have direct effects on individual black abalone. Oil spills appear to be of greatest concern with regard to black abalone conservation. We have very little information on how different types of oil affect black abalone, although there is evidence that black abalone were killed in past oil spills in California and Baja California (e.g., Torch oil spill, Tampico Maru spill). The impact of future spills on the species' status and recovery depends on several factors, including the type and amount of material spilled, the location, local environmental conditions, and the status of impacted populations. We cannot predict when and where spills will occur, but we can minimize the effects to black abalone by providing guidance on appropriate spill response activities, as well as providing guidance on post-monitoring efforts to learn from each spill and inform future response efforts. To develop this guidance, we need information on abalone habitat and presence throughout the coast; the effects of different types of oil and dispersants on abalone habitat and different life stages of abalone (e.g., survival, physiology, reproduction); decision-making tools for determining whether and when to collect abalone and bring them into captivity; methods to collect and hold animals from the wild; and methods to clean oiled abalone. We can also learn as much as possible from recent oil spills that affected black abalone and their habitat, including the Refugio oil spill in Santa Barbara County in 2015.

Ocean Acidification

Ocean acidification is an emerging threat that is particularly concerning for larval stages, possibly reducing larval survival and shell growth, promoting shell abnormalities, and reducing the quality of larval settlement habitat by affecting the growth of crustose coralline algae (Crim et al. 2011, Morash and Alter 2015). However, we have limited understanding of the potential effects of declining ocean pH on black abalone, due to variability in local conditions throughout the coast, natural variation in ocean pH, species adaptability, and uncertainty in projections of future pH levels. Species normally exposed to varying carbon dioxide levels may be acclimatized to ocean acidification, with species-specific variation in the responses. North Pacific waters, including the California Current Ecosystem, experience fluctuations in pH, including relatively low seawater pH values due to a variety of natural oceanographic processes (Feely et al. 2004, Feely et al. 2008, Feely et al. 2009, Hauri et al. 2009). Exposure to naturally fluctuating and low pH may make black abalone better able to adapt to the effects of ocean acidification if, for example, ocean acidification increases the duration or areal extent of acidified water. However, we do not know how black abalone may respond to further decreases in pH levels or to other effects of ocean acidification. Additional studies are needed to evaluate the potential exposure and response of black abalone and their habitat to ocean acidification.

Sedimentation

Burial and subsequent re-exposure of black abalone habitat occurred in autumn 2015 on San Nicolas Island within a span of several months, due to an unusual oceanographic event that moved large amounts of sediment around the island, including an entire sand spit that disappeared and then re-formed (pers. comm. with Glenn VanBlaricom, USGS/UW, on 23 Mar 2016, and with John Ugoretz, Navy/CDFW, on 25 May 2016). The event resulted in apparently precipitous mortalities of black abalone and many other intertidal plant and animal species. How that system recovers from this impact may provide insight to other areas of coastal California. As mentioned in Section 2.3.2.1 (Present or threatened destruction, modification, or curtailment of its habitat or range), a large landslide occurred along the Big Sur coast in May 2017, burying a segment of the coast in sediment. Sedimentation from continued erosion of the landslide has buried black abalone and black abalone habitat adjacent to the landslide (Raimondi et al. 2017), calling for emergency actions to minimize and monitor impacts to black abalone.

Environmental Pollutants and Toxins

We know of three cases where environmental pollutants and toxins directly affected the health and survival of black abalone. First, on the Palos Verdes Peninsula in the late 1950s and early 1960s, black abalone growth and reproduction declined due to poor water quality, resulting from the combined effects of a significant El Niño event and large-volume domestic sewage discharge by Los Angeles County (Leighton 1959, Cox 1962, Miller and Lawrenz-Miller 1993). Second, Martin et al. (1977) documented black abalone mortalities in Diablo Cove in the 1970s, resulting from the local power plant's release of effluent containing toxic levels of copper. Third, the grounding of the S/V Blue Mist near Pt. Piedras Blancas in northern San Luis Obispo County, and subsequent release of ballast shrapnel, led to the loss of at least one abalone, and possibly more (Lonhart et al. 2015). In most cases, the effects of the factors noted here were limited in temporal and/or geographic scope.

Larval Entrainment

Larval entrainment likely poses a low risk to recovery, given the low number of intakes (e.g., at power plants, desalination plants) along the coast and the small area affected (likely limited to the area directly around the intake). Intakes and outfalls can lead to larval impingement, entrainment, and shear stress, all of which could physically kill larvae. Therefore, future development or expansion of power plants or other major coastal-dependent industrial facilities should consider black abalone habitat when determining where to place intakes and outfalls to limit potential impacts.

2.4 Synthesis

The black abalone was listed as endangered in 2009 (74 FR 1937, 14 January 2009). Even prior to the listing, researchers and managers throughout California have been collaborating to monitor the status of black abalone populations in the wild. Long-term monitoring has been conducted throughout the coast, in some areas since the mid-1970s, providing valuable data to assess population trends over time. Based on these data, researchers were able to detect the severe declines in black abalone populations throughout southern California in the 1980s and 1990s, caused by the disease called withering syndrome. The disease contributed significantly to the species' extinction risk and was identified as the primary threat to the species in the 2009 Status Review (VanBlaricom et al. 2009).

Since the listing, NMFS has continued to work with partners throughout the coast on black abalone conservation and research. Partners include other Federal, State, local, and international agencies; universities and other research institutions; public aquaria; and non-profit organizations. Long-term monitoring continues throughout the California coast and has expanded to encompass additional sites, including potential sites in Baja California. Disease-impacted populations in southern California remain at low densities; in most areas, densities are below the estimated minimum adult density needed to support successful reproduction and recruitment. However, recent recruitment and increases in abundance have been observed at several locations throughout southern California and Baja California. These observations indicate that factors other than the density of abalone need to be considered when assessing population viability. For example, the tendency of black abalone to aggregate likely increases fertilization success in wild populations. Long-term monitoring and experimental studies are ongoing to improve our understanding of population dynamics and evaluate different tools to enhance population restoration (i.e., habitat restoration, local aggregation, translocation, captive breeding and outplanting), where needed.

Withering syndrome remains a primary threat to the species. The disease has progressed northward along the coast with sea-surface warming events, with disease-related declines observed in populations as far north as the Monterey/San Luis Obispo County line (Miner 2017, unpublished data). Healthy populations remain to the north, but have been exposed to the pathogen and therefore are at risk of withering syndrome. However, two factors may ameliorate the impacts of the disease on black abalone in the wild: the presence of a bacteriophage that infects the pathogen, reducing its pathogenicity and increasing the survival rate of infected abalone (Friedman and Crosson 2012, Crosson et al. 2014, Friedman et al. 2014a, b); and the potential for genetically-based disease resistance (VanBlaricom et al. 2009, Friedman et al. 2014a). Both are the subject of ongoing studies. In addition, studies on captive populations indicate that use of antibiotic (oxytetracycline) treatment can effectively remove the pathogen from abalone, which will be important as population restoration tools such as captive propagation continue to develop.

Other threats of particular concern include other abalone diseases, poaching, contaminant spills and their response activities, and potential impacts from ocean acidification and elevated water temperatures. Research on withering syndrome has advanced significantly over the past few years, but additional studies are needed to evaluate the susceptibility of black abalone to known and emerging abalone diseases worldwide. Regulations are in place to minimize the introduction and spread of these diseases to wild black abalone populations; however, enforcement and monitoring are needed. Black abalone harvest prohibitions have been established throughout the species' range, but further effort is needed to assess the level of poaching and its impacts on black abalone. Contaminant spills and their associated response activities pose a threat to black abalone throughout the coast. Plans are in development to guide response activities in the event of a spill, to minimize and monitor impacts to black abalone and their habitat. Ocean acidification is an emerging threat to black abalone and many calcifying organisms, and further studies are needed to evaluate the potential effects on the species' status and recovery. Elevated water temperatures can accelerate the transmission of withering syndrome and disease-related mortality; however, further study and monitoring are needed, given the potential for the bacteriophage and genetically-based disease resistance to improve survival despite increased water temperatures.

Overall, ongoing long-term monitoring and research continue to provide valuable information to inform our understanding of the species' status and threats throughout the coast. Black abalone populations in southern California that have been severely impacted by withering syndrome remain at low densities, with signs of recruitment and increasing numbers at a few localized sites. Healthy populations in central California that have not yet been affected by the disease remain at risk to withering syndrome, although the bacteriophage and genetically-based resistance could reduce the severity of the impacts. Other threats contribute to the species' high extinction risk, including other abalone diseases, poaching, contaminant spills and their response activities, and ocean acidification. Considering the status and continuing threats, black abalone remain in danger of extinction. Therefore, the recommended classification for black abalone is to remain the same: Endangered.

3.0 RESULTS

3.1. Recommended Classification

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
____ *Extinction*
____ *Recovery*
____ *Original data for classification in error*
_X_ No change is needed

3.2. New Recovery Priority Number

Brief Rationale: No change to the Recovery Priority Number is recommended at this time for black abalone. A Recovery Priority Number of 5 remains appropriate for black abalone because the species has a moderate extinction risk and a high potential for recovery, based on the 1990 Recovery Priority Guidelines (55 FR 24296, 15 June 1990). The status of black abalone remains largely the same as it was at the time of the listing, with a few improvements, such as reduced disease impacts (due to the bacteriophage and potential genetically-based disease resistance) and signs of recruitment and increasing numbers at a few southern California sites. Recovery will involve efforts to enhance the viability and the resiliency of black abalone populations and to monitor and manage potential disease risks.

4.0. RECOMMENDATIONS FOR FUTURE ACTIONS

The Recovery Plan for black abalone is expected to be available before the next five-year status review update. Finalizing the Recovery Plan and implementing priority recovery actions are primary future action recommendations. Other actions that would improve the status of and available information about black abalone include the following:

1. *Continue and/or expand long-term monitoring programs to evaluate population trends over time throughout the species' range.* Monitoring should include density, recruitment patterns, size structure, spatial structure (e.g., nearest neighbor), growth rates, sex ratios, health observations, and habitat characteristics. Establishment of regular monitoring sites in Baja California and exploration of subtidal monitoring is needed. NMFS should continue to collaborate with partners throughout the coast to maintain, expand, and/or refine monitoring efforts and coordinate management, analysis, and sharing of the data.

2. *Evaluate genetic structure and diversity of wild black abalone populations across local and broad spatial scales.* Understanding the genetic structure and diversity of black abalone will inform our understanding of population dynamics and implementation of population restoration actions, such as translocation, captive breeding, and outplanting. We need to inventory existing genetic samples and analysis results, as well develop and implement genetic sampling to assess population structure.

3. *Evaluate population restoration methods to enhance populations*. Studies are needed to evaluate the value and efficacy of population restoration methods such as habitat restoration, local aggregation, translocation, and captive propagation and outplanting. Pilot habitat restoration studies are proposed for sites in California (NMFS 2016b). Limited studies on local aggregation and translocation have been conducted (Ruediger 1999); key questions include methods to minimize the risk of injury/mortality when moving animals, and what spatial scale and number of animals constitutes an effective aggregation for population enhancement. Research is ongoing to develop reliable captive breeding techniques for black abalone (NMFS 2016a), which have proven difficult to spawn in captivity. The ability to captively breed black abalone would provide another tool for population restoration and another source of animals for use in laboratory studies.

4. *Improve tracking of poaching cases and violations.* CDFW has an existing database to track poaching cases in California; however, additional information is needed, such as identification of the species taken, the number of abalone taken, and the condition/status and disposition of the abalone. Guidance is needed on the disposition of dead and live black abalone confiscated during poaching cases. For example, live animals may be returned to the wild or brought into a captive facility for use in research. Coordinated efforts to enforce regulations should continue and additional actions to further deter poaching (e.g., increased penalties, outreach, and education) should be considered.

5. *Continue, refine, and expand research on withering syndrome and other abalone diseases*. Additional studies on withering syndrome are needed to inform our understanding and how to advance the species' recovery in the presence of this disease. Important research topics include: transmission dynamics, factors affecting susceptibility to infection and onset of disease, phage distribution and dynamics, genetic disease resistance, and effects of infection on fitness. Studies are also needed to evaluate the species' susceptibility to other abalone diseases, including diagnosing and understanding host-parasite relationships. In addition to disease research, existing regulations for live trade of abalone and other marine species should be reviewed and revised as needed to minimize the risk of transmitting pathogens.

6. *Develop interim plan for pre-emptive or non-preemptive removal of black abalone from the wild in response to events such as oil spills and vessel groundings.* A plan is needed to guide consideration of whether to remove animals from the wild and bring them into captivity in the event of an emergency, such as a catastrophic oil spill. This plan should provide decision-making tools and guidance; protocols for abalone care, cleaning, and holding over the short and long-term; a list of potential captive holding facilities; and guidance for returning animals to the wild.

7. *Evaluate pH tolerance and the effects of decreasing pH on various life stages of black abalone.* Studies are needed to evaluate the effects of decreasing pH on the development, survival, growth, and condition of different life stages of black abalone. Early life stages of abalone may be most susceptible to reduced pH levels. Results of these studies would inform our understanding of the threat of ocean acidification to black abalone and the development of measures to address this threat.

8. *Maintain and enhance coordination with Mexico on abalone conservation*. Communication and collaboration among abalone researchers in the U.S. and Mexico have increased in recent years. Opportunities to meet and exchange information on a regular basis should be sought or developed, for example, through annual or biennial workshops. Further collaborations should also be pursued on topics of shared interest, such as genetic, disease, and captive breeding research, and long-term monitoring.

9. *Develop key, unified messaging in collaboration with outreach and education partners*. Identification of key, unified messaging will be important to ensure a consistent message is relayed by the many partners involved in black abalone conservation. Outreach and education will involve development of signage and educational materials for use at facilities and in social media, as well as incorporation of key messaging into existing programs (e.g., K-12 school programs, docent training programs, citizen science groups working in the rocky intertidal).

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NATIONAL MARINE FISHERIES SERVICE
5-YEAR REVIEW
Black Abalone (*Haliotis cracherodii*)

Current Classification: Endangered

Recommendation resulting from the 5-Year Review

____ Downlist to Threatened
___ _ Uplist to Endangered
__ _ Delist
_X_ No change is needed

Review Conducted By: NMFS West Coast Region, Protected Resources Division

REGIONAL OFFICE APPROVAL:

Lead Regional Administrator, NMFS

Approve: ______________________ Date: 6 June, 2018

HEADQUARTERS APPROVAL:

Assistant Administrator, NMFS

✓ Concur _____ Do Not Concur

Signature______________________ Date: 7-10-18