Abalone

History of the Fishery

Archaeological evidence indicates that California Indians fished abalones extensively from coastal areas and the Channel Islands prior to European and Asian settlement of California. During the 1850s, Chinese Americans started a fishery in California that targeted intertidal green (*Haliotis fulgens*) and black (*H. cracherodii*) abalones, with peak landings of 4.1 million pounds of meat and shell in 1879. The Chinese worked shallow waters with skiffs, gaffing abalones dislodged by a long pole with a wedge on the end. This fishery was eliminated in 1900 by closure of shallow waters to commercial harvest. Japanese divers followed the Chinese by exploiting virgin stocks of subtidal abalones, first as free divers from surface floats and later, more successfully, as hard-hat divers. California Department of Fish and Game statistics showed an increase in landings from 1916 to a peak in 1935 of 3,900,000 pounds followed by a decline to 164,000 pounds in 1942 as fishermen of Japanese heritage were moved to relocation camps during World War II.

The red abalone (*H. rufescens*) was the only species reported in the commercial landing figures from 1916 to 1943. They were recorded as unidentified abalone. By 1960, the center of the fishery had moved from Monterey to the Morro Bay area, where the regions from Cape San Martin to Cayucos in the north and Point Buchon to Pecho Rock in the south were fished. Declining stocks of red abalones, caused largely by the combined effects of fishing and a growing population of sea otters, forced a shift southward in the late 1960s. Landings increased in the San Francisco area, supplying 34 percent of the 1988 red abalone landings. Evidence, including successfully prosecuted court cases, indicates that many of these abalones were poached from noncommercial areas in northern California. By 1990, landings of red abalones declined to 17 percent of the 1931 to 1967 average of 2,135,000 pounds.

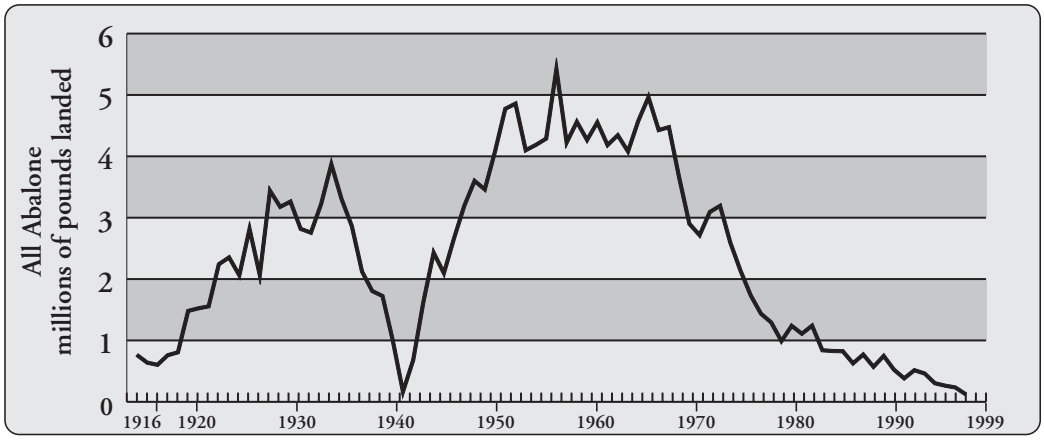
Commercial harvest of abalones was prohibited in southern California from 1913 through 1943, then reopened to increase wartime food production. The fishery has undergone successive development and decline as less desirable species were exploited. The abalone fishery underwent spatial and interspecific serial depletion following World War II. The fishery was managed as a single entity, and it was difficult to address the collapse of individual species in the face of stable landings. The fishery alternated from red to pink (*H. corrugata*) to green, white (*H. sorensensi*), and finally to black abalones, but the new target species could not provide the continuous demand. The combined-species landings reached a record 5,420,000 pounds in 1957. Pink abalone landings reached a maximum 3,388,000 pounds in 1952 and in 1990 were one percent of the 2,178,000 pounds averaged from 1950 to 1970. Green abalones peaked in 1971 at 1,090,000 pounds, declined rapidly to six percent of their 1968 to 1972 average catch of 488,000 pounds. White abalone was the shortest lived of the abalone fishery, beginning about 1968 peaking in 1972 with landings of 144,000 pounds, and quickly declining thereafter. Black abalones peaked in 1973 at 1,913,000 pounds, declining in 1990 to 13 percent of their 1972 to 1984 average catch of 687,000 pounds. Because the fishery was managed as a single entity, the total landings stabilized with the inclusion of the pink, green, white, and black landings, but each of these species quickly collapsed. Red abalone again became the dominant species with most of the landings originating from the southern part of central California, and the Channel Islands.

Complicating the issues was the effect of sea otter preempting the central California fishing areas. Red abalone, stocks were fully utilized around the historic center of the range, Monterey, and the fishery expanded southward. The expansion of the sea otter, also moving south, eventually removed much of the central California coast as a source of legal abalones.

Increased efficiency and effectiveness of the fishery, *i.e.,* faster boats and better diving technology, were factors which caused a continual expansion of the fishing grounds. None of these factors was adequately addressed, and necessary reductions in the fishing power in the fishery to protect the abalone resource never occurred.

Status of Biological Knowledge

In addition to the five species which have been commercially fished, flat (*H. walallensis*), threaded (*H. assimilis*) and pinto (*H. kamtschatkana*) abalones are also found in California; all have limited distributions and none is common. The threaded (*H. assimilis*) was once thought to be a separate species, but it has been included under the pinto as a southern sub-species. Depth and geographical distributions of all California haliotids are best described by seawater temperature. Black abalones are found from Oregon to southern Baja California and are largely intertidal, extending to a depth of about 20 feet in southern California. Red abalones, which also extend from Oregon into Baja California, are intertidal and shallow subtidal in northern and central California but are exclusively subtidal in southern California, where they are restricted to cooler upwelling locations along the mainland and the northwestern Channel Islands. Pink, green, white and threaded abalones are characteristic of the warmer waters south of Point Conception extending into Baja California and the southeastern Channel Islands. These species further sort out by temperature in their depth distributions: greens



Commercial Landings 1916-1999, All Abalone
Prior to 1949, commercial abalone landings consisted primarily of red abalone. Data Source: DFG Catch Bulletins and commercial landing receipts.

are centered at shallower depths than pinks, which are shallower than white abalones. Flat and pinto abalones are generally found in the cooler waters north of Point Conception.

California abalones feed primarily on algae, mostly the large brown kelps that form stands along the coast and islands. They feed on bacterial and diatom films when small, later switching to grazing on living plants and capturing algal drift, fragments of macrophytes moved by currents and surge. Most abalones feed preferentially on kelps but minor variations in preference appear to reflect the habitat where each is found. Specialization on drift algae puts abalones in competition with three species of urchins. Sea urchin grazing has been reported to limit kelp and abalone distributions in many regions of the state.

Seawater temperature also strongly influences abalone growth, and reproduction. Elevated seawater temperatures are low in nutrients and kelps, the food of abalone, do not tolerate these periods well. El Niño events bring warm seawater temperatures northward along the coast. This can have severe short and long-term effects on abalone populations through reduced food availability and the direct affects of warm water on the abalone. In red abalone, El Niño conditions have been observed to slow growth, and decrease settlement and recruitment. If sufficient stocks survive through the warm water period, reproduction will resume with the return of normal conditions, but several year classes may be absent. This will eventually be reflected in the future availability of fishable stocks.

Abalones are synchronous broadcast spawners, the males and females releasing their sperm and eggs directly to the sea. The duration and period of spawning varies with species. The fertilized egg sinks to the bottom, hatches and spends several days to a week in the plankton, depending upon temperature and species. Various oceanographic mechanisms are thought to keep the larvae in the vicinity of the adults. Nevertheless, settlement to the benthic existence appears to be hit or miss. To compensate, abalones produce millions of eggs. Additionally, broadcast spawners must be sufficiently close together to improve the chances of fertilization, which decrease with distance between spawners because of dilution. Distances greater that three or four feet may not support sufficient fertilization. While abalones can move and aggregate for spawning, often low numbers and physical barriers can prevent aggregation.

Recent research has shown that abalones may not successfully reproduce and recruit annually, likely because of all the reasons above. As abalones are removed during fishing, their numbers often will decrease to the point that few adults are sufficiently close for successful fertilization. In one Australian abalone, it has been shown that when stocks of abalone are reduced to about 40 percent of the virgin biomass, reproduction failure occurs. Most of the California abalones are well below that 40 percent mark.

Abalones, especially juveniles, are preyed upon by a wide variety of animals including crabs, lobsters, gastropods, octopuses, sea stars and fishes; larger abalones achieve a partial refuge in size from most of these. However, two predators, sea otters and humans, including the effects of human activity in and near the sea, are the keystone species that control the condition of the abalone resource.

Red abalone

Red abalone is the largest abalone in the world with a record maximum shell length of 12.3 inches. The shell color is brick red when red algae are part of the diet. A prominent muscle scar is visible on the inside of the shell. Typically three to four respiratory pores are open; these are slightly raised, tubular, and oval. The epipodium is smooth and black.

This abalone is associated with rocky kelp habitat ranging from Oregon into Baja California. In northern and central California they are found from the intertidal to the shallow subtidal depths. In southern California they are exclusively subtidal, restricted to upwelling locations along the mainland and the northwestern Channel Islands. Two canopy-forming kelps, bull kelp and giant kelp are primary components of the red abalone habitat and diet. Several other brown algae are reported as important food sources.

There is a clear distinction between juvenile and adult red abalone habitat, an indication that migration occurs as the abalone grow. There are two separate movement phases. The first phase corresponds with settlement as postlarvae on coralline algae and is ascribed to light avoidance (negative photoaxis) and/or downward attraction (positive geotaxis) into small spaces between rocks and under boulders. The second phase starts at 2.0 inches when they switch to feeding on drift kelp, moving from under boulders into crevices. Abalone in exposed crevices, under ledges, or on top of reefs are described as "emergent" with most red abalone emergent by six inches. Red abalone have been reported to move in response to environmental hazards such as sanding-in of reefs. They have been shown to move considerable distances of up to 0.4 miles. In northern California random movement in deeper, less intensely fished populations supports some of the replacement of the intertidal and shallow subtidal fished stocks.

Red abalone generally reach sexual maturity at a shell length of five inches, but may become mature as small as 1.6 inches for females and 3.3 inches for males in the wild. Fecundity ranges from a few thousand eggs at first spawning to up to six million eggs in large adults. Spawning is seasonal in northern and year round in southern California reflecting northern seasonal availability of kelp. A single spawning season from April to July with a peak in May was reported for northern California, based on histological evidence.

The optimal temperature for successful survival to settlement for red abalone larvae is 55° to 68° F. At these temperatures the average duration of the swimming larval phase is four days. Post settlement larval survival varies from year to year. Studies off southern and northern California showed occasional strong year classes followed by long periods of unsuccessful recruitment.

Growth is highly variable and depends on availability of food. Mark and recapture studies demonstrated higher yearly growth rates in southern California compared to northern California where food is seasonally available. An exception occurred during the 1982-1984 El Niño in southern California when kelp abundance declined dramatically. Recent evidence suggests abalone growth rates in the north have increased following the fishing down of their main competitor the red sea urchin.

Abalone are preyed upon by a broad range of predators including sea stars, octopus, crabs and lobster, and fishes, particularly sheephead, cabezon, and bat rays, all of which may be found in red abalone habitat. Sea otters are the major predator of red abalone in the current sea otter range from Año Nuevo (Santa Cruz) to south of Point Conception. Inside this range a few adult abalone survive in deep crevices.

In central and southern California, where species were serially depleted, red abalone had declined the least of all five species by the time the fishery was closed in 1997. Combined landings of red abalone declined during the period from 1969 to1982 stabilizing at 1/10 their historic average during the 14 year period before the 1997 closure. Detailed examination of catch by area and fishery independent assessments reveal that the stability in landings masked serial depletion by area, as successive areas declined by over two orders of magnitude. From 1952-1968 most red abalone were caught in central California, followed by southern mainland, Santa Cruz, Santa Rosa and San Miguel Islands. Catches declined first along the central coast under the combined effects of expanding sea otters and fishing pressure. Outside the sea otter range catches declined more slowly along the southern mainland than at Santa Rosa, Santa Cruz, and San Nicolas Islands. From 1983-1996, catch decreased off these three islands to three percent, for Santa Rosa, and less than one percent, for Santa Cruz and San Nicolas, of their respective peak catches by the 1997 closure. San Miguel Island and the north coast were the exceptions to this pattern. Catches from San Miguel Island, the farthest and most northern of the Channel Islands, and the north coast comprised 71 of the 87 tons landed in 1996 prior to the fishery closure in 1997.

A successful red abalone sport only fishery continues to the north of San Francisco county, where SCUBA has always been prohibited and commercial take was only allowed for a three year period during WWII. Breath-hold

Red Abalone, *Haliotis rufescens*
Credit: DFG

diving effort has increased in relation to shore picking beginning in the 1960s. In 1960, an estimated 11,000 diver-days were expended to take 118,000 pounds of red and black abalone, compared with 29,000 diver-days to take 192,000 pounds in 1972. By 1985 to 1989, average diver-days and shore picker-days per year were focused on red abalone in central and northern California. Estimated landings of red abalone in central and northern California for combined divers and shore pickers reached a high of 3,472,000 pounds in 1986 and had decreased to 1,161,000 pounds by 1989. In 1998 an abalone stamp was first sold to generate revenues for assessments. In 1998 and 1999 an average 33,000 stamps were sold showing effort levels are comparable to those estimated for the 1985 to 1989 period.

Pink abalone

Pink abalones occur from Point Conception to the central Baja California peninsula, Mexico. Its depth range extends from the lower intertidal zone to almost 200 feet, but most are found from about 20 to 80 feet. It has the broadest distribution of the southern California abalones. It may be identified by its nearly circular shell, black and white epipodium and black tentacles, and highly arched shell with protruding respiratory pores, two to four of which may be open.

In the early 1950s, pink abalone comprised the largest segment of the abalone fishery, about 75 percent, and had a significant effect on the total abalone landings (Figure 1). Commercial landings originated at the eastern northern Channel Islands (Anacapa, Santa Cruz), and the southern Channel Islands (San Nicolas, Santa Catalina, Santa Barbara, San Clemente). Because pink abalone are more fragile than others and grow more slowly, the level of take could not continue. The persistence of pink landings was due to expansion into unfished areas, but that occurred so quickly that depleted areas did not have time, or the ability, to recover. By the early 1980s the commercial pink abalone fishery had expanded throughout the available range and the landings dwindled to virtually nothing.

Pink abalone was important in the recreational fishery, being the second most taken species, after green abalone. This is not surprising as both species are easily targeted by sport divers. Since pink abalone inhabits areas south of Point Conception, until recently south of the range of the sea otter, its population condition has not been affected by that predator. The re-occupation of sea otter into southern California could have adverse consequences on the already depleted pink abalone.

Department research cruises to San Clemente, Santa Catalina, and Santa Barbara Islands in 1996 and 1997, were used to investigate pink, and other, abalones. The number of abalones sighted per unit of time was used to quantify stocks, and a factor was applied to estimate the number of commercially legal pink abalone that could be collected per hour. Estimates ranged from about one to 1.5 abalone per hour. Similar cruises conducted in 1999, estimated only 0.28 commercial legal pink abalone per hour. At Catalina Island, no commercial sized pink abalone were found. These estimates indicate how low the remaining numbers of abalone there are at the islands. The situation is no better on the front side of Santa Catalina Island, where it was closed to commercial take, but open to recreational fishing.

Fishery independent surveys conducted at the Channel Islands reveal a close association between the presence of small individuals and legal size sport and commercial sizes. The best locations were where refuges were present, *e.g.,* Anacapa Island. These areas supported higher numbers of legal sized abalone and had continued presence of smaller sizes. There needs to be large adults present to provide spawn for future generations, and the presence of the smaller sizes forms the potential fishable resource. This situation may point out that to have sustainable abalone resources the full size range must occur.

Natural climatic events may affect pink abalone both positively and negatively. Pink abalone is at the northern end of its range in southern California, so it would not be unusual for this species to be enhanced by the influx of warm water during an El Niño period, as was observed in 1982 to 1984. On the other hand, intrusion of nutrient-poor warm, El Niño-driven seawater severely depresses kelp, growth and survival, which limits the food of abalone. This may depress abalone growth and reproduction. Since pink abalone spawn throughout much of the year, they are able to overcome the detrimental effects of warm water and spawn successfully. Withering syndrome (WS), a lethal disease of abalones, is exacerbated by El Niño related sea water warming, and may cause severe local decline in numbers.

Green abalone

Green abalone is found on open coast shallow rocky habitat from Point Conception, California to Bahia Magdalena, Baja California, including parts of the Channel Islands that are influenced by warmer water regimes. The species is associated with the warm-temperate California region from Baja California to southern California. Green abalone were commonly found in rock crevices, under rocks and other cryptic cavities from the low intertidal to subtidal zones. They are mostly found between 10 and 20

foot depths, often associated with surf grass beds, but are sometimes seen at 50 and 60 foot depths.

The shell is brown with the surface marked by many low, flat-topped ribs which run parallel to the pores. The shell has five to seven pores with edges elevated from the surface and a groove that runs parallel on the outside edge of the pores. The edge of the foot, the epipodium, is mottled cream and brown, with a frilly edge and scattered tubercles. The tentacles are olive green in color. Green abalone attain a size of 10 inches but are usually smaller.

Sexual maturity occurs at about three and a half inch shell length (approx. 5 to 7 years). Individuals average about one half inch of shell growth per year for the first five to seven years. After maturity, shell growth slows down. The spawning season for green abalone is between early summer and fall and spawning often occurs several times during this period. Average fecundity for a population of greens at Santa Catalina Island was estimated to be about 2.5 million eggs per female per year.

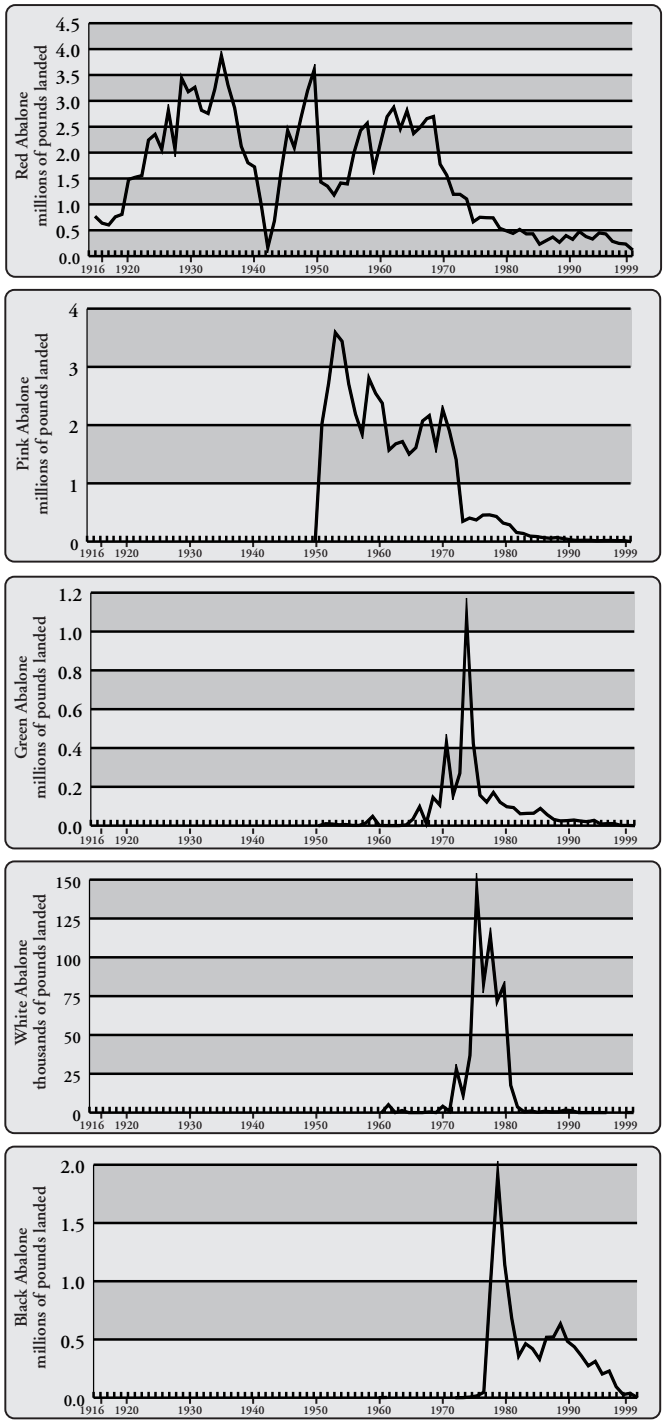
Green abalone are opportunistic drift algae feeders, and eat a wide variety of drift algae, but they prefer fleshy red algae. Predation of juveniles plays a major role in shaping adult population size. Abalone experience a high mortality early in life due mainly to predation. Some of the predators of juvenile abalone are crabs, lobsters, other gastropods, sea stars, octopuses, and fishes. The two spot octopus is the main predator of young green abalone at Santa Catalina Island. Larger individuals have a refuge in size from most of these predators. However, bat rays and sea otters prey selectively on larger abalones.

Since they prefer well sheltered, hidden niches, green abalone are able to exist in the high energy area of the low intertidal shallow subtidal areas where most other abalone species cannot exist. They are often concentrated in shallow subtidal surf grass beds where wave action facilitates a steady flow of drift algae.

Green abalone may occupy a particular site, called a homesite or scar. Abalone larger than one inch seldom leave their home scar to forage, relying on algal drift. Smaller individuals actively forage but return to their home scar in the day.

Black abalone

In black abalone the shell is smooth, black to slate gray in color, though some may have lost much of the outer layer leaving it white. This abalone has the most distinctive shell of the California species. The shell is usually clean though some have barnacles growing on them. There are five to nine open pores, which are flush with the shell. In more southern populations as many as 14 pores may be open. The epipodium has a smooth texture and is black.



Commercial Landings 1916-1999, Multiple Abalone

Data Source for all figures: DFG Catch Bulletins and commercial landing receipts. Graphs stacked to depict movement of catch effort from one abalone species to the next over time. Prior to 1949, identification of abalone species landed was not required. However, commercial abalone landings between 1916 and 1949 consisted primarily of red abalone. The data presented here for red abalone includes landings recorded as unspecified abalone during this time period. There were no commercial landings reported for pink or green abalone prior to 1950; no commercial landings are reported for white abalone prior to 1959; and no commercial landings are reported for black abalone prior to 1956.

The interior of the shell is silvery-white nacre (mother-of-pearl) and has a muscle scar.

Black abalone are reported from as far north as Oregon, but most are found south of San Francisco Bay to southern Baja California including the offshore islands. By the mid-1990s, only remnant populations existed at the Farallon and Channel Islands, and along the mainland southern California shoreline they were totally absent. Small populations exist in central and northern California.

Essential habitats includes rocky intertidal areas, often within the high energy surf zone. Consequently, it is exposed to a broad range of conditions, including wave wrack, exposure during low tides to hot, dry periods of direct sun, and to chilling cold winter conditions. Because natural populations of black abalone form exposed, easily accessible aggregations, protection from take is important, particularly along the mainland coast. In light of the growing human population in California, it is possible that coastal populations of black abalone will never return. Remote totally protected intertidal areas on the mainland and the Channel Islands may be required for reestablishment of natural populations.

It is not known whether subpopulations of this abalone exist. Because of the extensive distribution of suitable habitat, limited migration, and the method of reproduction, there may be genetic differences that have evolved among local populations, particularly at the extreme ends of the range, and between coastal and insular populations. Black abalone appear to recruit locally, but further examination of the recruitment pattern in this species is needed for better resource management and restoration.

Black abalone grow most quickly during the first five to 10 years. Growth varies between locations, and is likely affected by stress, including disease, food availability, and climatic variation. This abalone is a long-lived species, attaining an age of 25 years or more. Sexual maturity occurs at a relatively small size, with most individuals being mature at less than two inches. Spawning occurs in the spring and early summer, and a second period of spawning may occur in the fall.

Black abalone larvae settle onto hard substrate, and are often found in the vicinity of larger individuals. The newly settled larvae are cryptic, and remain so until they attain a length of four inches or greater. Small juveniles are found under rocks and deep in crevices, while larger black abalone in natural unharvested areas congregate on rocks and in tide pools, sometimes in great numbers. Newly settled and juvenile black abalone forage on bacterial films. As the abalone grows it shifts to larger drift algae brought into the intertidal areas by waves and currents.

Small black abalone are preyed upon by sea stars, octopus, and several crabs found in the intertidal areas. Larger individuals appear to be well protected from most predators, at least as long as they remain attached to the substrate. Sea otters are the main natural predator of this species. The absence of sea otters from southern California is the primary reason for the dense concentrations of abalone that developed in California and Mexico.

The recent commercial fishery in California began in approximately 1968 at the Channel Islands with the development of an Asian market. Landings peaked in the 1970s, and began a slow decline thereafter.

In 1985, weak, shriveled, and dying black abalone were observed by scientists in tide pools at the Channel Islands. Black abalone were literally falling off the rocks in large numbers at several of the islands. The disease is characterized by weight loss, pedal atrophy, weakness, and lethargy. Early experiments showed that once an abalone exhibited signs of this syndrome, it quickly died.

Withering syndrome (WS), caused by a Rickettsia-like procaryote is the causative agent of this catastrophic disease of abalone. It has ravaged all the Channel Islands and the remaining mainland populations of black abalone as far north as Pacifica, San Mateo county. Most locations experienced almost total loss of black abalone populations. A few individuals survive WS. These resistant abalone will be the basis of any natural recovery and are also utilized in captive breeding programs to develop resistant strains. In 1998, the NMFS added black abalone to the candidate species list for possible listing under the federal Endangered Species Act.

White abalone

White abalone inhabit deep, rocky substrata from 60 to 200 feet deep, from Point Conception, in southern California to Bahia Tortugas, in central Baja California, including the offshore islands and banks. Because it is found primarily in depths greater than about 75 feet, it wasn't described as a species until 1941.

The shell is high and oval in shape with a row of high pores spiraling to the highest part of the shell, the spire. Generally, the surface of the shell is free of heavy encrustation, but often the shell is covered with pink, coralline algae. There appears to be no harm to the abalone, and the algae often matches the shell to the surrounding habitat. The shell is considerably lighter in weight than the shells of other species. The interior of the shell is silvery-white nacre and lacks a muscle scar. Three to five of the largest pores are open, the rest being filled in during growth.

Little is known about natural growth of white abalone. Individuals settled in the laboratory grew at about 0.6 inch per year, less than that of other abalones. Estimates from a few individuals indicated that growth during the first

five years averages about an inch per year slowing down thereafter, which is a similar growth pattern to other California abalones. The life span of white abalone was estimated at about 35 to 40 years. There is no evidence of a significant recruitment event since the late 1960s or early 1970s; thus the remaining individuals are likely approaching the end of their life spans.

Reproduction in white abalone is probably similar to other species. Successful reproduction depends upon population density, spawning period, and fecundity, and conditions conducive to successful settlement. White abalone spawn in the winter, with synchronous gamete release, but the cue is unknown. The release of sperm initiates egg release in some abalones. Abalone may reproduce annually, but evidence suggests that settlement of the larvae may be only occasionally successful. Because of the short larval life, and the discontinuous habitat there are likely to be genetic differences between remote locations, particularly at the extremes of its range.

Abalone are herbivorous, feeding on bacterial and diatom films when small, and foraging on attached and drift kelp later. White abalone are associated with deep living kelps, and have been observed feeding on these. They have also been observed near the interface of sand and rock, a position that would facilitate the capture of drift algae.

Abalone predators include sea stars, octopus, crabs, lobster, and fishes, particularly sheephead, cabezon, and bat rays, all of which have been observed in white abalone habitat. Sea otters are likely not significant predators of white abalone, and are not responsible for low white abalone population numbers. Otters have been absent from most of the areas where white abalone occur since well before the establishment of the white abalone fishery.

As the nearshore abalone resources declined throughout California, divers went farther and deeper, eventually encountering virgin stocks of white abalone. The commercial fishery for white abalone began about 1965, though whites were probably taken incidentally before then. The high quality of the meat and the knowledge of the resource spurred commercial landings to a peak in 1972 of almost 144,000 pounds. Thereafter landings declined and became insignificant in the mid-1980s. The recreational fishery also took white abalone, but landings are unknown, and probably far less than the commercial landings. Relative to the whole fishery, white abalone comprised a small part of the landings, but its high quality and value bolstered the fishery for a short time.

In 1997, the NMFS added the white abalone to the candidate species list to be considered for listing under the federal Endangered Species Act. This action required a status review, which concluded that overexploitation was the major cause of the decline. In May 2000, white abalone became the first marine invertebrate to be proposed for listing as endangered under the federal Endangered Species Act.

Status of the Populations

Currently, all five major species of abalone in central and southern California are depleted, a result of cumulative impacts from commercial harvest, increased market demand, sport fishery expansion, an expanding population of sea otters, pollution of mainland habitat, disease, loss of kelp populations associated with El Niño events, and inadequate wild stock management. The political/legislative climate and limited funding has prevented the department from establishing and managing to sustain yields for each species and area. Fish and Game Commission and California legislative action halted sport and commercial fishing for abalones in southern California in 1997. Sport fishing is allowed north of San Francisco Bay. It seems paradoxical that all fishing for abalone would be closed in the southern two thirds of California, while a viable sport fishery exists in the north. The difference between the two areas is centered on the way abalones are taken. In the south, scuba and commercial dive equipment made all abalone available to harvest, while in the north only skin diving and shore picking are allowed. In the deeper areas beyond free diving depth, the population is dense and individuals are large, conditions that maximize reproduction and recruitment. It is these *de facto* refuge areas that provide a sustainable resource that can be fished year after year.

The northern California abalone fishery provides insight into what is necessary to maintain a sustainable resource, upon which a fishery can be allowed. In the northern fishery significant areas of good abalone numbers are unavailable to the fishery, including individuals larger than minimum legal size. Such areas are maintained passively because most skin divers cannot get to them in the often severe oceanic conditions found there. In contrast, all areas in southern California were available to commercial and sport divers, and eventually the larger individuals were taken, leaving little for stock rebuilding.

The primary regulation of the abalone fishery was the size limit, which was set at a relatively large size, allowing individuals as old as 15 years (in red abalone) to reproduce before entering the fishery. Implicit in size limits is the assumption of regular reproduction and more importantly, settlement. To have reproduction and settlement there must be large numbers of adults close together. Such areas are exactly what is sought in the fishery. Management efforts to protect stocks through size limits and limits on the number of commercial abalone fishermen have been ineffective. Stock declines have led to near extirpation of three species with red and pink

abalone reduced to remnant populations on islands in southern California.

The poor survival rates observed in most abalone seeding experiments suggest that seeding will not be an effective method for restoration of depressed stocks. Adult translocation to aggregate spawners may be the only hope to replenish depleted stocks or prevent extinction for some species. Unfortunately for most species, few adults remain to aggregate. Expensive artificial breeding programs may be necessary to obtain sufficient numbers of large abalones upon which to start rebuilding the resource. Additionally, unless stocks are reestablished in well-protected refuge areas, illegal take will undermine these efforts.

In northern California, red abalone stocks continue to provide abalone to an important recreational fishery. The continuation of this fishery depends upon the protection of the *de facto* deep water refuge, monitoring the annual harvest to assure that the resource can accommodate sport harvest, continued effective resource protection, education, and assessment. Recovery of the southern California abalone resource will likely require many years and the establishment of marine protected areas to encourage and protect dense populations of abalones.

Three natural phenomena will have a decisive effect on California's future abalone fisheries — disease, oceanographic events (El Niño), and sea otter expansion. Each is already influencing research and management decisions.

WS is a bacterial disease that has virtually eliminated black abalone from large areas of its habitat in southern California. The spread and effectiveness of the disease is enhanced by higher than average sea water temperatures. In black abalone, some individuals appear to be resistant to it, but because these individuals are healthy, they were often taken in the course of fishing. It is precisely these healthy individuals that are necessary to obtain natural recovery. After the discovery of WS, rather than establishing a general moratorium on the take of black abalone, each island was closed after populations had crashed. The continued fishing removed most of the potentially resistant abalones.

WS is known in each of the other California abalones, but little is known how it affects the other species, particularly along the mainland. Red abalone at San Miguel Island are infected, but incidence seems to be low. Green abalone, which overlaps with the distribution of black abalone, appears to have suffered from WS at some islands. A few northern California red abalone have been collected with WS pathogens, but it has not caused any symptoms. The cooler seawater temperatures off northern California are sufficient to prevent the occurrence of symptoms, but if environmental temperatures increase WS could become a problem.

WS has the capacity to eliminate abalones throughout large areas. A significant increase of the incidence could eliminate the remaining, already low, populations of abalones. Research is forthcoming about breeding resistant abalone and treating abalones held in captivity. Additionally, any management decisions about abalone must take disease effects into consideration.

Climatic and periodic oceanographic disturbances, particularly those that bring warm water northward can have severe effects on abalones, especially those in southern California. The effect of increased sea water temperature can affect disease susceptibility; lower growth in kelps, thus reducing abalone food sources; alter distribution patterns of marine animals; and bring storms which disrupt local habitats. Each of these could further place additional stress on abalone populations.

The southward movement of the sea otter into its ancient range in southern California would undoubtedly further reduce remaining abalone, and other invertebrate populations further. Along the central coast, sea otters have removed the larger emergent abalone populations, and restricted them to cryptic habitat.

Paradoxically, each of these three developments, are natural events with which abalone and all marine organisms, have endured to some extent in the past. The difference is that historically, populations were larger and more adaptable, and better suited to evolve strategies to cope with changing conditions. Today, populations are smaller, and they cannot respond sufficiently enough or quickly enough to adapt. In some cases, local, and perhaps total extinction of species will result.

Management Considerations

See the Management Considerations Appendix A for further information.

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