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# IS CLIMATE CHANGE CONTRIBUTING TO RANGE REDUCTIONS AND LOCALIZED EXTINCTIONS IN NORTHERN (*HALIOTIS KAMTSCHATKANA*) AND FLAT (*HALIOTIS WALALLENSIS*) ABALONES?

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## ABSTRACT

Abalone abundance surveys from the 1970s were repeated 30 yrs later following a period of increased sea surface temperatures along the Pacific coast of the United States. Northern abalone, *Haliotis kamtschatkana* (Jonas, 1845) once abundant enough to support commercial fishing in Washington and Canada, are now extremely rare in the southern portion of their range in southern and central California. They have also declined 10 fold in northern California in the absence of human fishing pressure. In Washington, northern abalone are in decline and exhibit recruitment failure despite closure of the fishery. Flat abalone, *Haliotis walallensis* (Stearns, 1899) no longer occur in southern California, and in central California have declined from 32% to 8% of the total number of abalones, *Haliotis* spp., inside a marine reserve. The distribution of flat abalone appears to have contracted over time such that they are now only common in southern Oregon where they are subject to a new commercial fishery. Given these range reductions, the long-term persistence of flat abalone and northern abalone (locally) is a concern in light of threats from ocean warming, sea otter predation, and the flat abalone fishery in Oregon. The likelihood of future ocean warming poses challenges for abalone restoration, suggesting that improved monitoring and protection will be critical, especially in the northern portions of their distributions.

Range shifts towards the poles have been documented for a number of species in meta-analyses and these shifts are consistent with predictions of global warming (Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003). A growing number of range shifts and contractions are documented from marine systems in which southern species replace northern species (Barry et al., 1995; Southward et al., 1995; Field et al., 2006). Northward shifts in species ranges (Zacherl et al., 2003) may not necessarily have negative impacts on abundance unless population shifts are unsuccessful due to biotic or abiotic factors limiting expansion. For example, black abalone, *Haliotis cracherodii* (Leach, 1814), populations could expand into the central California coast in response to oceanic warming, however, disease, sea otters, and poaching are acting synergistically to limit abundances in this region, north of Point Conception (Haaker et al., 1992; Raimondi et al., 2002; Harley and Rogers-Bennett, 2004).

Concern is rising over the fate of abalone populations on the Pacific coast of the United States (see Transboundary Abalone Recovery Group, Vancouver, March 2007), sparking interest in the potential impacts of oceanic warming for restoration planning (Hobday and Tegner, 2002; Vilchis et al., 2005). Abalone populations have declined dramatically precipitating the closure of multiple abalone fisheries (Karpov et al., 2000; Rogers-Bennett et al., 2002), as well as the listing of pink, *Haliotis corrugata* (Wood, 1828), green, *Haliotis fulgens* (Philippi, 1845), black, and northern, *Haliotis kamtschatkana* (Jonas, 1845) abalone as species of concern <www.nmfs.noaa.



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gov/pr/species/concern/>, and white abalone, *Haliotis sorenseni* (Bartsch, 1940), as endangered (Federal Register 66: 103, June 2001). Recent work has focused on the potential impact of ocean warming on abalone populations (Tegner et al., 2001; Hobday and Tegner, 2002; Vilchis et al., 2005) and its implications for successful restoration. Determining the impacts of ocean warming is complicated by confounding factors such as fishing. One way to discern the impacts of ocean warming, as distinct from fishery influences, is to examine population trends in unfished species (Moser et al., 2000), such as flat abalone *Haliotis walallensis* (Stearns, 1898), and populations inside marine reserves (Roberts and Hawkins, 1999).

The distribution of the northern subspecies, *Haliotis kamtschatkana kamtschatkana* (Jonas 1845), extends from southeast Alaska to Point Conception where the subspecies morphology converges with the southern threaded subspecies, *Haliotis kamtschatkana assimilis,* (Dall, 1878) which extends from Point Conception south into northern Baja California, Mexico (Geiger, 1999). Northern abalone and the former threaded abalone were determined to be subspecies of *H. kamtschatkana* because of little divergence between the two with respect to sperm lysin (Geiger, 1998). The threaded subspecies was taken in the commercial fishery (> 21,000 abalone) in southern California from 1971 to 1980 (Rogers-Bennett et al., 2002), but since then has remained scarce. All northern abalone fisheries are now closed along the Pacific coast including southeast Alaska (closed in 1995), British Columbia (closed in 1990), and Washington State (closed in 1994). Workshops have been convened to examine prospects for rebuilding northern abalone stocks in British Columbia (Campbell, 2000) and Washington, (J. Gaydos and B. Peabody, SeaDoc Society, pers. comm.).

Flat abalone, *H. walallensis*, have never been considered an abundant species (McMillen and Phillips, 1974; Owen, 2006). The traditional range of this species is quite narrow, extending from Newport, Oregon to Baja California, Mexico, with the type specimen from Gualala, California (Geiger, 1999; Owen, 2006). Flat abalone were never targeted by fisheries until 2001 when a commercial fishery was opened in Oregon [there is also a small recreational red abalone fishery in the state (S. Groth, Oregon Department of Fish and Wildlife, pers. comm.)].

Here, I examine northern and flat abalone along the Pacific coast of the United States, comparing recent data with historic records from 30 yrs ago to test whether there has been a shift in the southern range as would be predicted with ocean warming. I focus on northern abalone which is a species of concern, has a broad geographic distribution, and was once the basis of important commercial and recreational fisheries. Flat abalone has a narrow geographic distribution and has been unfished throughout its range (except recently in Oregon). The modern distribution of northern and flat abalone is assessed in relation to historic accounts of their distribution, abundances in marine reserves, and changes in water temperatures. Potential causes for reductions in range are discussed as are the implications of these range shifts for restoration.

## Methods

Southern California.—In southern California, abalone populations are surveyed by the Kelp Forest Monitoring Program (KFMP), part of the Channel Islands National Parks Service. This program quantifies abalone density along transects once per year at multiple sites around the northern Channel Islands. Two band transects each 10 × 3 m are placed on either side of a fixed 100 m line for a total search area of 60 $m^2$. Detailed descriptions of their methods can be found elsewhere <www. nature.nps.gov>.

Abalone numbers are also monitored annually within artificial habitats called Abalone Recruitment Modules (ARMs). Each module is composed of twenty ½ cinder blocks enclosed in a wire mesh cage stacked to leave an open core. The ½ cinder blocks are stacked in five layers of four bricks with a surface area of 5 $m^2$ (see Davis, 1995). Once a year these "habitats" are disassembled and the numbers of juvenile and adult abalone inside are recorded. Between 80–100 of these habitats are sampled each year at three islands: Anacapa, Santa Cruz, and Santa Rosa Island.

Central California.—In central California, we conducted abalone density estimates at the Hopkins State Marine Reserve (no fishing) in central California using the same methods as surveys in the 1970–1980s (Lowry and Pearse, 1973; Hines and Pearse, 1982). A fixed cable (270 m long) with meter demarcations still exists in the subtidal having remained since the earlier surveys. This cable allowed us to examine the same subtidal area (approximately 90 × 90 m) inside this small reserve as in the past. Dive teams started at positions 10 m apart starting at the 60 m cable mark and ending at the 150 m cable mark. Abalone were marked with yellow lumber crayon to prevent double counting. We estimate that our dive team searched approximately 800 $m^2$ of crevice habitat during 15 hrs and 13 min of search time over two consecutive days each year.

Density is often difficult to quantify within the range of sea otters, *Enhydra lutris* (Linnaeus, 1758), in which abalone occupy cryptic habitats. In this study, abalone density was determined within crevice habitat (about 10% of the total area) as had been done previously (Hines and Pearse, 1982). Earlier surveys of flat abalone recorded their numbers as a proportion of the total number of abalone (flat and red abalone) rather then as density ($m^{-2}$). Thus, we report our results using a similar metric to compare with historic records.

Northern California.—California Department of Fish and Game divers conducted timed swim surveys searching for northern, flat, and red abalone in 1975 at popular abalone fishing sites in northern California. Included in this survey were sites at two State Parks: Van Damme in Mendocino County and Fort Ross in Sonoma County. During each survey, two-person dive teams conducted 20 min swims enumerating the species and size of the abalone they observed. Similarly, California Department of Fish and Game assessed subtidal benthic communities during a series of surveys funded by the Pacific Gas and Electric Company in preparation for a proposed nuclear power plant at Point Arena, Mendocino County (Gotshall et al., 1974). Subtidal surveys of abalone populations were included in the ecological surveys from 1971 and 1972. This survey used a combination of 30 × 2 $m^2$ transects along with 30 $m^2$ arcs.

In 1999 and 2000, we revisited Van Damme and Fort Ross State Parks that had originally been surveyed in 1975. We used the same methods as in the previous survey with two person dive teams recording the number and species of abalone found during timed swims. In June of 2003, we revisited Point Arena and surveyed 38 transects 30 × 2 $m^2$ transects.

Oregon.—In 2000, the Oregon Department of Fish and Wildlife (ODFW) partnered with a commercial abalone fisherman to examine the density of unfished flat abalone populations at four sites prior to the opening of a limited commercial fishery. Sites included Goat Island, Mack Arch (Brookings), Nellie's Cove (Port Orford), and Rogue Reef (Gold Beach). At each site, three 100 m transects were established and flat abalone were counted in 1 $m^2$ plots every 10 m along each transect. Transects ranged in depth from 7 to 20 m. In addition, the size of each rocky area suitable for flat abalone was estimated at each site. We are not aware of any data before or after 2000 for flat abalone or of any data for northern abalone in Oregon.

Washington State.—In 1979, Washington Department of Fish and Wildlife (WDFW) divers conducted timed swim surveys searching for northern abalone throughout sites in the Puget Sound in Washington State. During each survey, a dive team searched for abalone for a minimum of 20 min. All abalone encountered were measured unless they were inaccessible in a rock crevice. Swims were conducted in the winter and spring months.

In 2005, we repeated these timed swim surveys at rocky habitats known to have had abundant northern abalone populations in the past in and around sites in the San Juan Channel where abalone were surveyed in 1979. Swim surveys were made in March and July of 2005. One dive team surveyed 10 sites during 30–40 min timed swims. The size of all abalone encountered was recorded along with the substrate type the abalone was found on, either a rock surface or in a rock crevice.

Temperature.—Sea surface temperature (SST) data obtained by the Shore Station program at Scripps Institution of Oceanography (SIO) from five sites along the Pacific coast of the United States were used to examine temperature trends over the past 30–50 yrs (http://shorestation.ucsd.edu/). Historical SST data were collected from SIO, Hopkins Marine Station, Bodega Bay, Charleston Oregon, and Neah Bay, Washington. These data were collected by parent institutions and then complied and served by SIO. At the Scripps Pier personnel from the Birch aquarium collect sea SST data at 32°52.0´N, 117°15.5´W daily. Similarly, personnel from Hopkins have been collecting daily SST data from the north side of Point Cabrillo at 36°37.3´N, 121°54.2´W. In Bodega Bay, SST data are collected by the Bodega Marine Laboratory UC Davis from Horseshoe Cove at 38°19.0´N, 123°04.3´W. Temperature recordings at Bodega Bay were automated with the installation of the MOMs (meteorological oceanographic monitoring system) in 1989. In Charleston, the shore station is run by Oregon Institute of Marine Biology, University of Oregon, at 43°20.7´N, 124°19.3´W. In Neah Bay, the tide gauge station is run by NOAA and is located near Cape Flattery at the entrance to the Strait of Juan de Fuca at 48°22.1´N, 124°37.0´W. Data after 1994 at Neah Bay are from an automated system which can run 1 °C cooler than historical data and so we did not incorporate these newer data (1995 to present) into the analysis.

Data from these stations were collected as monthly means and then converted to yearly means. The mean for the entire time series was determined for each site. We used SIO temperature data starting in 1955–2004, Hopkins starting in 1955–2004 (3 yrs of missing data 1975–1977), Bodega Bay data from 1957 to 2002; Charleston from 1967 to 1994; and Neah Bay from 1955 to 1994. Anomolies from these overall means were plotted.

## Results

Southern California.—Northern (threaded) abalone are rare today in southern California. None have been found along the band transects surveyed by the Kelp Forest Monitoring Program in the northern Channel Islands since 1982. In 2001, following a report of a rare abalone, nine threaded abalone all < 75 mm were found at depths ranging from 14–17 m at Naples Reef, Santa Barbara. One live threaded abalone was found at San Miguel Island at Crooks Point (D. Richards, Channel Islands National Parks Service, pers. comm.). One confirmed report of a threaded abalone was made from the Point Loma Kelp Forest in San Diego in Dec. 2006 (http://week.divebums.com/2006/Dec11-2006/index.html; D. Rudie, pers. comm.).

In the past 5 yrs, 21 threaded abalone have been found inside the more than 80 ARMs surveyed each year in the northern Channel Islands (Table 1). All these abalone were found at a single site on the leeward side of Santa Cruz Island. The abalone range in size from 11 to 112 mm averaging 48 mm. From 1984 to 2000, no northern (threaded) abalone were observed in the ARMs.

Central California.—There have been a few scattered reports of northern abalone (threaded morphology) in the central California area in the past 10 yrs. In central California, I am aware of three sightings of live northern (threaded) abalone in the Monterey area in 20–30 m depth off Monastery Beach, one in shallow water on the Monterey Breakwater and one in deeper water (22 m) at Stillwater Cove (A. Drae-

Table 1. Abalone Recruitment Module (ARMs) data from southern California in the northern Channel Islands and in northern California from Van Damme State Park in Mendocino County. Note: All threaded abalone are from Santa Cruz Island.

| Year | South | | | North | | |
|---|---|---|---|---|---|---|
| | # ARMs | # threaded abalone | # flat abalone | # ARMs | # northern abalone | # flat abalone |
| 2001 | 82 | 4 | 0 | 12 | 0 | 16 |
| 2002 | 87 | 6 | 0 | 12 | 0 | 19 |
| 2003 | 88 | 8 | 0 | 12 | 0 | 20 |
| 2004 | 90 | 2 | 0 | 12 | 0 | 48 |
| 2005 | 100 | 1 | 0 | 12 | 0 | 26 |
| 2006 | 100 | 0 | 0 | 12 | 1 | 14 |

ger, pers. comm.; D. Benet, pers. comm.). It is in this region that the two morphologies are very difficult to distinguish based on shell morphology.

In our surveys at the Hopkins State Marine Reserve, we found that the combined densities of abalones has not changed significantly since 1972, however there has been a sharp decrease in the abundance of flat abalone relative to red abalone (Table 2). The percent of flat abalone compared with red and flat abalone has declined from 31% in 1972, to 27% in 1978, and 6% in 2001. Today, densities of flat abalone are very low with five flat abalone per 800 $m^2$ in crevices (0.00625 $m^{-2}$). No live northern abalone were found at this site from 2001–2005 although we did find one small northern abalone shell.

Northern California.—Both northern and flat abalone have declined dramatically in the Sonoma County State Park at Fort Ross (Table 3). No live northern or flat abalone were observed during our timed swims in 1999. We found very low numbers of flat (n = 2) and northern (n = 3) abalone during more extensive transect surveys searching 2220 $m^2$ recently at Fort Ross in Sept. 2006 (Rogers-Bennett, unpubl. data). Fewer flat abalone were found farther north at Point Arena in 2003 compared with the early 1970s and no northern abalone were found (Table 3). North of Point Arena at Van Damme State Park the numbers of northern abalone have declined from > 100 in 344 min of search time to 2 in 918 min of searching. This decline is also apparent for flat abalone, although again, flat abalone declines have not been as dramatic in northern California compared with those of the northern abalone (Table 3).

Table 2. The abundance of flat abalone, *Haliotis walallensis* compared with the total number of abalone observed in this and previous studies in the Hopkins State Marine Reserve, central California. Note: One northern abalone shell 56 mm was found along the transects in June 2002.

| Study | Total abalone | flat abalone (%) | northern abalone |
|---|---|---|---|
| McLean, 1962 | | "common" | |
| Ebert, 1968 | | "common" | "common" |
| Lowry and Pearse, 1973 | 81 | 25 (31%) | |
| Cooper et al., 1977 | 135 | 51 (38%) | |
| Hines and Pearse, 1982 | 112 | 30 (27%) | 0 |
| Karpov et al., 1997 | 40 | 2 (5%) | 0 |
| Rogers-Bennett, unpubl. data (2001) | 81 | 5 (6%) | 0 |
| Rogers-Bennett, unpubl. data (2002) | 70 | 8 (11%) | 0 |
| Rogers-Bennett, unpubl. data (2003) | 111 | 10 (9%) | 0 |
| Rogers-Bennett, unpubl. data (2004) | 29 | 0 | 0 |

Table 3. The number (#) of northern and flat abalone found in northern California in 1975 compared with 1999–2003. Data from 1975 are from California Department of Fish and Game (CDFG) timed swims surveys (S. Schultz and D. Burge) which were repeated in 1999–2003 by CDFG. Data from 1971–1972 was from Gotshall et al., 1974 and was repeated by Humboldt State University (HSU) divers.

| Location | Search time/Area | # northern abalone | # flat abalone |
|---|---|---|---|
| Van Damme State Park | | | |
| CDFG, 1975 | 344 min | 117 | 46 |
| CDFG, 2000 | 918 min | 2 | 29 |
| Fort Ross S.P. | | | |
| CDFG, 1975 | 256 min | 42 | 64 |
| CDFG, 1999 | 242 min | 0 | 0 |
| Point Arena | | | |
| Gotshall, 1971–1972 | 2,070 $m^2$ | 67 | 21 |
| HSU, 2003 | 2,280 $m^2$ | 0 | 11 |

Oregon.—In 2000, fishery independent density surveys of flat abalone in Oregon indicated that there are at least three areas—Port Orford, Gold Beach, and Brookings—in the southern portion of the state with flat abalone. Density estimates from Nellie's Cove showed the highest density with an average of 5.6 abalone $m^{-2}$ while Goat Island had the lowest density of the four sites surveyed with 1.8 flat abalone per $m^2$. Estimates of the approximate size of the area suitable for flat abalone were 416 Ha. (ODFW, 2001).

A commercial flat abalone fishery began in Oregon in 2001 when the state issued an experimental fishery permit with a size limit of 114 mm (4.5 in) and a maximum yearly landing quota of 1.36 mt (J. McCrae, Oregon Department of Fish and Wildlife, pers. comm.). Commercial landings of flat abalone in the limited experimental fishery have been at or near the annual quota since its inception (Table 4; J. McCrae, pers. comm.). The majority of the landings come from Gold Beach and Port Orford with fewer landings from Brooking, and more recently, Charleston. In total, 7845 kg of flat abalone (Table 4) have been taken in the commercial fishery (2001–2006). Assuming an average weight of 0.408 kg for a legal size (114 mm) flat abalone, this is roughly 19,228 flat abalone. There are no data that we are aware of for northern abalone in Oregon.

Washington.—Divers surveyed eight sites in 1979 inside the Puget Sound around the northern San Juan Islands. During these surveys WDFW divers spent an estimated 20–40 min (average 30 min) searching and measuring abalone on each swim. A conservative estimate of the time spent searching for the two divers would be 480 min. During this time they saw abalone at all eight sites and recorded 219 northern

Table 4. Commercial flat abalone landings (kg), Oregon 2001–2006.

| Year | Port Orford | Gold Beach | Brookings | Charleston |
|---|---|---|---|---|
| 2001 | 592 | 619 | 157 | No fishing |
| 2002 | 590 | 543 | 228 | No fishing |
| 2003 | 590 | 451 | 41 | 271 |
| 2004 | 448 | 608 | 42 | 131 |
| 2005 | 252 | 718 | 270 | 121 |
| 2006 | 500 | 621 | 0 | 55 |
| Total | 2,972 | 3,560 | 738 | 578 |

Table 5. Northern abalone found during timed swims in Puget Sound, Washington, in 1979 by the Washington Department of Fish and Wildlife (WDFW). These surveys were repeated in 2005 by Rogers-Bennett. Data from WDFW were provided by D. Rothaus.

| Program | # Sites | Search time (min) | # northern abalone |
|---|---|---|---|
| WDFW, 1979 | 8 | 480 | 219 |
| Rogers-Bennett, 2005 | 10 | 694 | 17 |

abalone total (Table 5). The northern abalone ranged in size from 32 to 139 mm of which 13 were < 75 mm and the average size was 98.77 mm.

In 2005, divers found a total of 17 northern abalone at 10 sites. One timed swim was conducted at each site. Each diver searched for abalone for approximately 30 min and the two divers searched for 694 min. Abalone were found at four of the 10 sites with the majority of abalone (n = 14) found at just two sites, Shark Reef and Long Island (Table 5). Abalone ranged in size from 75–142 mm averaging 107 mm with no abalone < 74 mm. The majority of northern abalone were on exposed rock surfaces with only three found in cryptic locations. The dominate substrate type supporting these abalone was rock habitat with some in rock crevice and one on a boulder. No other species of abalone were found. Likewise, no flat abalone have been found in dive surveys conducted by WDFW in the western Strait of San Juan de Fuca and the coastal area around Cape Flatery (D. Rothaus, Washington Department of Fish and Wildlife, pers. comm.). Preliminary reports suggest that a couple of abalone collected at the southern end of San Juan Island which morphologically look like northern abalone genetically resemble flat abalone (K. Straus, University of Washington, pers. comm.). We are not aware of any abalone surveys on the outer coast of Washington or northern Oregon.

Temperature.—The mean SST for each site generated from the time series was: 17.24 °C at SIO for 48 yrs of data, 13.35 °C at Hopkins for 47 yrs of data, 11.58 °C at Bodega Bay for 46 yrs of data, 11.31 °C at Charleston which had the least number of years of data at 28 yrs, and 9.93 °C in Neah Bay from 40 yrs of data. Seawater temperatures from 1976 to 2000 were warmer than earlier years at each of the sites, showing positive anomalies from the means (Fig. 1). Temperature data from Oregon were not available to examine the past 30 yrs and this short data set had the least positive anomalies compared with the other sites. These temperature records indicate a warming trend that was coast-wide over the past three decades and is consistent with other records of SST.

## Discussion

Northern Abalone.—Northern abalone are declining in the southern portion of their range in California. No northern abalone were found in the central California site despite the observation that they were “common” there in 1966. In northern California, populations have declined nearly ten-fold despite the large size limit in the recreational red abalone fishery (178 mm) which effectively excludes this smaller bodied abalone (L. Rogers-Bennett, pers. obs.). This pattern of decline is repeated throughout much of the southern portion of their range in California where there is no northern abalone fishery suggesting ocean warming may be playing a role.

While ocean temperatures may be playing a role in the decrease of abalones in the southern portions of their range, this factor is coupled with human fishing pressure

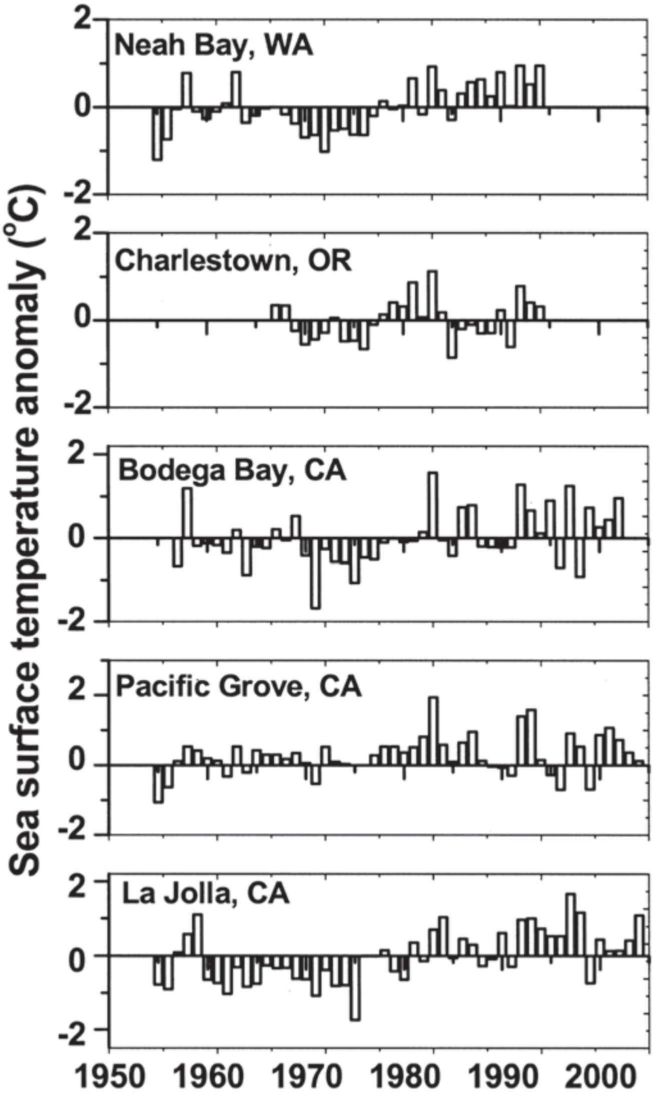


Figure 1. Sea surface temperature anomalies for five shore stations along the Pacific coast of the United States. Yearly temperature anomalies are taken from the longer term mean temperature for each site over the time series.

and predation by sea otters. In southern California, threaded abalone are now rare, having been common in areas such as Naples Reef, Santa Barbara, and Tyler Bight, San Miguel Island (D. Kushner, Channel Islands National Park Sevice, pers. comm.). In Puget Sound, Washington, northern abalone have declined precipitously and there is recruitment failure. Northern abalone are continuing to decline in Washington State at index sites monitored by WDFW in 1992 (n = 351) and again in 2003 (n = 137) with no evidence of recruitment since the fishery closure (D. Rothaus, Washington Department of Fish and Wildlife, pers. comm.). In contrast, northern abalone in British Columbia, while low in abundance, appear to be reproducing successfully and recruiting to both natural and artificial habitats (ARMs), with juveniles the most abundant size class observed (DeFreitas, 2003). Despite some recruitment and abalone at densities of 200–2900 $ha^{-1}$ in rocky habitats in British Columbia (Lucas et al., 2000) abalone abundance has declined over time, even after the closure of the fishery in 1990. On the south coast of Vancouver Island, abalone abundances are declining at multiple sites except in front of a prison with armed guards (*defacto* reserve); clearly implicating poaching elsewhere (Wallace, 1999). Increasing ocean temperatures may be having a synergistic effect with fishing further impacting populations (Harley and Rogers-Bennett, 2004). Little fishery independent information is available for abalone on the outer coast of southeast Alaska. In 1995, the commercial fishery was closed and sea otters have been expanding their range, further limiting prospects for abalone range expansions and restoration (Woodby et al., 2000).

A species' geographic distribution can influence the degree to which they are at risk of global extinction (Roberts and Hawkins, 1999). Northern abalone, while vulnerable to local extinctions, may be somewhat buffered from global extinction by their wider geographic distribution from Alaska to Mexico, unlike flat abalone which have a narrower geographic distribution (Owen, 2006). Similarly, the endangered white abalone has a narrow geographic range from Point Conception, California, to Punto Abreojos, Baja California, Mexico (Hobday et al., 2001; Butler et al., 2006), and is at risk of global extinction.

Flat Abalone.—Flat abalone range from central Baja California, Mexico, to Newport, Oregon (Owen, 2006), however the southern border of the range appears to be contracting north. In 1959, a sample of abalone shells from Baja California included 13 flat abalone, whereas today flat abalone are absent from south of Point Conception (Owen, 2006). Flat abalone once made up 32% of the abalone found in central California in the 1970s, while today they have declined dramatically coincident with increasing sea surface temperatures. Similarly, cold-water species have shifted their ranges north and have been replaced with warm-water species in the intertidal in central California where ocean temperatures have warmed by almost 1 °C between 1930 and 1990 (Barry et al., 1995; Sagarin et al., 1999; but see Helmuth et al., 2002). The southern Kellett's whelk, *Kelletia kelletii* (Forbes, 1850), has shifted its range north from Point Conception into central California (Zacherl et al., 2003) as has the volcano barnacle, *Tetraclita rubescens* Darwin, 1854 (Connelly and Roughgarden, 1998). The potential mechanisms for the northern range contraction in flat abalone are unknown but could be related to larval survival, reduced reproduction in warm-water (Vilchis et al., 2005), or direct adult mortality. In the 1990s, a die-off of flat abalone was observed in northern California possibly coincident with warm-water El Niño events (Owen, 2006). Models of red abalone show model populations shifting their latitudinal range north given a 0.5 °C increase in SST (Hobday and Tegner, 2002).

Flat abalone are considered rare (McMillen and Phillips, 1974; Owen, 2006), but there are now concerns about local extinctions in the southern portion of the range where population densities have fallen below minimum viable population thresholds as defined for abalone by Shepherd and Brown (1993). In central California, flat abalone now occur at very low densities (0.00625 $m^{-2}$), suggesting that their chances of fertilization success are low if low densities are coupled with long distances (> 2 m) between nearest neighbors. Furthermore, since red abalone densities are moderate in the reserve, hybridization is possible. Thus, Allee effects may be important for flat abalone at low population densities (Stoner and Ray-Culp, 2000) in the form of sperm limitation (Levitan and Peterson, 1995), low fertilization success (Babcock and Keesing, 1999), and demographic stochasticity (Lande, 1998; Fugiwara and Caswell, 2001). Moreover, intense predation by sea otters (Wendell, 1994) coupled with ocean warming (Tegner et al., 2001; also see Hobday and Tegner, 2004) inside the Hopkins State Marine Reserve may also be contributing to declining numbers of cold-water flat abalone (Cox, 1962).

Southern Oregon now appears to be the area of highest abundance for flat abalone following the range constriction over the past 30 yrs. One caveat to this conclusion is that it is based on 1 yr of survey data from southern Oregon prior to the opening of the commercial fishery. The highest density of flat abalone appears to be at the northern end of the range, making them similar to other intertidal invertebrates with skewed distributions rather than having the highest densities in the center of the distribution (Sagarin and Gaines, 2002). Suitable habitat for flat abalone in Oregon is less than one third (416 Ha.: ODFW) of that found in northern California (1480 Ha.; Rogers-Bennett et al., 2002), potentially further constricting the range. There is a very real need for quantitative abalone and habitat surveys both in Oregon and south of Point Conception to determine the status, geographic distribution, and center of the range of flat abalone. Furthermore, if flat abalone are now predominantly in southern Oregon, dispersal north into Washington may be impeded by the short duration of the larval period coupled with the large expanse of sandy habitat in northern Oregon.

Baseline abundance estimates for flat abalone in northern California are approximately 83,800 having changed little from 1971 when estimates were 71,000 (Rogers-Bennett et al., 2002). Flat abalone abundance estimates based on 1 yr of surveys are higher in Oregon (ODFW), however, over the past 6 yrs, one commercial diver has removed approximately 19,228 flat abalone (> 114 mm). For two minor species in the California fishery, threaded and white abalone, populations did not recover after the fishery removed 21,066 and 360,476 abalone, respectively (Rogers-Bennett et al., 2002). With so little density information available for flat abalone this brings into question the sustainability of the limited commercial abalone fishery in Oregon given that all fisheries in the United States are mandated to be sustainable under the Magnuson-Stevens Fishery Conservation and Management Act (National Marine Fisheries Service, 1997). Restoration of cold-water species such as flat abalone could be problematic given the multiple threats identified including warming ocean conditions, sea otter predation in central California, and the emerging commercial fishery for flat abalone in southern Oregon.

Restoration and Ocean Warming.—Abalone have been promoted as flagship species highlighting the need for conservation of kelp forest communities (Sloan, 2004) and are currently included with other mollusks as an important indicator assemblage (Gladstone, 2002). Despite the importance of abalone, a number of threats have been identified, making the restoration of abalone on the Pacific coast a challenge. First, abalones are a data-poor group highlighting the need for assessments along the entire Pacific coast of the United States. For example, there are no federal or state programs to assess unfished species of abalone such as flat abalone. Second, abalone are now in the paradox of fishery funding, with revenues tied to landings whereby as landings decline, funding for restoration declines and frequently ceases altogether when the fishery is closed. Even restoration funding for the endangered white abalone is severely limited (\$130,000 $yr^{-1}$), despite the high profile of being the first marine invertebrate on the federal endangered species list (M. Neuman, National Marine Fisheries Service, pers. comm.).

A number of threats, in addition to data and funding challenges, have been clearly identified for northern and flat abalone restoration. In Alaska, northern abalone face the combined threats of low population densities following human fishing and the range expansion of the sea otters. In British Columbia, abalone were federally listed as threatened in 1999 and restoration programs are now being implemented (Campbell, 2000). In Washington State, low population densities following fishing have resulted in a collapse in recruitment and the need for human intervention. In Oregon, flat abalone are being commercially fished, however, there are few baseline data to determine what levels of fishing are sustainable. In California, northern and flat abalones may be declining in part due to the rise in ocean temperatures (over the past 30 yrs) constricting the southern border of their ranges north. While restoration efforts can not address ocean warming directly, knowledge of the populations' response—constricting their ranges north—should trigger immediate intervention to protect flat abalone in Oregon from overfishing, initiate northern abalone restoration efforts in Washington State, and provide anti-poaching education for northern abalone in British Columbia.

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