Abalone (Haliotidae) in Oregon: Trends in Populations and Fisheries

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Introduction

Biology

Abalones, marine mollusks from the family Haliotidae, are generally found in sparse populations constrained by their narrow habitat requirements and life history parameters. They feed on marine vegetation found in rocky nearshore areas. Globally, these rocky vegetated habitats, which are ideal for abalone populations, are uncommon; strongholds for populations include the nearshore kelp beds of western North America, South Africa, Japan, Australia, and New Zealand (Lindberg, 1992). Abalones are dioecious and reproduce by broadcast spawning, where males and females simultaneously emit gametes into the water column. When fertilization is successful, resulting larvae have a short free-swimming phase prior to benthic settlement, suggesting limited dispersal (Miyake et al., 2017). Reproductive success may be limited when individuals are not in close proximity; higher density stocks are found to have higher fertilization rates (Babcock and Keesing, 1999). Given the low probability of reproductive success, abalones have adapted long life spans (Tegner et al., 1996; Rogers-Bennett et al., 2007; Leaf et al., 2008). Low density populations of abalones have been shown to depend on spatial aggregation, sheltered embayments, and consistent kelp availability (Hart et al., 2020). The paucity of suitable habitats with favorable environmental conditions combined with their life history constrain abalone spatial distribution and abundance.

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doi: https://doi.org/10.7755/MFR.85.1-4.2

Fishery History

Abalones are a highly desirable seafood and have been used by many cultures. Native American tribes throughout the U.S. west coast treasured abalones not only as a food source but also as one of the most prized shells in trade (Heizer, 1940; Bonnot, 1948). Beginning in the 1850's, Chinese immigrants developed intertidal commercial fisheries for California abalones, where catch rose to over 1.8 million kg in 1879. That fishery gave way to a dive fishery undertaken by Japanese immigrants. In turn, the Japanese fishery gave way to the Caucasian immigrant fishery beginning in 1929. By the 1940's large scale commercial fisheries of California abalones were principally undertaken by Caucasians (Cox, 1962). While this describes activities central to abalone population, little documentation is available for early fisheries in Oregon.

Commercial fisheries occurred for all abalone species along the U.S. west coast, each showing a "boom and bust" pattern. By 1969, commercial fishing for abalones in California slowed down, then closed in 1997 (CDFW, 2005). A small commercial fishery for flat abalone, *Haliotis walal-*

ABSTRACT—Abalones (Haliotidae) are highly prized and eagerly sought; however, their populations are particularly sensitive to fishing and environmental changes. All seven abalone species living along the U.S. west coast are imperiled to some degree. Historically, four species of abalones have occurred in Oregon, and three are currently found. Along the U.S. west coast, fisheries have occurred for some of these species; however, all were suspended as of 2018. Red abalone, Haliotis rufescens*, are at the northern extent of their range in Oregon, and populations are sparse but individual size is very large. Red abalone were fished commercially (1958–62) and recreationally (1900's–2018), but both were closed due to sustainability concerns. Oregon's recreational red abalone fishery began as a "food" fishery, but recognizing their large individual size, lowering catch limits, and increasing scarcity eventually moved to a "trophy" fishery. Oregon's red abalone are sparse, but population levels have varied widely; environmental changes including tsunami and coastal flooding in 1964 and oceanographic changes in the late 2010's have severely affected their abundance.*

Southern Oregon (nearshore waters from Coos Bay to California/Oregon border) is a stronghold for populations of flat abalone, H. walallensis*, a smaller species which is naturally rare throughout their range. They were the subject of a small but valuable artisanal commercial fishery (2001–08), which closed due to sustainability concerns. Oregon's commercial flat abalone fishery showed clear effects of fishing, despite its small scope and short duration. Since the closure of the fishery, stocks appear to have further declined, probably owing to environmental changes and latent fishing effects.*

Pinto abalone, H. kamtschatkana*, and black abalone,* H. cracherodii*, have also been found in Oregon, but in very low numbers and not consistently over time. Overall, abalones in Oregon have undergone large shifts across the past century. Oregon's abalones are currently imperiled and there is interest to both maintain their populations and allow fishing opportunities. Finding ways to utilize societal investment in Oregon's abalones may be key to assuring sustainability.*

lensis, was open in Oregon from 2001 to 2008, detailed later. Recreational fishing for red abalone, *Haliotis rufescens*, endured in Oregon but ended in 2017 (Groth[1]).

Abalone populations are particularly sensitive to fishing, confounding sustainability of their fisheries. Abalones are often sessile and occupy shallow depths, limiting refugia from fishing. Typically, fishing effort focuses first on areas of high densities, which, in the case of abalone, are spawning aggregations containing the most critical individuals to the population. Once spawning aggregations are fished down, serial depletion is likely (Karpov et al., 2000; Hobday et al., 2001; Hilborn et al., 2005).

Consequences of serial depletion are evident in the many abalone fisheries which have collapsed. Along the U.S. west coast, two of the seven abalone species (*H. cracherodii* and *H. sorenseni*) are listed as "endangered" under the Endangered Species Act (ESA).[2] The remaining five west coast abalone species are listed as "critically endangered" or "endangered" with the International Union for Conservation of Nature (IUCN[3]).

Abalone in Oregon

In Oregon, four species of abalone have been found within the state's biogeographic range: red abalone, *Haliotis rufescens*; flat abalone, *H. walallensis*; pinto abalone, *H. kamtschatkana*; and black abalone, *H. cracherodii* (Fig. 1). Abalones are principally found in southern Oregon where rocky nearshore kelp beds are prevalent but discontinuous. Red abalone are found as far north as Coos Bay, Oreg., though a few individuals have been found as far north as Depoe Bay (McCauley and Marriage, 1955). Flat abalone are found throughout southern Oregon and northward in areas around Depoe Bay.

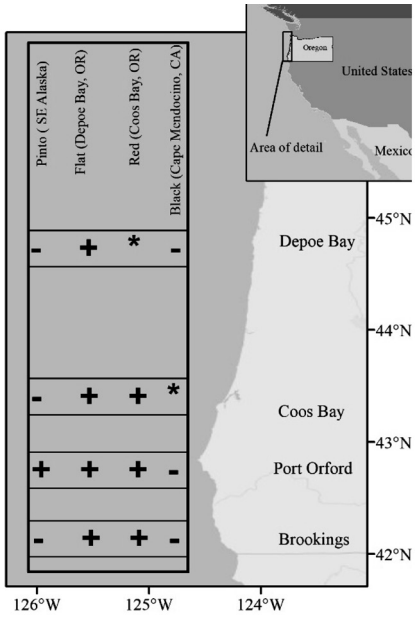


Figure 1.—Condition of known presence of four abalone species (black, red, flat, and pinto) in Oregon at key locations. Plus signs indicate definite presence, minus signs indicate no records of finding, and an asterisk indicates special conditions described in sections for each species.

The geographic range of the flat abalone is not well documented; some publications list Newport, Oreg. (Rogers-Bennett, 2007), while others extend their range well into Washington (Geiger, 1999). Because morphological identification is most common, the phenotypic plasticity found for flat and pinto abalone (Straus, 2010) may confound published range extents, especially for flat abalone. Pinto abalone range from southeast Alaska to Point Conception, Calif. (Geiger, 1999; NMFS, 2014); however, they are extremely rare in Oregon. The northern range termination of black abalone, *H. cracherodii*, is currently Point Arena, Calif. (NMFS, 2018); however, the northern termination of the historic range may extend to Coos Bay. (Marriage[4]).

Red abalone (right) and red sea urchins (left) found under a rock near Port Orford, Oregon. Photo: Scott Groth.

Red Abalone

Red abalone occur cryptically in nearshore kelp beds of southern Oregon. Their populations have been affected by fisheries, ecological changes, stock enhancements, and devastating environmental events. Red abalone have been reported in the Brookings, Oreg., area since at least the early 1900's (McCauley[5]). Since that time, their northern range termination was extended incrementally until it was defined as Coos Bay, Oreg., in 1957 (Lyons, 1957). Red abalone are the largest species of abalone in the world (Cox, 1962) and are especially prized in fisheries. The largest specimens of red abalone have been found in Oregon. A brief exploratory commercial fishery existed from 1958 to 1962, while a recreational fishery persisted from 1953 to 2017.

Ecological changes which have affected populations of red abalone include the removal of sea otters, *Enhydra lutris*, a key abalone predator in the late 1800's (Jameson et al., 1982), and in recent years increased spatial competition by sea urchins (Groth, 2023) and lowered food abundance (Rogers-Bennett and Catton, 2019). Given their rarity and desirability for expanded fisheries, two major stock enhancement efforts have been made. Lastly, freshwater influx and ocean warming events in recent history have

[1]Groth, S. March 16, 2018. Modifications to the red abalone fishery. Oregon Fish and Wildlife Commission, Salem, OR (avail. at https://www.dfw.state.or.us/agency/commission/minutes/18/03_Mar/index.asp).

[2]https://www.fisheries.noaa.gov/species-diectory/threatened-endangered

[3]IUCN (International Union for Conservation of Nature). 2023. Available at https://www.iucnredlist.org/, accessed 23 Apr. 2023.

[4]Marriage, L. D. 1954. Distribution of abalone in Oregon. Oreg. Fish. Comm. Unpubl. internal memo.

[5]McCauley, J. E. 1953. The mussel, piddock, and abalone resources of Oregon's outer coast. Oreg. Fish. Comm. unpubl. internal memo.

likely had substantial impacts on Oregon's red abalone population.

Fisheries

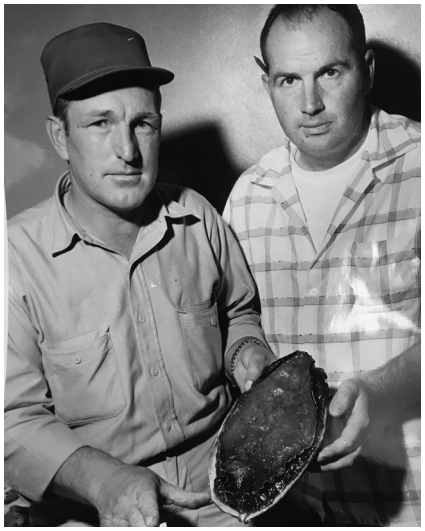
Exploratory Commercial, 1958–62

From 1958 to 1962, the Oregon Fish Commission (OFC) worked with contract divers to explore the commercial fishing of red abalone in exchange for data collection. Data collected from this effort included: 1) dive reports describing sites, abundance, habitat, spatial competitors, etc. and 2) length measurements of abalones. From 1958 to 1959, at least nine abalone were taken during 27 dives. In 1960, at least 102 red abalone were taken in 31 dives. During 1961–62, few dives were performed as momentum for this project waned. Over the term of the contract, at least 111 red abalone were taken, then sold or shared. After four years, this work yielded knowledge of red abalone distribution and biology. In 1962, the Oregon Fish Commission (OFC) staff recommended cancellation of this commercial fishery until greater concentration of red abalone were found (Snow[6]). To date, no further commercial fishing for red abalone has occurred in Oregon.

Recreational Fishery and Management, 1950's–2021

Oregon's recreational red abalone fishery has grown in popularity over time, despite fishery rules becoming more strict due to increased participation and concern for stock depletion. Recreational red abalone fishing began in Brookings prior to the early 1950's (McCauley et al., 1955). In 1959, Oregon adopted its first rules for the fishery: 1) 203 mm (8 inches) minimum legal size (MLS), 2) required to measure abalone before removing, and 3) limit of 3 abalone per every 7 days (Snow[7]). In 1973, a red abalone catch reporting permit was introduced to elucidate catch rates (OFC[8]); the permit remained in place until 1979. In 1996, rules were established that 1) reduced the daily limit to 1 abalone, 2) reduced the annual limit to 5, and 3) added the requirement of a catch reporting permit. In 2018, the Oregon Fish and Wildlife Commission (OFWC) suspended the fishery for a period of 3 years (Groth[1]). In 2021, the recreational fishery was suspended an additional 3 years (Rumrill[9]). In each case, management actions responded to concerns about red abalone population levels, viewed by fishery participants and managers of each era as further imperiled.

Fishermen with abalones from Oregon's commercial red abalone fishery in the vicinity of Brookings, Oregon. Photo: ODFW Archives.



Lee Narin (commercial fisherman) and Dale Snow (OFC biologist) posing with a red abalone during Oregon's exploratory commercial red abalone fishery. Photo: ODFW Archives.

Catch Report Permits

Catch report permits were required (at no cost to participants and not limited in issuance) in the recreational red abalone fishery during 1973–79 and 1996–2017. Permit data included information about catch (i.e., number taken, location, depth, method, etc.) and demographic information about the permittee. Issuance of each year's catch permit required submission of the prior year's catch data.

In 2013, the catch report permit was expanded to also include rock scallops, *Crassodoma gigantea*, often collected by the same people who target red abalone. A census of 2014 permittees found 15% targeted rock scallops only (Gregory[10]). We used this estimation to isolate permits used to target red abalone for years 2013–17, when both species were on the same permit.

From 1973 to 1979, on average, 126 catch reporting permits were issued, compared to 175 from 1996 to 2017. Permit issuance trended up sharply during 1996–2017, peaking in 2017 at 280 permits (Fig. 2).

Catch Data

To develop catch rates, reported permits were tabulated, then expanded to account for non-reported permits. A total of 4,946 permits were issued and 2,692 were submitted. Non-reported catch was accounted for by expansion using rates of reporting and catch by year using methods from a sepa-

[6]Snow, D. 1962. Abalone research studies 1958–1962. OFC unpubl. memo.

[7]Snow, D. 1959. Suggested personal use regulations for red abalone (*Haliotis rufescens*) in Oregon. OFC unpubl. memo.

[8]Oregon Fish Commission. 1972. Staff request for a permit system to harvest red abalone. ODFW unpubl. memo.

[9]Rumrill, S. February 12, 2021 Suspension of recreational abalone fishery. Oregon Fish and Wildlife Commission, Salem, OR (avail. at https://www.dfw.state.or.us/agency/commission/minutes/21/02_Feb/index.asp).

[10]Gregory, K. 2018. Estimates of total harvest of red abalone in Oregon. ODFW unpubl. memo.

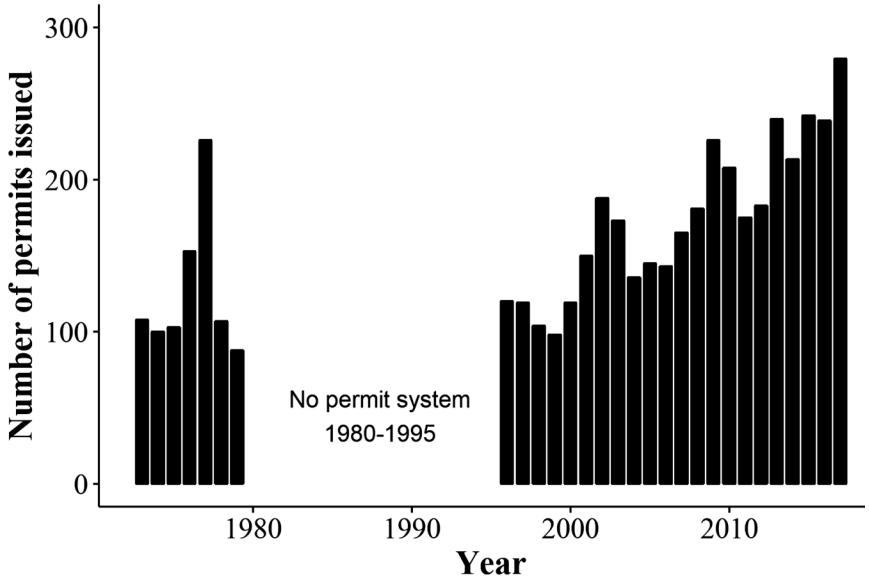


Figure 2.—Oregon recreational red abalone permits issued from 1973 to 1979 and 1996 to 2017.

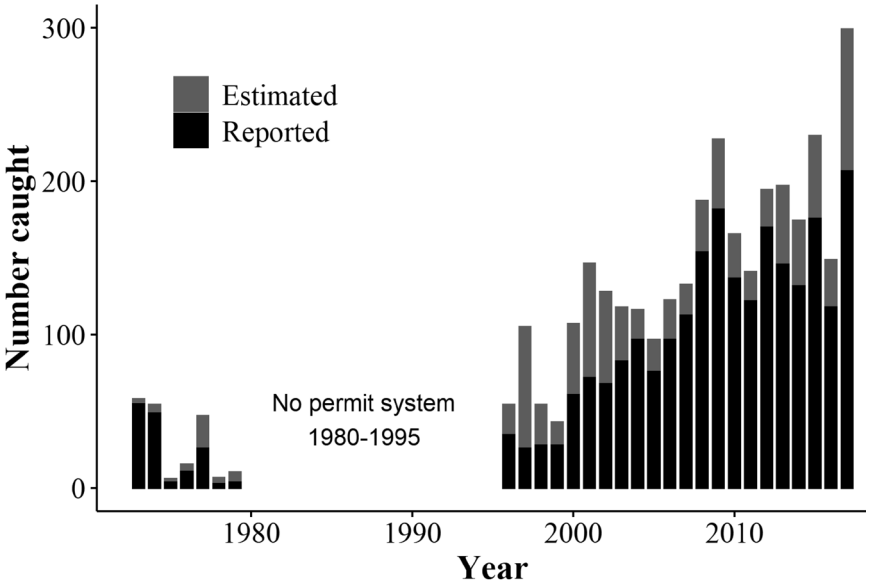


Figure 3.—Oregon recreational red abalone fishery catch from 1973 to 2017.

rate study (Gregory[10]). To quantify the total catch, reported and non-reported catch were combined. Total annual harvests have increased over time owing to higher effort and success rates. From 1973 to 1979, an average of 28 red abalone were taken, then from 1996 to 2017 the average increased to 145, peaking in 2017 when 299 red abalone were taken (Fig. 3).

Harvest Methods, Depth, and Area

Harvest methods for red abalone in Oregon include: 1) scuba, 2) free diving (snorkeling or breath-hold diving), and 3) shore picking (i.e., tide pooling or rock picking). Total catch among all years (1973–79 and 1996–2017) was 2,494 red abalone. Of these, 51.4% were taken using scuba, 29.3% by free diving, and 19.2% from shore picking (n=2,494). Mean depth of catch was 5.2 m for scuba, 4.0 m for free diving and 0.3 m for shore picking (n=2,169).

Beginning in 2005, permittees were required to report harvest areas and activity was strongly focused on southern Oregon. Most catch (95.4%) was reported (n=2,221) near Brookings, while 3.3% was reported in Port Orford and less than 1% was reported at areas near Gold Beach and Coos Bay (Fig. 4).

Catch Size

In Oregon's recreational red abalone fishery, participants are primarily motivated to take trophy-sized shells, not simply for harvest of meat (personal observ.). Conventionally, a trophy-sized red abalone shell is greater than 254 mm (10 in), and many participants go so far as to carry measuring devices (typically fixed arm calipers) capable of assessing this size rather than simply meeting the minimum legal size (MLS).

Owing to the motivation for trophy shells, the fisheries' MLS did little to govern catches. The MLS of red abalone is 203 mm shell length (SL), but the fishery mean size was 245 mm SL. While this may seem like a minor difference of the linear shell measurement, by weight, the two examples would be 1.6 and 2.8 kg. The large mean size indicates larger animals were targeted and available; however, the lack of new recruitment and availability of smaller animals may also contribute.

By method, scuba and free divers found the largest red abalone. We examined mean shell lengths from two eras using a Mann-Whitney U (MW) test, since each era's shell length data is independent and non-parametric. The mean shell length of red abalone (all methods) significantly increased from the 1970–79 era (230.5 mm) to

Table 1.—Mean shell length (and standard deviation) of red abalone in Oregon from catch reporting permits by era 1970–79 and 1996–2017.

	Scuba		Shore Pick		Free dive		Total	
Era	Mean size	Count	Mean size	Count	Mean size	Count	Mean size	Count
1970–1979	233.2 (19.8)	113	221.5 (9.2)	9	221.7 (19.6)	26	230.5 (19.8)	148
1996–2017	247.2 (17.6)	1,137	232.8 (19.6)	429	251.4 (17.9)	703	245.8 (19.2)	2,269
Avg.	246.0 (18.3)	1,250	232.6 (19.5)	438	250.3 (18.7)	729	244.9 (19.6)	2,417

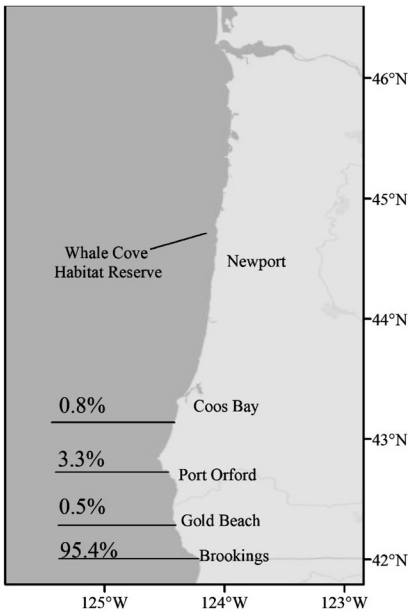


Figure 4.—Percentage of reported recreational red abalone fishery catch by area from 1996 to 2017 in Oregon (*n*=1,894). Note: only one red abalone was reported as caught north of Coos Bay, Oregon.

the 1996–2017 period (245.8 mm) ($p<0.0001$ MW test) (Table 1).

Surveys

In the 1950's, soon after the documented geographic range of red abalone was extended into Oregon, investigations began to develop further understanding. From 1958 to 1962, the OFC contracted with divers to survey red abalone. The nature of the surveys was qualitative, though communications and measurements of catch improved understanding of the population. From the 1960's to 1990's, the OFC (later renamed the Oregon Department of Fish and Wildlife (ODFW)) performed qualitative surveys and worked with the public to continue building an understanding of Oregon's red abalone. Quantitative surveys for red abalone were first attempted in 2011, formalized in 2015, then repeated in 2019 and 2022.

Pilot Surveys, 2011

In 2011, a 2-day experiment tested two methods to quantify density of red abalone and describe their size distribution. These methods were 1) polygonal index sites and 2) timed surveys. These methods were tested in an area near Brookings, the most important site to the recreational red abalone fishery.

On 23 June 2011, to test a method for red abalone density measurement, a 77 hectare polygonal index site was developed from the shoreline to a 10 m bathymetric line, encapsulating the most heavily used harvest area. Random points were drawn to begin subtidal belt transect lines and ten, 30 x 2 m transects were performed. The result of this survey was that zero red abalone were found within transects. A key takeaway from this result was that even in the most dense locations in Oregon, red abalone may be too rare to practically perform simple random sampling methods.

On 24 June 2011, to focus on size distribution of red abalone, divers performed timed surveys. While timed surveys have not proven to be an accurate density metric (Gorfine et al., 1996), they can provide robust size distribution data at low density locations. A team of two divers was deployed at sites where the fishery operates (red abalone were expected to be present). Each diver recorded the number and size (SL) of abalones found. The result of this survey was 55 shell length measurements and a count-per-hour density measurement.

Index Surveys in 2015, 2019, and 2022

In 2015, index sites were selected by identifying areas where the fishery operated (near Port Orford and Brookings) and therefore a relatively high density of abalones was expected. Teams of two divers performed 30 x 2 m subtidal belt transects, identifying and enumerating all abalones and sea urchins. Forty-four transects were performed during 5 days, 20 in Port Orford (Fig. 5a) and 24 in Brookings (Fig. 5b). The index survey method provided a measurement of both density and size distribution of abalones at each site. In 2019, 11 sites in Port Orford were repeated and in 2022, 13 sites in Brookings were repeated. This method is biased towards high density locations since transects are performed where the fishery operates. In this way, it may only be appropriate to compare relative abundances found at surveys temporally.

Trends in Abundance

Abalone abundance is not easily measured, and methodology in Oregon have been sparsely assessed and inconsistent over time, confounding comparisons. Surveys focusing on capturing relative abundance, a measure of density used to index populations, to determine the total number of abalones in Oregon (absolute abundance) has been seen as too costly. Early surveys were simply timed dives with recorded notes about how many abalones were found in each dive.

Timed survey data from 1969 and 2011 show a much higher detection rate in recent years; however, these results could easily be affected by diver expertise, a key problem with timed surveys (Table 2). The results of 2015 index surveys showed

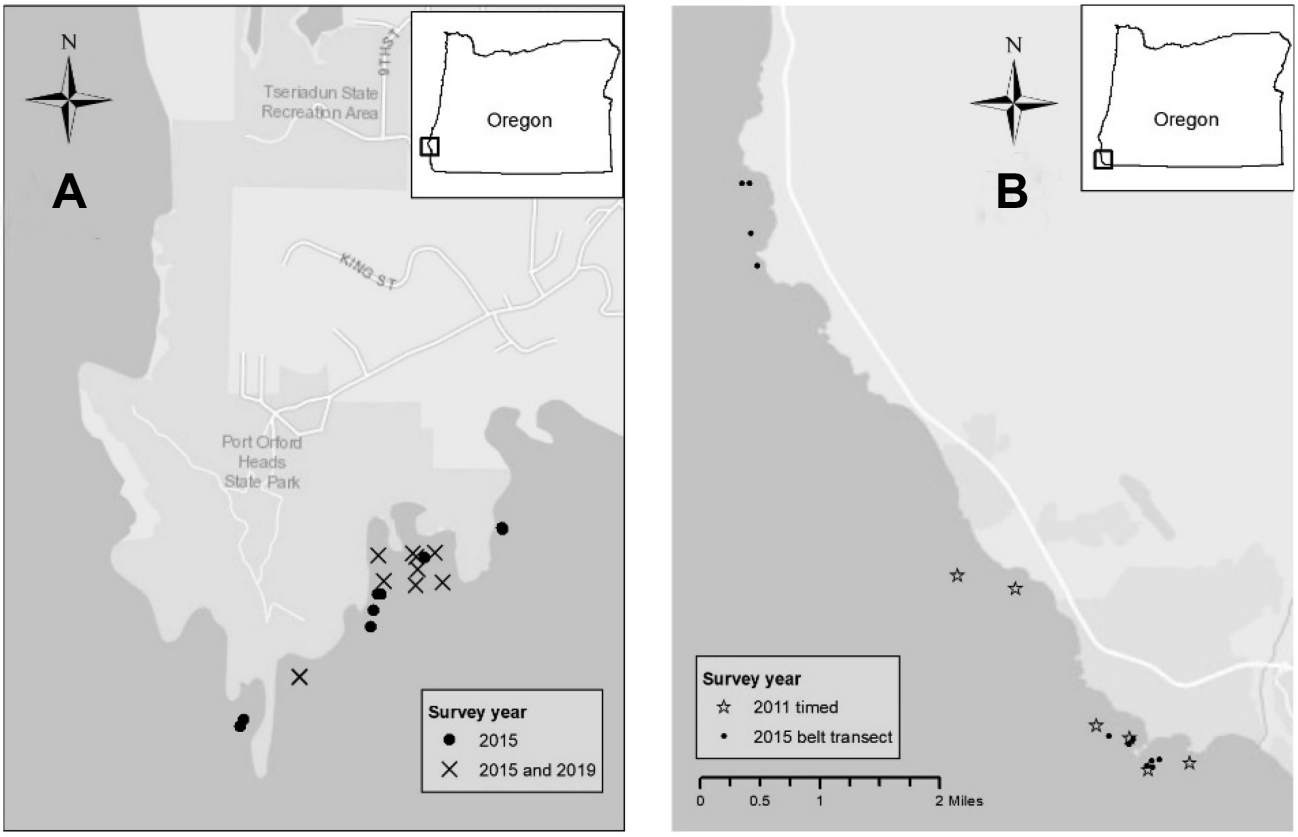


Figure 5.—Abalone survey sites at A) Port Orford, Oreg. (belt transects) and B) Brookings, Oreg. (timed and belt transects) for 2015 and 2019.

Table 2.—Number of red abalone seen in timed dives by year (1969, 2011) in Brookings, Oreg.

Year	No. seen	Survey min	Abalone/hr
1969	46	250	11.15
2011	55	127	24.39

Table 3.—Red abalone densities (per m^2) from fishery independent index sites in 2015, 2019, and 2022 by port in Oregon.

	Port	
Year	Brookings	Port Orford
2015	0.047	0.030
2019		0.017
2022	0.014	

low density of red abalone at both Port Orford and Brookings (0.047/m^2 and 0.03/m^2, respectively), subsequent surveys (Brookings in 2022 and Port Orford in 2019) showed further lowered densities at both sites (0.014/m^2 and 0.017/m^2, respectively) (Table 3).

Size Distribution Trends

All qualitative and quantitative surveys measured only emergent abalones (i.e., those found without use of lights or by moving substrate) optimizing comparison of size distributions despite methodological differences. Pooled (state-wide) red abalone size distributions have been relatively similar throughout time; however, some changes became evident in 2019 (Fig. 6).

Mean SL of red abalone among area by year has not changed significantly ($p>0.1$ in all comparisons in Brookings (MW test)), which include data up to 2015, (Table 4), however Port Orford size length data has significantly changed (reduced) in recent years, which include 2019 surveys ($p=0.02$ MW test). It seems likely that the change in size distribution found in 2019 is due to detection rate, where smaller abalones have come out of cryptic habitats in search of kelp, given low kelp abundances in recent years.

Enhancement Projects

Given the difficulty of maintaining sustainability in abalone fisheries compared to the ease in which abalones are cultured in a laboratory, stock enhancement is an inviting opportunity. Worldwide, the most large-scale and successful abalone stock enhancement efforts have occurred in Japan, with 10 million seed cultured and distributed in one year (1979) alone (Leighton 1989; Tegner and Butler, 1989). Although abalone seed have been successfully hatched and distributed, juvenile survival rates vary based on species and geographic circumstances. Tegner and Butler (1989) attempted to apply Japanese seeding techniques to southern California red,

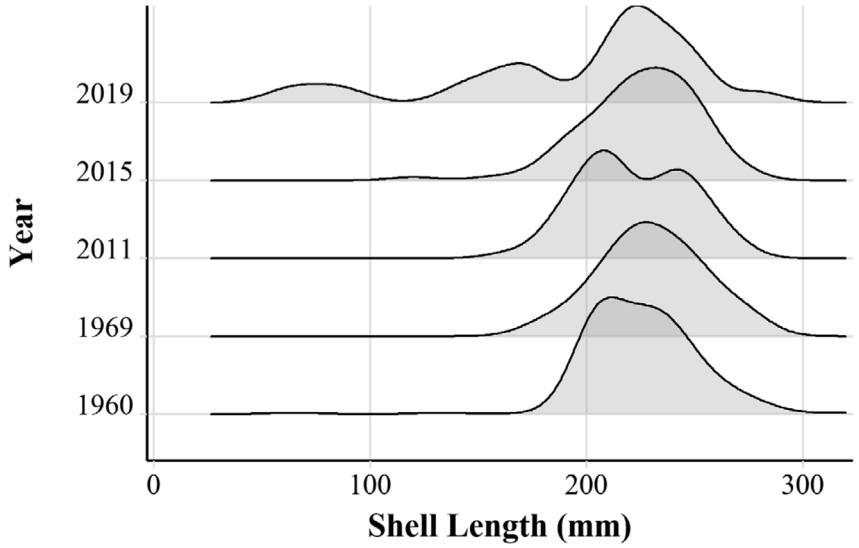


Figure 6.—Red abalone shell lengths from Brookings, Oreg., survey data 1960, 1969, 2011, 2015, and 2019.

Table 4.—Mean shell length (and standard deviation) of red abalone in Oregon by port from survey data for 1960, 1969, 2011, 2015 and 2019.

	Area			
Year	Brookings	*n*	Port Orford	*n*
1960	225.5 (25.5)	221		
1969	230.1 (23.9)	86		
2011	221.9 (24.5)	55		
2015	225.7 (23.8)	51	222.6 (30.2)	33
2019			196.9 (56.1)	26

green, and pink abalone populations but had minimal success, and another enhancement experiment in northern California also found low juvenile red abalone success rates (Rogers-Bennett and Pearse, 1998). ODFW has made two efforts to bolster red abalone stocks, a 1960's project at Whale Cove and a 1990's effort in southern Oregon (Golden[11]).

Whale Cove, 1967–2018

ODFW attempted to create new spawning stocks of red abalone to develop a new fishing opportunity near Whale Cove, a small area just south of Depoe Bay and 100 miles north of their northern range extent. Hatchery-reared juveniles and transplanted adult red abalone were introduced into the small cove due to its protected rocky habitat, abundance of marine vegetation, and ease of access. Conceptually, a protected Whale Cove red abalone population would serve as a spawning stock for adjacent catch areas and provide experimental data on growth and reproduction. Accordingly, Whale Cove was designated as a Habitat Refuge (HR) in 1967, disallowing take of shellfish (Nielsen[12]). Staff introduced red abalone from 1967 to 1974, then surveyed the resulting population from 1967 to 2018.

From 1967 to 1974, 5,660 juvenile and 277 adult red abalone were introduced to the intertidal areas of Whale Cove HR. First, in May 1967, 660 hatchery-reared juvenile red abalone were introduced; those abalone survived, then in July of 1967 an additional 5,000 juveniles (5–20 mm SL) were planted. Then, in 1968–69, 261 adult red abalone collected at Fort Bragg, Calif., were placed in Whale Cove. The last outplanting occurred in March 1974 (16 adult red abalone). To track populations, red abalone were tagged. In total, 576 red abalone were affixed with stainless steel tags secured using wire through their respiratory holes. Intertidal surveys of red abalone within Whale Cove were performed annually (1968–91) then sporadically (1992–2018) to measure mortality and growth.

The Whale Cove red abalone project provided some baseline information about growth, age, longevity, and reproduction rates in Oregon. It was reported that growth rates of these red abalone to legal harvestable size (203 mm SL) could be as little as 10 years (Lukas[13]), while earlier calculations from the same study suggested that legal size red abalone would be around 22 years old (Gaumer[14]). Red abalone from this initial planting were found up until 1991 when annual surveys were suspended. These red abalone were most likely from the 1967 planting, then being 24 years old (*n*=12, mean size 190 mm SL). Further, surveys in 2009 (*n*=4, mean size 208 mm SL) and 2017 (*n*=4) found 4 adult red abalone (Metzler[15]) which were almost certainly from the original planting (at the same locations as recalled by historic staff) that are likely as old as 50 years. Recapture rates estimated that 241 of the 5,500 (4.3%) red abalone planted in Whale Cove persisted in 1975, eight years after planting (Gaumer[14]). Throughout this study, no evidence of new, wild reproduction was found (no new recruits were found in periodic searches). A few tags (apart from shells) and shells with tags were found in the modern era (2005–17) demonstrating recent demise; however, no live animals with tags have been found recently (personal observ.).

[11]Golden, J. T., and C. Langdon. 1995. Development of a red abalone broodstock from abalone native to Oregon, abalone culture and outplanting experiment. ODFW unpubl. memo.

[12]Nielsen, J. 1967. Whale Cove shellfish regulations for Fish Commission public hearing. Oreg. Fish Comm. Hearing.

[13]Lukas, J. 1978. Abalone research and management activities, 1958–77. ODFW unpubl. memo.

[14]Gaumer, T. F. 1975. Whale Cove abalone. ODFW unpubl. memo.

[15]Metzler, J. 2017. ODFW abalone snorkel surveys. ODFW unpubl. memo.

OFC biologist tagging red abalone at Whale Cove, Oregon. Photo: ODFW Archives.

Flat abalone, surrounded by encrusting invertebrates in Nellies Cove, Oregon. Photo: Scott Groth.

Ultimately, this project had no noticeable effect in creation of a new fishing opportunity for red abalone. From catch permit data (1972–79 and 1996–2017), only one red abalone was taken north of Coos Bay among the 2,221 reported.

Southern Oregon Enhancement Project, 1994–99

In 1994, another red abalone outplanting project was developed, a cooperative effort between ODFW and Oregon State University (OSU) (Golden[16]). The goal of this project was to develop rearing methods for red abalone that were locally adapted, making new populations to serve as a local spawner source. The project was delayed due to infection concerns (i.e., renal coccidian, withering foot) due to importation of hatchery stock from California. The program then shifted objectives to creating a broodstock population from red abalone collected in Oregon. Approximately 20 red abalone were collected by staff and contracted divers. Spawning was successful and approximately 50 juvenile red abalone were reared until they reached outplanting size. The project was halted in 1999 due to lack of funding and momentum (Langdon[17]). In 2002, many red abalone remaining from this program were outplanted near Charleston by commercial sea urchin divers (Foley[18]), though no follow up surveys occurred.

Environmental Events

In the nearly 70-year historical record of reports regarding red abalone in Oregon, two environmental events were coincidental to major reductions in red abalone populations. First, in 1964, a tsunami and coastal flooding are likely to have reduced abalone populations substantially. On March 27, 1964 a high-magnitude earthquake, originating in Alaska produced severe waves and current in southern Oregon (Witter et al., 2001), likely strong enough to dislodge or destroy intertidal fauna. During flooding, massive sedimentation from flooding was exacerbated by the adjacent construction of Highway101. ODFW staff notes from the time reported high sedimentation, many empty red abalone shells washing up, and a lack of live red abalone in areas where qualitative surveys had documented them prior (Lukas[13]).

Next, from 2014 to 2017, a series of events caused another major reduction in red abalone abundance in Oregon. Bull kelp beds during this period were dramatically reduced across the region due to intense ocean warming, loss of sea stars (via sea star wasting syndrome), and dramatic increases in sea urchin populations (Rogers-Bennett and Catton, 2019). The loss of bull kelp beds resulted in abalone starvation causing once again high numbers of empty abalone shells found on Oregon beaches (personal observ.). Survey data also shows substantial reductions in red abalone populations, where low densities found in 2015 were reduced even further, to around half what they were in previous work (Table 3).

Flat Abalone

Along the U.S. west coast, flat abalone are considered a minor species in the context of fisheries due to their small size and sparse abundance. Southern Oregon is a rare stronghold for flat abalone, a species uncommon in California (Rogers-Bennett, 2007) and largely absent in Washington (Straus, 2010). While flat abalone were not a target of a recreational fishery in Oregon, they were the target of a commercial fishery.

[16]Golden, J., and J. Martin. 1995. Abalone and salmon culture at former Oregon Aqua site. ODFW unpubl. memo, 22 p.

[17]Langdon, C. 2019. Oregon State University, Corvallis. Personal commun.

[18]Foley, T. 2019. Oregon commercial sea urchin diver. Personal commun.

Commercial Fisheries, 2001–08

Fishery Management

Oregon's commercial fishery for flat abalone began in 2001, and in 2008 it was closed amid sustainability concerns. The fishery was managed by: 1) limited entry (one permit), 2) an annual quota, and 3) minimum legal size (MLS). The permittee was required to keep logbooks, allow access to catch for measurement, and perform pre- and post-fishing surveys. Quota was established at 1,361 kg (3,000 lb) per year in 2001, then reduced to 907 kg (2,000 lb) per year in 2008, the final year of the fishery. A MLS was set at 114 mm (4.5 in) SL in 2001, then increased in 2008 to 121 mm (4.75 in).

Logbooks and landing receipts were required. The 2001–08 commercial flat abalone fishery logbooks included date, catch area, dive time, mean depth, and estimated weight of catch. Landing receipts recorded date, port, whole weight, and value.

In each year of the fishery, the quota was met, amounting to total landings of 10,092 kg (22,249 lb) of flat abalone from 2001 to 2008. By port, fishing was focused on south coast ports with 44% landed in Port Orford and 41% landed in Gold Beach. The remaining landings occurred at Brookings, Charleston, and Depoe Bay (8.2%, 5.7%, and 1.1%, respectively). By catch area, focus was on Oregon's two large offshore reefs, Rogue Reef (43.4% of catch) near Gold Beach and Orford Reef (20.2%) but also included high catch from Nellies Cove (22.1%), a small protected cove near Port Orford. The remaining 14.3% of catch was from other areas along the south coast but also with some catch in the central coast near Depoe Bay (Fig. 7). Fishery metrics showed "fishing down" effects. Fishing time became longer (Fig. 8a), depth of catch became deeper (Fig. 8b), and CPUE decreased (Fig. 8c).

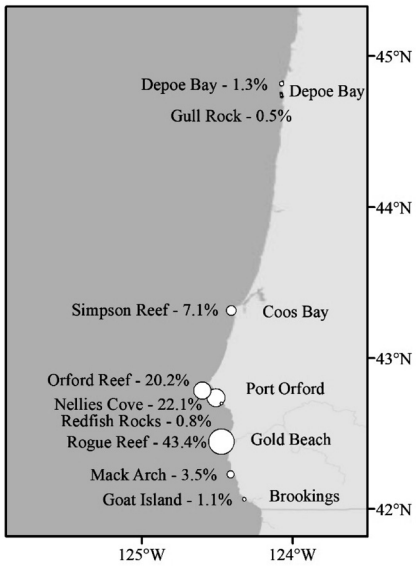


Figure 7.—Catch in Oregon's commercial flat abalone fishery by reef area on the south coast from 2001 to 2008.

Fishery Management

Market sampling was conducted sporadically. Fishery deliveries were selected haphazardly, then 50 flat abalone per delivery were selected randomly and measured with 300 mm Vernier calipers. Shell length was measured for each flat abalone; whole weight, sex, and gonad condition data were occasionally included. Market samples showed a 54:46 male to female sex ratio for the 1,443 flat abalone where sex was determined. Overall, there was little variation in mean size by area or time, typically remaining close to the minimum size length in the rules of the fishery (Table 5).

To establish a length to weight relationship for flat abalone, shell length (SL) of flat abalone from catch samples were converted to their biomass equivalents (W) (based on wet weight of all individually weighed samples collected between 2004 and 2008, R^2 =0.87, *n*=937) using this allometric relationship: $W = 0.0000928 \times SL^{3.0852}$ (Fig. 9).

Surveys

Two survey efforts have quantified flat abalone populations at key areas: 1) fishery dependent surveys conducted during the 2001–08 commercial fishery (within fishing areas) and 2) fishery independent surveys of 2015 and 2019 at two sites (Port Orford and Brookings).

Fishery Dependent Surveys (2001–08)

Surveys for flat abalone were performed (by the permittee) each time fishing began in a new area (2001–02),

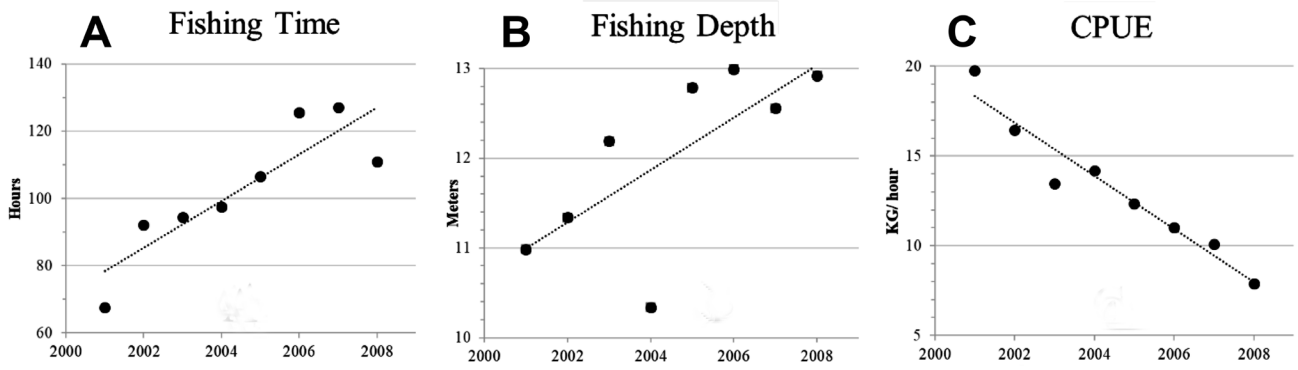


Figure 8.—Fishery metrics of Oregon's commercial flat abalone fishery from 2001 to 2008, by year. A) fishing time (hours) and B) fishing depth (m) showed increasing trends while C) fishery CPUE (catch (kg)/ fishing time) had a decreasing trend.

Table 5.—Mean shell length (mm) and count of measurements (in parentheses) from flat abalone market samples from 2001 to 2008 in Oregon.

	Area						
Year	Rogue Reef	Nellies Cove	Orford Reef	Depoe Bay	Goat Island	Gull Rock	Total
2001	131.6 (10)				146.9 (25)	142.0 (30)	142.3 (65)
2004	134.8 (109)	129.3 (38)					133.4 (147)
2005	128.7 (236)		121.5 (70)				127.1 (306)
2006	129.8 (141)		127.9 (103)				129.0 (244)
2007			126.9 (259)				126.9 (259)
2008	137.6 (268)	130.0 (113)	130.2 (257)	138.0 (228)			134.5 (866)
Avg.	133.0 (764)	129.8 (151)	127.7 (689)	138.0 (228)	146.9 (25)	142.0 (30)	131.7 (1,887)

then revisited approximately 5 years later (2006–08). Survey sites were typically within kelp beds, in highly rugose habitats and at depths of 5–15 m. A 100 m transect was surveyed, where in each 10 m interval a 1-m² quadrat was evaluated for count and size of flat abalone. This methodology is strongly biased towards "hot spots"; however, it could serve as a maximum abundance survey or for temporal comparison.

Surveys conducted prior to fishing (2001–02) showed robust populations of flat abalone. Follow-up surveys (2006–08) showed substantial "fishing down" of those same populations. Densities at the primary catch areas (Rogue Reef, Orford Reef, and Nellies Cove) declined by 59%, 28%, and 80%, respectively (Table 6). Survey methodology (particularly its fishery dependence) was not ideal; however, they were performed carefully and directly in cooperation with ODFW. This was necessary because ODFW did not have a diving program after 1999. The declines in density at each catch site were expected and, despite suboptimal methodology, agree with other fishery metrics (i.e., changes to effort, depth, and CPUE (Fig. 7)).

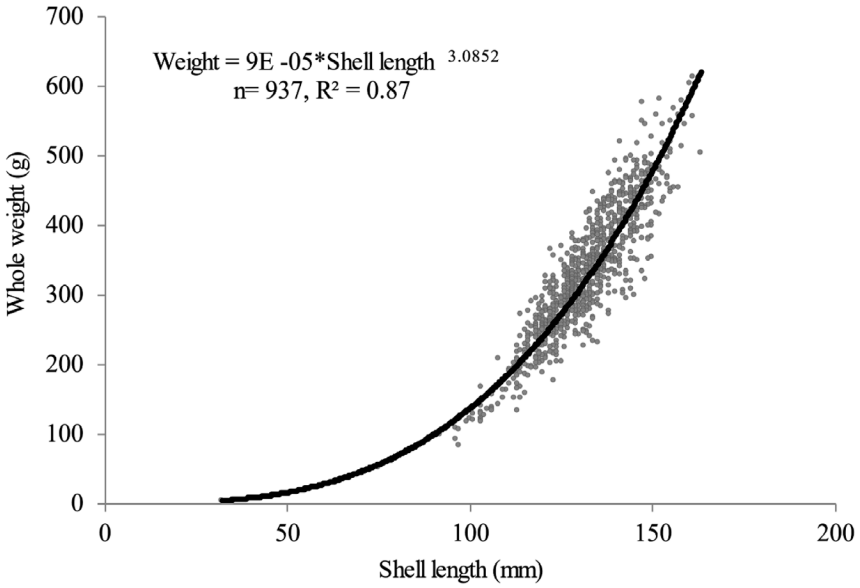


Figure 9.—Length/weight relationship of individually measured flat abalone market samples (n=937) from 2001 to 2008 in Oregon.

Fishery Independent Surveys in 2015 and 2019

Two efforts to quantify flat abalone abundance occurred in areas where flat abalone are historically common. Quantitative surveys for abalones occurred at Port Orford and Brookings (methodology described in red abalone section) in 2015 and 2019. The results of these surveys show two things: 1) the overall very low density of abalones in Oregon and 2) the significant decrease ($p<0.01$, MW test) of flat abalone between 2015 and 2019 (Table 7).

The flat abalone abundance was reduced sequentially, likely reacting to fishing, then poor environmental conditions. An important example of Oregon's flat abalone population trajectory is Nellies Cove, an area which has historically had a robust population. Densities found in fishery dependent surveys of 2001 were 5.6 flat abalone/m^2. By 2008, flat abalone density reduced to 1.1/m^2.

Next, fishery independent surveys showed a low density of flat abalone in 2015 (0.013/m^2). By 2019, density reduced to 0.002/m^2; only one flat abalone was found within 11 belt transects, covering 660 m^2 of high quality abalone habitat. The reduction in abundance of this once prominent species appears nearly complete, where a species once found in commercial quantities could become locally extinct.

Pinto Abalone

Pinto abalones range from southeast Alaska to Baja California, Mexico, encompassing Oregon. Despite being central to its range, pinto abalone are extremely rare in Oregon. Although targeted searches using methods known to detect pinto abalone were preformed, no live specimens were found in Oregon for many years (Marriage[4]; Reimers[19]), includ-

[19]Reimers, P., and D. Snow. 1975. Rare and endangered species. ODFW unpubl. memo.

Table 6.—Density of flat abalone (per m^2) from fishery dependent surveys (2001–08) in Oregon.

	Area								
Survey	Rogue Reef	Nellies Cove	Orford Reef	Depoe Bay	Mack Arch	Goat Island	Redfish Rocks	Simpson Reef	Average
Baseline	2.2	5.6	3.2	1.1	3.1	1.8	2.3	2.5	2.7
Post-harvest	0.9	1.1	2.3						1.4
Average	1.8	3.4	2.7	1.1	3.1	1.8	2.3	2.5	2.4

Table 7.—Densities of flat and pinto abalone from fishery independent surveys (2015 and 2019) at Nellies Cove, Port Orford, Oreg.

	Densities (per m^2)		
Year	Flat	Pinto	Surveyed area
2015	0.013	None	900
2019	0.002	0.014	660

ing more than 50 years of ODFW dive surveys.

In 2009, the first known live pinto abalone was discovered in Oregon, at Orford Reef by sea urchin divers. Since 2009, pinto abalone have been found more frequently, noted as seen by sea urchin divers a few times a year (Ashmon[20]). In 2015, surveys specifically targeting high quality abalone habitats found no pinto abalone; however, in 2019, nine pinto abalone were found (personal observ.).

Black Abalone

Black abalone have an ambiguous record of presence within Oregon. Early publications identify Coos Bay as its northern range extent (Bonnot, 1948; Cox, 1962; Marriage[4]), citing a general book on marine shells of North America (Oldroyd, 1927). Oldroyd lists the range of black abalone as extending to Coos Bay, although the furthest north a museum specimen has been collected is Crescent City, Calif. (Geiger, 1999). Oldroyd referred to two earlier documents (Leach, 1814; Reeve, 1845) when describing black abalone, neither of which included specific geographic range information. It appears likely Oldroyd's geographical reference was from field observations of the time; however, these were not described specifically. Recently, when black abalone were listed as "endangered" under the ESA, this ambiguous nature of their history in Oregon was highlighted (Butler, et al., 2009:16–17).

A thorough internal ODFW historical document review may elucidate the issue of black abalone presence in Oregon. OFC biologist Lowell Marriage describes his personal finding of live black abalone one mile south of Coos Bay in 1952 and 1954 letters to colleagues (Marriage[4, 21]). Considering the expertise of Marriage, we believe this finding to be accurate. In addition, a University of Oregon biology professor offered some evidence of black abalone presence, though the findings appeared inconclusive (McConnaughey[22]). Over many years, ODFW performed different types of surveys in suitable habitats; however, to our knowledge, no black abalone have been found since.

Discussion

Changes in Abundance

Over a relatively short period, shifts in abalone range and abundance have occurred in Oregon. Populations of each of the four abalone species occurring in Oregon have not been stable.

Red abalone population levels have varied substantially over time. While populations were initially thought to be robust enough to support a commercial fishery (1950's), by the 1960's and 1970's they were difficult to find (evidenced in biologist notations and low success in the recreational fishery). By the 1990's and 2000's they were easily found in the recreational fishery, being taken at high rates and even intertidally. Quantitative surveys of the 2010's showed a low number of red abalone, then a marked decrease was found in 2019 and 2022 surveys.

It is important to note that both major decreases (1960's and 2010's) appeared tied to environmental events (tsunami/floods of 1964 and environmental conditions of late 2010's). At these two times, empty (dead) red abalone shells were reported en masse at Oregon beaches, particularly noteworthy given how rare they are. The causative relationship of these environmental events to the declines of red abalone are difficult to assess. More robust and frequent fishery independent surveys are needed to properly understand trends and mechanisms. The future of red abalone populations appears to be in jeopardy; however, the species did make a comeback from low levels (albeit unquantified) following the 1964 environmental events.

Flat abalone were noted commonly throughout qualitative red abalone surveys in the 1950's–70's. In the late 1990's interest by a sea urchin diver indicated abundances were high enough to make a commercial fishery viable, which occurred from 2001 to 2008. As the fishery progressed, abundance declined rapidly. One site that was typically a stronghold of flat abalone, Nellies Cove (near Port Orford), experienced an 82% reduction in abundance from 2001 to 2007, likely corresponding to fishing. Subsequent fishery independent surveys showed further reduced populations; in 2015 (Groth[1]), then in 2019 only one flat abalone was found during a survey (personal observ.) of a site which in the past had yielded catch rates of more than 100 flat abalone per hour during the early years of the commercial flat abalone fishery. A recent and dramatic decline in flat aba-

[20]Ashmon, M. 2019. Oregon commercial sea urchin diver. Personal commun.

[21]Marriage, L. D. 1952. Presence of abalone in Oregon. OFC unpubl. memo.

[22]McConnaughey, B. H., Univ. Oreg. 1952. Letter regarding abalone distribution in Oregon.

lone has also been noted in California populations (Rogers-Bennett[23]).

Pinto abalone populations have also changed. After years of exploration and surveys, no live specimens had been documented in Oregon until 2009 when a few were found (personal observ.). Since 2009, they appear to be more prevalent, even to be quantifiably detected in 2019 surveys, when a few individuals were found.

Lastly, black abalone, a species where individuals were once found in Oregon, has not reappeared since findings of the 1950's (Marriage[4, 21]; McConnaughey[22]). This past discovery and disappearance; however, may give insight into the ephemeral nature of this species group beyond its range extents.

Red Abalone
Size in Oregon

It is common for this species to grow to its largest individual size in the coldest environments within their range (Bergmann, 1847; Vinarski, 2014). Oregon's population of red abalone are well characterized by this biological rule as they are uncommon, but grow to the species largest sizes at their polar range extent. Accordingly, Oregon's red abalone follow this model.

The largest abalone shells in the world have been found in Oregon. Most famously, a 313 mm (12.32 inch) red abalone, frequently cited as the world record abalone shell, is widely reported to be Oregon taken both by these authors many personal communications and by online sources (Tissot[24]). Less famously, ODFW records show at least two other red abalone shells found in Oregon have been larger.

1) ODFW staff measured a 318 mm (12.5 inch) red abalone during the 1958–62 exploratory commercial fishery (Snow[6]), probably from the Brookings area.
2) In 1972, ODFW staff recovered another 318 mm red abalone (shell) near Port Orford (unpubl. data, ODFW).

The large individual size of red abalone presents a rare situation in marine invertebrate fisheries, where trophy shell catch, rather than food sourcing, has motivated most fishery participants. In recent years, as daily and annual limits for red abalone have declined, divers have focused on catching the greatest individually sized red abalone (Tissot[24]). Incorporating the unique trophy size of Oregon's red abalone could be used as a management tool to increase the fisheries sustainability by narrowing fishery selectivity and reducing total catch.

Oregon's Abalone Future

Worldwide and regionally, abalone fisheries have been scrutinized closely given frequent failures (Vileisis, 2020). As of 2018, all Oregon abalone fisheries have been closed or suspended due to sustainability concerns. While fisheries are valuable in developing societal investment in resources and contribute to the local economy, sustainability must be achieved to allow both to persist. For abalones, sustainability has proven hard to achieve. Given their paucity, fisheries for flat, pinto, and black abalone in Oregon appear unlikely to be sustainable at any level; however, the high value of large-sized red abalone may be particularly useful to management.

The recreational red abalone fishery in Oregon persisted for many years, ultimately closing due in largest part to environmental conditions, not overfishing. Despite the many years of fishing, catch rates were highest in the most recent years. The exceptionally large size of red abalone in Oregon allows fishery participation to be valuable even at extremely low levels of catch.

Improving the sustainability of Oregon's recreational red abalone fishery would require better population data and the development of appropriate targets and limits. Few quantitative surveys have occurred; these have allowed a window into density trends but little more. More survey data are needed to understand: 1) the number of surveys required to appropriately assess population levels, 2) the range and species diversity of abalones in Oregon, and 3) the abundance of abalone relative to restoration needs and fisheries allotments.

Modern abalone management uses density metrics; however, being at the edge of their range, densities in Oregon are likely to never meet the minimums of other areas where durable fisheries have occurred. Choices for the future could include: 1) no fisheries for red abalone, 2) limited open access fisheries, or 3) highly limited "big game" style fisheries. While the choice of "no fisheries" is appealing and appropriate from an immediate conservation point of view, long term conservation must consider societal investment. For abalones this investment appears strongest among fishery participants. Developing small fisheries, such as a trophy fishery may be possible given Oregon's unique red abalone population and could retain the societal investment critical to conserve stocks of red abalone.

Acknowledgments

We thank the many past generations of ODFW biologists who have contributed to our knowledge of abalone in Oregon: Neil Richmond, John Schaefer, Jean McCrae, Jim Golden, Laimons Osis, Jerry Lukas, Dale Snow, Lowell Marriage, and James McCauley. Ryan Pitcher and Katie Gregory made significant contributions to the development of red abalone catch estimates and organization of updated surveys. Members of the recreational and commercial fisheries have also been critical. Last, we thank Steve Rumrill, Dave Fox, Aaron Galloway, Meaghan Palmer, and two anonymous reviewers for their guidance and helpful reviews of this manuscript.

[23]Rogers-Bennett, L. 2021. California Department of Fish and Wildlife. Personal commun.

[24]Tissot, B. 2014. The hunt for monster red abalone, accessed April 2, 2023 (avail. at https://briantissot.com/2014/09/07/the-hunt-for-monster-red-abalone).

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