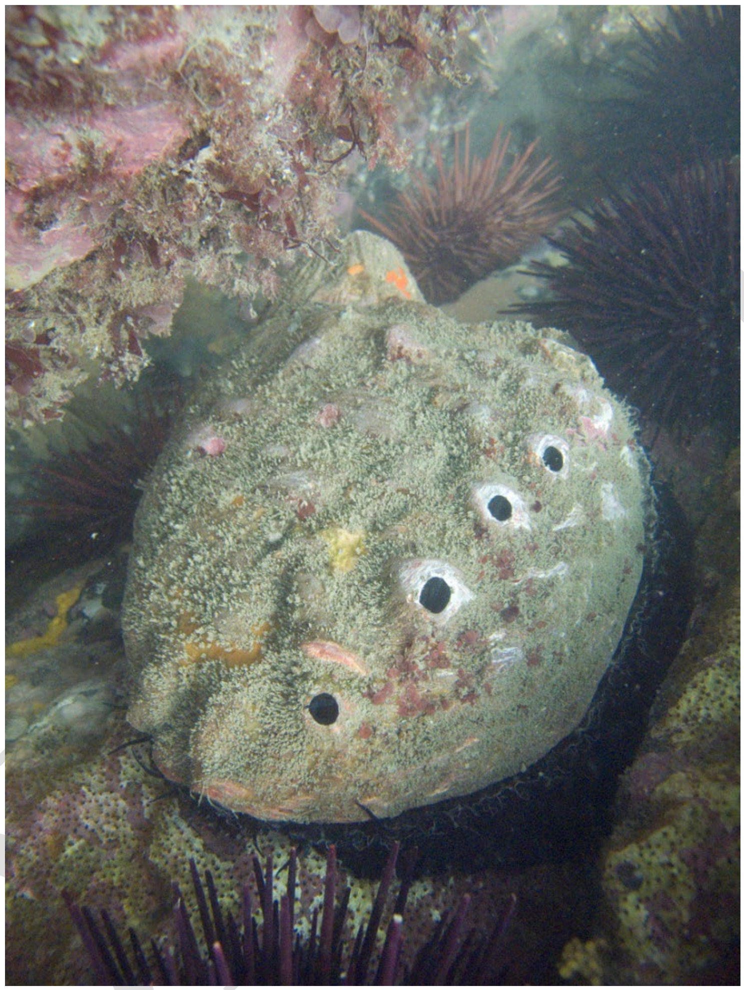
Conservation and Fishery Management Plan for Red Abalone in Oregon



Oregon Department of Fish and Wildlife

Marine Resources Program

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Photo by Scott Groth

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Introduction

Purpose and need

Red abalone (*Haliotis rufescens*) are large marine snails that inhabit rocky intertidal and shallow subtidal areas throughout the United States west coast where they extend from Oregon to Baja California. Like other abalone fisheries worldwide, the recreational red abalone fishery in Oregon is vulnerable to overexploitation and challenging to manage for sustainability (Tegner, 1992; Vileisis, 2020). Abalone fisheries are particularly susceptible to depletion or collapse due to patchiness of populations, life history strategies that promote endemism and episodic recruitment, variability in reproductive output, and lack of resilience to environmental changes (Hobday *et al.*, 2000). Red abalone populations are difficult to quantify in subtidal rocky reef habitats due to the paucity of individuals, cryptic behavior of adults and juveniles, and fluctuating characteristics of their high-energy underwater habitat in Oregon. However, red abalone are in high demand by recreational harvesters throughout their natural range along the west coast, and they are prized for their large size (Estes *et al.*, 2005), desirable meat, and beautiful shells.

The high commercial, recreational, and cultural value of red abalone calls for development of a conservation and management strategy that considers the historic and current status of the abalone population and is adaptive to changing conditions along the Oregon coast. We address this need through a Conservation and Fishery Management Plan for Red Abalone in Oregon (CFMP) that prioritizes conservation activities to sustain sensitive populations, coupled with guidelines for a *de minimis* recreational fishery that could re-open sometime in the future in the event that red abalone in Oregon rebound to a level where limited recreational take can be sustainable with minimal impacts. It is anticipated that this CFMP for red abalone will be updated whenever there are significant changes in the population, the regulatory environment, or at least every 10 years.

The recreational red abalone fishery in Oregon is managed by the Oregon Department of Fish and Wildlife / Marine Resources Program (ODFW/MRP). Quantitative stock assessments and surveys of the patchy populations of abalone that occur along the Oregon coast have not been carried out on a regular basis to reliably determine annual variability in spatial distribution, abundance, population structure, and sustainable levels of harvest. Instead, ODFW/MRP has historically managed the recreational red abalone fishery with an individual permitting system that includes prohibition of harvest for abalone with shell lengths less than 203 mm (8 inches), coupled with close coordination regarding fisheries closures and management in northern California. Public interest and harvest levels in the recreational red abalone fishery in Oregon both increased steadily since the 1970s until recent suspension of the fishery (2018-present) due to declining populations and poor environmental conditions. Identification of an effective conservation and management strategy is a pressing need at this time to maintain viability of red abalone populations in Oregon as a valued living resource for enjoyment by current and future generations of Oregonians.

The recreational red abalone fishery in Oregon faces numerous threats posed by changing socio-cultural considerations, biological factors, and shifting environmental conditions. This Conservation and Fishery Management Plan for Red Abalone in Oregon describes these challenges and presents a series of recommendations and suggested tools designed to address ecological challenges and pressing management issues.

The purpose of the Conservation and Fishery Management Plan for Red Abalone in Oregon (CFMP) is to:

> *"provide the overall framework for protection and maintenance of red abalone populations coupled with careful management of a de minimis recreational fishery. The CFMP presents an assessment of the current state of knowledge about red abalone in Oregon marine waters, describes the historic and current management strategies that regulate harvest, and identifies recommendations for future conservation measures to enhance sustainability of this valuable living resource."*

Goals

The CFMP for Red Abalone in Oregon was developed to identify an integrated approach to management that evaluates the conservation status of red abalone populations in Oregon and explores the possibility to develop a minimal-impact (*de minimis)* recreational fishery. The primary management goals of the CMFP are:

1) **Ecological** – Ensure the long-term sustainability, reproductive capacity, and natural dynamics of the red abalone population in Oregon at the northern limit of its biogeographic range, and foster their resiliency in response to changing conditions in the nearshore marine environment;
2) **Social/cultural** – Promote diverse opportunities for present and future generations of Oregonians to harvest, use, and enjoy the red abalone resource; and
3) **Economic** – Support the economic vitality of red abalone as a high-value target for a *de minimis* recreational fishery that provides multiple benefits to Oregon's coastal communities.

Framework for Oregon marine fisheries management plans

The framework for Oregon's management of marine fisheries provides pragmatic context and administrative structure to guide development of species-specific Marine Fisheries Management Plans (MFMPs). The MFMPs may address single or multiple species and ensure orderly fisheries and equitable access to marine resources by different users, while maintaining ecological integrity of the living resources (Oregon Department of Fish and Wildlife, 2015). The Framework outlines a consistent approach for MFMP development that includes a comprehensive evaluation of fishery resources and a detailed assessment of harvest management strategies. Specifically, the Framework identifies information included in MFMPs to achieve the following broad goals:

1) Provide access to marine resources for present and future generations;

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2) Minimize bycatch, incidental catch, and mortality related to fishery interactions with non-target marine organisms;
3) Coordinate the management of commercial and recreational fisheries;
4) Minimize complexity of management;
5) Consider the socioeconomic needs of local communities, including both consumptive and non-consumptive uses and values; and
6) Involve the public in the fisheries management process.

Major state policies and planning documents

Several overarching policies and planning documents guide the management of marine fishery resources and development of Marine Fishery Management Plans in Oregon. These policies are described in the MFMP Framework and are listed below:

- Food Fish Management Policy (1975; Oregon Revised Statute § 506.109)
- Wildlife Policy (1973; ORS § 496.012)
- Native Fish Conservation Policy (NFCP; 2003; Oregon Administrative Rule 635-007-0502 through OAR 635-007-0509)
- Oregon Nearshore Strategy (2015; ODFW, 2016)
- Oregon Territorial Sea Plan (1994; OPAC, 1994)
- Statewide planning goals (DLCD, 2010; OAR 660-015)

Document organization

This CFMP for Red Abalone in Oregon follows the structure outlined by the Framework and is organized into two sections. Section A - Resource Analysis provides a comprehensive description of the historic and current status of the red abalone resource in Oregon, including biological and ecological information, an analysis of stock status, factors affecting the species, and areas for future research. Section B -Management and Conservation Strategy articulates historical and current management practices, goals for the resource, issues facing the fishery, and conservation actions, and appropriate tools for future management of a *de minimis* recreational red abalone fishery.

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Acronyms

CCS: California Current System
CDFW: California Department of Fish and Wildlife
CFMP: Conservation and Management Plan
CPUE: Catch-Per-Unit-Effort
CSWG: Competitive State Wildlife Grant
DO: Dissolved Oxygen
ESA: Endangered Species Act
FDA: U.S. Food and Drug Administration
FMP: Fishery Management Plan
HAB: Harmful Algal Bloom
HCR: Harvest Control Rule
LRP: Limit reference point
MFMP: Marine Fisheries Management Plan
MRP: Marine Resources Program
MSC: Marine Stewardship Council
MVP: Minimum Viable Population
NOAA: National Oceanic and Atmospheric Administration
OAR: Oregon Administrative Rule
ODA: Oregon Department of Agriculture
ODFW: Oregon Department of Fish and Wildlife
OFWC: Oregon Fish and Wildlife Commission
ORS: Oregon Revised Statute
OSP: Oregon State Police
OSU: Oregon State University
PDO: Pacific Decadal Oscillation
PLD: Pelagic Larval Duration
PSMFC: Pacific States Marine Fisheries Commission
SCUBA: Self-Contained Underwater Breathing Apparatus
SPR: Spawning Potential Ratio
SST: Sea Surface Temperature
TAC: Total Allowable Catch

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Definitions

Biogeographic range: The geographic northern and southern extent of a species connected through sharing of genetic information.

Biological Reference Point (RP): Biological metrics that reflect stock dynamics and are used as an index to assess stock status for fishery management.

California Current System (CCS): The Pacific Ocean current system running along the West Coast of North America including the southward moving California Current. The system also includes the southward coastal jet, northward winter surface Davidson and subsurface California Undercurrent and the Southern California Eddy and Countercurrent.

Catch-per-unit-effort (CPUE): An indirect measure of relative abundance of a target species, derived from the quantity of catch divided by a defined measure of fishing effort undertaken to obtain the catch.

Conservation: Management of a natural resource to prevent exploitation or destruction.

***De minimis* fishery:** A fishery with limited take that is designed to have little to no impact on the health of the natural resource.

Dispersal: The process of movement of a species, either away from an existing population or from the parental organism for either maintenance or expansion of the population.

Dispersion: The resulting geographic extent of a population's dispersal by way of maintenance or expansion.

Fishery-Independent data: Data from scientific surveys targeting juvenile, sub-adult or adult individuals not subject to fishing pressure.

Fishery-Dependent data: Data acquired about a population or biological processes of a natural resource using information from fishery participants.

Fishing mortality: Mortality due to fishing.

Genetic connectivity: The linking of spatially discrete populations through the exchange of genetic material.

Hypoxia: A period of low environmental oxygen often associated with mortality events.

Intertidal: The area in Oregon coastal bays, estuaries, and beaches between mean extreme low water and mean extreme high-water boundaries (OAR 635-005-0240).

Landing: The portion of the catch that is brought into ports and offloaded from a vessel onto a dock or pier.

Lecithotrophic: A non-feeding larval type that relies on maternal reserves (yolk) for energy during the planktonic life cycle phase.

Lifecycle: The series of developmental changes in the life of an organism including reproduction, growth, development, senescence, and death.

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Life-history strategy: Strategy utilized by an organism that defines its pattern of survival and reproduction events throughout its life cycle.

Limit Reference Point (LRP): A type of Biological Reference Point that defines a trigger for concern in the health of a fished population. Limit Reference Points are used to trigger a closure in fisheries.

Marine heatwave: A period of persistent anomalous warm ocean temperatures which often causes negative impacts on sensitive marine organisms at both the individual and population levels.

Marine herbivore: An animal in the marine environment whose diet consists of algae and kelp.

Metapopulation: A collection of populations of spatially separated discrete habitat patches that are genetically linked through occasional dispersal.

Minimum Legal Size (MLS): A fisheries management tool that sets a minimum size for legal take in a fishery meant to protect juveniles and allow individuals to contribute to reproduction in the fished stock.

Minimum Viable Population (MVP): An ecological threshold that signifies the minimum number of individuals in a population that can allow the population to persist for a defined amount of time.

Natural mortality: Death of a fished species due to all causes except fishing.

Nearshore: The area from the outer boundary of Oregon's Territorial Sea at 3 nautical miles to the supratidal zone affected by wave spray at extreme high tides, and up into the portions of estuaries where species depend on the saltwater that comes in from the ocean (ODFW, 2016).

Ocean acidification: The decrease in the ocean's pH caused by the uptake of carbon dioxide from the atmosphere.

Pelagic Larval Duration (PLD): The amount of time a marine species spends in the planktonic larval phase prior to settlement.

Pre-measurement: A fishery management tool designed to diminish mortality associated with fishing, commonly used in abalone fisheries. This requires each fishery participant to carry a measurement tool while fishing that is consistent with the Minimum Legal Size (MLS) set by rule. Prior to removing an abalone from hard substrate, the fishery participant is required to use the measurement tool to ensure the desired abalone is at least the MLS.

Recreational fishery: The legal harvest of living marine species for personal use (as defined in ORS § 506.006).

Shell Length (SL): Measurement of abalone size, using calipers to measure the length of the shell from posterior to anterior side.

Size-at-age: A statistical measure of the relationship between an organisms typical individual size at a developmental age that indicates the health and growth of a population.

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Spring transition: The transition from a winter downwelling state to a summer upwelling state along the west coast of the United States because of winds from the south shifting to a predominately equatorward direction.

Stock: An aggregation for management purposes of fish [or shellfish] populations which typically share common characteristics such as life histories, migration patterns, or habitats (OAR 635-007-0501).

Stock assessment: A fishery management tool utilizing a scientific process of collecting and analyzing the condition of a fish stock for application in assessing and reporting the health of a population in the marine environment.

Sub-population: Groups of a species within one linked population that share defined traits.

Sustainable: A designation given to fisheries that are managed in a way that allows the fished stock to continue to reproduce and grow while being fished at a measured and consistent rate with little to no impact on the health of the population.

Take:

- *As defined under the U.S. ESA* – To harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct (16 U.S.C. § 1532(19)).
- *As defined under Oregon law* – Fish for, hunt, pursue, catch, capture or kill or attempt to fish for, hunt, pursue, catch, capture or kill (ORS § 506.006).

Total Allowable Catch (TAC): A fisheries management tool used to limit the amount of catch of a species in a fishery.

Upwelling: The offshore movement of surface shelf waters and subsequent replacement by cold, nutrient-rich deep waters from off the shelf.

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A. Resource Analysis

This Resource Analysis provides a description of the red abalone (*Haliotis rufescens)* resource in Oregon, along with a review of its biology and ecology, synthesis of available data, and analysis of the stock status. Both non-fishery and fishery-related threats to red abalone and its habitats are assessed along with recommendations for management actions to foster conservation and sustainable harvest levels. Finally, we compile a prioritized list of research gaps and information needs related to the assessment, ecology, and conservation of red abalone in Oregon.

Red abalone were first described by William John Swainson in 1822 (Swainson, 1822). The red abalone (phylum Mollusca; class Gastropoda; subclass Prosobranchia; order Archaeogastropoda; family Haliotidae) is the largest species of abalone in the world (Cox, 1962; Geiger, 1999; Estes *et al.*, 2005). Red abalone are broadcast spawning marine invertebrates with separate sexes that live in the rocky nearshore environment, feeding on drift kelp and living sedentary adult lives.

Red abalone are an important component of rocky intertidal and subtidal ecological communities, and they are the target of recreational fisheries along the west coast of the United States. Datasets to characterize the red abalone fishery are limited for Oregon and include fishery-dependent data compiled from permitted recreational and commercial harvest activities, and information generated by periodic fishery-independent surveys of abalone. Threats to the red abalone resource and fishery include changing ocean conditions and associated ecological shifts, increased fishing pressure and public interest, and the potential re-introduction of sea otters to Oregon. Catch levels in Oregon have historically been low in comparison with northern California, with the highest annual average take by the recreational fishery in Oregon reaching an estimated 299 abalone taken in 2017. It is expected that potential harvest levels of red abalone will remain low in the future to reflect minimal population levels in Oregon. More information is needed about the biology and ecology of red abalone including recruitment variability, movement studies, natural mortality, potential interactions with marine mammals, as well as plausible impacts from changing climatic conditions and other possible threats. This need is amplified due to the added difficulty of studying and measuring populations at the northern extent of their range, which characteristically exhibit population-level differences when compared to populations in the central portion of their range with higher densities and more robust scientific monitoring history.

I. Biology and ecology of red abalone

Effective fisheries management is dependent upon a detailed understanding of the biology, ecology, and life history characteristics of the targeted species. Numerous studies focusing on red abalone indicate that the level of complexity is high regarding the suite of biological and ecological factors that control spatial distribution, abundance, and population dynamics (Tegner, *et al.* 1989; Karpov *et al.* 1998; Kawana *et al.* 2019; Rogers-Bennett *et. al.* 2010; Rogers-Bennett & Catton, 2021). Despite high interest and a wealth of scientific information about red abalone, many aspects of their local adaptation to habitat conditions are unknown. This subsection synthesizes current and historical literature on the biology and ecology of red abalone.

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a. Biology

Range and dispersal

Red abalone occur throughout the rocky intertidal and subtidal waters from Coos Bay, Oregon to Baja California, Mexico (Cox, 1962). The highest densities of red abalone are found in the central portion of their biogeographic range from southern California to northern California, with patchy extensions down to Baja California, Mexico at the southern range termination and up into Coos Bay, Oregon at the northern range termination (Geiger, 1999). The primary and extended biogeographic range of red abalone are influenced by the California Current System (CCS) which is a broad, slow meandering ocean current that generally flows southward along the continental shelf from Vancouver Island to the central coast of Baja California during the spring, summer, and fall seasons (Checkley & Barth, 2009). The CCS is comprised of the equatorward flowing California Current, coastal jet, the California Undercurrent and seasonal currents such as the northward Davidson Current. The entire CCS is characterized by several complex physical processes including seasonal wind-driven upwelling, variable local wind dynamics, and freshwater input (Hickey & Banas, 2008). These different components of the CCS are associated with unique characteristics of productivity in the nearshore marine environment that affect the reproductive biology and ecology of abalone at a local level and contribute to localized variability and persistence of suitable habitat and availability of food. Interannual variability in these processes is closely tied to shifts in the characteristics of rocky reef habitat which impact red abalone throughout their life cycle.

Red abalone are patchily dispersed throughout the rocky intertidal and subtidal environment, commonly found in areas protected from the most exposed high wave impact areas on rocky, rugose locations where they have consistent access to kelp (Ault *et al.*, 1985; Mclean, 1962; Estes *et al.*, 2005). While their larval lives are highly affected by nearshore ocean currents; as adults, red abalone tend to be cryptic and sedentary, moving throughout their habitat only when needed due to low food availability or presence of predators (Ault & Demartini, 1987).

Morphology

General morphological characteristics of red abalone are similar to other abalone (Figure 1). Adult red abalone vary in color, but typically have a large, brick red shell with 3-4 open respiratory pores and a large soft body that is surrounded by a shell-secreting mantle, a head with specialized structures for sensing and eating food, and a large muscular foot that allows them to locomote (Cox, 1962). They have a large, flattened spire on the posterior dorsal side. The ventral side has a muscular foot used to hold onto rocks. Covering the foot and protecting the abalone's internal anatomy is a large fleshy extension of the mantle called the epipodium. The epipodium in red abalone is pigmented black and has many tentacles surrounding the body allowing the abalone to sense its environment (Ault *et al.*, 1985; Cox, 1962).

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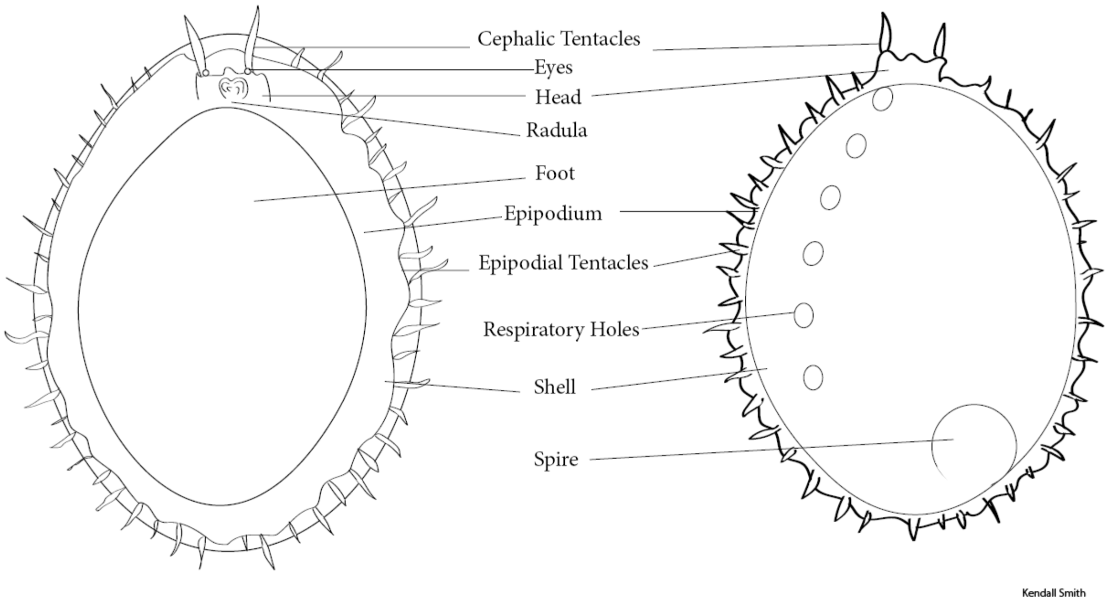

Figure 1: General external morphology (l. ventral, r. dorsal) of red abalone (*Haliotis rufescens*).

Life-history and reproduction

Fundamental information about the life-history and reproductive biology of red abalone is essential to improve our understanding about their ecological interactions and for effective conservation and management of wild stock fisheries along the Oregon coast. Although site-specific investigations about the reproduction of red abalone have not been conducted in Oregon, information compiled for populations in northern California are considered to be representative of reproductive processes near the northern limit of their primary geographic range (Young & Demartini, 1970; Giorgi & DeMartini, 1977; Rogers-Bennett *et al.* 2004).

Like other species, red abalone exhibit a bi-phasic life-history strategy that includes long-lived adults and short-lived lecithotrophic (yolk-rich, non-feeding) larvae. Key stages in the abalone life cycle include long-lived adults, gametogenesis and fecundity, spawning of eggs and sperm, trochophore and veliger larvae, post-larvae, and juveniles (see Figure 2).

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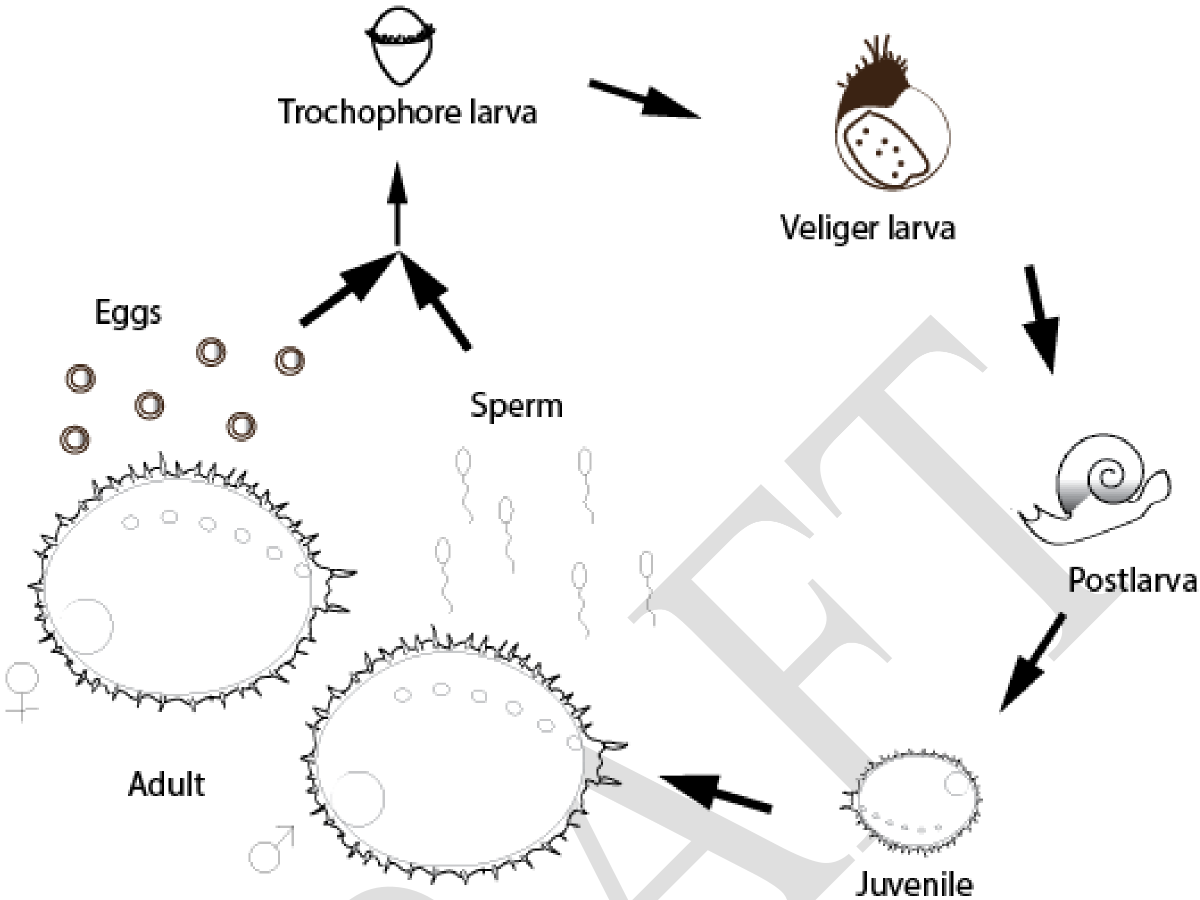

Figure 2: Life cycle of red abalone (*Haliotis rufescens*).

Spawning

Red abalone spawn seasonally, and their spawning times are variable across different regions of their biogeographic range. In the northern region, peak spawning is cued once by a seasonal change in temperature, whereas red abalone may spawn twice a year in the southern region as a result of more frequent ideal environmental conditions (Price, 1974). However, other laboratory studies conducted with red abalone in southern California reported spawning every month of the year (Leighton, 1974), while red abalone in northern California were observed to spawn from April through July. Both laboratory and field studies found that red abalone in central California (Monterey), whose population is characterized by low densities and concentrated aggregations, are capable of spawning and showing signs of recruitment year-round (Boolootian & Giese, 1962; Hart *et al.*, 2020; Leighton, 1974; Price, 1974). Further laboratory studies of specimens from northern California documented spawning during the spring bloom of macrobenthic brown algae concurrent with downwelling ocean conditions, when onshore transport of ocean surface waters and higher sea surface temperatures occur. Earlier studies, however, suggested that temperature did not correlate closely with spawning and that three distinct types of reproductive cycles may occur within a single population of red abalone. The three types include: Type I - annual gametogenesis and complete spawning; Type II - gametogenesis with incomplete spawning; and Type III - gametogenesis with no spawning (Young & DeMartini, 1970; Georgi & DeMartini, 1977). In Oregon, investigations of spawning in red abalone are limited and largely unsuccessful, with laboratory-induced spawning failing to result in any fertilized embryos or larvae (Lukas, 1973; Nielsen, 1967). Field observations of red abalone spawning in Oregon are also inconclusive, with all red abalone having full gonads, even during their hypothesized spawning season of April through July (S. Groth, ODFW; pers. observation).

Spawning stimuli for red abalone are not well understood. Laboratory studies have shown that addition of hydrogen peroxide (H_2O_2) to seawater causes gravid male and female red abalone to spawn due to activation of enzyme catalysis in the reproductive cells of the abalone gonads and release of prostaglandin (Morse et al., 1977). It is not known, however, what causes induction of natural spawning of red abalone in the wild. It has been suggested that addition of hydrogen peroxide to seawater could mimic natural spawning as a secondary response to a primary environmental trigger, such as a change in temperature or shift in environmental oxygen associated with downwelling conditions and availability of algal food.

Reproductive strategy

Red abalone are broadcast-spawning marine invertebrates, and this reproductive strategy is widely considered to be highly risky, variable, and to play a major role in the dynamics of the population and the biogeography of the species (Vance, 1973; Christiansen & Fenchel, 1979; Llodra, 2002). Multiple strategies have evolved to help ensure fertilization success in broadcast spawners, including: (1) aggregation of spawning adults; (2) synchrony in the release of gametes; and (3) release of a high volume of sperm to counter dilution. Red abalone have been observed to aggregate when environmental conditions are ideal (Button, 2008) and gravid adults are often triggered to release gametes in response to spawning by a nearby conspecific adults (Morse *et al.*, 1977). Lastly, male red abalone produce comparatively large amounts of sperm in relation to their volume-to-body ratio (Rogers-Bennett & Kashiwada, 2004). Abalone are dioecious broadcast spawners and adults with separate sexes release gametes into the water column simultaneously. If successful fertilization occurs, the embryos develop into lecithotrophic (non-feeding) trochophore larvae (Carlisle, 1962; Crofts, 1937) that may disperse in the water column for a period of 2-5 days (Searcy-Bernal, 1999). The short-lived trochophore larvae of abalone generally swim upwards due to positive phototaxis or negative geotaxis, followed by a subsequent period when they alternatively swim upward and then sink (McShane 1992). It is likely that this swimming behavior exhibited by some abalone trochophore larvae limits their dispersal away from the spawning site, as well as restricts the localized dispersion of individual larvae away from their siblings.

Swimming trochophore larvae quickly develop a shell and transform into veliger larvae after about 2-3 days, and the veliger larvae typically retain the ability to swim for about 1-2 weeks (Searcy-Bernal, 1999). However, recent work by (Mccormick *et al.* 2012) shows that red abalone larvae may continue swimming for longer periods over 30 days, but survivorship was greatest for veligers that remained in the water column for less than 20 days. These results indicate that a larval competency period of 20 days is substantially longer than the 1-2 week period often used to estimate dispersal for red abalone larvae.

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As a group, abalone are known to exhibit substantial variability in their modes of larval dispersal in nearshore ocean currents (Miyake, *et al*., 2017), with some species traveling long-distances in the planktonic larval phase while others exhibit only localized/limited dispersal (Smith, 2022). Adaptive or variable dispersal has also been observed in other species in which the spatial extent of larval dispersal changes in response to shifts in local environmental conditions. Red abalone can exhibit all three suggested modes of larval dispersal, including short distance dispersal, long distance dispersal and dual dispersal (Miyake *et al*., 2017). Suggested plasticity of larval dispersal in red abalone indicates the potential adaptability of red abalone larvae under ideal environmental conditions. This adaptability could lead to long distance dispersal events that extend the potential geographic distance of red abalone and maintain genetic connectivity between the larger population under ideal environmental conditions (Smith, 2022).

Gametogenesis and fecundity

Red abalone reach sexual maturity when they attain shell lengths of about 75-95 mm (males) and 100-130 mm (females). Gametogenesis of the red abalone gonad was followed by conventional histology over an annual cycle for a population in northern California (Giorgi & DeMartini, 1977). During the winter season, the gonads were mature (ripe), and all specimens contained maximum densities of spermatozoa or large oocytes (> 160 um dia). Necrotic oocytes were present in the ovaries of some females during the late winter. Spawning occurred in the spring season, and the gonads were generally depleted or contained both early and late stages of eggs and sperm; the ovaries of some females contained many small oocytes (< 40 um dia). These observations indicate that the adults likely conducted partial spawning coupled with secondary spermatogenesis and oogenesis. During the summer and fall, some specimens were still full of spermatozoa or large oocytes (160 to 250 microns), but many of the oocytes were necrotic. By the fall season, about 90% of the oocytes were degraded and necrotic, while other specimens contained stages indicative of early and late gametogenesis including residual gametes from the preceding spawning.

The fecundity of red abalone increases exponentially with body size (Rogers-Bennett *et al*., 2004), and the maximum fecundity from a large gravid female has been estimated at over 12 million eggs (Giorgi & DeMartini, 1977). Smaller females (105 mm SL) produce on the order of 2,400 eggs per year, while the larger abalone (> 220 mm SL) can typically produce about 3-4 million eggs per year (Rogers-Bennett *et al.* 2004).

Larval settlement and metamorphosis

During their period of planktonic development, red abalone veliger larvae acquire sensory structures which denote the onset of competency to complete settlement and metamorphosis (Slattery, 1987). Once their cephalic tentacles develop, abalone veligers are competent and able to settle. Larval settlement occurs when acceptable habitat and conditions are detected, characterized by ideal water temperature, presence of cues derived from crustose coralline algae, and the presence of conspecific adults.

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Similar to many other marine invertebrates, settlement and metamorphosis of red abalone larvae is induced by chemical cues that presumably indicate favorable habitat for the juvenile and subsequent adult (Barlow, 1990). In the field, juvenile abalone (1-20 mm) are most commonly observed in natural "nursery habitats" composed of crustose red algae suggesting that the cues to settlement and metamorphosis may be associated with the red algal crusts. The ability of swimming red abalone larvae to detect the red algal crusts is thought to be mediated by contact-dependent chemical receptors (Morse & Morse, 1984; Barlow, 1990). In particular, (Morse *et al.* 1979; 1980) discovered that a gamma-aminobutyric acid (GABA) mimetic peptide (neurotransmitter) and phycoerythrobilin were sequestered at the surface of the crustose red algae, and that these substances induced settlement and metamorphosis of red abalone larvae (Slattery, 1987). In addition to the biochemical cues, larvae also required physical contact with the appropriate substrata to trigger settlement and metamorphosis (Morse *et al.,* 1980).

Following settlement and metamorphosis of red abalone veligers into newly settled juveniles, they commonly exhibit cryptic behavior residing in cracks, crevices, and under boulders until spawning age is reached (3 or 4 years for females) (Ault *et al.,* 1985). Specifically, red abalone become sexually differentiated at a shell length (SL) of about 50mm, but reach sexual maturity, denoted by thick ovary tissue and mature oocytes, at variable sizes for females. (Rogers-Bennett & Kashiwada, 2004) found that at a size of 130mm SL, all female red abalone had reached sexual maturity, and males reach sexual maturity at smaller sizes (60mm). Fecundity in red abalone increases with size, reaching a peak at a SL of 215mm, and found to become senescent, indicated by a high percentage of necrotic eggs. This indicates that larger individuals contribute to recruitment at an unequally high rate; however, the very largest red abalones may be senescent.

Maximum size, life span, and age

Maximum size

Red abalone are the largest species of abalone in the world (Cox, 1962; Estes *et al.* 2005). The largest individuals have been found in Oregon waters, with the maximum recorded size for a red abalone found in southern Oregon (Owen & Dinucci, 2005; Groth & Smith, 2024). Occurrence of red abalone with large shells at the northern extent of their primary biogeographic range is consistent with “Bergmann’s Rule” which stipulates that species from the same taxonomic clade generally have large body sizes in cooler regions (Olalla-Tarraga *et al.,* 2006; Olalla-Tarraga, 2011; Manyak-Davis *et al.*, 2013; Campbell *et al.*, 2021). It is likely that the oldest red abalone individuals have a life span that exceeds 50-60 years or more. In California, red abalone mature at between 3 and 7 years of age and it is estimated that they may live for 35 to 54 years (Haaker *et al.*, 1986; Haaker *et al.*, 1998).

The ODFW / Marine Resources Program conducted periodic surveys of the size-frequency distribution for red abalone populations in shallow subtidal rocky reef habitat along the southern Oregon coast over a period spanning nearly 60 years (1960-2019). These surveys provide evidence that red abalone reach consistently large shell sizes in Oregon coupled with a lack of small individuals (Figure 3). In addition, the time-series of surveys suggest that red abalone populations in Oregon may experience long periods without measurable input of new juveniles, and that episodes of recruitment most recently occurred to replenish the population sometime between 2015 and 2019. Because body size and growth of abalone reflect conditions of the surrounding environment, it is important to understand and quantify size-at-age for the purposes of conservation and management of abalone fisheries.

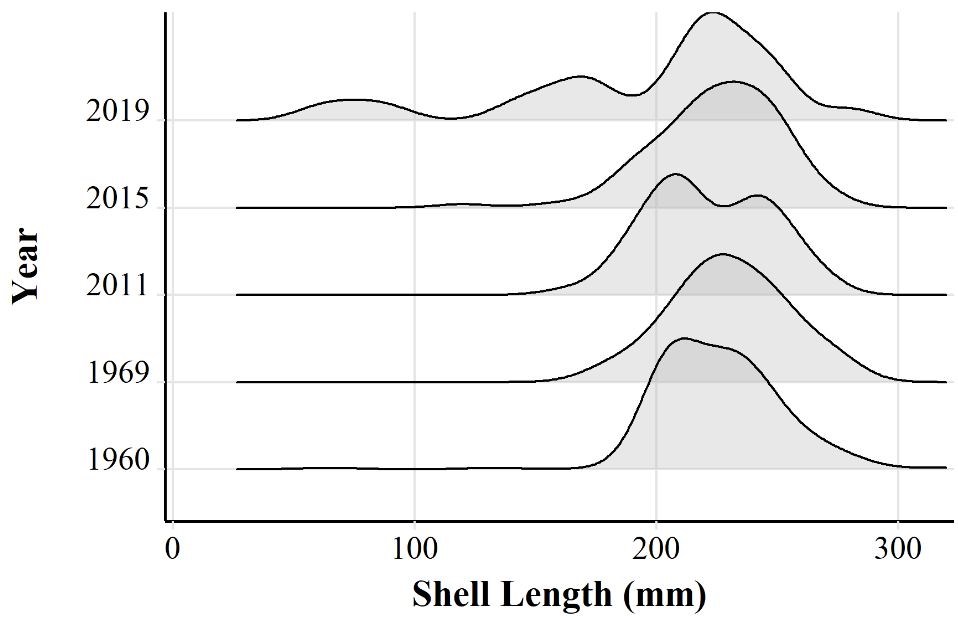

Figure 3: Size-frequency distribution of red abalone (*Haliotis rufescens*) in shallow subtidal rocky habitat along the southern Oregon coast. Data source: shell length (SL) mm measurements from ODFW/MRP survey data (1960, 1969, 2011, 2015 and 2019) in Brookings, OR (Groth & Smith, 2024).

Age

Size-at-age is an important metric for understanding rates of growth and onset of maturity for red abalone, as well as for determination of the appropriate Minimum Legal Size (MLS) for take in management of an abalone fishery. Estimation of age is difficult and variable for abalone (Warwick *et al.,* 1994; Haaker *et al.*, 1998), and efforts undertaken to quantify age-at-size relationships for red abalone in California have generated inconsistent results. For example, mark-recapture studies determined that red abalone in northern California exhibit different rates of natural mortality based on size-class, habitat, and presence of predators (Leaf *et al.*, 2007). Specifically, the smallest size class of red abalone (<100mm SL) experienced the highest mortality in northern California and mean annual mortality rates decreased with increasing size. Juveniles and smaller adult abalone typically occur in cryptic habitats and crevices where they are exposed to predation by octopus, crabs, and sea stars (Tegner & Butler, 1985; Tegner *et al.*, 1989). In contrast, large emergent individuals may have a refuge from predation due to larger body size, greater motility, and an increased ability to adhere tightly to the substrate. These size-dependent differences in susceptibility to predation and mortality indicate that it is insufficient to extend estimates of survivorship from one size class to the population as a whole. Another study of northern California red abalone found that it takes about 12 years to reach a shell length of 178mm (Leaf *et al.*, 2008), and bomb radiocarbon dating was used to age a large (251mm SL) red abalone at about 30-33 years old. Maximum age of red abalone has not been determined but is estimated to be upwards of 50 years (Cox, 1962; Karpov *et al.,* 1998; Leaf *et al.,* 2008). Although size-at-age relationships have not been specifically identified for red abalone in Oregon, information from a red abalone enhancement effort north of their natural range suggest that individuals in Oregon planted between 1967 and 1974 were likely as old as 50 years old when last surveyed in 2017 (Groth & Smith, 2024).

Growth

Red abalone exhibit temporal variation of growth which can be attributed to differences in: (1) temperature, (2) food availability, and (3) population density (Jiao *et al.*, 2010). However, growth rates are similar among all species of abalone in their first few years (Ault, 1985). Following initial settlement, post-larval red abalone remain on coralline algae for two weeks and then find more cryptic habitats. After one to three months, red abalone have attained a shell length (SL) of about 2mm and begin to form respiratory pores. At the end of their first year, red abalone are about 20mm SL and by the end of the third to fourth year they are 75-100mm SL (Ault, 1985). Although red abalone grow to very large sizes, they grow slowly (Leaf *et al.*, 2008). Red abalone in northern California require approximately 12 years to reach 178mm SL in California. Further, this study determined that comparatively, red abalone in northern California had a slower growth rate than red abalone in southern California (Rogers-Bennett *et al.*, 2007). Variability in length at age within and among cohorts can be a result of ocean conditions (Jiao *et al.*, 2010). Variability in size at age may also be a result of population levels, size distribution, genetic composition, and individual energy allocation (Jiao *et al.,* 2010). Lastly, size selective mortality by predation can lead to a truncated size distribution. Although specific growth studies have not been performed on abalone in southern Oregon, a red abalone enhancement effort in Oregon provided some information about growth rates of red abalone in Oregon. This enhancement effort took place in central Oregon, where 5,660 juvenile and 277 adult red abalone were introduced to a small cove north of their natural range called Whale Cove between 1967 and 1974. Surveys were performed sporadically between 1968 and 2018 to measure mortality and growth and found that growth rates to reach legal harvestable size in Oregon (203 mm) could take between 10 and 22 years (Groth & Smith, 2024).

Population genetics

Information about the genetic composition of abalone populations is increasingly important for decision-making leading to conservation actions and management of commercial and recreational fisheries (Morgan & Shepherd, 2006). Broadcast spawning marine invertebrates, such as abalone, are difficult to monitor due to the fluid and variable nature of larval dispersal (Mccormick *et al*., 2012; Miyake *et al.,* 2017; Miller *et al.,* 2014; Rogers-Bennett *et al.,* 2016; Wang, 2005). Maintaining genetic diversity within an imperiled, sensitive, or at-risk species is of high priority when considering alternative actions to aid conservation, and vital to understanding how populations share genetic information, how frequently mixing occurs, and how these characteristics influence the genetic diversity and health of the greater population (An *et al.,* 2012; Díaz-Viloria *et al.,* 2009; Gruenthal *et al.,* 2007; Hamm & Burton, 2000).

Red abalone have been the focus of several studies that seek to identify spatial (or latitudinal) variation in the genetic structure of populations along the west coast of North America (Burton & Tegner, 2000; Gruenthal *et al*., 2007; de Wit & Palumbi, 2013). Results generated by these investigations of genetic variability indicate that red abalone exhibit homogeneous mixing and remarkably little population structure over large geographic distances, despite their low potential for gene flow. Consequently, the scattered collections of red abalone dispersed throughout their primary biogeographic range along the west coast of North America are considered to operate as a single connected metapopulation (de Wit & Palumbi, 2013). It is likely that the rare individuals occasionally observed in the northern extended biogeographic range constitute a non-viable pseudo-sink population (Watkinson & Sutherland, 1995; Morgan & Shepherd, 2006). Genetic studies have confirmed that red abalone populations in southern and northern California are genetically connected through a combination of short distance and long-distance dispersal (Gruenthal *et al*., 2007).

The genetic variability of red abalone populations has not been fully characterized previously for Oregon. Consequently, it was not known if the populations in Oregon exhibited a low level of genetic diversity and function as a single breeding group, or if they exhibited sufficient genetic diversity to suggest that distinct sub-populations may exist along the Oregon coast. New information about the specific genetic connections and population structure exhibited by red abalone in Oregon was generated during development of this CFMP (Smith, 2022). In order to address this important gap in knowledge about the genetic diversity of red abalone in Oregon, samples of red abalone were collected for genetic analysis in 2021 from four discrete locations in Oregon, and the findings were compared with red abalone collected from California and Mexico through a collaboration with Dr. Andrew Whitehead and Dr. Joanna Griffiths in the UC Davis Department of Environmental Toxicology. Results of this effort provide preliminary evidence that all four subpopulations within Oregon are genetically connected to populations throughout California and Mexico (Figure 4). Principal Component Analysis (PCA) revealed that the red abalone samples were closely related with a single distinct cluster centered in four quadrats along the PC1 axis (Principal Component 1), indicating a high level of genetic similarity among populations throughout the biogeographic range (Figure 4). Further analysis of Oregon red abalone samples compared to northern and central California red abalone samples indicate exchange of genetic material through spawning and dispersal (Figure 5). These findings suggest

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Oregon red abalone are reliant on the health and reproductive potential of populations in northern and central California where historic densities are higher (Smith, 2022).

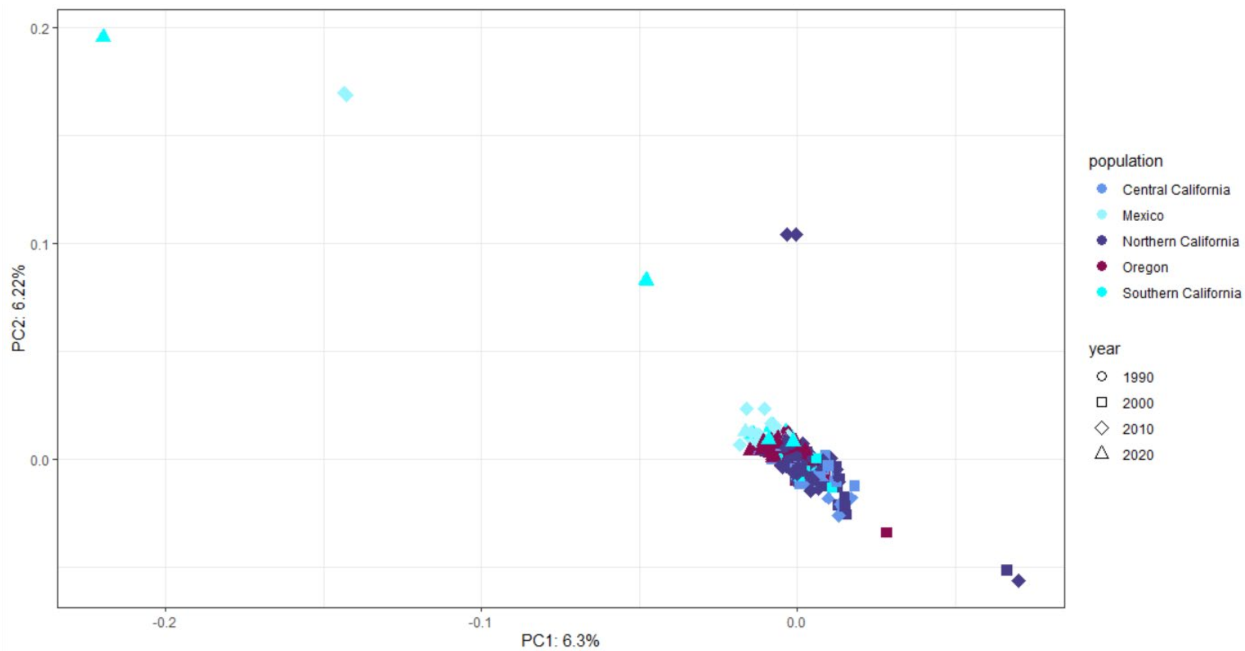

Figure 4: Principal Components Analysis (PCA) plot for red abalone (Haliotis rufescens) samples collected from 1990-2021 from Mexico, California, and Oregon (preliminary analysis assembled by UC Davis Whitehead Lab by Dr. Joanna Griffiths).

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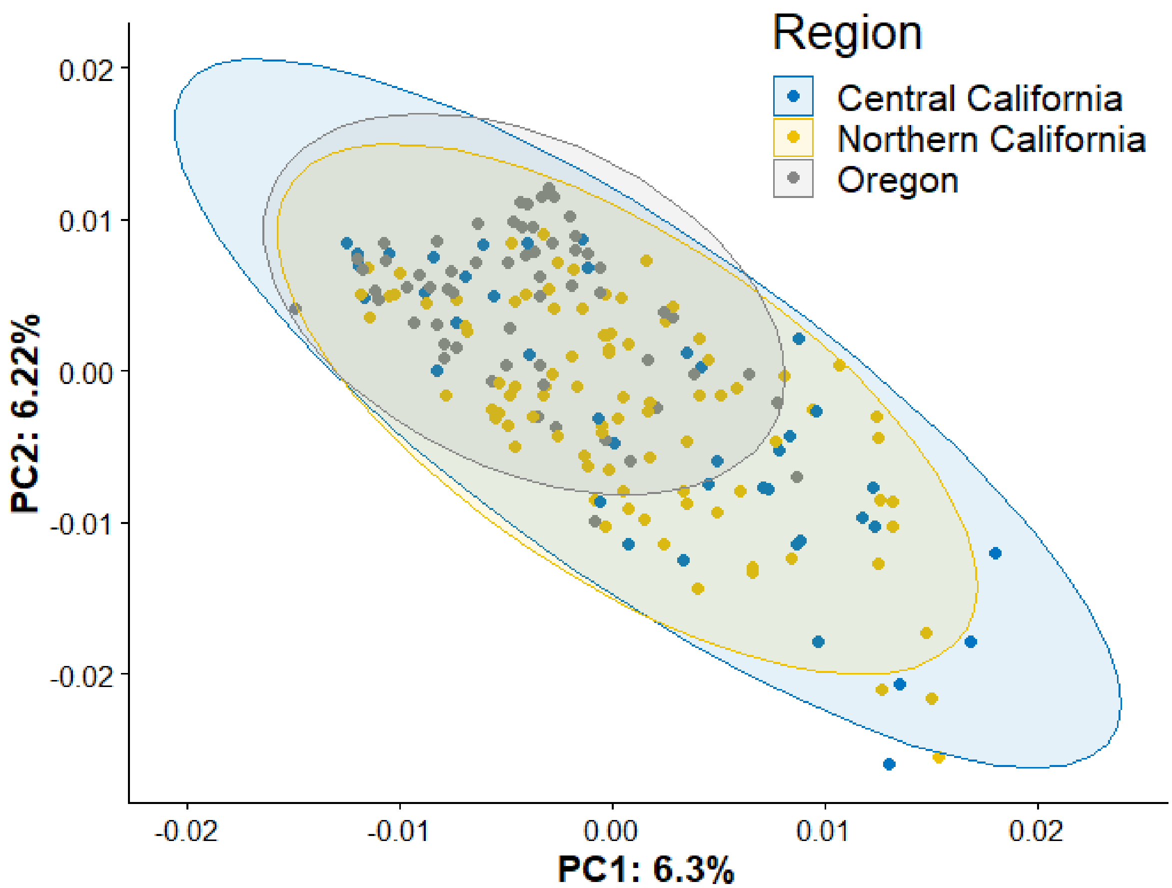

Figure 5: Principal Components Analysis (PCA) plot comparing red abalone (*Haliotis rufescens*) genetic samples collected in central California, northern California and Oregon from 1999-2021 with outliers removed (Smith, 2022).

Analysis of genetic variability among red abalone from four locations along the southern Oregon coast showed little localized differences among abalone sampled from Charleston, Port Orford, Rogue Reef, and Brookings (Figure 6). The greatest variation was observed for samples collected from Brookings, and the similarity in preliminary allelic diversity suggests a high level of genetic connectivity among locations. Comparison between two sampling events separated by over a decade (2008 and 2021) demonstrates only slight differences in the genetic composition of red abalone sampled from Brookings (Figure 7).

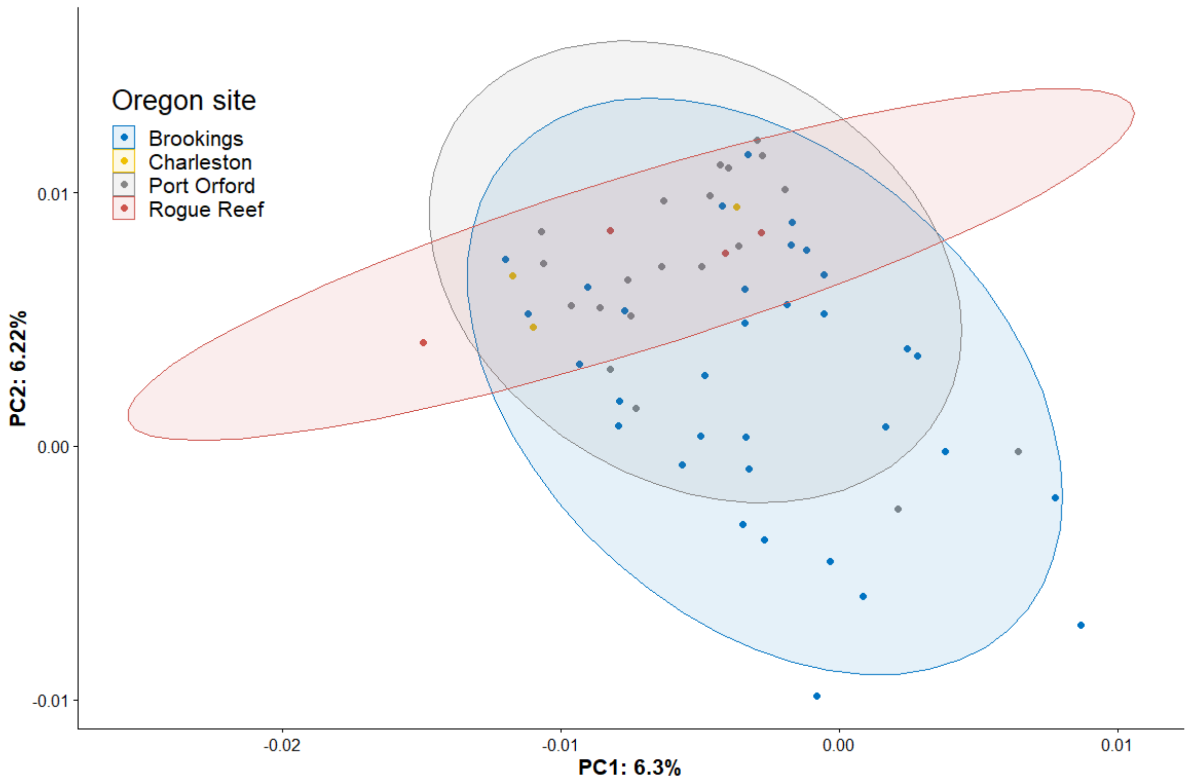

Figure 6: Principal Components Analysis (PCA) plot comparing red abalone (Haliotis rufescens) genetic samples collected in Oregon at four sites in 2008 and 2021 with outliers removed (Smith, 2022).

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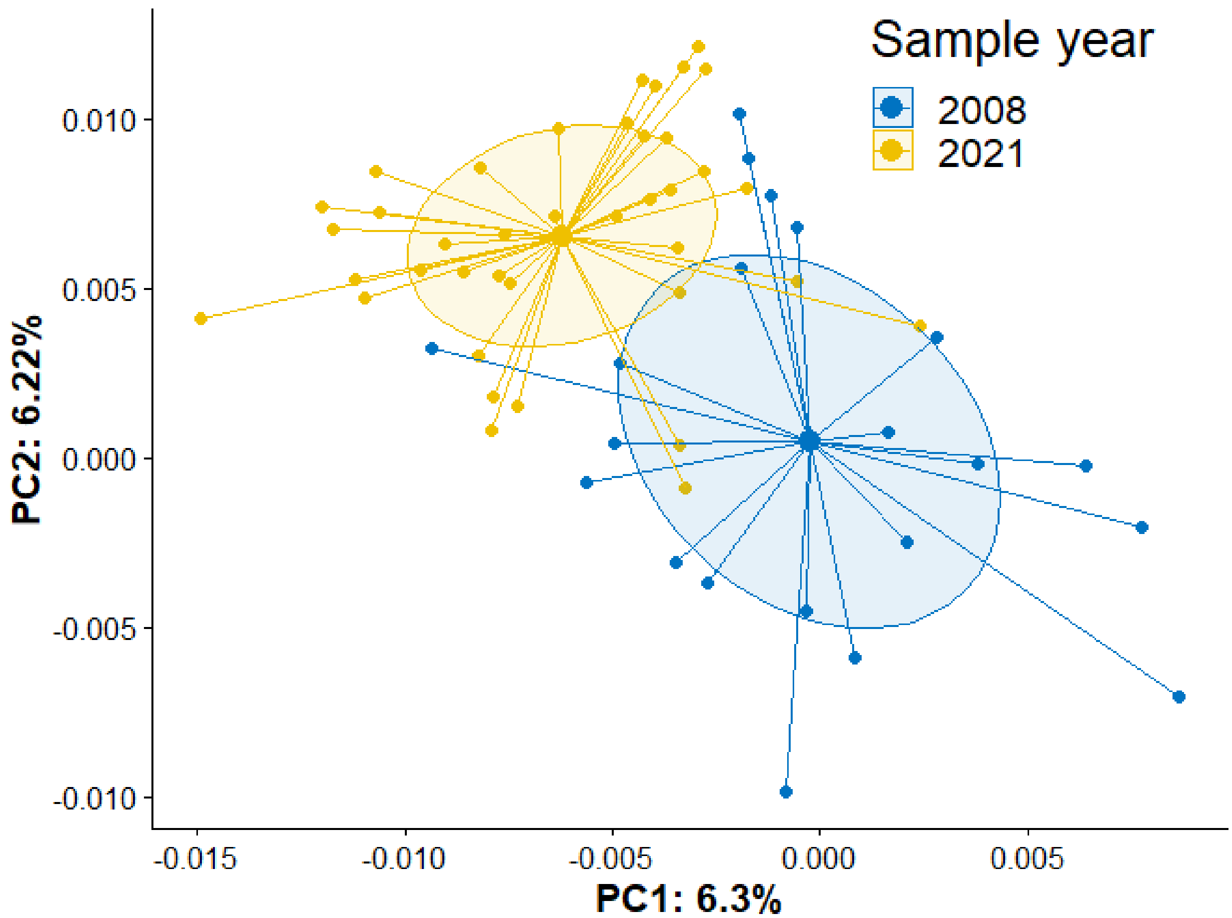

Figure 7: Principal Components Analysis (PCA) plot comparing red abalone (Haliotis rufescens) genetic samples collected in Brookings, OR in two sample years, 2008 and 2021 (Smith, 2022).

These new findings for the Oregon population of red abalone provide further evidence that they exhibit homogeneous mixing and little population structure over large geographic distances, despite their low potential for gene flow. Further, results from the investigation suggest that red abalone in Oregon can be considered as a single connected population that is not genetically distinct from the population in northern California (Smith, 2022). Management implications for these findings are discussed in the Management and Conservation Strategy section of this plan, with particular emphasis in the recommended actions section.

b. Ecology

Habitat and movement

Red abalone habitat is characterized by shallow, rugose rocky areas with consistent access to drift kelp. Red abalone persist at variable depths and habitat types throughout their range, living deeper in southern California (down to 100 feet/30m), shallower in northern California (down to 20 feet/6m) and shallowest in Oregon, with catch permits reporting average depths of 10 ft/3m (Groth & Smith, 2024). Red abalone can live at shallower depths in northern California and in Oregon due to the cooler water temperatures of 8-15 ˚C, compared to warmer waters in central (10-15 ˚C) and southern California (15-21 ˚C) (California Department of Fish and Game, 2005).

Adult red abalone live mostly sedentary lives; however, some studies have found that red abalone may move considerable distances (>350m) in response to food availability (Ault & Demartini, 1987). In northern California, red abalone may occupy shallower habitats in the spring and winter and move to deeper waters in the summer and fall (Ault & Demartini, 1987). Red abalone also exhibit habitat movement when transitioning through life stages, with juveniles occupying more cryptic habitats and moving into more exposed habitats as they grow, and dietary requirements shift (Ault *et al.,* 1985; Ault & Demartini, 1987; Tegner & Butler, 1989).

Abiotic factors

The physiological tolerance of an organism to changes in environmental conditions (e.g., temperature and salinity) is closely tied to their dispersion and habitat. Ocean temperatures strongly influence spawning in red abalone and changing ocean temperatures could affect the biogeographic range of red abalone through impacts on reproduction and overall health (Kawana *et al.,* 2019; Rogers-Bennett *et al.,* 2010). Ocean temperatures highly impact reproduction potential in red abalone, affecting sperm production in males, mature oocyte production in females and fertilization success. Specifically, lab experiments with red abalone found that at 18 ˚C, 71% of males had no sperm following 6 months of exposure (Rogers-Bennett *et al.*, 2010). Females were less affected overall by temperature increases, but fertilization of ova was found to occur at temperatures of 12-15˚C, whereas an increase to 18˚C decreased fertilization from 100% to 80%. As discussed in the reproduction section, spawning stimuli of red abalone is not well understood.

Diet

Red abalone are herbivores that feed on algae and kelp, with a preference for kelp. In Oregon, bull kelp, *Nereocystis leutkana,* is the dominant canopy-forming kelp, present in high densities seasonally and a primary dietary source for red abalone. Red abalone eat other types of algae, and their shell can differ in color based on whether abalone are eating brown, green or red algae (Ault *et al.,* 1985). In ideal environments, red abalone can acquire all of their dietary needs from kelp and do not need to forage. When algal densities are low, red abalone may leave their

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crevices and rock overhangs to forage for food at the base of kelp stalks (Ault & Demartini, 1987; Rogers-Bennett & Catton, 2019).

Predation

Red abalone have two distinct stages in their life cycle with differing implications for trophic web interactions. Red abalone juveniles (<100mm SL) are preyed upon by many benthic marine organisms, and therefore exhibit cryptic behavior by remaining under rocks, cobble, and seeking shelter under red sea urchin spine canopies (Tegner & Butler, 1989). As red abalone reach sexual maturity and grow, they face predation from larger predators that vary depending on the geographic species distribution of the red abalone population. As post larval and small juveniles <100mm, red abalone are highly predated upon by sea stars, cancer crabs, octopus, and fishes. Juvenile red abalone have been found to have high mortality due to predation, which is thought to be a main driver in cryptic behavior observed in juvenile red abalone (Ault *et al.,* 1985; Ault & Demartini, 1987; Rogers-Bennett *et al.,* 2016; Rogers-Bennett & Pearse, 2001).

Adult red abalone have few predators, especially as they increase in size. Sea otters (*Enhydra lutris*) are a main predator of red abalone and have population-level behavioral effects on red abalone. Specifically, in areas where sea otters are present, red abalone are smaller in size and are located exclusively in crevices and under rock overhangs. In contrast, areas where sea otters are absent, red abalone grow to larger sizes and occupy areas outside of crevices (Hines & Pearse, 1982; Watson, 2000; Wendell, 1994).

II. Available data

The ODFW Marine Resources Program (MRP) has periodically collected data on red abalone since the 1950s. Various data sources contributed to the current understanding about the Oregon red abalone fishery and population. Data sources include: 1) fishery dependent data 2) fishery independent data and 3) other data (i.e., educational/scientific take and enhancement projects). This section catalogs known data sources for Oregon's red abalone.

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ODFW Data Confidentiality

Data collected, prepared, or held by ODFW are subject to public disclosure under Oregon public records law (ORS § 192.314). However, certain fishery and other resource-related data collected by the ODFW Marine Resources Program are considered confidential data; accordingly, these data are conditionally exempt from the legal requirement to allow inspection of public records (ORS § 192.345).

In general, biological and research data about fishery species and habitats are not confidential. However, information related to fishing business operations (e.g., how and where fish are caught, income from fishing) is confidential. This includes commercial fish landing receipts, commercial fishing logbooks (e.g., OAR 635-005-0445), and operational data from recreational charter fishing vessels.

ODFW regularly receives requests for confidential data for use in various analyses (e.g., biological, regulatory, economic). ODFW evaluates all requests on an individual basis and will opt to provide non-confidential data whenever possible. To accomplish this, confidential data may be redacted, aggregated, or summarized to prevent any individually identifiable information from being released. If it is determined to be in the public interest, ODFW may release confidential data, protected through a non-disclosure agreement to restrict the use and distribution of confidential fishery data. In general, confidential data are only released to researchers conducting science that will improve the state's ability to manage Oregon's fishery resources.

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a. Fishery dependent data

Recreational fishery

In Oregon, harvest of red abalone has been primarily carried out by the recreational sector. Available data from the recreational red abalone fishery (1950s-2018) was collected through returned catch report permits. Catch report permits were first introduced in 1973 at no cost to obtain more information about the fishery and catch rates. Available data from permits contain catch and permittee information, including: 1) number caught; 2) catch location; 3) catch depth; 4) fishing method; and 5) permittee's county of residence. Two eras of catch report permit data are available (1973-1979 and 1996-2017). In 1973-1979, an annual average of 126 catch reporting permits were issued, with an annual catch average of 28 red abalone. In 1996-2017, both number of participants and annual catch increased, with an annual average of 175 permits issued (Figure 5) and an annual catch average of 145 red abalone (Figure 6). Catch area data was not required prior to 2005, but data from all permits with catch area demonstrated a strong focus on the south coast, particularly near the Brookings area. Specifically, 95% of catch occurred near Brookings, whereas 3% occurred near Port Orford, and the remaining catch (<1%) near Gold Beach and Coos Bay (Figure 7). Among the three methods of catch (SCUBA (self-contained underwater breathing apparatus), free dive, and shore pick), 51% used SCUBA with a mean depth of 5.2 m, 29% used free dive with a mean depth of 4m and the remaining 19% used shore pick with a mean depth of 0.3m (n=2,169) Groth & Smith, 2024).

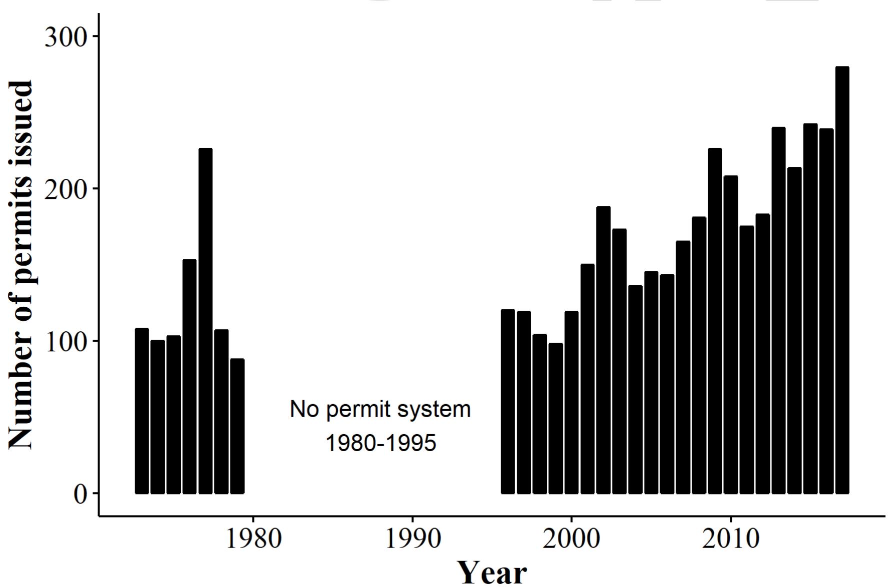

Figure 8: Recreational red abalone (*Haliotis rufescens*) permits issued from 1973-1979 and 1996-2017 in Oregon, from (Groth & Smith, 2024).

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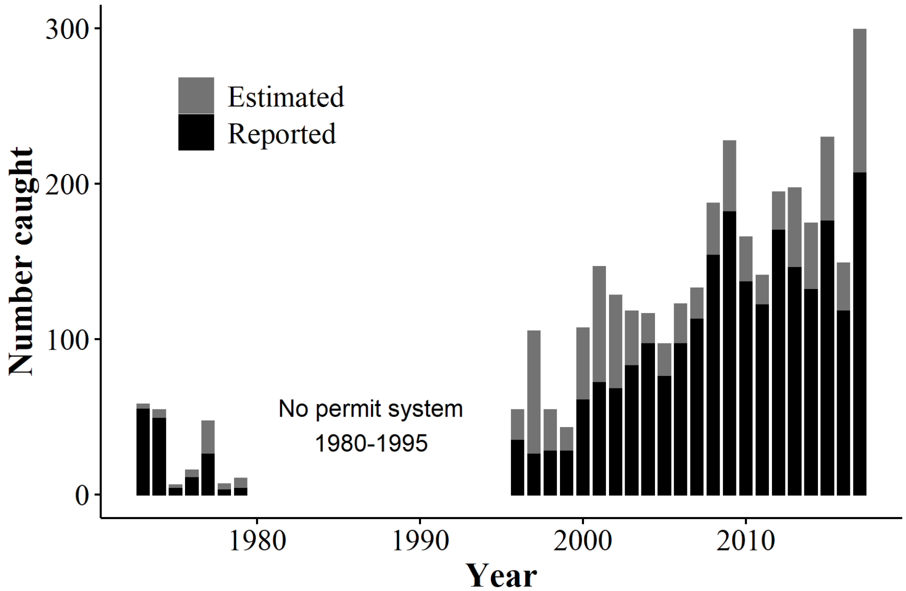

Figure 9: Recreational red abalone (*Haliotis rufescens*) fishery catch from 1973-2017 in Oregon, from (Groth & Smith, 2024).

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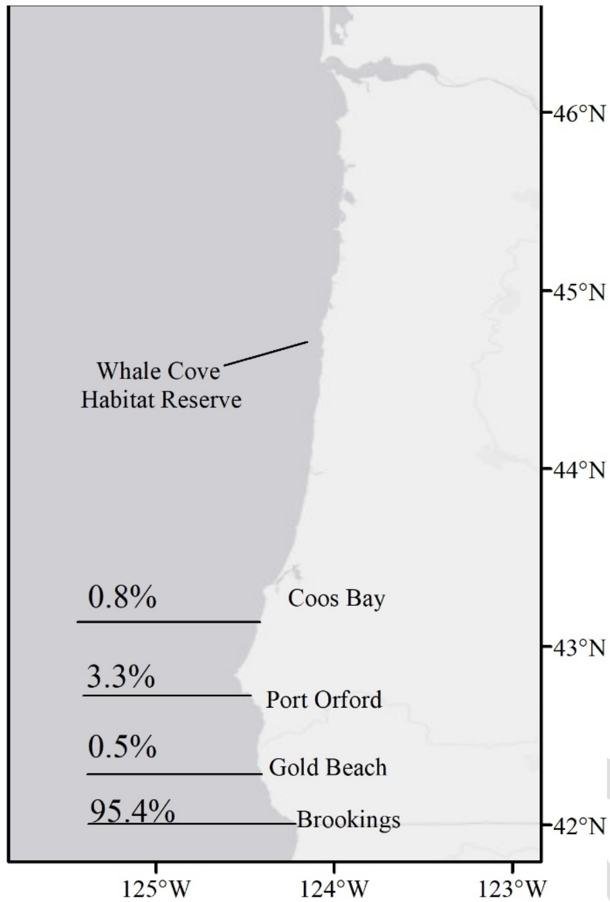

Figure 10: Percentage of recreational red abalone (*Haliotis rufescens*) fishery catch by area from 1996-2017 in Oregon (n=1894) (Groth & Smith, 2024).

Exploratory commercial fishery

A small exploratory fishery operated in southern Oregon from 1958-1962. Available data from this effort include dive reports and red abalone size measurements, providing qualitative data about red abalone habitat in Oregon and abundance. A total of 58 dives were completed from 1958-1960, with at least 111 red abalone caught and measured. The exploratory effort was terminated in 1962 as momentum lowered and only a few dives were performed (Snow, 1962).

b. Fishery independent data

Survey data for red abalone in Oregon is limited, as quantitative surveys were only first attempted in 2011 and not formalized until 2015. Prior to 2011, two iterations of qualitative surveys were performed by ODFW. First by contract from 1958-1962, in which red abalone were removed, measured and their location was noted. The second iteration of qualitative surveys was performed by ODFW divers from the 1960s-1990s as spot checks to bolster further understanding of the stock.

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The first attempt at quantitative surveys occurred over a two-day period in June 2011, evaluating polygonal index site surveys and timed surveys. Results of this survey effort determined that random transect locations for index sites would not accurately detect abalones in Oregon, and timed surveys can be used for size distribution data collection, but not density measurement (Table 1).

Table 1: Number of red abalone (*Haliotis rufescens*) seen in timed dives by year (1969, 2011) in Brookings, Oregon (Groth & Smith, 2024).

Year	Number seen	Survey minutes	Abalone/hour
1969	46	250	11.15
2011	55	127	24.39

In 2015, the first quantitative surveys were performed in Oregon, with two index sites chosen where the fishery operates in Port Orford and Brookings. Forty-four 30 x 2m subtidal belt transects were performed, 20 in Port Orford and 24 in Brookings respectively (Table 2). In 2019 and 2022 a subset of baseline surveys were conducted.

Table 2: Red abalone (*Haliotis rufescens*) densities (per m^2) from fishery independent index sites in 2015, 2019, and 2022 by port in Oregon (Groth & Smith, 2024). *note 2022 data is preliminary.

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

c. Other data

ODFW's educational and scientific take permitting system

In addition to fishery take, ODFW has an educational and scientific take permitting system that has allowed take of all abalone species. This scientific take of abalone is regulated through ODFW's educational and scientific take permitting system (ORS § 508.111). However, this take is issued based on scientific merit of a proposed research project with consideration of population levels, and it is currently prohibited to take abalone of any kind unless specifically noted by this permit. A summary of reported educational and scientific take of abalone in Oregon has been very low (Table 3).

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Table 3: Requested and reported educational and scientific take in Oregon 2002-2022. NR denotes take that has not been reported.

Year	Requested take	Actual take	Mortality	Action
2021	122	1	0	Collect
2022	151	NR	NR	Harass

Enhancement projects

As abalone fisheries are difficult to manage sustainably, but have a large amount of interested harvesters, projects to enhance the population of abalone are common. In Oregon, two enhancement efforts targeted at bolstering the fishery and increasing the stock were employed with varying results. The first project took place in the 1960s at Whale Cove (a no-take reserve), which is just north of Depoe Bay, OR and is 100 miles north of the biological range extent in Coos Bay, OR. The goals of this effort were to create a new fishing opportunity for red abalone in Oregon and to create a spawning stock that was protected from fishing pressure (Nielsen, 1967). Between 1967 and 1974, a total of 5660 juvenile and 277 adult red abalone were placed in Whale Cove from both hatchery stock and northern California wild populations. The results of this effort did not increase fishing opportunities in Oregon. However, this project did provide researchers with some information about red abalone growth, age, and reproduction in Oregon (Groth & Smith, 2024).

The second enhancement project in Oregon was designed to enhance the spawning stock of wild red abalone in Oregon and took place between 1994-2002 as a partnership with Oregon State University (OSU) (Golden & Langdon, 1995). Juvenile red abalone were reared from adult red abalone collected in Oregon; however, the results of this project are unknown because monitoring was not in place at the time. Several red abalone from this project were introduced in Oregon waters near Coos Bay in 2002 (Groth & Smith, 2024).

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III. Analysis of stock status

Stock status of red abalone has been tracked by relative indices in California (Karpov *et al.,* 1998; Karpov *et al.,* 2000; Karpov *et al.,* 2001). In Oregon, methods have historically been variable and infrequent, and ODFW initiated a consistent program to repeatedly survey belt transects within harvest areas in 2015. Further, the population is difficult to survey due to both habitats and red abalones' cryptic and elusive nature. While traditional methods provide a relative indicator of the status of the red abalone population, they are costly and difficult to perform in Oregon. Adaptive and non-traditional methodologies could be assessed to improve effectiveness for quantifying red abalone in Oregon. Utilizing the stock assessment metrics and application of

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California's red abalone population is a useful convention that may be considered for Oregon. Sections below detail considerations for Oregon's red abalone stock status.

a. Stock assessments

Stock assessments for red abalone in Oregon are limited, with one index survey performed in 2015 at two sites. The details of this survey and its results are in section A.II.b. Findings of this survey indicated much lower densities of red abalone than results from fished areas in California.

Stock assessments for red abalone in northern California historically occur at eight index sites, with four sites in Sonoma County and four sites in Mendocino County. Index sites were chosen based on catch data, with chosen sites making up 48% of fishery catch overall (California Department of Fish and Game, 2005). These sites are intended to allow for early detection of population levels that exceed the Limit Reference Points (LRPs) for California. For each site, 36 randomly selected depth stratified 30 x 2m transects are performed, taking approximately three years to complete. To compare these 3-year surveys, relative time periods were utilized to determine changes in the red abalone population. An evaluation of these surveys in 2013 indicated non-actionable changes to red abalone densities between baseline surveys in 1999-2000 and 2003-2007 but trended downward 36% between 2003-2007 and 2009-2012. Recent stock assessments (2016-2018) in northern California indicated very sharp decline in red abalone populations, with densities lowering between 2016-2017 by 48-82% and further declines of 43-96% between 2017-2018 (Rogers-Bennett & Catton, 2019).

Similar to the decline in northern California, the populations of red abalone in Oregon exhibited substantial declines in the range of 50-70% loss over a period of seven years. For example, in 2019, ODFW personnel revisited one site (Port Orford) and performed belt transect surveys that demonstrated a similar decline in densities, with a decrease from 0.030 red abalone per m^2 in 2015 dropping to 0.017 red abalone per m^2 in 2019 (Groth & Smith, 2024).

In 2022, ODFW staff revisited index sites in Brookings and performed belt transect surveys which further bolstered the findings from previous surveys. Red abalone densities at subsampled sites from fell from 0.047 red abalone per m^2 in 2015 to 0.014 red abalone per m^2 in 2022 (Groth & Smith, 2024).

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b. Limit reference point

Limit Reference Points (LRPs) are used by fisheries managers as data driven metrics which are designed to assist with decision-making to effectively manage natural resources (Caddy & Mahon, 1995). LRPs established for the recreational red abalone fishery in northern California are currently in place and have been modified over time. However, LRPs have not been formally established for the recreational red abalone fishery in Oregon.

In 2005, CDFW published and adopted the Abalone Recovery and Management Plan (ARMP), which details aspects of biology, stock status, ecology and management for abalone fisheries and recovery in California (California Department of Fish and Game, 2005). Based on a long history of population trend data, minimum viable population (MVP) was determined to be 0.66 red abalone per m^2 to sustain fishing, and 0.2 red abalone/m^2 for unfished recovered populations. If densities of red abalone in California fall below 0.2 red abalone per m^2, the population could be susceptible to collapse. This LRP metric was determined using minimum spawning densities evaluating historic levels at a designated spatial extent (Shepherd & Brown, 1993), and densities that preceded the decline of red abalone in southern California (Karpov *et al.,* 1998; Tegner *et al.,* 1989). Using the MVP for red abalone in northern California, the catch reduction trigger was set at 0.5 red abalone per m^2 which would require considerations for reducing catch. The level set for closing a particular fishing site was set at 0.25 red abalone/m^2. In addition to these LRPs, a total allowable catch (TAC) was determined for all northern California sites combined.

In Oregon, densities of red abalone measured during each fishery independent survey have been well below the threshold set by California as indicated by densities measured during ODFW index surveys in 2015, 2019, and 2022 (see stock assessment section above).

LRPs for abalone utilize site-specific information about their density along with associated biological metrics (SPR, belt transect densities, etc.). If this approach were to be applied in Oregon, resource managers would have to proceed with only sparse data about red abalone populations at the northern edge of their biogeographic range, and to attempt to integrate ancillary information about other observations and potential metrics into the process for decision-making.

c. Synthesis of results

Application of density levels from surveys to management actions is variable for abalone fisheries worldwide and differs based on the size of the fishery, localized environmental factors and biological information. In Oregon, densities for red abalone have not previously been used to establish LRPs, to set a TAC, nor to engage in adaptive management by fishery zone.

In California, the application of survey and catch data to management for abalone fisheries has been updated through time. In 2005, CDFW adopted the ARMP which regulated catch levels in northern California's red abalone fishery. A TAC is set (400,000 red abalone) based on projected catch then reduced (280,000 red abalone) and adjusted based on actual catch on an annual

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basis through reductions or increased in daily and annual limits. Further changes to this strategy are currently in progress, with a Management Strategy Evaluation (MSE) completed in 2018 by The Nature Conservancy (TNC), evaluating previous management strategies outlined in the ARMP. The results have been incorporated into a new FMP (Summary of the Management Strategy Integration Process for the North Coast Recreational Red Abalone Fishery Management Plan) prepared in 2020 (Jackson *et al.,* 2020). The review focused on the need for creating flexible and site-specific management objectives with considerations for spatial variability.

IV. Threats to the red abalone resource

a. Fishery-related

As fisheries target specific organisms and increase in efficiency with time, increased fishing pressure can threaten a resource through removal of more individuals than the population can effectively replace. The recreational red abalone fishery in Oregon increased in popularity reaching its peak just before the fishery was suspended in 2018 (Figure 6). The demand for abalone fishing opportunities has increased worldwide as environmental conditions have shifted, causing further strain on the imperiled population. In addition to increased fishing pressure, red abalone are often harvested from “hotspots” where many abalone are aggregated. Removing adult red abalone from these aggregations can have adverse effects on both reproduction and overall population health. Further, red abalone are often targeted by their large size as trophy abalone (SL>250mm), especially in Oregon where the recreational fishery is primarily a trophy fishery. As red abalone produce more eggs as they increase in size, removing the larger abalone has the consequence of unequally affecting reproduction (Rogers-Bennett & Kashiwada, 2004). Declines in kelp density correlated with warming events have led to more emergent behaviors in red abalone, providing them with less food and increasing exposure to predation (Rogers-Bennett *et al.,* 2019, 2021).

b. Habitat impacts

Red abalone habitats in Oregon are limited and recently experienced changes, with red abalone only inhabiting the southernmost part of the state, primarily found in the ten most southern miles of coastline. Red abalone habitat is characterized by rocky reefs and kelp beds (Ault *et al.,* 1985). In recent years kelp has dramatically reduced across the west coast, deeply affecting abalone populations (Kawana *et al.,* 2019; Rogers-Bennett & Catton, 2019). Warm water conditions and kelp density loss have led to increased red abalone mortality due to starvation. In addition to ecological changes, freshwater inputs associated with development have been reported to cause mass die offs in Oregon, through decreased numbers of live abalone collected by ODFW personnel during qualitative surveys (Groth & Smith, 2024). Further, sediment deposits are likely due to a combination of coastal construction and development, and it will be important to monitor the effects on the nearshore communities.

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c. Changing ocean conditions

Environmental conditions are changing, and effects have been detected, expecting to increase. Ocean condition shifts that will impact red abalone populations include ocean acidification, warming sea surface temperatures, decreased oceanic oxygen and other ecological stressors.

Ocean acidification

Ocean acidification has increased and is expected to accelerate (le Quéré *et al.,* 2016). More acidified seawater has consequences for different life stages and processes of marine organisms. Benthic organisms that live deeper and have shells made from calcium carbonate ($CaCO_3$) may be the most vulnerable to ocean acidification effects due to the lowest pH at deeper oceanic depths as well as limitations to migration (Hauri *et al.,* 2009). Red abalone create their shells out of aragonite, a soluble form of calcium carbonate ($CaCO_3$), through the process of biomineralization which is negatively impacted by lower oceanic pH and varies with intensity through different life stages. Specifically, studies have found that survivorship is lower for larval red abalone when exposed to acidified seawater and thermal stress, particularly at the pre-torsion and late-veliger stages of larval life; however, expression of genes responsible for biomineralization were unaffected (Zippay & Hofmann, 2010). Although ocean acidification does impact red abalone, there is a higher consequence for deeper-living abalone species, and combinations of environmental stressors during development.

Hypoxia

Hypoxia, or low oxygen zones, are common in nearshore marine waters particularly during summer months when upwelling is increased, bringing deeper low oxygen water to the surface. As ocean circulation patterns are thought to be changing in conjunction with climate change, hypoxic events are likely to become more frequent and longer in duration (Gobler & Baumann, 2016).

Low oxygen zones are most likely to impact larval and juvenile stages of red abalone, with laboratory studies finding that prolonged exposure to low oxygen levels results in increased mortality for juvenile red abalone (Kim *et al.,* 2013). However, high variation in growth rates under low oxygen and decreased pH has suggested cryptic phenotypic plasticity among red abalone. Recent genetic studies have investigated this phenomenon by comparing genes that regulate oxygen levels in red abalone and have suggested that localized adaptation to hypoxia is occurring throughout their range (de Wit & Palumbi, 2013; Kim *et al.,* 2013).

Climate change

In addition to changes in ocean chemistry, several other shifting parameters associated with climate change may also exert stress and cause impacts to nearshore marine habitats and species. These impacts include increasing ocean temperatures, sea level rise, changing nutrient availability, increased storm intensity, and altered circulation patterns including changes to upwelling and stratification. These physical changes, in turn, may alter biological processes

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through shifts in species ranges, invasions and local extinctions, and ecosystem regime shifts (Brierley & Kingsford, 2009).

Growth models of red abalone have been explored in California, and hierarchical models which can account for growth variability have suggested that increasing sea surface temperatures (SST) will result in slower growth rates (Jiao *et al.,* 2010). Lowering growth rates could also be caused by decreased kelp densities, which would also slow growth rates. Warmer temperatures may also cause lower food availability, reduced reproduction rates, and increased disease (Boch *et al.,* 2017; Brierley & Kingsford, 2009; Gobler & Baumann, 2016; Leighton, 1974; Rogers-Bennett & Catton, 2019). Accounting for increased SST and its impacts on red abalone growth will be an important variable to monitor when considering fishery models and management as ocean conditions change.

d. Diseases

Few diseases affect the health of wild red abalone populations, but there are two known threats to abalone populations that could increase as environmental conditions continue to change in the marine environment. Withering foot syndrome (WS) is caused by the intracellular bacterium *Candidatus xenohaliotis californiensis* and infects the gut tissue of red abalone. The main side effect of this syndrome is a shrunken foot muscle which affects mobility, substrate attachment and overall gut health (Crosson *et al.,* 2014). Although southern California red abalone populations have been found to be severely affected by this disease, northern California populations experience lower water temperatures and therefore have fewer bacteria. Oregon red abalone population occupy very similar conditions to northern California (Crosson *et al.,* 2014; Moore, 2002). As sea surface temperatures rise, increased cases of WS are expected to occur as elevated temperatures are more conducive to bacterial growth.

e. Ecological changes

As environmental conditions continue to shift causing complications and cascading effects in the rocky nearshore environment, consideration of the ecological changes which are affecting the red abalone population in Oregon is critical. Specifically, physical changes to the environment, described in the changing ocean conditions and climate change sections above, may have increasing effects on biological interactions including range shifts, local extinctions, shifting dynamics, food availability and predator-prey interactions. Organism dispersion, presence and increases that would affect or have already affected the red abalone in Oregon are pinto abalone (*Haliotis kamtschatkana*), the green sea urchin (*Strongylocentrotus droebachiensis*) and purple sea urchin (*Stronglyocentrotus purpuratus*). Although the biogeographic range of pinto abalone is from southeast Alaska to Point Conception, CA (Geiger, 1999), they are rare in Oregon. However, pinto abalone have recently been found more frequently in Oregon waters by sea urchin divers and during sea urchin surveys (Scott Groth pers. Comm.).

In addition to increasing competition for food and space, the disappearance of predators in the rocky nearshore environment is of high concern, in relation to the red abalone. Purple sea urchins are preyed upon in the subtidal and intertidal environments by large soft bodied predatory sea stars which have effectively disappeared from the environment. Sea Star Wasting Disease (SSWD) has decimated populations of *Pycnopodia helianthoides*, *Solaster dawnsonii* and *Solaster stimpsoni* in Oregon. Without these predators, purple sea urchins outcompete red abalone for both kelp and space. In 2020, the sunflower star (*P. helianthoides*) was classified as critically endangered on the International Union for Conservation of Nature (IUCN) red list, and efforts are underway to address this problem (Gravem *et al.,* 2021).

f. Re-introduction of sea otters

In Oregon, sea otters have been absent since their extirpation by hunting in the early 1900s (Jameson, 1974). Currently re-introduction of sea otters to Oregon is being considered. Sea otters prey on benthic invertebrates, with special preference for abalones and sea urchins. The effect of introducing sea otter populations into an area that was previously unoccupied is well documented for central California (Hines & Pearse, 1982; Watson, 2000; Wendell, 1994). Although sea otters are thought to stabilize abalone populations through predation pressure which leads to behavioral and physiological shifts, the red abalone population in Oregon could be uniquely affected by this re-introduction. (Hines & Pearse 1982) found that larger red abalone in their study site were removed by sea otters and were not protected by refugia in crevices. An important consideration for the red abalone resource in Oregon is the nature of the recreational fishery as a trophy fishery, with a fishery mean size of 245 mm SL, potentially indicating that the re-introduction of sea otters would immediately remove large red abalone in Oregon. Removing large red abalone from the environment could diminish reproduction due to the increased reproductive output of large red abalone (Rogers-Bennett *et al.,* 2007; Rogers-Bennett & Kashiwada, 2004; Rogers-Bennett & Leaf, 2006). Fisheries for abalone and resident populations of sea otters have been shown to be mutually exclusive (Hines & Pearse, 1982; Watson, 2000; Wendell, 1994). A sea otter reintroduction in Oregon would likely require permanent closure of the red abalone fishery in Oregon, coupled with increased monitoring to address conservation concerns.

V. Sustainable harvest levels

Our understanding of sustainable harvest levels for the red abalone population in Oregon is weak and mostly draws on fishery dependent data. Recreational red abalone permit data from the 1970s demonstrates that harvest was low at that time. Specifically, permit data from 1973-1979 reported an annual average of 28 abalone caught per year. In contrast, between 1996-2017, annual average harvest increased to 145 red abalone per year. Reported take peaked in 2017, with 299 red abalone caught (Groth & Smith, 2024). As population data varies and is always moving, annual harvest can change based on fishing and environmental pressure.

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Future sustainable harvest limits for red abalone would be very limited or *de minimis*. Levels should be adjusted to lower than 50% of historic peaks or based on new survey information. Implications for management and recommendations are explored in section B.IX.

VI. Information gaps and research needs

More information about the red abalone population in Oregon is needed to further understand the dispersion, health, and viability. In addition to fishery management criteria, conservation is a priority of this framework and ODFW. This section outlines the information gaps and research needs for effective conservation and management of red abalone in Oregon.

a. Stock assessment

An important metric for determining management and conservation practices and limits for a species is understanding how to quantify abundance, dispersion, and connectivity. Due to difficulties in red abalone life history and access to their habitat, established stock assessment methods have not been established for Oregon. Quantifying red abalone abundance through adaptive methodologies, determining population trends and potentially an absolute number (i.e., effective population size) is needed to accurately assess the status of red abalone in Oregon. Further studies and surveys focused on determining metrics for consistent monitoring and setting limits for biological resilience are important for future management and conservation considerations.

b. Recruitment variability

Red abalone recruitment is not well understood, but it has been shown to vary based on local environmental and biological conditions. Studies on red abalone in California have shown that in the south, they can spawn twice a year, in the central areas they can spawn year-round and in the north spawning peaks in April through July in conjunction with the spring algal bloom (Ault, 1985; Ault *et al.,* 1985; Hart *et al.,* 2020; Price, 1974; Tegner & Butler, 2021). In Oregon, there have not been studies to determine when spawning occurs, and it is thought that the variable nature of the environment and low number of individuals could lead to low recruitment levels or a "black hole sink" phenomenon (Holt & Gomulkiewicz, 1997). This would mean that red abalone in Oregon could receive all recruits from a geographically separate "source" and it does not provide genetic information as a "sink" population (Gomulkiewicz et al., 1999; Holt *et al.,* 2003; Holt & Gomulkiewicz, 1997). However, further studies focused on determining when seasonal recruitment in Oregon occurs would help to increase understanding of the stock. The proposed management strategy for northern California's red abalone fishery is based on quantifying successful reproduction through Spawning Potential Ratios (SPR), and this would be a useful metric for Oregon as well.

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c. Climate change

Ocean conditions are changing, and the impacts of ocean acidification, hypoxia and increased temperature changes are expected to impact marine organisms and accelerate in the future (Section AVC). Research indicates that changing conditions are likely to affect the distribution and productivity of red abalone, but quantitative estimates are lacking. Understanding climate sensitivities of red abalone and incorporating into monitoring changes would aid management in adapting to these changes.

d. Larval dispersal

Since adult abalones are known to move minimally (Bonnot, 1948; Cox, 1962; Hines & Pearse, 1982), larval dispersal is likely to be the primary mechanism for the dispersion of the species. Movement within and between populations is a key component in understanding red abalone stock structure. Few studies have looked at larval movement, behavior, and dispersion for red abalone (Mccormick *et al.,* 2012; Rogers-Bennett *et al.,* 2016; Watson *et al.,* 2010), and none have determined the pattern of dispersal and movement for red abalone in Oregon. Increased information about how Oregon red abalone populations disperse over short and long-term temporal scales would allow managers to better understand the potential source/sink dynamics within the coastwide context of the greater red abalone population.

e. Natural mortality

Few studies have investigated natural mortality of red abalone, and none have addressed natural mortality (M) specifically for red abalone in Oregon. (Rogers-Bennett *et al.,* 2007) found that red abalone are slow growing with low to intermediate natural mortality rates ranging from 0.11-0.23 y^{-1}. Natural mortality is a key variable used when considering biologically sustainable harvest levels and is known to vary widely across a species range. An accurate estimate of M in Oregon would be useful to apply to biological reference points and could serve as an appropriate metric for conservation and management.

f. Marine mammal interactions

Currently there are no significant marine mammal interactions that affect Oregon's red abalone. However, recent considerations to re-introduce sea otters would likely have a major impact on red abalone populations. Increased understanding of the impacts on red abalone and the implications for dispersion are important information gaps to consider for conservation goals.

B. Management and Conservation Strategy

This Management and Conservation Strategy articulates the overall management approach, goals, and conservation practices needed to sustain sensitive populations, coupled with guidelines for a potential *de minimis* recreational fishery where limited recreational take can be sustainable. Related goals and objectives are defined considering ecological and socioeconomic aspects of the utilization of red abalone. A description of management practices and current

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issues facing the fishery is provided and followed by an evaluation of available management tools. It is anticipated that this conservation and management plan will be updated whenever there are significant changes in the population or the regulatory environment or at least every 10 years.

I. Management approach

Prior to the suspension of the red abalone recreational fishery in 2018, the management approach for red abalone in Oregon was simplistic and relied upon a combination of Minimum Legal Size (MLS), a reporting permit, and annual harvest limits. Together, these requirements allowed monitoring with minimal confines of red abalone but did not account for variability in environmental conditions, shifts in the level of interest in the abalone fishery, nor adapt to changes in the population of red abalone.

Here, explicit management goals and objectives are suggested to serve as guidelines for a more deliberative and pro-active management/conservation strategy that could be followed into the future.

The goals of future red abalone management should meet explicit biologically informed reference points, incorporate flexibility with respect to ecological shifts and consider the implications for social and economic impacts.

a. Management goals

The management goals described in this strategy apply to red abalone harvested recreationally in Oregon waters. The identified goals reflect long-term desired outcomes for the Oregon red abalone fishery, coastal communities, and larger ecosystem. These include:

1) **Ecological** – Ensure the long-term reproductive capacity and health of the red abalone population, minimize impacts to other species, and support ecosystem health.
2) **Social/cultural** – Promote diverse opportunities for present and future generations to use, enjoy, or harvest the red abalone resource.
3) **Economic** – Support the economic importance of red abalone in Oregon through education, conservation, and potential fishing opportunities.

b. Management objectives

To accomplish these goals, there are specific objectives that will be re-evaluated in subsequent revisions of this plan.

Management objectives include:

Ecological

1.1. Maintain, develop, and implement management strategies that maintain red abalone at or above the levels necessary to ensure species and ecosystem productivity.

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1.2. Maintain, develop, and implement management measures that prevent serious or irreversible harm to the key elements of ecosystem structure and function, and that support ecosystem structure, function, and resilience to changing climate and ocean conditions.

1.3. Conduct periodic reviews of the best available information on the biological status of the resource and impacts of the fishery to inform management decisions.

Social/cultural

2.1 Maintain, develop, and implement management measures that consider the cultural and aesthetic value of the red abalone fishery and species in Oregon.

2.2 Provide access to either harvest or enjoyment of red abalone that ensures harvest sustainability and considers the needs of recreational users.

Economic

3.1 Maintain, develop, and implement management measures that optimize long-term harvest from the red abalone fishery and, to the extent possible, minimize adverse economic impacts on coastal communities.

3.2 Support coastal tourism by creating red abalone enjoyment opportunities, considering the non-consumptive economic value of red abalone in Oregon, and providing a framework for future fishing opportunities.

Considerations for implementing objectives

c. Interstate management approaches

Regulations that are passed in one state have the potential to impact fishing effort or activity in other states. For example, several of Oregon's key regulations addressing recreational red abalone fishing in Oregon were developed in response to data, experiments and regulations explored and passed in California. Although rules are adopted in each state through independent processes, the regulations and management structure are generally consistent; however, there are several key differences among the regulatory processes in these two states which impact coastwide red abalone management.

Oregon

Oregon's abalone fishery is governed by a series of Oregon Revised Statutes (ORSs) that are adopted or modified by the Oregon Legislature, and Oregon Administrative Rules (OARs) that are adopted or modified by the Oregon Fish and Wildlife Commission. The OFWC (established under ORS 496.090) consists of seven governor-appointed commissioners who are charged with setting policies and developing general state programs that provide for the productive and sustainable management and utilization of fish and wildlife resources by all user groups. Implementation of both ORSs and OARs is overseen by ODFW with enforcement functions carried out by the Oregon State Police.

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The ODFW / Marine Resources Program provides management and oversight for the conservation, recreational take, and commercial harvest of fish and shellfish residing in marine waters. Oregon suspended the recreational abalone fishery in 2018, and the prohibition of recreational take is currently scheduled to expire at the end of 2023. Since that time, Oregon has conducted new surveys of abalone populations, engaged in research about shifts in the condition of underwater habitats, generated new understanding about the population genetics of red abalone, and developed the guidelines presented in the CFMP.

California

Regulations related to recreational abalone fishery management in California are adopted by the California Fish and Game Commission in the California Code of Regulations. The California Fish and Game Commission is comprised of five governor-appointed members broadly charged with ensuring the long-term sustainability of California's fish and wildlife resources. Enforcement and implementation of regulations for the recreational red abalone fishery is performed by CDFW.

California has suspended their recreational red abalone fishery until 2026 (Taniguchi & Traverso, 2021). Currently, an integrative management plan is in progress, with many of the proposed management strategies referenced in this plan, utilizing information provided in the Management Strategy Integration Process final report (Jackson *et al.,* 2020). Management of the recreational red abalone fishery in California is divided into fishery zones that encompass different geographical areas, each that has its own total allowable catch (TAC).

II. Conservation approach

Previous management of the red abalone resource in Oregon has been conservative and reactive, through monitoring of the stock and catch metrics. However, as ocean conditions continue to change and impact red abalone populations, a shift towards a proactive and precautionary approach is needed. This conservation approach serves as a guideline in the absence of an open fishery for appropriate conservation of the red abalone resource in Oregon, as well as a framework for continuing to support the possibility of a *de minimis* fishery should environmental and biological conditions allow.

a. Conservation goals

The conservation goals described in this strategy apply to red abalone in Oregon waters. The identified goals reflect long-term desired outcomes for the Oregon red abalone population and health of the larger ecosystem. These include:

1. Monitor the red abalone population in Oregon.
2. Increase understanding of the dynamics of red abalone populations.
3. Allow for recovery of the red abalone population in Oregon.

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4. Improve habitat and food availability for red abalone populations in Oregon through research and monitoring.

b. Conservation objectives

To accomplish these goals, there are specific objectives that will be re-evaluated in subsequent revisions of this plan.

Conservation objectives include:

1. Monitoring

1.1. Conduct fishery-independent surveys to routinely monitor red abalone at two sites periodically.

1.2. Evaluate monitoring strategies through assessment of non-traditional and adaptive methodologies to determine efficacy and cost effectiveness for consistent monitoring.

2. Stock status

2.1. Utilize the best available science to determine population dynamics for red abalone in Oregon.

3. Recovery

3.1. Remove fishing pressure for red abalone populations in Oregon until metrics for recovery are established.

4. Habitat

4.1. Monitor the spatial distribution and health of kelp and rocky reef habitats along the Oregon coast.

4.2. Consider supplemental methods of conservation such as: outplanting red abalone, kelp, or physical modifications of habitats critical to red abalone populations.

III. State authority

The red abalone resource in Oregon is managed at the state level by the Oregon Department of Fish and Wildlife.

IV. Oregon red abalone fishery description

Two red abalone fisheries have been formally prosecuted in Oregon, an exploratory commercial fishery 1959-1962 and a recreational fishery 1950 to 2018. Here we describe the history of both the recreational red abalone fishery in Oregon and the exploratory commercial fishery in Oregon as well as entities involved in management and conservation that must be considered when creating the future regulation of the red abalone resource.

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a. Fishery sectors

Recreational fishery

Oregon's recreational fishery for red abalone began in the early 1950s, with increasing interest and harvest leading to adoption of initial rules in 1959. A catch report permit was introduced in 1973, but not required for harvest until 1996. Few rule changes have been made to the fishery since its inception in 1959. Rules at the inception of the fishery included a 203 mm (8 inches) Minimum Legal Size (MLS), daily limit of 3 per day every 7 days, and required participants to measure abalone before removing them from substrate for harvest. In 1996, a catch report permit was required, daily take was reduced to 1 per day, and annual take was reduced to 5 per permit holder. In 2018, the fishery was suspended for 3 years, and in 2021, the suspension was extended for another 3 years, set to expire in 2024.

Exploratory commercial fishery

A short exploratory commercial fishery for red abalone persisted from 1958-1962 focused on determining more information about Oregon's red abalone stock and if a commercial fishery was feasible. In 1962, following limited harvest and decreasing project momentum, the contract with divers was terminated citing a higher need for conservation rather than commercial harvest (Snow, 1962).

b. Entities involved in management

In the 1950s through 1970s, fish and wildlife regulation in Oregon was accomplished through separate Fish and Game Commissions which were periodically reorganized to keep pace with increasing interests in game and game fish and shifting priorities. In 1975, the separate State Wildlife Commission and State Fish Commission were integrated into a single Department of Fish and Wildlife overseen by a State Fish and Wildlife Commission. Today, the following entities have a legal role in the management of the red abalone resource in Oregon.

Oregon Department of Fish and Wildlife

The Oregon Department of Fish and Wildlife (established under ORS § 496.080) is the executive branch of state government responsible for managing Oregon's fish and wildlife and their habitats. ODFW is authorized in statute by the state Legislature and in administrative rule by the OFWC, to administer the regulation and management of Oregon's commercial and recreational fisheries.

ODFW implements this authority for Oregon's red abalone fishery through the Marine Resources Program within the agency's Fish Division. The MRP carries out state management actions through work focused on three main categories:

1) Marine resource management, policy, and regulation
2) Monitoring and sampling of marine fisheries

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3) Research and assessment of marine fisheries, species, and habitats

MRP staff represent Oregon as members of numerous groups which coordinate interstate fishery management processes, such as the Pacific Fishery Management Council and the Pacific State Marine Fisheries Commission.

Oregon State Legislature

Statutes (i.e., ORSs) are created and passed by the Oregon Legislature. The Oregon Legislature also appropriates and allocates funding on a two-year (biennial) budget cycle to all state agencies, including ODFW. Legislative approval for ODFW's staffing and budget has generally been stable or growing since the late 1990s, including staffing and funding appropriated to the MRP.

Oregon Fish and Wildlife Commission

The Oregon Fish and Wildlife Commission (established under ORS 496.090) consists of seven governor-appointed commissioners who are charged with setting policies and developing general state programs that provide for the productive and sustainable utilization of fish and wildlife resources by all user groups.

Oregon State Police

The Oregon State Police play a key role in supporting ODFW's mission as the single entity tasked with enforcement of fish and wildlife regulations. Within the OSP Fish and Wildlife Division, seven troopers and a sergeant are assigned to a Marine Fisheries Team that is responsible for coastwide enforcement of commercial and recreational fishing regulations.

ODFW and OSP use cooperative enforcement planning as a tool to set enforcement priorities for each species. Personnel from each agency meet annually to discuss priority issues and objectives so that cooperative enforcement plans (CEPs) can be developed. This ensures that enforcement efforts are in line with ODFW's management priorities and goals. OSP also works collaboratively with other enforcement entities (NOAA enforcement, the USCG, WDFW, and CDFW) through the PFMC process.

Oregon Department of Agriculture

The Oregon Department of Agriculture (ODA) regulates natural resources which are harvested for human consumption. ODA samples and tests various shellfish that might harbor bacteria or harmful diatoms that could impact human health. Red abalone in Oregon have not been impacted by harmful bacteria that have caused diseases such as Withering Syndrome (WS) in past years. However, as ocean conditions continue to shift to warmer temperatures, ODA could become more involved in testing red abalone for bacteria if re-opened for human consumption.

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Department of State Lands

The Oregon Department of State Lands (DSL) regulates two important factors that influence the red abalone resource in Oregon. Subtidal and intertidal rocks, which act as substrate and essential habitat for red abalone, and kelp, the main food source for red abalone, are managed by DSL.

c. Other entities

The red abalone fishery has always been managed by the state, but other entities have been and are currently involved in management processes.

Research institutions

ODFW partners with a variety of researchers and natural resource professionals from different institutions to expand research and monitoring efforts that are critical to informing effective management of Oregon's fishery resources. This conservation and fishery management plan is the result of a collaboration between ODFW, Oregon Sea Grant and the University of Oregon.

d. Fishing method and gear

Three fishing methods for red abalone in Oregon have been utilized by fishery participants, including: 1) SCUBA (Self-Contained Underwater Breathing Apparatus), 2) free dive and 3) shore pick. Catch report permits indicate that the majority of red abalone fishing is performed by SCUBA diving (51.4 % of users), followed by free dive (29.3% of users) and lastly shore pick (19.2% of users).

Fishery participants are required to premeasure red abalone prior to removing the animal from substrate to ensure minimal damage to undersized red abalone. The use of an abalone iron for removal and caliper for measurement is a common practice.

e. Season

Oregon's recreational red abalone fishery has not been restricted by season historically. However, due to diving and weather conditions in Oregon, abalone fishing has been limited based on environmental factors. In California, the red abalone fishery was closed for the month of July to allow for spawning to take place without fishing pressure, as well as December through March. Future management regulations could implement a seasonal closure for spawning or have a limited number of fishing days to regulate take.

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f. Social and economic components

Recreational fishery economic contribution

Recreational red abalone fishing in Oregon is a unique opportunity for participants and has grown in popularity with divers worldwide, though the economic contribution of the red abalone fishery in Oregon has not been quantified. For northern California, an estimated 10 million USD in annual direct expenditures, and over 17 million USD in final output for local economies (California Department of Fish and Game, 2005) has been suggested. Oregon's red abalone fishery has had an average of 300 issued permits in the last ten years (2007-2016), compared to an estimated 25,000 participants in the northern California fishery (2002-2015).

Non-consumptive value

Red abalone have direct consumptive value through their harvest, but also have non-consumptive value. Non-consumptive value refers to functions or services of a natural resource in an ecosystem, and the preservation of red abalone in Oregon has value for future use and enjoyment (Walpole & Thouless, 2005). Integrating the non-consumptive use of abalone has been applied to South African fishery policy (Crookes, 2016; Nielsen & Martin, 1996), and could be considered for red abalone management in Oregon.

V. Current issues

There are several prominent issues currently facing the red abalone resource and fishery in Oregon. Some of these present complex management challenges that are active areas of research and discussion.

Climate change

A full description of the changing ocean conditions and the potential effects to red abalone, including ocean acidification, hypoxia and climate change can be found in section *A.V.c*. Monitoring changing ocean and climate conditions will be critical to achieving management and conservation goals for the red abalone in Oregon.

Sea otter reintroduction

The Pacific Sea Otter (*Enhydra lutris*) was once a prominent part of the marine subtidal ecosystem in Oregon, but since their extirpation by the early 1900s, the ecosystem has adapted to their absence. In the case of red abalone, behavioral changes that shape the health and structure of wild populations are a side effect of the absence of sea otters. Without sea otters present, red abalone exhibit emergent behavior in which abalone do not solely occupy rock crevices, but instead emerge out into the subtidal and even up into the intertidal (Hines & Pearse, 1982; Watson, 2000). This effect is exacerbated by lack of kelp, forcing red abalone to forage, and eliminating their cover from potential predators (Rogers-Bennett & Catton, 2019). The re-introduction of sea otters to the southern Oregon coast would threaten the remainder of

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the red abalone population in Oregon, without allowing time for adaptation to cryptic behaviors.

As plans to discuss and implement the re-introduction of sea otters continues to progress, it is important for both management and biological considerations of the red abalone population in Oregon to be considered and addressed.

Population concerns

As populations of red abalone throughout their range are suffering from declines and health issues, quantifying population levels is of increasing importance. In Oregon, specifics about population structure and size are still largely unknown and it is difficult to determine fishery possibilities and metrics without understanding the stock confidently. Increasing understanding of the stock and monitoring changes both environmental and biological will be critical for both management and conservation goals of the red abalone in Oregon.

VI. Other social and cultural uses

Red abalone are an important social and cultural component of the south coast of Oregon. Documentation of abalone use by both indigenous peoples and later European settlers is minimal in the coastal Pacific Northwest, even further limited for the southern Oregon coast. However, ODFW documentation provides information regarding use of red abalone through fishery regulations in the 1950s (McCauley, 1953). This resource has remained an important part of the southern Oregon region socially, culturally, and economically. Investigations to determine the source of red abalone use in indigenous communities in Oregon have hypothesized that red abalone shells, used for decoration and ceremonial applications, were acquired through trade (Zobel, 2002). Earlier documentation suggests that red abalone shells were brought to the Pacific Northwest tribes through trade from Monterey, California where red abalone were plentiful and their use in California tribal communities is well documented (Bonnot, 1948; Heizer, 1940; Leechman, 1942).

As red abalone remain an integral part of both southern Oregon social and cultural communities, it is an important consideration when creating management and conservation regulations.

VII. Evaluation of management tools

The management tools utilized in the Oregon red abalone fishery are a minimum legal size (MLS), daily and annual limits, required pre-measurement of red abalone, and catch reporting. These tools are commonly used in abalone fisheries worldwide due to enforcement ability and biological understanding; however, they have not always been successful in limiting catch rates

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or effects of harvest on reproduction and abundance. Here, we evaluate each management tool for consideration in future strategies.

Management tool: Minimum Legal Size (MLS) of 203 mm (8 inches)

The use of a MLS in abalone fisheries is common and often allows reproductively immature abalone to be protected from removal. In the case of red abalone in Oregon, the MLS of 8 inches (203 mm) did little to govern catch size due to the nature of the fishery. As a trophy fishery, participants target larger red abalone almost exclusively with the mean fishery catch size being well above the MLS at 254 mm (10 inches). A minimal increase in MLS would likely not have a meaningful impact on the harvest of red abalone in Oregon; an increase to 11 inches (279 mm) could reduce catch rates and could be a consideration for alternative management options.

Management tool: Daily and Annual limits (1/day, 5/year)

Daily and Annual Limits are useful for enforcement purposes, allowing catch rates to be limited and enforced. Although daily and annual limits can be useful for fishery management, they require a quantifiable metric as a basis for setting limits. In the case of the red abalone fishery in Oregon, a discrete number of allowable caught in the form of a total allowable catch (TAC) with a limited entry system could be more appropriate.

Management tool: Required pre-measurement

Required pre-measurement of red abalone is appropriate in a fishery with an effective MLS in place. This requires each fishery participant to carry a measurement tool while fishing that is consistent with the MLS set by rule. Prior to removing an abalone from hard substrate, the fishery participant is required to use the measurement tool to ensure the desired abalone is at least the MLS. A larger MLS may be sufficient to increase effectiveness of proposed management tools.

Management tool: Catch report permit

Catch report permits are useful for understanding and reporting the amount of take in a fishery, as well as location information for spatial purposes. Catch report permits could be considered as a minimum requirement for biological and spatial information when setting new management protocols.

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VIII. Recommended actions

Through understanding of the biology, ecology, available data and threats to the red abalone resource, a comprehensive conservation and fishery management strategy can be established for present and future managers to consider. Sections are divided up into conservation measures and management recommendations.

Conservation measures are specific actions designed to reach goals aiming to increase understanding and potential interventions for improving the health of the red abalone population in Oregon.

Management recommendations are to utilize conservative Limit Reference Points (LRPs) that serve as a buffer between concern for low population levels and the possibility of a fishery to guide future management actions.

a. Conservation measures

Proposed conservation measures are organized by conservation goals and objectives for the red abalone resource in Oregon.

1. **Goal**: Monitor the red abalone population in Oregon.

Objective: Conduct fishery independent surveys at two sites every 5 years or as funding allows.

Measures:

1.1 Secure funding to support a program for surveys of red abalone populations and their habitat.

1.2 Establish and conduct a consistent red abalone monitoring program within MRP.

1.3 Support current personnel to organize, participate, and analyze datasets generated by surveys of abalone in Oregon waters.

1.4 Create a new staff position to manage conservation of abalone, conduct periodic surveys, and engage in collaborative research.

Objective: Evaluate monitoring strategies through assessment of non-traditional and adaptive methodologies to determine efficacy and cost effectiveness of consistent monitoring.

Measures:

1.5 Conduct survey methodology evaluations.

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1.6 Contract divers to conduct density surveys comparing radial transect, adaptive cluster and traditional belt transect methods.

2. **Goal:** Increase understanding of the red abalone stock.

   Objective: Utilize the best available science to determine population dynamics.

   Measures:

   2.1 Perform age studies on red abalone in Oregon to develop an age-at size estimation.

   2.2 Secure funding or collaborate with researchers to perform larval dispersion studies for further understanding of life history strategies of red abalone and dispersion in Oregon.

   Objective: Perform genetic analysis for the structure of the red abalone population in Oregon.

   Measures:

   2.3 Secure funding for genetic analysis to determine effective population size.

   2.4 Secure funding for genetic analysis to determine genetic diversity.

3. **Goal:** Allow for recovery of the red abalone population in Oregon.

   Objective: Remove fishing pressure for red abalone populations in Oregon until metrics for recovery are established.

   Measures:

   3.1 Extend fishery closure until LRPs are met.

   3.2 Alter fishery regulations to support recovery of red abalone in Oregon.

4. Improve habitat and food availability for red abalone populations in Oregon through research and monitoring.

   Objective: Monitor kelp beds in Oregon with special consideration for those which support red abalone populations.

   Measures:

   4.1 Monitor spatial distribution and health of kelp beds and rocky reef habitats along the Oregon coast.

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4.2 Consider supplemental implementation of conservation such as: outplanting of abalone, kelp, or physical modifications of habitats critical to red abalone populations.

b. Management recommendations

The red abalone population in Oregon is imperiled and cannot currently support a fishery. The recommended conservation goals, objectives and measures listed in this plan are designed to support red abalone recovery to ensure the persistence of the resource for present and future generations. It is anticipated that this conservation and management plan will be updated whenever there are significant changes in the population or the regulatory environment or at least every 10 years.

Suggested Harvest Control Rules (HCR)s for the red abalone fishery are that the fishery remains closed at least until biological Reference Points (RPs) are met as lined out in the CFMP.

Biological reference points

Biological Reference Points (RPs) have recently been suggested as a precautionary approach to management of fisheries (Caddy & Mahon, 1995). Further work by the Food and Agricultural Organization (FAO) focused on applying well-defined RPs to management situations with particular interest in cases that are data-poor, which may require empirical RPs with a number of options to be evaluated and adapted through time (Caddy 1998). Limit Reference Points (LRPs) are a type of biological reference point that defines the beginning of the “danger zone” for a population, stock, or fishery. An LRP identifies the limit beyond which the state of a fishery and/or a resource becomes concerning, and action should be taken to reduce imperilment.

LRPs are considered here as a series of consultatory conditions, advisory criteria, or guidelines that will alert marine resource managers to consider changing Harvest Control Rules (HCR)s. In the event that the LRPs are reached, ODFW will closely evaluate the situation and determine the most appropriate adaptive management action, coupled with research activities to address conservation concerns.

Recommendations are presented below for defining specific LRPs for the recreational red abalone fishery in Oregon, accompanied by potential adaptive management considerations if LRPs are reached. Prior to the emergency closure and suspension of the recreational red abalone fishery in Oregon in 2018, there were no LRPs in place to trigger a closure or suspension.

Oregon’s red abalone population is located at the northern range extent of the species and is less robust than neighboring sections of the larger genetically connected metapopulation. Setting a limit reference point for Oregon that stipulates the regional red abalone fisheries must be open provides protection for the overall red abalone population along the west coast of North America. This LRP protects the overall health of the west coast red abalone population by only allowing fishing at the northern range extent if the central stock is at healthy and sustainable levels.

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Utilizing densities measured at ODFW index sites is a reliable management tool to assess the health and abundance of the red abalone population comparatively through time. Quantitative surveys for red abalone first performed by ODFW in 2015 (at a time when stocks were expected to be declining) indicated that Oregon's red abalone population measured 0.05 red abalone per m^2 at Brookings. Creating a buffer by doubling the highest measured baseline density of 0.05 red abalone per m^2 would ensure that a fishery would be possible only when historic population levels were sufficient to minimize any impact on the population.

Based on these evaluations, we propose the following Limit Reference Points for the Oregon recreational red abalone fishery.

Limit reference points

1. A regional recreational fishery for red abalone must be active.

Rationale: Oregon's fishery was traditionally <0.1% of the regional fishery and the red abalone populations are connected, therefore fisheries should be considered regionally. The population of red abalone in Oregon is considered as a peripheral population that exists at the northernmost limit of the primary breeding population in northern CA, and it is likely that the small OR population is not self-sustaining, but subsists by periodic dispersal and input of larvae that drift northward from CA.

2. Red abalone densities at ODFW index sites must reach a minimum value of 0.1 red abalone per m^2.

Rationale: Oregon's red abalone densities are naturally sparse relative to higher densities that occur in the central population further south. A density of 0.1 red abalone per m^2 is half of the minimum required for a fishery opening in the center of their range (0.2) and (roughly) double the density observed in Oregon in 2015 (0.047). The LRP of 0.1 abalone/m2 was selected as the metric for a future population of red abalone in Oregon to occur at a density that is ½ of the minimum density required to maintain a sustainable breeding population in northern CA, which is located at the central area of the primary breeding population for the west coast region. The LRP selected for Oregon (0.1 abalone/m2) is also twice the density that occurred at a time when the population in OR was first observed in decline. The LRP selected for Oregon (0.1 abalone/m2) serves as a further safeguard because the LRP would only come into effect in the situation when the population of red abalone in northern CA reaches a density of 0.2 abalone/m2, and CDFW re-opens the sport red abalone fishery.

The red abalone fishery in Oregon is currently suspended until March 2024 (Rumrill, 2021). We suggest adaptive guidelines below for a *de minimis* recreational fishery that could re-open sometime in the future in the event that red abalone in Oregon rebound to a level where limited recreational take can be viable.

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A management response may involve adaptive actions including:

1) **Fishery closure**
    - Closing or suspending the fishery until more information is acquired or density levels return to normal will allow for more information to be acquired and eliminate fishing pressure on the population.
2) **TAC reduction**
    - Reductions in the Total Allowable Catch (TAC) could be a consideration when deciding how to minimize impacts on the population and environment.

If LRPs are met, management will reassess the possibility and need for a recreational red abalone fishery in Oregon. Management will present updated red abalone fishery and population information to the Oregon Fish and Wildlife Commission (OFWC) if LRPs are met and make recommendations based on stock assessment and environmental conditions. Below are three options for a recreational red abalone fishery structure if the LRPs are met as example guidelines for future managers.

Option 1: *De minimis* fishery

In the event that the LRPs are achieved, a *de minimis* fishery could be possible for red abalone in Oregon.

A *de minimis* fishery would warrant minimal take; proposed regulations for this fishery are:

1. The red abalone fishery operates in two designated areas: Brookings and Port Orford, defined by extents of fishery independent surveys.

2. A total allowable catch (TAC) for all areas combined is set at 50% of the last 10-year average of catch.

    a. Area-specific catch is designated by historic percentage, as 97% of historic red abalone harvest has occurred in Brookings, 97% of the TAC for the state of Oregon will be allocated to the Brookings area.

3. Surveys for fished areas will be performed biennially to ensure densities are double previous baseline densities set at 0.1 red abalone per m^2.

4. If either LRP is no longer met, all areas will close effective immediately.

Option 2: Alternative fishery

An alternative to a de minimis fishery if LRPs cannot be met, but a fishery need is determined, is a biological fishery. A bio-fishery would allow for minimal harvest of red abalone but would also provide some biological information to managers and create a unique harvesting opportunity.

Regulations for a proposed alternative fishery are as follows:

1. Biological fishery
    a. Minimal take of red abalone is allowed for biological research.
    b. All harvested red abalone must be turned in to ODFW on the day of harvest for accrual of biological information.

Option 3: Open fishery

A third option for management would be to re-open the recreational red abalone fishery when LRPs are met with status quo rules. This option would be appropriate if the need for red abalone fishing opportunities exceed the conservation needs.

Regulations for an open fishery are as follows:

1. Minimum legal size (MLS) of 8 inches (203 mm) SL.
2. Daily limit of one red abalone per permit holder.
3. Annual limit of 5 five red abalone per permit holder.
4. Required pre-measurement of red abalone.

Red abalone fishery management implications

Adaptive management is a key component of ODFW's approach to addressing several current issues. Each fishery option utilizes a different fishery management strategy and has varying implications for the red abalone population in Oregon. This conservation and management strategy will be updated when there are significant changes in the red abalone population, regulatory environment, or at least every 10 years.

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